WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

White Paper

Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation

In collaboration with Accenture

January 2018

Contents

REF 190118 - case 00039558

Preface

Production is the beating heart of commerce. But it is a double-edged sword, supplying necessities and amenities for humanity while depleting the global commons that sustain life on earth. Our aim in the Accelerating Sustainable Production project is to leverage production as a tool for meeting the United Nations Sustainable Development Goals (SDGs) and as a source for business competitiveness. The opportunities for doing so have expanded with the advent of Fourth Industrial Revolution technology – an ecosystem that holds a dizzying amount of innovation across digital, physical and biological spheres. As the volume of innovation explodes, the cost of advanced technologies is plummeting. Consider genome sequencing: the first human genome cost $2.7 billion to sequence; today, it costs $1,000.

The combined effects of technology and its free-falling cost are accelerating progress exponentially. But which will play the bigger role in impacting SDGs and boosting business competitiveness? That is the central question of this White Paper and the work conducted by the World Economic Forum in collaboration with Accenture. In this paper, we examine technological advancements as leverage points (or obstacles) for achieving sustainable production from cradle to factory gate. The result is something entirely new – a framework, by industry, for prioritizing innovation wrought by the Fourth Industrial Revolution. Such a framework helps quantify the potential for sustainable value creation so that governments and businesses can design their growth strategies accordingly. It also enables them to scale their contribution towards the United Nations 2030 Agenda for Sustainable Development, thus enhancing economic and industry competitiveness.

This collaborative effort demonstrates how to harness the technological progress of the Fourth Industrial Revolution for sustainable innovation and value creation in four manufacturing industries and across major global regions. We started our work with these sectors and geographies because they serve as solid examples for exploring the sustainability agenda from the perspective of production systems.

Our ambition is to put the findings and assets to use in a government-mandated pilot on sustainable production value assessment. Looking ahead to our vision for the third year of the project, our objective is to work towards the scoping of on-the-ground interventions based on regional in-depth analyses.

Helena Leurent
Head of Future of Production System Initiative,
Member of the Executive Committee,
World Economic Forum

Omar Abbosh
Chief Strategy Officer,
Accenture

Foreword

A world of opportunities is emerging and the “future” of production may as well be “today”. Decades ago, science alerted us to the unsustainability of human economic activities and consumption patterns. Incremental gains in resource efficiency were offset by global consumption growth, in an increasingly globalized economy with mostly “take-make-dispose” business models. The global economy was found to be too resource intensive – incompatible with our climate change mitigation goals or the earth’s finite resources – and consuming nearly twice what the planet can regenerate each year. Social externalities were observed, too; jobs were lost or displaced, and new ones took too long to emerge in multiple markets. It is now time to be bold in our ambition to turn these patterns around – to be not only optimistic, but even confident. The time has come to lead, implement and transform socio-economic systems of production as we enjoy a unique combination of favourable conditions: social momentum, public-sector understanding, technology and investment resources. The 2018-2030 era is no doubt going to be a fantastic one of opportunities for many. Challenges will persist and evolve, but they can mostly reside only in our own ways of thinking, our lack of imagination or determination. I am proud to contribute this foreword to the white paper, the fruit of intense collaboration between a variety of stakeholders. May it inspire all of us to implement a “One-Planet-Compatible-Future-of-Production”. Now.

Annette Clayton, Chief Executive Officer and President, North America Operations; Chief Supply Chain Officer, Schneider Electric, USA

In addition to the promise of technology-led gains and efficiencies, one of the key drivers ensuring that the Fourth Industrial Revolution benefits everyone is its delivery of more sustainable production and consumption around the world. The world’s track record has not been good; in the past, profits from destroying the planet were privatized while the cost for addressing the damage was socialized. Now, we are at a crossroads where this pattern can be reversed. Government and business must become closer partners in delivering on the shared compact of the United Nations 2030 Agenda for Sustainable Development, with consumers being beneficiaries of a more enlightened approach to sustainability issues. This White Paper represents a significant step in this direction and serves as a pragmatic, forward-looking approach to achieving a world where environmental well-being and business competitiveness go hand in hand.

The ideas represented in these pages are a natural extension of the theme of the World Economic Forum Annual Meeting 2018: Creating a Shared Future in a Fractured World. The aim of the meeting is to bring people together, bridging political and commercial factions to address the biggest challenges of our times.

Far too often, sustainability has been viewed as a cost. That perception needs to change to ensure we collectively understand that it can also represent a major business opportunity, and should be an important component of any modern business plan. In some areas, we are on the right track. Since 2016, the world has invested more in solar and wind technology than it has in coal and oil, but we need to stay the course. This effort and others will help leverage the United Nations Sustainable Development Goals as a compass to steer the world towards a more sustainable future.

Arancha González Laya, Executive Director, International Trade Centre (ITC), Geneva

The Fourth Industrial Revolution has the potential to dramatically change the course of economic development but also the distribution of wealth. New technologies are enabling ever higher levels of productivity and efficiency. On the other hand, low- and middle-skilled jobs are increasingly under threat of replacement. Our role as governmental leaders is to ensure that no one is left behind. It is crucial to help industrial SMEs to start transformation as well as integrate small and medium technology suppliers to release their full potential. At the same time, the key challenge is to address the problem of the digital competence gap. The role of national as well as international policy is to make sure that this great revolution we are witnessing will bring benefits for all.

Mateusz Morawiecki, Prime Minister and Minister of Economic Development and Finance of Poland

The production of the future will cater to rapidly evolving consumer needs by delivering products and services within a well-designed supply chain that fully embeds innovation and sustainability. At P&G, we are committed to delivering products and services that make everyday life better for people around the world. We believe there is value in embracing the UN SDGs when it comes to strengthening competitiveness and value creation.

We need to fully leverage digital, physical and biological tech advancements to be able to predict and capture consumer demand, and connect it seamlessly through production operations and materials sourcing in a blueprint that minimizes the environmental footprint. This will require reskilling and empowering our workforce to harness the new forces of technology. When doing this responsibly, we create value across the chain, using resources sustainably and helping our surrounding communities prosper.

Mohamed Samir, President, India, Middle East and Africa, Procter & Gamble, United Arab Emirates

Executive summary

The end goal of Accelerating Sustainable Production, a project of the World Economic Forum System Initiative on Shaping the Future of Production, is to harness innovation to strengthen competitiveness while delivering increased efficiency, improved human well-being and less environmental damage. Getting there will require a new level of public-private collaboration, as well as tapping into the developments wrought by the combined effects of biological, physical and digital technologies to create realities previously thought to be unobtainable.

The project is a guide for optimizing the benefits of the Fourth Industrial Revolution. It helps countries and businesses identify ways to transform their production systems to achieve sustainable growth while supporting their commitments under the United Nations Sustainable Development Goals (SDGs) and boosting their competitive capabilities.

Fourth Industrial Revolution developments and the United Nations Sustainable Development Goals

Work in this initial phase focuses on four industries. A selection of low- and high-tech manufacturing sectors were chosen based on the interest of the project community and the opportunities for higher environmental productivity.[1] We identified the technological developments that have a high potential to deliver value when seen through the lens of the SDG targets.[2] Phases two and three will focus on applying this knowledge to quantify the economic value and initiate on-the-ground projects.

Which developments of the Fourth Industrial Revolution hold the most promise for accelerating sustainable production? Many were specific to a given industry or geography, and are discussed in detail in Chapter One. While no single technology is likely to constitute a strategy for addressing challenges of production sustainability in any industry, five cross-industry trends emerged:

Advanced remanufacturing: Innovation in physical and digital technologies is fast becoming an enabler for closing the loop with cost-effective returns processing, robotic disassembly and advanced material sorting. Connected devices feed information back to design and engineering to improve product durability and performance. A cluster of technologies – augmented workforce systems and cobotics, in combination with digital track-and-trace systems to manage reverse logistics – can drive substantial triple-bottom-line value, boost a brand's reputation and mitigate growing supply chain risks.

New materials: These include new types of packaging, green electronics and alternatives to plastic, leather and meat. The materials are poised to play a greater role across industries in the near term as they become better (and cheaper) than traditional materials, thanks to advances in nano- and biotech, green chemistry and smart lab technology. Advances, however, will also depend on the speed with which new materials processing technology and investment can be scaled from research and development to commercial production capacity.

Advanced agriculture: Increased demand on land and water for organic feedstock for manufacturing (e.g. bio-based plastics) makes agri-food systems a cross-industry issue. The greatest source of innovation is in precision and automated agriculture and biotech, where the internet of things, data and analytics are coupled with crop science to optimize farming decisions on everything from fertilizer and irrigation to harvesting time and seed spacing. Advances drive substantial yield gains and, with planning, could help address food scarcity while safeguarding human and ecosystem health.

Factory efficiency: Near-dark factories use automated processes, from smart warehousing to advanced additive manufacturing, to increase resource productivity, shorten supply chains and reduce consumption of non-renewable resources. While they allow manufacturing to move closer to demand markets, care must be taken to manage labour market changes.

Traceability: From tracing the origin of spare parts in the automobile industry to timestamping coffee cherries, technologies such as blockchain coupled with sensors and data tags are enabling companies to provide verified information about the materials, processes and people behind products. Enabling data flows through supply chains is critical for building trust, eliminating low-value-added processes, ensuring fair earnings for smaller suppliers, and enabling remanufacturing and recycling through reverse logistics applications.

Regional opportunities

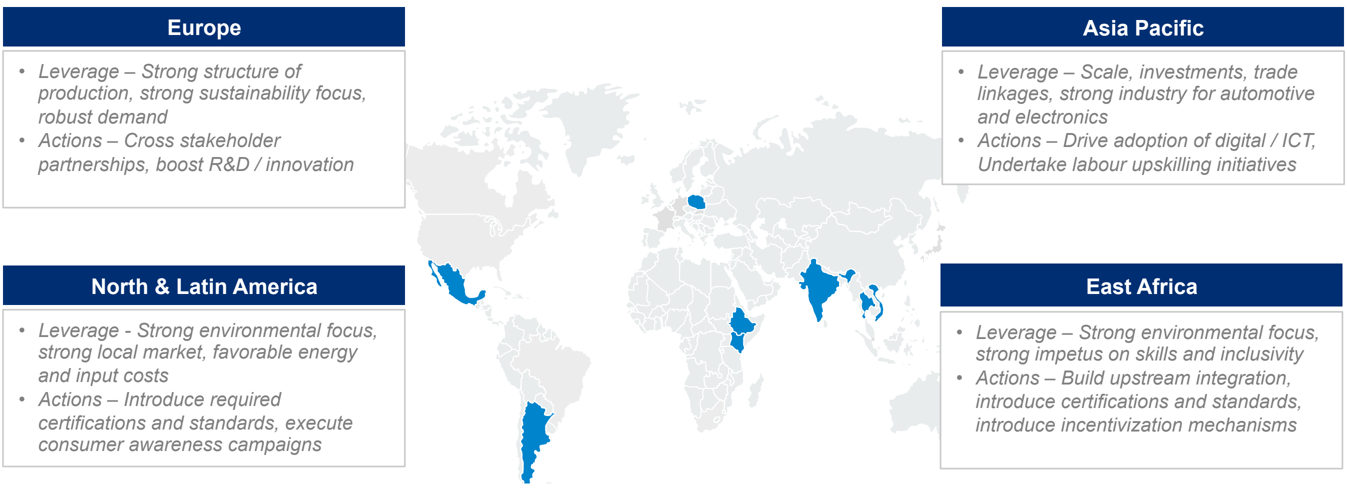
Fourth Industrial Revolution developments span across innovations in areas such as digital technologies, new materials, innovative operating models for closed loop manufacturing and factory automation. Given the breadth of these developments, it is critical to identify which are best suited for diffusion and the actions required to help innovation spread.

Data from the World Economic Forum Country Readiness Index framework and our analysis of case studies revealed that each region has its own local context, which allows it to adopt specific Fourth Industrial Revolution developments. Regional variations in opportunities to diffuse sustainable production practices are explored. To keep the analysis specific yet representative, the following geographies were examined: Europe (Poland), Africa (Kenya, Ethiopia), Asia Pacific (India, Thailand, Vietnam) and Latin America (Argentina, Mexico).[3] Although answers cannot be derived for an entire region from one or two countries, promising trends can be identified and thus help to "connect the dots" of which developments are particularly relevant given a region's characteristics.

- In Europe, Poland is one country with complex structures of production, robust trade linkages with strong demand and a rapidly rising consumer consciousness of production's effect on the environment. Industrial innovations, such as cobots and supply chain traceability, are exciting opportunities for the region.
- Within African economies, Kenya and Ethiopia, among others, reflect a strong focus on workforce agility and adaptability, as well as on sustainability. Agri-tech hotspots such as Kenya are ideally positioned to embrace agricultural innovations.
- The focus economies in the Asia-Pacific region, such as India, Thailand and Vietnam, are characterized by scale, strong capital inflows and manufacturing hubs. Given their robust trade linkages, these economies are well positioned to import innovations in the regionally significant automotive and electronics industries. Low-tech sectors, such as textiles, apparel and agri-food production, can also benefit significantly.
- Latin American economies, such as Mexico and Argentina, have strong consumer demand and a robust physical and technological infrastructure. With significant meat-processing sectors, these countries are well positioned to embrace innovations in the food and beverage industry.

Figure 1 summarizes the potential leverage points and actions for each region. Additionally, Chapter Two provides case studies, as well as potential actions and implications, for business leaders and policy-makers.

Figure 1: Regional opportunities to accelerate sustainable production



Source: A.T. Kearney research, Accenture Strategy analysis

The Accelerating Sustainable Production framework

Talking about sustainable production is one thing; measuring progress towards achieving it is another. This is the driving force behind this work because major milestones are looming: in 2018, progress towards SDG 12 on sustainable consumption and production will be reviewed by the United Nations High-Level Political Forum on Sustainable Development.

To ensure business and government are on track, we have created the first online framework for evaluating the business and sustainability potential of Fourth Industrial Revolution developments. The framework has two purposes: (1) to measure the total value created from implementing a given development in the production system, and (2) to identify sources of impact on the SDGs and the underlying targets and metrics. As a result, the link at a strategic level between industry value creation and the SDGs can be visualized, and the benefits of Fourth Industrial Revolution innovation in the production systems optimized.

Introduction

Context

The Accelerating Sustainable Production project seeks to inspire the creation of production systems that drive increased productivity and efficiency, while simultaneously benefitting society and the environment.

As part of the World Economic Forum System Initiative on Shaping the Future of Production, the project provides a platform for leaders across sectors and industries to ensure the future of production is based on inclusive and sustainable economic growth. This growth is enabled by technology innovation and dissemination, careful consideration of global common assets, and human-centred workforce strategies. Introduced in 2016, the System Initiative's global community has grown to over 50 businesses from 18 industry sectors, 27 ministers of industry as well as top engineering universities, labour unions and relevant civil society organizations. Other projects in this System Initiative are:

- **Country Readiness for the Future of Production:** pinpoints the critical success factors required for diffusing and scaling Fourth Industrial Revolution technologies
- **Employment and Skills for the Future of Production:** examines shifting technological, manufacturing industry and macro trends highlighting the risks created by skills supply and demand mismatches globally
- **Technology and Innovation for the Future of Production:** examines digital opportunities in downstream manufacturing based on three trends: connectivity, intelligence and flexible automation
- **The Future of Production in ASEAN:** analyses the trends affecting manufacturing in the Association of Southeast Asian Nations and member countries' current competitiveness in manufacturing in this context

This White Paper complements the work of these projects and is indebted to them, particularly to the Country Readiness Index framework, which helped shape the review of opportunities to diffuse regional sustainable production.

Objective

This White Paper provides the foundational insight and tools for the second and third years of the Accelerating Sustainable Production project by exploring high-impact technologies, regional opportunities for diffusion and the value at stake for cross-sector stakeholders. At its core, this work is a strategic framework enabling government and business to harness innovation in production for sustainable development and competitiveness. How? They can do so by understanding the potential of certain developments for achieving SDGs in a given region. This first White Paper of the project seeks to answer three questions:

- What changes will the Fourth Industrial Revolution bring to systems of production, and how will they affect sustainability?
- What geographical opportunities exist to scale and diffuse sustainable opportunities?
- What value can these Fourth Industrial Revolution developments create for business, society and the environment, and how can they help achieve the SDGs?

The output is a prioritized set of emerging technology developments in each of the focus industries, with potential sustainability impacts identified on a global level.

Scope

The project developed from community meetings in Berlin, Dalian and New York in 2017. Four sectors reflecting our stakeholders' experiences were identified; these are low- and high-tech product manufacturing industries with high environmental productivity, end-consumer visibility and good potential for further transformation. The technology group classification is based on OECD (2005) technology classification based on R&D intensity relative to value added and gross production statistics:[4]

- Automotive
- Electronics
- Food and beverage
- Textiles, apparel and footwear

To keep the analysis specific yet representative, the following geographies were examined: Europe (Poland), Africa (Kenya, Ethiopia), Asia Pacific (India, Thailand, Vietnam) and Latin America (Argentina, Mexico). The methodology section in this paper's appendices provides details on the research scope, as well as terms and definitions.

Defining sustainable production

According to the Oslo Symposium of 1994:

> *Sustainable production is the manufacturing of products and creation of related services, which respond to consumer and market needs, and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants so as not to jeopardize the needs of further generations.*

Structure

Chapter One of this White Paper reveals a clear understanding of the 40 disruptive technology developments across four industries that can help accelerate sustainable production.

Chapter Two presents case studies where these developments have enabled sustainable production and competitiveness, and identifies opportunities to scale and diffuse leading practices across geographies.

Chapter Three sets out a quantitative framework to evaluate the benefit to business and the effect of Fourth Industrial Revolution technology developments on sustainability to help prioritize action and influence national, municipal and corporate strategies.

Audience

This paper is aimed at decision-makers in business and national and municipal governments who will use it to shape and guide the implementation of Fourth Industrial Revolution technologies, and thereby work towards achieving two goals: economic growth, and social and environmental betterment.

Next steps

This work is intended to spur conversation between business, government and civil society; to help explore the connection between industrialization and the attainment of SDGs; and, ultimately, to enable collaborative, action-oriented projects to address challenges and optimize benefits.

Methodology

Chapter One: Fourth Industrial Revolution industry developments and the United Nations Sustainable Development Goals

Our evaluation framework is based on the SDGs and indicators. Developments in Fourth Industrial Revolution technology were assessed against relevant SDG targets based on desk research and interviews, noting upside potential and risks. Fourteen of the 17 SDGs were selected and grouped to make up three areas for assessing sustainability (economic, social and environmental; see Figure 2). The full list of the related targets and indicators was narrowed down to those relevant to production systems in the in-scope industries.

See Appendix 2 for a full description of Chapter One methodology.

Figure 2: Sustainable Development Goals linked to production activities grouped by three assessment areas

Source: Accenture Strategy analysis

Chapter Two: Regional opportunities

The regional assessment of opportunities for accelerating sustainable production is based on the World Economic Forum data-driven Readiness for the Future of Production Assessment, which is made up of two dimensions: the structure of production (the current baseline of production) and the drivers of production (the key enablers that position a country to capitalize on emerging technologies to transform its production systems).

To understand regional opportunities for diffusing sustainable production developments, we gathered relevant case studies, identified the critical success factors and mapped them against the levers in the framework. We then identified the changes required to support diffusing innovation in sustainable production in the selected countries versus the baseline performance of drivers of production data.

See Appendix 2 for a full description of Chapter Two methodology.

Chapter Three: The Accelerating Sustainable Production framework

Arguably the most important part of the work lies in the Accelerating Sustainable Production framework (also available as an online visualization tool available to Future of Production community members). Its objective is to give businesses a way to manage the impact of SDGs strategically, building their own competitive strength in the bargain. The model itself is agile, and its methodology allows it to be tailored for different technological interventions.

The framework builds on the value at stake approach developed as part of the World Economic Forum Digital Transformation of Industries project, but is extended to cover physical and biological technologies and adjusted to address the specificity of manufacturing sectors. Connections were established between the lowest-level value levers in the value at stake framework and SDG indicators through a detailed analysis of the indicators and their definitions. Our aim was to create causal links between value levers and SDG indicators, where changes to value levers contribute to the SDGs.

See Appendix 2 for a full description of Chapter Three methodology.

Chapter One: Fourth Industrial Revolution industry developments and the United Nations Sustainable Development Goals

For 40 years until the turn of the millennium, global business was predicated on a pattern: commodity prices decreased as growth surged. Society benefitted from an increasingly comfortable lifestyle; corporations made shareholders wealthy, and everyone became complacent.

But with the rise of urban populations and middle-class consumption, the pattern reversed, leading to acute shortages of many resources while putting others, like water and fertile soil, under greater stress. And while business became efficient at extracting resources, it fell behind at preserving them.

We now know (or most of the world acknowledges) a simple truth: the way the world manufactures cannot be sustained. The "take-make-dispose" linear economy approach results in significant resource inefficiency.

Consider this: Global manufacturing consumes about 54% of the world's energy[5] and a fifth of its greenhouse gas (GHG) emissions.[6] Industrial waste makes up to half of the world's total waste generated each year.[7] Production activities are gobbling up primary resources; metal ore extraction, for example, rose by 133% over the last three decades.[8] At the same time, resource extraction from non-renewable stocks grew, while extraction from renewable stocks declined.[9]

Innovating production for green growth can go a long way towards mitigating negative environmental consequences and decoupling the creation of gross domestic product (GDP) and use of natural resources. The *OECD Environmental Outlook to 2050* suggests that technological progress can indeed improve the intensity of economies in the coming decades.[10] And although no single development will be a silver-bullet solution, we can safeguard the global commons and boost industrial competitiveness in the bargain by developing a range of approaches. In this section, we identify the developments of the Fourth Industrial Revolution with the most potential for accelerating sustainable production in the automotive, electronics, food and beverage, and textiles, apparel and footwear industries.

Automotive

Context

The automotive industry has experienced strong sales and growth in recent years,[11] but has been disrupted by global macrotrends. These include the evolution of ownership models, the shift of demand and supply to emerging markets, changing supply chain dynamics and the advancement of electric and autonomous vehicles. Innovation-related challenges are shifting the distribution of earnings and the boundaries between original equipment manufacturers (OEMs) and Tier-One and Tier-Two suppliers, as well as between technology and automobile companies. A recent example is Tesla's decision to build the seats for its Model 3 itself rather than use a supplier,[12] seemingly bucking the trend of the last 30 years towards contract manufacturing.[13]

Health, safety and emissions regulations are tightening across both developed and developing markets. And, while sustainability is most often linked with the use of the end product, issues such as sustainable sourcing and the circular economy are of increasing importance for the automotive industry.[14] As electric vehicles change the industry's focus from tailpipe emissions to manufacturing, battery life cycles and end-of-life impact, technological advances upstream present opportunities for enhanced resource efficiency, productivity gains and reduced material footprint. Asset light manufacturing, enabled by predictive maintenance, dynamic adjustment of flows and automation, equates to higher machine utilization, reduced capital investment requirements and reduced carbon.

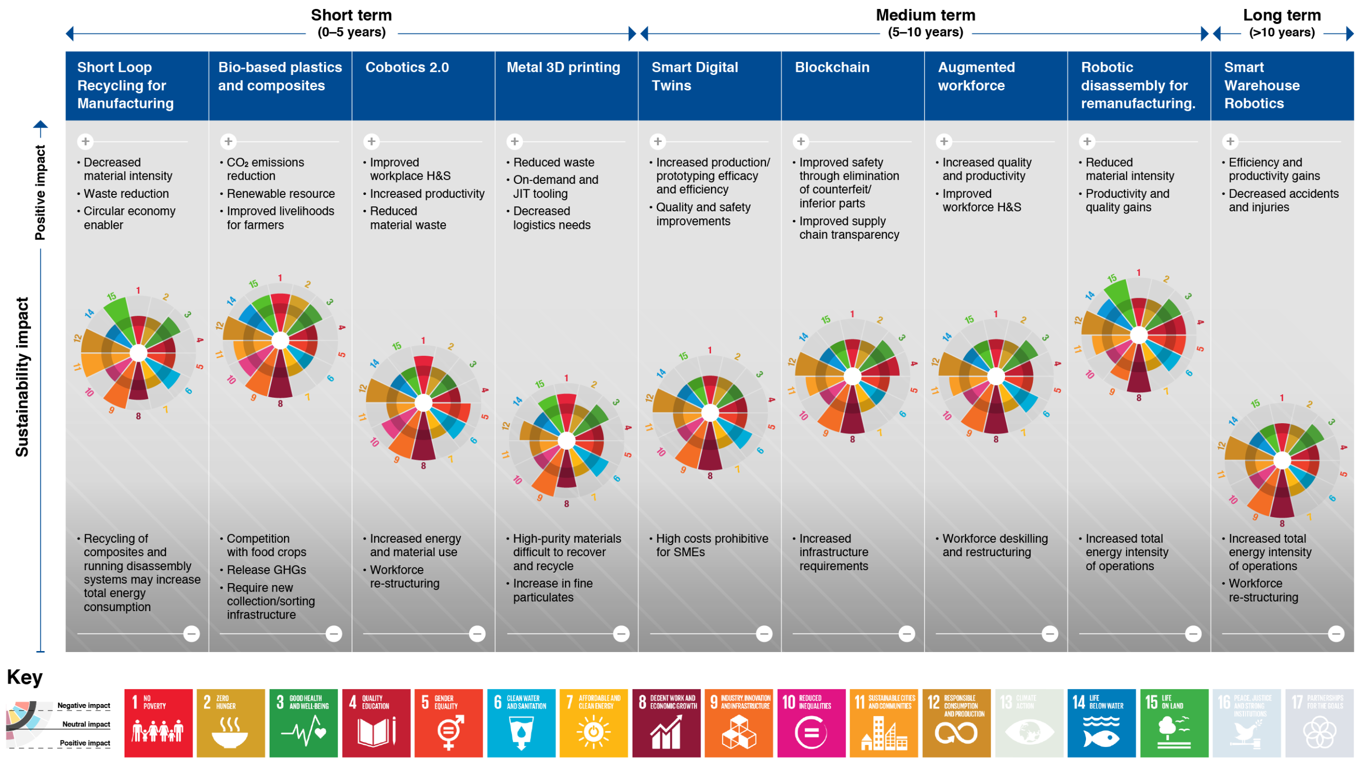
While global in reach, the automotive industry is surprisingly regional in nature. According to the Organisation for Economic Co-operation and Development (OECD), "European Union countries source the majority of their intermediates from other European countries, while NAFTA partners largely source from within NAFTA. Also, in Asia, a clear regional integration has developed through the sourcing of intermediates largely from within the region".[15] This regional structure makes sense considering the cost of logistics and lower value-to-weight ratios of component parts. Further localization seems likely, with Fourth Industrial Revolution technologies enabling smaller, more flexible microfactories close to centres of demand, reducing supply chain flows.

Fourth Industrial Revolution developments

Automotive production processes are a clear example of how innovation can drive increased efficiency, competitiveness and sustainability. Our research identified nine ways in which the Fourth Industrial Revolution will change systems of production through innovation in digital, physical and biological technologies (Figure 3).

In the following section, we consider the top-three developments presenting the most significant upside potential for SDG value creation in the industry (Figure 4), as well as the business and sustainability opportunities and challenges they present. These are short loop recycling, bio-based plastics and composites, and robotic disassembly for remanufacturing.

Figure 3: Sustainability assessment of Fourth Industrial Revolution developments in the automotive industry



Source: Accenture Strategy analysis

Figure 4: Top three automotive industry developments with greatest upside potential and descriptions

Development	Brief overview
Short loop recycling for manufacturing	Short loops, in which all recycling processes remain in the automotive sector, are set up to recover and recycle materials for (re)manufacturing leveraging multiple partnerships enabled by digital platforms and geo proximity. Current examples of such short loops are set up to recycle raw materials such as steel, copper, textiles, and plastics, keeping them as much as possible in the local automotive industry.
Bio-based plastics and composites	Replacing heavier metal and plastic components with engineering-grade biopolymers and/ or lighter natural-fibre-reinforced plastics created partially or wholly by using plant feedstock. For example, structures can use flax fibres and bio-epoxy resin intermingled with carbon fibres in hybrid composites, which are lighter, cheaper and more environmentally sustainable than conventional polymers. These materials and parts are suitable for multiple vehicle systems, including powertrain applications.
Robotic disassembly for re-manufacturing	Robots are widely used in automotive manufacturing but not in remanufacturing, particularly at the critical stage of disassembly. Advances in this sphere could mean that end-of-life product disassembly for remanufacture will become easier, faster and more cost-effective, driving efficient resource use and enabling the circular economy in the industry.

Source: Accenture Strategy analysis

Short loop recycling for remanufacturing represents the greatest potential for accelerating sustainable production in the near term. In a short loop, recovery and recycling processes remain in the automotive sector, and materials are recovered for (re)manufacturing, thus leveraging partnerships with geographically close supply chain partners. To apply this effectively, a combination of physical and digital technologies is required (particularly digital track-and-trace for monitoring and managing material and component flows), supported by advanced material sorting and efficient robotic, cobotic or worker-assisted disassembly systems.

One leading example is ICARRE 95, a growth-generating project for Renault. The project demonstrated that 95% of material from end-of-life vehicles could be recovered and 85% recycled under profitable conditions for all stakeholders.[16,17] Its innovations include specialized dismantling tooling, vehicle and part traceability, and optimized logistics and worker assistive systems for component identification and disassembly.

"The transition to a more efficient and circular use of raw materials in the automotive sector is far more than an environmental issue; it's the only way to meet the ever-increasing demand for mobility in the context of finite natural resources. Circular economy innovation has been continuously contributing to Renault's industrial competitiveness and increasing net profits for the past five years."

Jean-Philippe Hermine, Vice-President, Strategic Environmental Planning, Renault-Nissan Alliance, France

End-of-life vehicle recovery is commonly a distributed activity, relying on small specialized players. On the upside, optimizing local activities can result in reduced localized environmental risks and increased total material productivity for organizations. The downside is that recycling of complex composites, additional inventory tracking and management, and running disassembly systems may require significant investment in fixed assets, as well as increased total plant energy consumption.

Robotic disassembly for remanufacturing, where automation is leveraged in the critical stage of disassembly, is poised to become more prevalent in the longer term. Advances mean end-of-life product disassembly for remanufacture will become easier, faster and more cost-effective, driving efficient use of resources and enabling the industry's circular economy.

Bio-based plastics and composites are based on renewable resources and have good upside potential in contributing to reducing GHGs and closing material loops. These biomaterials, such as flax fibres and bio-epoxy resin intermingled with carbon fibres in hybrid composites, can be used to produce vehicle components that are lighter, cheaper and more environmentally sustainable than those made from conventional polymers. Natural fibres use less energy in production (11.4 megajoules per kilogram [MJ/kg] of product) compared to glass fibres (48.3 MJ/kg); can offer a 5-15% reduction in weight, contributing to reduced CO_2 emissions;[18] and are suitable for multiple vehicle systems, including powertrain applications.

The production of bio-based polymers is expected to triple, from 5.1 million tonnes in 2013 to 17 million tonnes in 2020.[19] Examples of innovation in this space are growing. BioMat, developed in a partnership between Faurecia and Mitsubishi Chemical, is a 100% bio-based material used to replace petroleum-based plastics in automobile interiors.[20] Flaxpreg, developed in collaboration with Peugeot-Citröen, is a lightweight composite using unidirectional, non-woven flax as structural flooring in a vehicle's passenger compartment.[21] In addition, Audi, BASF and Covestro have developed a 70% biomass auto body coating.[22] These rapid developments are underpinned by advances in green chemistry and chemical engineering, where smart lab technologies in the research and development (R&D) phase can accelerate the development, manufacturing and testing of new composites.

"In traditional manufacturing, production quantities are known: inventory, input and output are all fixed. In remanufacturing, however, there is a lot more uncertainty in both the demand and supply sides of the production system. The problem is even more challenging with electric vehicle components such as batteries, where an inventory of cells needs to be kept to guarantee delivery, but where cells degrade if not used."

Jun Ni, Professor of Manufacturing Science, University of Michigan, USA

Vattenfall, a Swedish power company, is exploring the possibilities of a more resource-efficient variety of carbon fibre. In Europe, CO_2 emission standards for cars are pushing manufacturers to switch materials to reduce weight while maintaining safety. Vattenfall has explored alternative routes for carbon fibre manufacturing based on renewable electricity. Making a new car creates as much carbon pollution as driving it,[23] and the embodied energy of virgin carbon fibre is comparatively high at approximately 200 MJ/kg.[24] The most promising path is basing propylene production on methanol instead of petroleum. Methanol, in turn, can be produced using hydrogen from renewable electricity combined with CO_2. In this way, CO_2 can be used to create a valuable substance instead of being released into the atmosphere.

Use of bio-based polymers and composites is not without its challenges, however. Foremost is the risk that growing plant material for automobile applications competes with cultivating human food crops, which could exacerbate hunger, water scarcity and poverty, particularly in developing nations. Before increasing the use of bio-based polymers, stakeholders should consider wider implications. In addition, substituting petroleum-based plastics for bio-plastics does not guarantee a GHG benefit. Decomposition of biomaterials, and agricultural waste generated while growing plants for automotive applications, release methane. A switch to bio-polymers must be accompanied with a recovery and reuse plan to maximize the environmental benefit.

Additional highlight: 3D printing builds products "from the bottom up" and therefore reduces waste, which can run up to 30 pounds of raw material per pound produced by traditional means. It also carries a cost advantage, especially when precious materials like titanium and nickel-alloy steels are involved in production. Additive manufacturing (processes that make three-dimensional products from a digital design) can reduce material costs by up to 90% and energy costs by up to 50%.[25] By 2025, 3D printing could potentially reduce manufacturing costs by about $593 billion.[26]

Most applications in the automotive industry focus on tooling, rapid manufacturing, prototyping and manufacturing of spare parts. For example, Audi prints spare parts for its vehicles on demand, and Honda uses 3D printing for bespoke products to meet customer demands.[27] By extending this to replacing failed parts on critical production line machinery, 3D printing replacements can also help reduce downtime.

The use of 3D printing to manufacture new vehicles is emerging with companies such as LocalMotors,[28] which can develop a tailor-made car in under six months. It uses an asset-light business model, and connects and digitizes design, engineering and manufacturing to reduce the time to market, engineering cost, and asset and resource consumption.

Increased industrial uptake is expected to generate $1.1 billion in the automobile industry by 2019[29] and $2.3 billion by 2021.[30] But the technology is not without pitfalls: metal 3D printing has a low processing throughput, and repeated recycling can degrade high-purity materials and metal powders. While the recyclability issue is even more pronounced with plastics, some alternatives exist, such as polylactic acid recycling.

Opportunities to accelerate sustainable production

As technological and business innovation converge, the opportunity for greater focus and deeper integration of remanufacturing in the automotive industry remains strong. Scale-up will require coordinated investment in reverse logistics infrastructure and process innovation, and closer partnerships between vehicle OEMs and suppliers. In this new value equation, OEMs will need to co-invest with suppliers to make collaborative changes that drive value for both parties, and to create platforms for innovation and process change. The industry's regional nature can be leveraged to back local policy-supported remanufacturing scale-up initiatives and help encourage clean economic growth.

As bio-based plastics get closer to meeting or exceeding performance and cost requirements, sustainability benefits must be maximized and the momentum used to scale, bearing in mind challenges in food security and land use. Scale-up of biomaterials will require R&D into new materials, and investment into biomaterial supply chains and end-of-life planning. Within the industry and across industries, alliances could support and scale the sourcing and disposal of bio-based parts and components. By supporting Fourth Industrial Revolution developments across industries, governments can facilitate the benefits cascading into the agri-food industry.

Additive manufacturing should be considered in the context of material flows in the industry production system. Tailored additive-manufacturing cybersecurity solutions can be created to limit the risk of intellectual property (IP) infringement. Moreover, regulatory guidelines regarding end-of-life protocol must be implemented to help maximize the benefits of industrial additive manufacturing while minimizing the risks.

Electronics

Context

The electronics industry is characterized by complex global value chains driven by high-value products. The value chain consists of diverse firms across different countries that can be broadly categorized into two types: lead firms that carry brands, and contract manufacturers that assemble products for those firms. Most lead firms are in developed countries, with Japan as a major player, while their manufacturing counterparts are in emerging markets, with East Asia and China as major hubs. Underscoring Asia's role, an estimated 90% of all electronics R&D takes place on the continent.

The industry faces significant environmental challenges related to energy and material intensity and use of chemicals. In fact, 70-80% of the GHG emissions of personal electronic devices occurs during the manufacturing phase.[31] With the number of devices (and device complexity) rising, the industry will continue to contribute to GHG emissions. Recent studies have revealed challenges regarding lack of transparency, sourcing and tracking of metals (and, consequently, more counterfeit products), and limited use of secondary materials.

Fourth Industrial Revolution developments

Our research identified eight Fourth Industrial Revolution developments (Figure 5) that could significantly affect the electronics industry's manufacturing systems, while driving a sizeable impact on sustainability.

In the following section, we examine the top-three developments with significant upside potential for the industry (Figure 6) – namely, semiconductor fab 4.0, autonomous disassembly and green electronic materials – along with underlying opportunities and challenges.

Semiconductor fab 4.0 demonstrates high potential for immediate impact and carries the least amount of uncertainty. It refers to applying advanced manufacturing techniques for electronic components while saving significantly on energy and resources. For integrated circuit manufacturing, which accounts for roughly 50% of the energy consumed over the life of an average device,[32] driving down energy consumption with production-line data analytics, and efficiently managing resources by using augmented reality to monitor component inventory levels, can generate significant environmental benefits while enhancing cost-competitiveness for manufacturers.

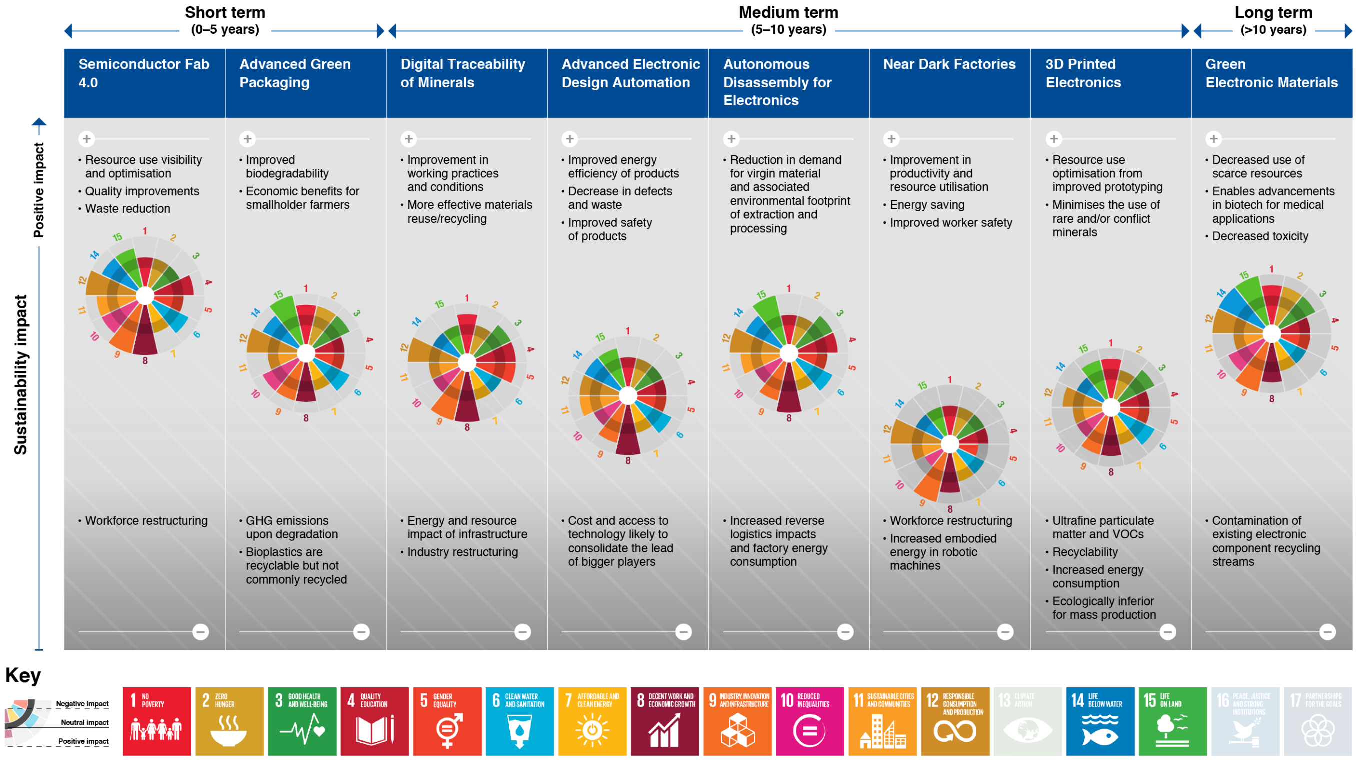
Autonomous disassembly could reduce the demand for virgin material and enable closed material loops. Apple's Liam project, which facilitates the autonomous disassembly of iPhones, helps the company reduce hazardous e-waste while recovering precious metals, such as gold, platinum, silver and rare metals.[33] The project also enhances the organization's competitiveness by using resources efficiently. Robots can disassemble an iPhone in about 11 seconds, creating adequate capacity to disassemble roughly 2.4 million phones each year.[34]

Green electronic materials can potentially drive environmental benefits through a shift towards the use of organic sources and a reduced dependence on non-renewable or potentially toxic materials. The development could also promote economic growth by generating additional income opportunities for farmers. For example, the bacteria Geobacter produces bio-wire and can be grown on cheap organic feedstock.[35] Thanks to this development, farmers can now sell crop residue as feedstock for growing bacteria.

Additional highlights: Advanced green packaging is good for the planet and profits, and is used by companies such as Dell and HP.[36] Green materials made from wheat straw are broken down by specialty enzymes through an organic process. Research indicates that packaging sourced this way can lead to a 40% saving in energy and a 90% reduction in water required for production.[37]

Near-dark factories (facilities with few or no humans) are gaining in uptake but need to be considered carefully. On the upside, these factories can reduce product defects in some cases by up to 80% and boost productivity by a huge 250%.[38] This development's potential downside is in increasing income inequality from reshoring production close to market or in downsizing the workforce in developing areas. Cambridge Industries Group, a leading China-based telecom manufacturer that is converting its production units into near-dark factories, is laying off two-thirds of its 3,000-strong workforce.[39]

Figure 5: Sustainability assessment of Fourth Industrial Revolution developments in the electronics industry



Source: Accenture Strategy analysis

Figure 6: Top-three electronics industry developments with greatest upside potential and descriptions

Intervention	Brief overview
Semiconductor Fab 4.0	Refers to the application of advanced manufacturing techniques to the production of electronic components such as silicon wafer fabrication, semiconductors and microchips, which is very energy and resource intensive. Optimising operations can help improve sustainability significantly with a focus on the adoption of IIoT, big data, advanced analytics, machine learning and cobotics in both front and back-end fabs, especially in emerging markets where there is a considerable opportunity for energy and resource efficiency gains.
Autonomous disassembly for electronics	Refers to the disassembly of electronic products for component reuse and recycling, reducing the demand for virgin material and enabling closed material loops and Circular Economy business models. This development is enabled by modular design technology and advanced robotics and automation within mini disassembly factories. It decreases supply chain risk, mitigates reputation risk in the case of electronics and conflict minerals, and ensures the continuous reuse and valorisation of raw materials.
Green Electronic Materials	Synthetic biological materials from organic sources like bacteria and microbes can help meet the increasing demand for making smaller and more powerful devices. Currently functioning as wires, transistors and capacitors, these materials can decrease the dependence on non-renewable resources and the use of toxic components in electronics in a cost-efficient way. Proposed applications include biocompatible sensors, computing devices and as components of solar panels.

Source: Accenture Strategy analysis

Opportunities to accelerate sustainable production

Given the nature of the electronics industry, where innovation is critical for competitive differentiation, companies in the sector should harness these innovations to accelerate their positive effects. Strategic partnerships with academia and research institutions could help achieve this.

Developments such as autonomous disassembly will require simultaneous business model innovation, both up and down supply chains. Along with developing take-back incentives and infrastructure with customers, manufacturers will need to map critical downstream value chain partnerships, invest in transformation of their supplier networks, and leverage product usage data to drive production system efficiency. Smart devices can feed field data back into engineering and manufacturing processes to reduce obsolescence, and increase the useful life of products.

Businesses must ensure their infrastructure keeps pace with fast-evolving marketplace requirements. Consider those for robotic technology (for developments such as near-dark factories and autonomous disassembly), blockchain solutions for digital traceability or digital assets for 3D printed electronics: all demand capital investments supported by the business sector. Leading organizations are identifying avenues for strategic investments to gain a competitive edge. Foxconn, the manufacturer of Apple's iPhone, piloted a blockchain project, disbursing working capital loans worth $6.5 million to its manufacturing supply chain partners.[40]

From a policy perspective, framing incentivization mechanisms is an opportunity to seamlessly channel funds needed for capital investments. Governments could consider the implications of fully automated production facilities for local economies, and could mitigate risks by ensuring they have a viable industrial strategy in place.

Food and beverage

Context

The food and beverage industry is characterized by a relatively small number of multinational companies linking small producers from around the world with consumers.[41]

Developing and emerging economies are key players, often heightening the importance of sustainability issues. The industry is low-tech (according to the OECD's technology classification based on R&D intensity relative to value added) and can absorb innovation without significant societal downsides. In fact, analysis by the United Nations Industrial Development Organization (UNIDO) shows that the industry can sustain value-added growth across various stages of economic development, thanks to continuing labour productivity gains at a rate similar to per-capita growth of GDP and a very slow decline in employment.[42]

The sustainability challenges for food and agriculture in the short and medium term are particularly acute. Agriculture accounts for 80-90% of freshwater consumption[43] and 24% of global GHG emissions.[44] A quarter of all food, measured by calorie content, is wasted from "farm to fork", and 8% of the loss occurs in the upstream value chain.[45] Agri-food systems contribute significantly to soil erosion and pollution because of fertilizers, pesticides, deforestation and over-irrigation. The International Food Policy Research Institute indicates that 5 to 10 million hectares of cropland are lost annually to severe degradation, and that declining yields can be expected over a much larger area.[46]

Feeding the world in 2050 will require a 70% increase in overall food production because of population growth and changes in consumption driven by an expanding middle class,[47] with demand for red meat and dairy products increasing by up to 80%.[48] Every opportunity presented by the Fourth Industrial Revolution must be used to realize a global food production system that can address challenges with limited environmental impact while harnessing growth, innovation and development opportunities. The Business and Sustainable Development Commission estimates that opportunities to create value for the SDGs in agri-food value chains could potentially reach $2.3 trillion annually by 2030.[49]

Fourth Industrial Revolution developments

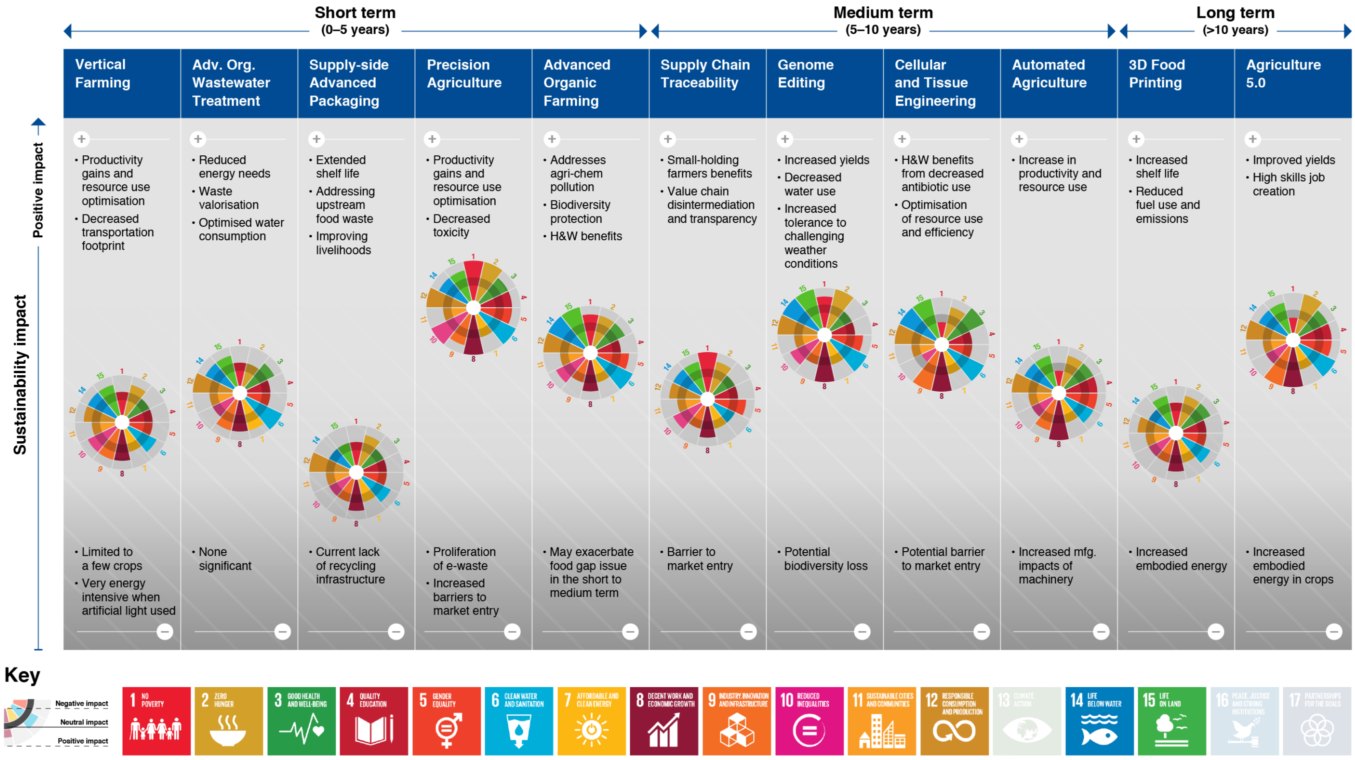
This analysis focuses predominantly on upstream value chain segments due to the low-tech nature of food and beverage processing and production, and the substantial potential for improving efficiency in agri-food activities. Our research identified 11 ways in which Fourth Industrial Revolution developments will change production systems in the food and beverage industry through innovation in digital, physical and biological technologies (Figure 7).

In the following section, we consider the top-three developments with the most significant upside potential for SDG value creation in the industry (Figure 8) – namely, precision agriculture, advanced bio-farming and genome editing for food crops – as well as the business and sustainability opportunities and challenges they present. An example of how precision agriculture works is by deploying moisture sensors and analysing data at an automated irrigation system.

Precision agriculture works by deploying moisture sensors and analysing data at an automated irrigation system. Water consumption was reduced on one Californian almond plantation by 20%.[50] Analysis to date has indicated that growing a single almond consumes as much as 3.8 litres of water, making for considerable environmental gains.[51]

IBM research suggests that 90% of all crop losses are due to weather.[52] Predictive modelling and precision agriculture techniques could reduce weather-related crop damage by 25%.[53] This has significant consequences, especially for national and regional economies that rely on agri-food production. As a testament to the importance of precision agriculture, agricultural tech investment jumped to a record $25 billion in 2016.[54]

Figure 7: Sustainability assessment of Fourth Industrial Revolution developments in the food and beverage industry



Source: Accenture Strategy analysis

Figure 8: Top-three food and beverage industry developments with greatest upside potential and descriptions

Development	Brief overview
Precision Agriculture	Integrates data and analytics with crop science to enable scientific farming decisions. It leverages technologies such as GPS, soil sensors, weather data and IoT for decisions related to fertiliser, irrigation, harvesting time, seed spacing etc. It is applicable to the entire agricultural production system and drives substantial yield gains whilst optimising for resource use.
Advanced Bio Farming	The convergence of precision Ag-Tech and the use of biological solutions for agriculture developed via advanced green chemistry (e.g. bio-stimulants and bio-pesticides). They represent a broad spectrum of products based on naturally occurring micro-organisms for pre- and post-harvest application. The solutions reduce chemical pollution to land and water, help address biodiversity decline and mitigate risks to human health and wellbeing from conventional agri chemicals.
Genome Editing	A technique that enables scientists to hack into genomes, make precise incisions, and insert desired traits into plants. In contrast, traditional genetic modification alters DNA to include genes from other organisms to produce a desirable trait. Genome editing can promote drought tolerance, increase in yields and productivity from agri equipment.

Source: Accenture Strategy analysis

But downsides do exist too. Precision agriculture could exacerbate global inequality as less developed economies struggle to invest in rural internet infrastructure, affordable finance and e-skills programmes for farmers. In addition, the large-scale deployment of devices could lead to increased and localized electronic waste, especially in geographies where waste management infrastructure is lacking.

Advanced bio-farming is the convergence of precision ag-tech and biological solutions for agriculture, developed through advanced green chemistry and microbiome technologies.

Artificial fertilizers have had tremendous success boosting agricultural productivity. Yet, nitrogen and phosphorous from agricultural run-off has affected marine ecosystems and created man-made “dead zones” in 10% of the world’s oceans,[55] with a notable example lying in an 8,500 square-mile swathe of the Gulf of Mexico near the Mississippi River Delta.[56]

The environmental, social and economic benefits from large-scale deployment of bio-based solutions are vast. A 21st-century approach to organic farming should leverage the soil and crop microbiome for production breakthroughs, in combination with precision agricultural techniques, to close the conventional organic-yield gap (currently at about 19%[57]) and create biodiversity benefits. The opportunity is already attracting start-ups and multinationals investing billions of dollars, while creating a new frontier for agri-food production.[58]

Genome editing presents an efficient and cost-effective opportunity to accelerate traditional selective breeding and cultivation practices in farming.[59] Changes that took decades, even centuries, to make can now be done in a few months thanks to new gene editing tools, such as CRISPR/Cas 9. Such tools come with fewer of the risks associated with past genetic engineering techniques.[60]

The technology creates significant business value. For one, getting genetically modified crops approved for use is a complex and expensive process. Successes to date include large commodity crops, such as corn and soya.[61] The technology can democratize and scale bioengineering to economically and environmentally critical plants, cut costs, increase yields and enable the value created to be shared between industry stakeholders. Consider this: every year, the porcine reproductive and respiratory syndrome virus costs pig farmers in Europe nearly $1.6 billion, and $664 million in the United States.[62] Genome editing could be used in livestock to make animals healthier and more productive, helping to reduce economic losses from disease.

Regarding environmental sustainability, the technology enables research into breeding plants that are more drought tolerant, resource efficient, and adaptive and resilient to climate change. Further, it can help improve the genetics of native livestock in tropical latitudes,[63] bettering the livelihoods of hundreds of millions of smallholding farmers dependent on livestock. Appropriate regulation and access to the technology are critically important in realizing and sharing this technology's economic, social and environmental value.

Additional highlight: Cellular and tissue engineering are applied to end products, such as meat, eggs and milk. Animal-based foods, particularly beef, are resource intensive and offer little resource productivity compared with other protein sources, such as plants or fish. In fact, while animal-based food production accounts for 75% of the land used globally for food production, and for two-thirds of the GHG emissions associated with agriculture, it delivers only 27% of total protein consumption.[64] Changing cultures and diets could take decades in the best of scenarios. Turning to technology may be the preferred (or only) choice if society is to safely navigate the challenges that future food needs will impose on common global assets.

Opportunities to accelerate sustainable production

The World Resources Institute points to the task of feeding 9.8 billion people by 2050[65] while also advancing rural development, reducing GHG emissions and protecting valuable ecosystems as the greatest challenge of our era.[66] Thus, critical success factors are shifting for the industry: competitiveness is a strategic balancing act between creating economic value, considering environmental consequences and managing social implications. Increasing yields at the farm level and optimizing processing incrementally can no longer chart the future for food and beverage production. The Fourth Industrial Revolution offers opportunities for transforming agri-food systems while driving net positive effects on SDGs.

Realizing the potential value of these developments involves additional R&D, considerable capital investments, institutional support and the availability of talent, as well as physical and digital infrastructure. Few players have the resources and capabilities to pursue it alone. However, by working together, gene editing labs and manufacturers of agri-technology can accelerate the development of food varieties better adapted to existing or prototyped agricultural robots. Digital farming solution providers can work with local funding institutions to secure affordable finance for the customers they seek. Tailoring, scaling and deploying precision agricultural solutions globally go hand in hand with developing funding and upskilling programmes. Both represent areas where collaboration is critical; shaping the future of organic food production in chemical and biotech industry coalitions is another.

"The key challenge is industry and government working together to promote a strong, risk-based regulatory environment to encourage the commercialization of new technologies and investment through the entire agriculture value chain – from seeds to packaging."

Lisa Schroeter, Global Director, Trade and Investment Policy, Dow Chemical Company, USA

Governments must shape policy that stimulates and enables development. To do so, they need to stay abreast of technological advances in the industry, and carefully evaluate socio-economic implications and the necessary enabling environment on a case-by-case basis. The digitization of agriculture, for example, will require access to finance and skills programmes that could be government backed. This is especially important for developing countries that risk falling behind, as the Fourth Industrial Revolution and concerns about climate change begin to shift the geographic dynamics of agri-food systems.

Textiles, apparel and footwear

Context

The demise of the Multi-Fibre Agreement in 2005 has defined the industry's competitive landscape. That agreement imposed quotas on the amount of yarn, fabric and clothing developing countries could export to developed ones, thus triggering a shift of production from the latter to the former group. Consequently, the industry accounts for a high proportion of total manufacturing jobs in many countries where economic development is a central issue.[67]

The global textiles, apparel and footwear industry has been led by market forces and dominated by a small number of larger organizations, with apparel brands and lean retailers exerting downward pressure on prices. The result is limited technological change beyond design, capacity and speed-to-market variables, and an industry heavily intertwined with sustainability issues.

In the past, sustainability efforts focused on safe and fair working conditions, and eradicating child labour practices. In recent years, the growing concern has been the industry's environmental impact, which tends to vary depending on the type of fibre used. Challenges focus on resource depletion and GHG emissions from processing fossil fuels for synthetic fibres, significant water and chemical use related to production of fibre crops, and water, toxicity and hazardous waste and effluents related to the production stage.[68] For example, polyester production for textiles in 2015 alone released GHGs equivalent to the annual emissions of about 185 coal-fired power plants.[69] Moreover, producing one cotton shirt still requires about 2,700 litres of water,[70] and global textile consumption is expected to triple by 2050 compared to 2015 levels.[71]

Nevertheless, global clothing production doubled between 2000 and 2014.[72] The current "fast fashion" means garments are made at a rate of 50 cycles per year versus the two cycles of traditional fashion.[73] Consumers are becoming aware of the fashion value chain and expect companies to step up regarding sustainable production practices, as evidenced by numerous certification schemes. This poses a challenge for businesses – namely, how to capture exploding demand from discerning and less predictable consumers, while preparing for a cleaner and leaner industry where technology transformations are shifting upstream.

Fourth Industrial Revolution developments

This analysis focuses on upstream value chain segments due to the low-tech character of the industry, and the sustainability implications of fibre origin, production and processing. Our research identified 12 ways in which the Fourth Industrial Revolution will change systems of production in the textiles, apparel and footwear industry, with innovation in digital, physical and biological technologies (Figure 9).

In the following section, we consider the top-three developments with the most significant upside potential for SDG value creation in the industry (Figure 10) – namely, alternative natural fibres, gene-edited fibre crops and biofabricated leather – as well as the business and sustainability opportunities and challenges they present. In fact, the greatest potential for accelerating sustainable production in the near term is in alternative natural fibres and precision agriculture for fibre crops. (This commentary will focus on alternative natural fibres, as issues regarding precision agriculture were addressed in the food and beverage section.)

Alternative natural fibres can be used to produce textiles with superior properties from raw inputs that are renewable and biodegradable. Based on recent market developments (e.g. decreasing paper consumption) and scientific evidence, forest-based textile fibres can also be included in this group.[74]

Thanks to green chemistry and enzyme science, innovators have solved the stiffness that plagues bast fibres, such as flax, hemp or jute.[75] Hemp requires much less water than cotton; it also grows quickly, and its roots aerate the soil, leaving it rich for future crops. Moreover, hemp yields about three times more fibre per acre than cotton.[76] While the sustainability of forest fibre production depends largely on the wood sourcing and chemical treatments used, these materials can deliver strong environmental performance.[77] Importantly, these benefits come with few risks related to land use and deforestation.

Scaling production would translate into socio-economic benefits for farmers in developed and developing countries globally, with new opportunities to create value from waste streams (e.g. pineapple leaves) or to grow alternatives to cotton, which is costlier than oil-based synthetics.[78] The latter group of materials presents a challenge whose scale and far-reaching consequences are only beginning to emerge from urban waterways and oceans alike.

"A groundbreaking innovation to close the loop is our RefibraTM fibre, which uses pulp from cotton scraps as a raw material. The final target is to close the loop also on post-consumer waste. Technologies have gotten better, chemically and mechanically. The challenge lies in identifying the chemical composition of waste streams of fibres. Digital technologies can help address this along the value chain."

Stefan Doboczky, Chief Executive Officer, Lenzing, Austria

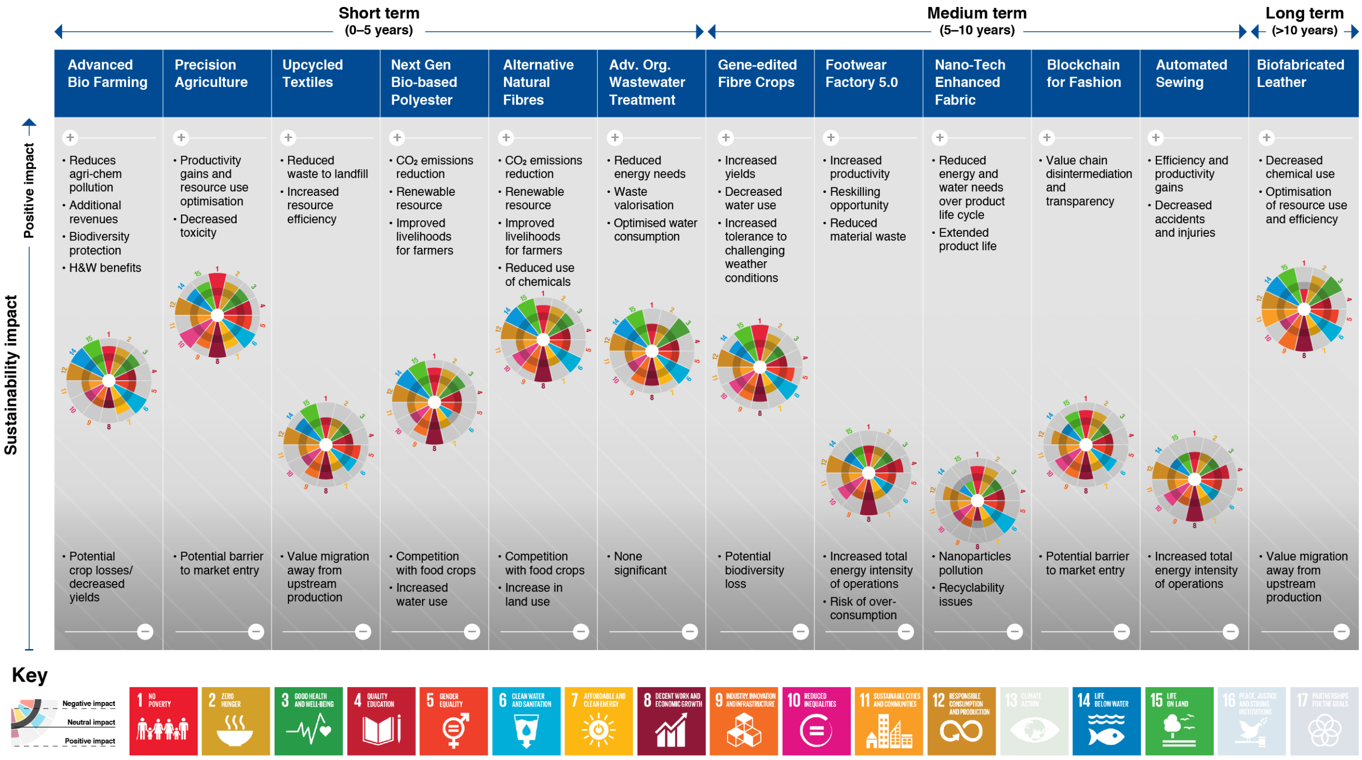
Recent tests have shown that billions of people around the world drink water contaminated by microplastic, with 83% of samples found to be polluted.[79] Developments in green chemistry would mitigate microplastic pollution driven by synthetic clothing.

Gene-edited fibre crops leverage the same technologies mentioned in the food and beverage industry section of this White Paper. They improve the productivity of fibre crops and can be used to manipulate the physical properties of yarns and fabrics.

The development of cultivated upland cotton has plateaued in its ability to create further value-added products in a non-genetically invasive way.[80] The complex genome feature of allotetraploid[81] cotton is challenging, but the latest research has proven that CRISPR/Cas9-mediated mutation of cotton genes is feasible although the heritability of these gene modifications requires further study.[82] Considering that cotton occupies 2.4% of the world's crop land and accounts for 24% and 11% of the global sales of insecticides and pesticides, respectively,[83] further improvements in cultivated cotton can have a significant effect on sustainability.

This development opens the door to applying genome editing to cotton, and possibly to other natural fibre plants. Genetic modifications to cotton have resulted in the reduction of insecticides and increases in yields, but not without unintended consequences, such as a loss of biodiversity and a monopoly in seed supply.[84] Open

Figure 9: Sustainability assessment of Fourth Industrial Revolution developments in the textiles, apparel and footwear industry



Source: Accenture Strategy analysis

Figure 10: Top-three textiles, apparel and footwear industry developments with greatest upside potential and descriptions

Development	Brief overview
Alternative Natural Fibres	Textile fibres made from non-edible plants or parts of plants that are high in cellulose (e.g. pineapple leaves, coconut husks, banana stems). The source of fibre is farm residue that is often not of much commercial value. This also includes natural textile fibres that could be used as alternatives to cotton and petroleum-based textiles, pure or in textile blends, such as flax, hemp, bamboo and seaweed. These plants can provide fibres with superior properties that are renewable and biodegradable.
Gen-Edited Fibre Crops	Leveraging CRISPR/Cas9 genome editing for fibre crop improvement, especially in relation to cotton. The technology has the potential to address issues of decreasing yields due to soil erosion, water intensity and overuse of agri chemicals, whilst presenting a value creation opportunity for industry leaders and major exporting countries of cotton, such as China, India and US.
Biofabricated Leather	The production of leather without the use of animal hides via lab-grown biofabricated tissue from in-house created collagen cells. The collagen is purified and finished utilizing a simplified process of tanning that uses fewer chemicals. There is no waste because size and shape are determined by design whilst physical properties, such as variable sheet topography, are customisable. The process is faster and cleaner, resulting in an ethical product with reduced environmental footprint.

Source: Accenture Strategy analysis

source platforms with commercial plant genome data and editing technologies can help democratize the access to improved, more resource-efficient textile fibres.

Biofabricated leather is the latest option available in the long list of leather substitutes and alternatives. However, current alternatives to animal leather are mostly inorganic, non-biodegradable, less durable and heavy contributors to environmental pollution.[85] An estimated 430 million cows will need to be slaughtered annually to satisfy global fashion demands by 2025, making for a potentially significant effect from lab-grown materials. (These estimates exclude industrial demand, such as in the automotive sector.[86]) Skin is the most economically important byproduct of the meat industry.[87] Leather's environmental impact is related to that of industrial farming and leather processing, the latter being highly toxic.

For example, levels of tanning-related toxins in the Ganges River near Kapur, India are about 6.2 milligrams per litre versus a government-mandated limit of 0.05 milligrams per litre.[88]

Along with addressing ethical and environmental issues related to leather production, lab-grown or biofabricated leather can be lighter, thinner and stronger.[89] Businesses can capture demand from ethically conscious shoppers and develop new products that mimic the properties of even rare or extinct animals. In fact, lab-grown leather can offset the decreasing supply of traditional leather.[90] However, although the industry is expected to continue growing in many developing and newly industrialized countries,[91] the negative effect on existing industry workers is a potential risk should this technology scale quickly. (It should be noted that no other industry uses livestock hides and skins.)

Opportunities to accelerate sustainable production

While no single alternative natural fibre can either replace cotton, or take the considerable market share of oil-based synthetics, a combination of these materials at scale, along with awareness campaigns targeted at end users, can contribute significantly towards decoupling the industry's growth from its ecological footprint. Technology is already enabling this, but further research is needed. In addition, existing collaborative efforts for scaling can benefit from governmental support, similar to how traditional fibre crop subsidies are used, such as those for the US cotton programme.[92]

Gene-edited varieties of fibre plants can be adopted at scale to improve yields, drive down maintenance costs and increase earnings for farmers. This, in turn, will positively affect a country's economic growth and GDP, while mitigating the industry's supply-side and reputational risks. Biofabricating leather is a nascent development on a longer-term commercial horizon. While it has socio-economic downsides, biofabrication is a real opportunity for meeting burgeoning global demand without increasing the number of livestock. The ability of start-ups to deliver volumes and uptake by major apparel brands is fundamental. Special collaboration platforms that safeguard IP rights can be created to advance this idea.

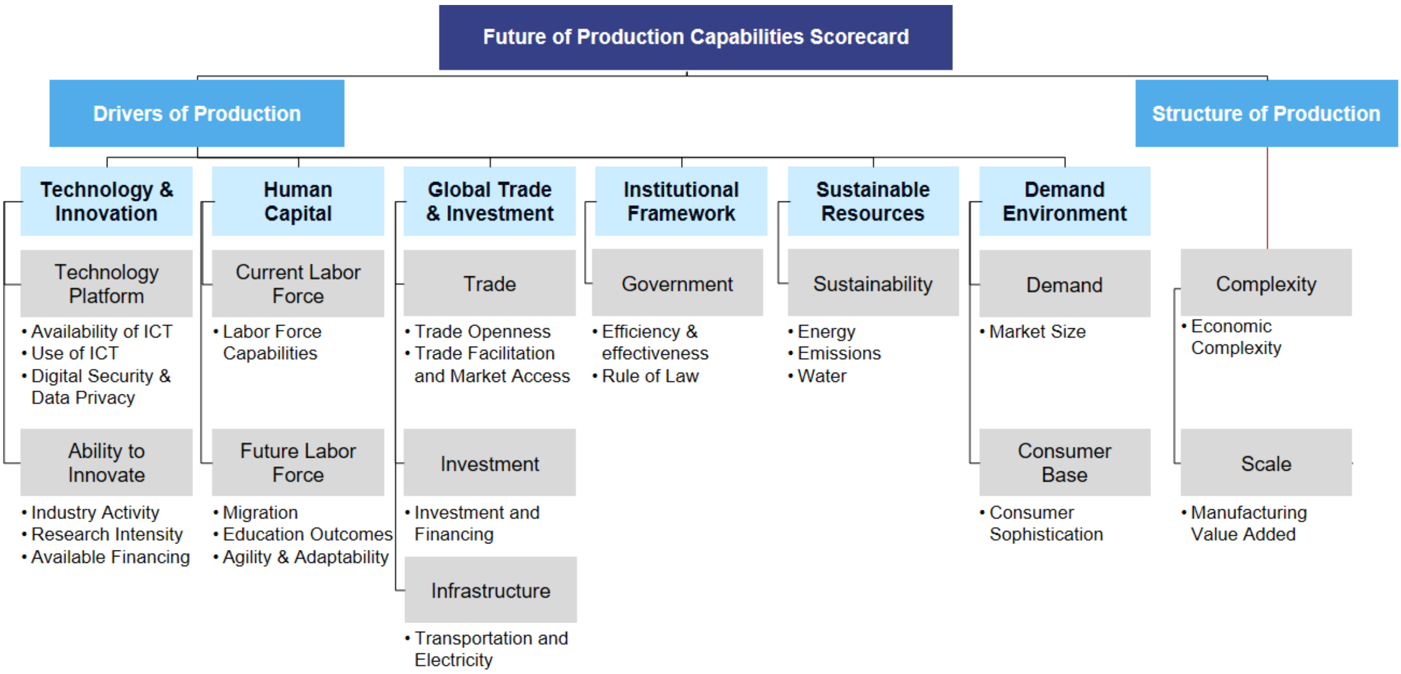
Chapter Two: Regional opportunities

The Fourth Industrial Revolution will likely deploy very differently across regions, varying in speed and scale between those with legacy assets and those starting from scratch. The classic economic development trajectory – from agrarian to industrial to post-industrial society – is becoming obsolete. Industry will go directly to the most sustainable and competitive model by combining technology, asset-light processes and new business models.

This chapter explores opportunities for accelerating sustainable production practices based on understanding the regional context (drawn from the World Economic Forum Readiness for the Future of Production assessment 2017-2018) and identifying critical success factors for adopting sustainable production developments drawn from case study analysis.

The forward-looking country readiness assessment uses a framework (Figure 11) based on two dimensions: the structure of production (the baseline of current production) and the drivers of production (the key enablers that position a country to capitalize on emerging technologies to transform its production systems).

Figure 11: Country Readiness Index framework to assess the future potential of production

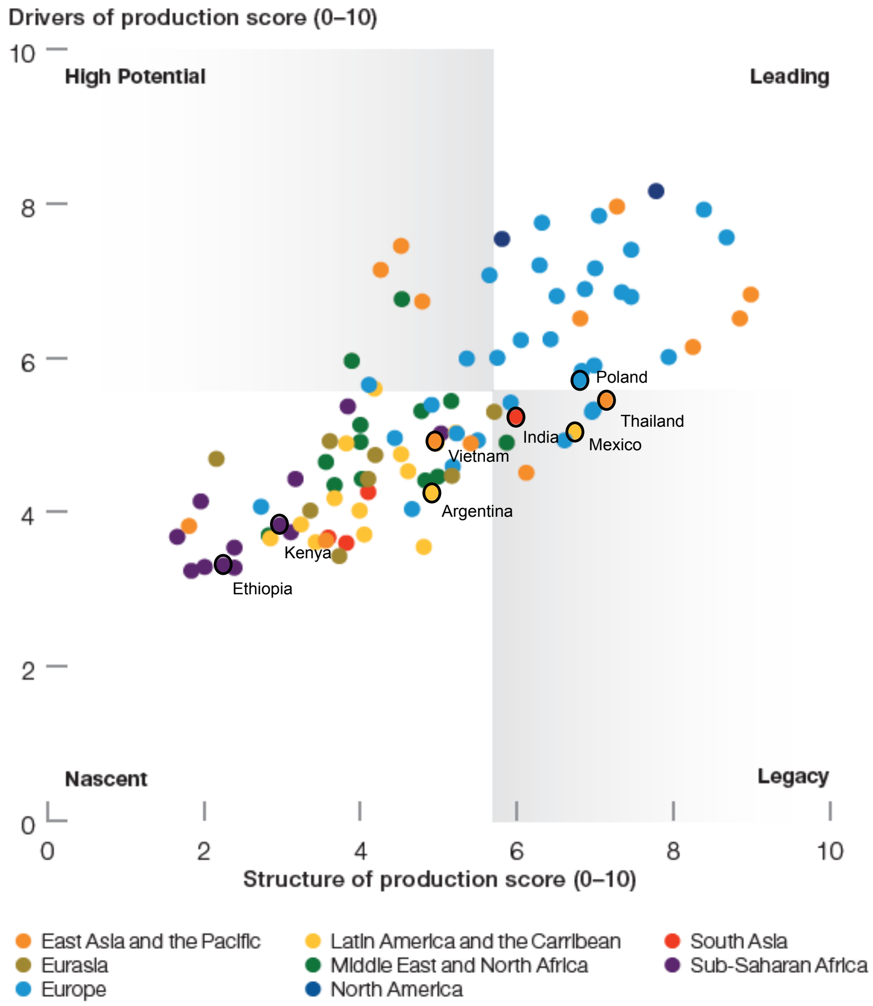


Source: A.T. Kearney/World Economic Forum analysis

The framework leverages a data-driven approach to map countries across four broad archetypes (Figure 12) – (1) global leaders: strong current base and positioned well for the future, (2) legacy champions: strong current base but at risk for the future, (3) high potential: limited current base but positioned well for the future, and (4) followers: limited current base and at risk for the future.

To keep the analysis specific yet representative, the following geographies were studied closely – Europe (Poland), Africa (Kenya, Ethiopia), Asia Pacific (India, Thailand, Vietnam) and Latin America (Argentina, Mexico).

Figure 12: Relative positioning for the future of production (eight countries analysed)



Source: A.T. Kearney/World Economic Forum analysis

Europe (Poland)

Regional context

From the framework, the local context in Poland (Figure 13) positions the country strongly on the following categories:

- **Strong trade infrastructure** (robust trade linkages and access to markets)
- **Robust physical infrastructure**
- **Complex structure of production** (high maturity in collaboration across the value chain as well as across industries)
- **Strong focus on sustainability**

Poland has experienced growing consumer consciousness regarding sustainability,[93] a trend that could increase demand for traceability of products, eliminate counterfeit products and provide fair information for consumers.

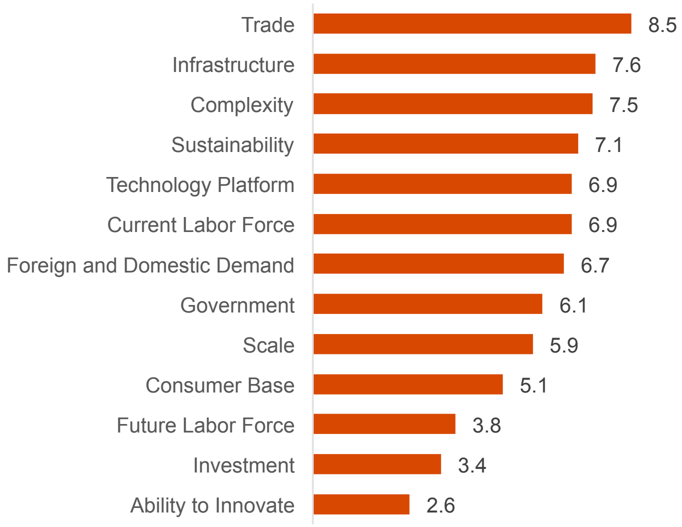
Diffusion opportunities

Given the complex structure of production and strong focus on sustainability, Poland appears to be receptive to innovations related to industrial production. For example, the YuMi cobot, developed by ABB, allows for designing and testing through ongoing operations, provides better quality, increases productivity and reduces shop-floor commissioning time by up to 25%.[94] Kurtz Ersa, a Germany-based manufacturer of electronic production equipment, was the first organization to select YuMi cobots to perform repetitive soldering tasks for small and medium production volumes.[95]

Automated cobots in Germany: collaborative automated production

The YuMi cobot, a collaborative dual-armed robot, is human-sized and weighs 38 kilograms. Precise and fast, it returns to the same point in space over and over again to an accuracy of 0.02 mm, and moves at a maximum velocity of 1,500 mm per second. Priced at $40,000, the YuMi has a payload capacity of 0.5 kilograms per arm and can be easily integrated with a workstation.

Figure 13: Country Readiness Index framework score - Poland



Source: A.T. Kearney/World Economic Forum analysis

From an implementation perspective, accelerating developments such as cobots may require a greater focus on R&D and an ability to innovate – something Poland could improve on, as reflected by its relatively low score on these parameters in the framework.

Growing consumer consciousness could underpin manufacturing innovations that have the potential to support **local consumer demand at scale.** Adidas' Speedfactory, a footwear factory in Germany, enables adapting shoe design to meet customer demand at scale.[96] Through Speedfactory, Adidas created city-specific sneakers for London, Paris, Los Angeles, New York, Tokyo and Shanghai.[97]

Adidas' Speedfactory: Digital and flexible manufacturing

Adidas Speedfactory uses automation, additive manufacturing technology and smart digital twins to manufacture shoes. The Speedfactory idea is to flexibly produce product parts directly from raw material instead of ordering components, shortening its value chain. Speedfactory will allow Adidas to shorten its development and manufacturing time to market from months to days and reduces batches to as little as 500 pairs, or ultimately even individually tailored products. Adidas uses this capability to create localised designs. Speedfactory technology is also being utilized in the traditional supply chain to increase flexibility and speed.

Burgeoning consumer consciousness in Poland could position it strongly for innovations that potentially enhance **consumer trust and transparency**. For example, Walmart's blockchain-based traceability system is a collaboration with IBM that seeks to trace the provenance of its products in its food supply chain. As a result, Walmart can track the source of mangoes from Mexico in just 2.2 seconds;[98] before blockchain, the same process took nearly a week. Regarding execution, innovations such as cobotic production systems, Speedfactory or blockchain-based traceability systems may require supply chain innovations and active collaboration across different partners. The YuMi cobot was created after extensive R&D and innovation through ecosystem collaboration between YuMi and its end users.

Implications and actions

Opportunities to accelerate Fourth Industrial Revolution developments in Poland are centred on boosting R&D and fostering industrial collaboration. Businesses could consider partnerships with academic institutions and R&D centres to develop state-of-the-art technologies. Over 700 companies are currently working with faculty and students at the Massachusetts Institute of Technology on collaborative industry-specific problem-solving. The companies include BAE, BP, Boeing, Du Pont, Eni, Ford Motor, Google, Intel, Lockheed Martin, Novartis, Quanta Computer, Raytheon, Samsung, Sanofi, Shell, Siemens and Total.[99]

Policy opportunities include fostering cross-border alliances and partnerships through incentivization mechanisms, such as the European Commission's Circular Economy Package helping European businesses and consumers transition to a stronger and more circular economy.[100] Policy mechanisms like these could allow Poland to leverage the R&D maturity of neighbouring countries, such as France and Germany. (In the Readiness for the Future of Production Assessment 2018 edition scale of 10, France and Germany are rated at about 6-7 on parameters such as research intensity and ability to innovate.)

Africa (Kenya, Ethiopia)

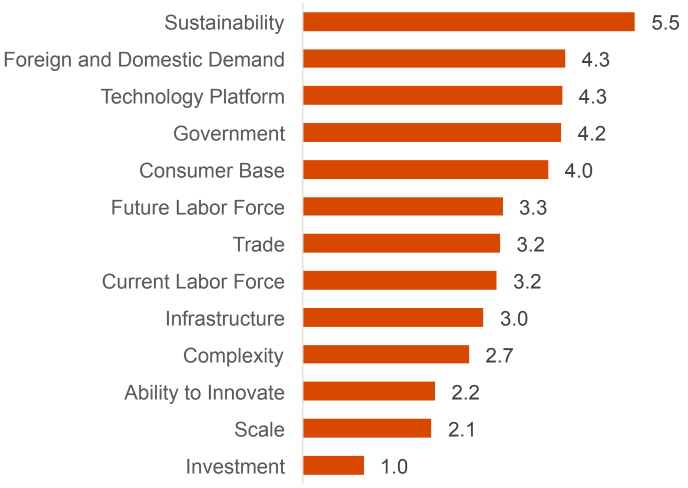
Regional context

The average country readiness scores for Kenya and Ethiopia (Figure 14) reveal strong positioning in the region on:

- **Sustainability** (high focus on efficient usage of natural resources and active measures to minimize the negative effects of production on the environment)
- **Technology platform** (advanced, secure and connected information and communications technology [ICT] infrastructure to support production technologies)

Additionally, the data provided in the underlying subcategories (not depicted in the figure) reveal that the two countries are also relatively strongly positioned on agility and adaptability of the workforce. In fact, while the average scores for Kenya and Ethiopia are less than 4 across most of the subcategories, their average scores on agility and adaptability stand at 5.0 and 4.3, respectively. Additionally, agricultural activities play a critical role in both countries and for the continent overall. The study considered this fact: Kenyan agriculture makes up about 25% of the country's GDP and accounts for roughly 75% of its workforce.[101]

Figure 14: Country Readiness Index framework score - average for Kenya and Ethiopia



Source: A.T. Kearney/World Economic Forum analysis

Given these regional nuances, Kenya and Ethiopia could be well positioned to leverage their agile and largely agrarian workforces to embrace agricultural innovations, such as vertical farming, precision farming and non-food-based bio-textiles.

Diffusion opportunities

The diffusion of agricultural innovation can be seen in companies such as Clean Air Nurseries South Africa (CAN-SA). Having implemented **vertical farming** units across South Africa, CAN-SA produce is claimed to have lower environmental impact and greater health benefits.

Manufacturing leather from Pinatex fibre requires technology to convert pineapple waste into leather in an environmentally friendly way.[102] The innovation could be particularly beneficial for Ethiopia, where pineapple cultivation is increasing.[103]

Pinatex fibres: manufacturing leather from pineapple leaves

Pinatex is the commercial name of a fibre used to make leather developed from pineapple leaves. Long fibres are extracted from the leaves through a process called decortication. The fibres are degummed and processed in the Philippines to form a non-woven mesh. This intermediate product is shipped to Spain, where it is turned into durable leather. Leaves from 16 pineapple plants are required to create one square metre of Pinatex, which is priced at £18.

Pineapple agriculture globally generates about 13 million tonnes of waste, a significant portion of which can be converted into Pinatex. The waste generated from decortication can also be used as fertilizer or to generate biogas.

The region could also benefit from advances in **precision agriculture**. Monsanto, for example, acquired the Climate Corporation for about $1 billion in 2013.[104] The acquisition enabled Monsanto to collect extensive data about field and weather conditions, allowing the company to leverage this information as real-time intelligence to farmers who could then lock-in profits in case of drought, heavy rain and other adverse weather. The initiative helps farmers via higher yields and a lower risk of crop failure, while Monsanto benefits from a wealth of data that can be used to develop better farming products.

Implications and actions

Businesses can play a unique role in accelerating agricultural innovations through upstream integration and collaboration. With their scale and agility, they could help shape ecosystems made up of farmers, non-governmental organizations and academia, and use the combined expertise to accelerate development.
Policy-makers could:

- **Develop new certifications and standards** to ensure safety requirements and help create awareness among consumers. For example, People for the Ethical Treatment of Animals (PETA), an American animal rights organization, has certified Pinatex as a cruelty-free label.[105] Similar certifications in local African geographies could play a crucial role.
- **Acceleration mechanisms** could provide an opportunity to leverage incubation centres, innovation hubs and funding mechanisms to encourage entrepreneurial initiatives. These initiatives could complement the geographies' strong position regarding an agile and adaptable workforce.

Asia Pacific (India, Thailand, Viet Nam)

Regional context

Figure 15 shows that India, Thailand and Viet Nam are strongly positioned in the Asia-Pacific region on:

- **Demand** (access to foreign and local demand, and a sophisticated consumer base driving diverse industrial activities)
- **Scale** (high manufacturing added value as a percentage of GDP)
- **Physical infrastructure**

Along with these characteristics, industries also play a role. Electronics exports in Asia contributed to nearly one-third[106] of all exports. Though China has been a large contributor to date, countries such as Viet Nam and India are gaining traction.[107] In the automotive industry, Asia contributes nearly half of global passenger car production, with India and Thailand as the fifth- and twelfth-largest automotive manufacturers in the world, respectively.[108]

On a regional basis, local economies in Asia Pacific may be more receptive to manufacturing innovations, particularly in the automotive and electronics industries. Strong trade linkages in these countries could help diffuse best practices from developed economies.

Diffusion opportunities

In the automotive industry, Toyota's foray into bio-polymer components[109] for its new vehicles could be an interesting development for local manufacturers to consider. Through this initiative, the company aims to replace a portion of traditionally plastic components with bioplastics.

In Europe, Renault's short loop recycling programme could serve as another inspiration. The company embarked on this revolutionary project as part of its circular economy strategy. Through a network of industry partners and vehicle dismantling centres across France, Renault is successfully reusing 95% of end-of-life vehicles[110] (85% by material recovery and 10% by energy generation). Currently, the company's vehicles manufactured in Europe comprise 36% of recycled material by mass.[111]

Toyota's foray into bio-polymer components: biomass to replace plastic

The company has stated that 20% of all its plastic components will be bioplastics fully sourced from bio- or organic materials. To realize this ambitious goal, Toyota Tsusho, the group's trading arm, has partnered with US-based Anellotech, a producer of 100% bio-based plastics. Anellotech uses a specialized technology for converting non-edible biomass into plastic for producing polymers. A testing facility has been commissioned and a commercial-scale facility for production of bio-polymer components may be licensed by 2020.

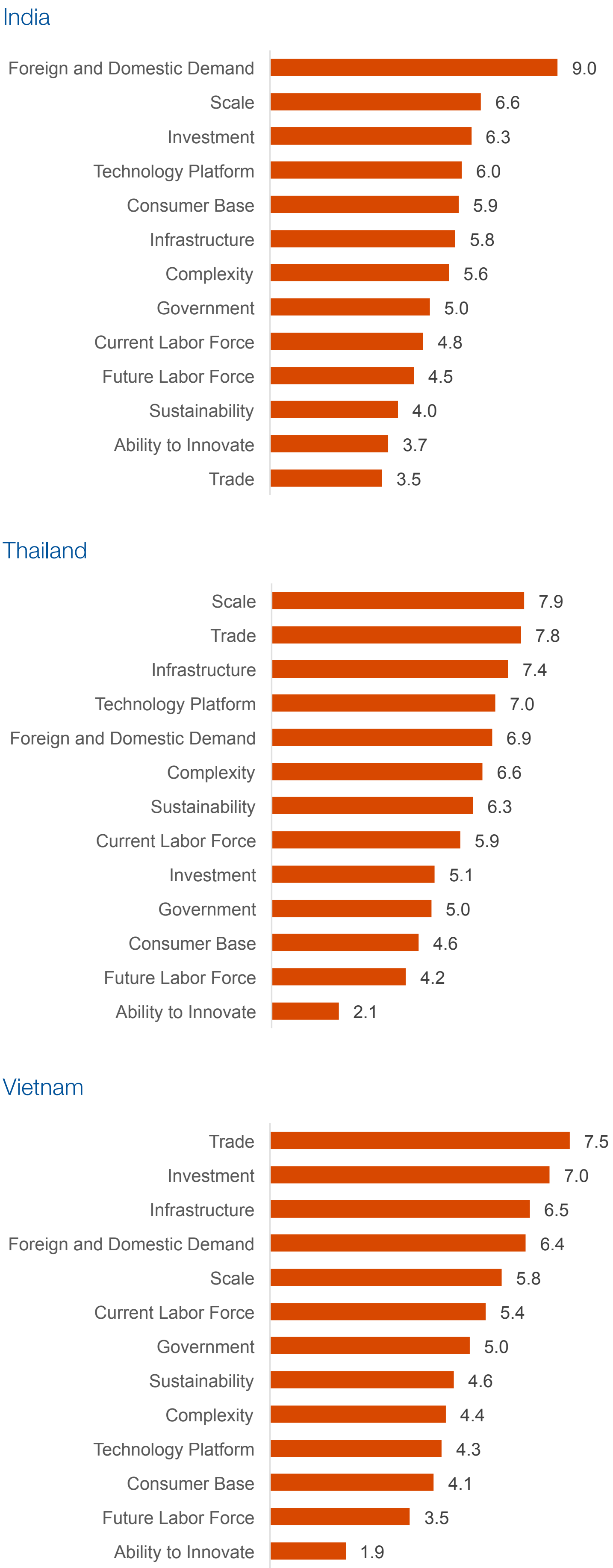
Ford is investing heavily in the United States to transform itself into a major player in three areas: electrification, autonomy and mobility.[112] Its capabilities are underpinned by connectivity. Through these investments, the company has started to transform its business model from focusing on selling products to selling outcomes – namely, mobility over vehicles. The OEM will add 13 new vehicles to its product portfolio by 2020, offering electrification on more than 40% of its vehicle line-up by 2020.[113]

Electronics is another industry with diffusion opportunities for scale-up economies in Asia Pacific. The region already accounts for a significant share of global electronics R&D. Moreover, it is well positioned to embrace innovations, such as bio-nanowires[114] being developed by the University of Massachusetts (USA).

Bio-nanowires: US-based electronics innovation

Geobacter (a type of bacteria) can transfer electrons to electrode surfaces. Bio-nanowires made from this technology are highly conductive and can be produced with low toxicity and low energy costs. Geobacter nanowires can conduct a charge similar to carbon nanowires, and could potentially be integrated into electronic devices and sensors.

Figure 15: Country Readiness Index framework score



Source: A.T. Kearney/World Economic Forum analysis

The 3D-printed Organ-on-a-Chip[115] represents a promising innovation in the United States. Organ-on-a-Chip technology mimics bodily functions, including digestion, breathing and cardio-pulmonary systems. This expands the avenues of research for disease testing, toxicology and drug screening, and is an alternative to animal testing. 3D printing of such devices has facilitated automated fabrication, with increased levels of complexity at potentially lower costs.

Implications and actions

Cross-border partnerships could accelerate the adoption of innovations in the automotive and electronics sectors in countries such as Viet Nam, Thailand and India. Local automotive and electronics manufacturing companies could form partnerships and joint ventures with relevant players from more mature geographies.
Government and policy-makers could explore actions, including:

- **Driving the adoption of digital technologies and ICT infrastructure:** Governments and policy-makers could consider introducing policy mechanisms to drive the use of digital technologies and investment in ICT infrastructure to enable hyperconnected systems of production. India, for example, is already developing such mechanisms through programmes like the Digital India campaign,[116] but many countries lack pervasive broadband connectivity to fully realize the potential.
- **Upskilling the labour force:** Given the region's relatively low score (roughly 4.1) on the Future Labour Force category, upskilling the labour force is a potential opportunity. The workforce must have a basic understanding of innovative technologies, and needs to be exposed to them from primary school on up. Government can play a critical role by introducing upskilling programmes, such as the Pradhan Mantri Kaushal Vikas Yojana[117] initiative launched by the Government of India. It aims to enable young people to gain industry-relevant skills, helping them to secure a better livelihood.

Latin America (Argentina, Mexico)

Regional context

Across North and Latin America, Mexico and Argentina are strongly positioned on the following framework attributes (Figure 16):

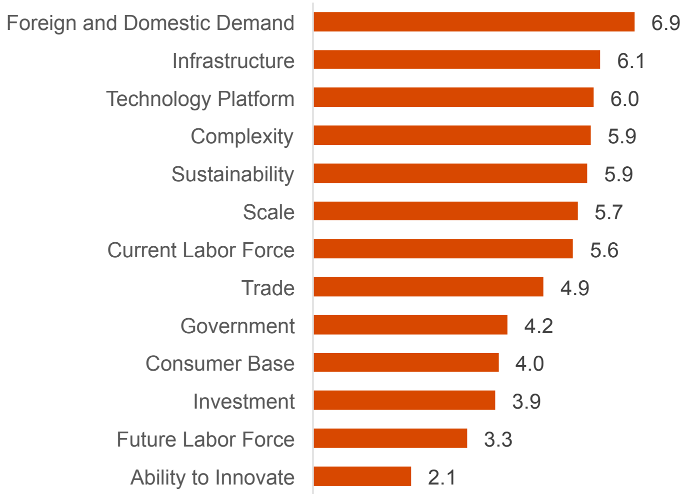
- **Demand** (access to foreign and local demand, and a sophisticated consumer base driving diverse industrial activities)
- **Robust infrastructure and technology platform**

The food and beverage industry in the Americas is heavily focused on meat products. In fact, Argentina has the world's highest per-capita consumption of meat.[118]

Memphis Meats: lab-developed products with less impact

Food technology start-up Memphis Meats is developing lab-grown meat in the United States. Starter cells taken from live animals are made to proliferate in a growth medium inside a bioreactor. Initial taste tests for beef, chicken and duck have produced positive results. The company claims that lab meat production reduces GHG emissions, as well as land and water use, by a huge 90%. In March 2017, the production cost of one pound of meat was $9,000. The company expects affordable consumer prices by 2021.

Figure 16: Country Readiness Index framework score - average for Argentina and Mexico



Source: A.T. Kearney/World Economic Forum analysis

Diffusion opportunities

The region is well positioned for upstream innovations in the food and beverage industry. US-based DuPont, for example, leveraged **CRISPR gene editing tools**[119] to develop a variety of corn with higher starch content and reduced water requirements. The technology can also be used to target disease reduction in crop growth. DuPont expects to commercialize this technology by 2020.

Some newer innovations are being introduced in the Americas that bring sustainable practices to the sector. Taste tests of **lab-grown meat** developed by US-based Memphis Meats[120] have demonstrated good results across products from different animals. Lab-grown meat also provides an environmentally and animal friendly alternative to the traditional product. Tencel® lyocell fibres, made from renewable-resource wood, represent another development with potential. Fibres are ecologically sourced and have a significantly smaller environmental footprint in the production process, thanks to lower demand for water, solvents, dyes and bleaches.[121] This technology can be scaled up to geographies such as Mexico and Argentina, both of which have dense growth of eucalyptus trees.

Lenzing's Tencel® branded lyocell fibres: environmentally friendly textiles

The Austrian company Lenzing has developed the Tencel® lyocell fibre from wood. The trees require no irrigation, and pesticides are sourced from sustainably managed forests and plantations. The wood is crushed into chips that are dissolved, and a solvent spinning process generates the fibre. The pure white fibres do not require bleaching and need less dye due to high absorbency. The production process recovers over 99% of the solvent inputs for reuse, making it a closed loop process. A ton of Tencel® lyocell fibre can be manufactured from trees harvested from 0.3 hectares (0.7 acres) of land year by year; producing the same amount of fibre from cotton would require four times the land and more than 20 times the water.

Implications and actions

Consumer scepticism and inertia tend to hobble innovations in the food and beverage industry. Business could thus consider **consumer awareness campaigns:** lab-meat producers could explore campaigns that socialize the upside of production and allay fears surrounding "artificial" products.

Policy-makers could consider **developing new certifications and standards** to promote and monitor new sustainable fibres. For instance, environmentally friendly fibres may face consumer scepticism without Ecocert certification.[122] Developing similar standards may help instil the necessary consumer and industry confidence.

Chapter Three: The Accelerating Sustainable Production framework

The precipitous pace of technology development is easily noticed, both in industry and everyday life. But understanding and quantifying how that change creates value and simultaneously contributes to the SDGs (in place since 2015) are far more difficult. This represents the challenge taken on with the Accelerating Sustainable Production framework.

The United Nations High-Level Political Forum on Sustainable Development will review progress on Goal 12 (sustainable consumption and production) in July 2018. Production systems, however, can potentially contribute to a far wider range of SDGs. The Accelerating Sustainable Production framework will help businesses and policy-makers map out a coherent strategy to boost progress against the spectrum of SDGs by understanding the links between the innovations of the Fourth Industrial Revolution and the SDG targets.

The first task in constructing the framework was to measure the value to industry from implementing a Fourth Industrial Revolution development in the production system. The team leveraged the value at stake approach, developed by the World Economic Forum Digital Transformation of Industries project, with the scope extended to cover physical and biological technologies in addition to digital. Six industry value levers were considered in this part of the framework: the potential effect on an industry's operating profits (value addition); the profits that shift between industry players (value migration); the customer benefits, and the effects on labour, society and the environment.

In addition, an understanding was required of the connections between these industry value levers and the SDGs. The 17 SDGs were revisited, with a detailed review conducted of the underlying 232 indicators and their definitions. This allowed to map the six value levers to the SDGs at their lowest level, creating causal links that help to understand which levers can be pulled by industry to contribute directly to the SDGs (Figure 17, for the automotive industry).

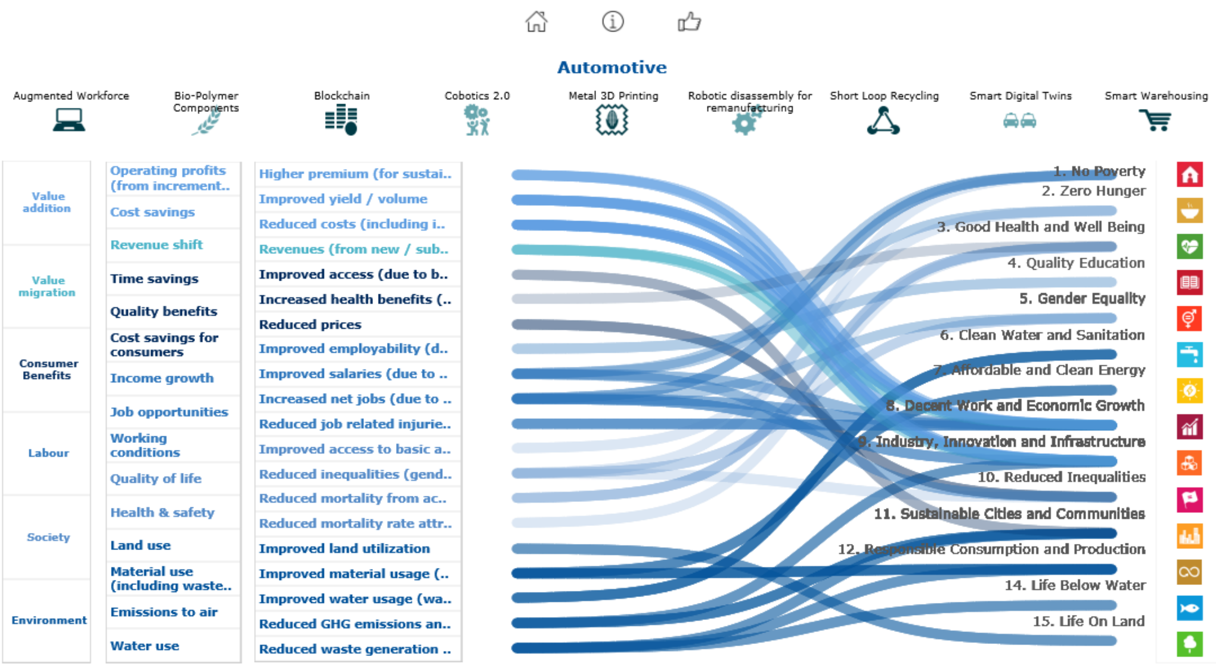
Finally, the 40 sustainable production developments identified in this White Paper were mapped to the relevant value at stake levers and SDG indicators. This resulted in a framework that can be used to measure the business value and SDG contribution of the Fourth Industrial Revolution developments identified in this paper, but which can also be applied to understand the effect of innovations not discussed here. (Appendix 2 provides information on the methodology behind the framework.)

The framework has been translated into an interactive tool. Leaders can use it to navigate the sustainability impacts and opportunities of the Fourth Industrial Revolution for a given set of innovations in their industry. In addition, they can wield them strategically to gain a triple-bottom-line value. The tool also enables stakeholders to run scenarios for any other development outside those identified in this paper.

Business leaders can see the complex network of effects; when targeting an SDG, they can determine which levers to pull. Additionally, business leaders can understand and communicate their contribution to the United Nations 2030 Agenda for Sustainable Development. Imagine being part of the automotive industry and wanting to understand the effect of blockchain (Figure 18). The tool maps the connection between the Fourth Industrial Revolution development and the SDGs, shows the links to the drivers of value creation and provides information on the time horizon, the technologies involved as well as the associated benefits and risks (Figure 19).

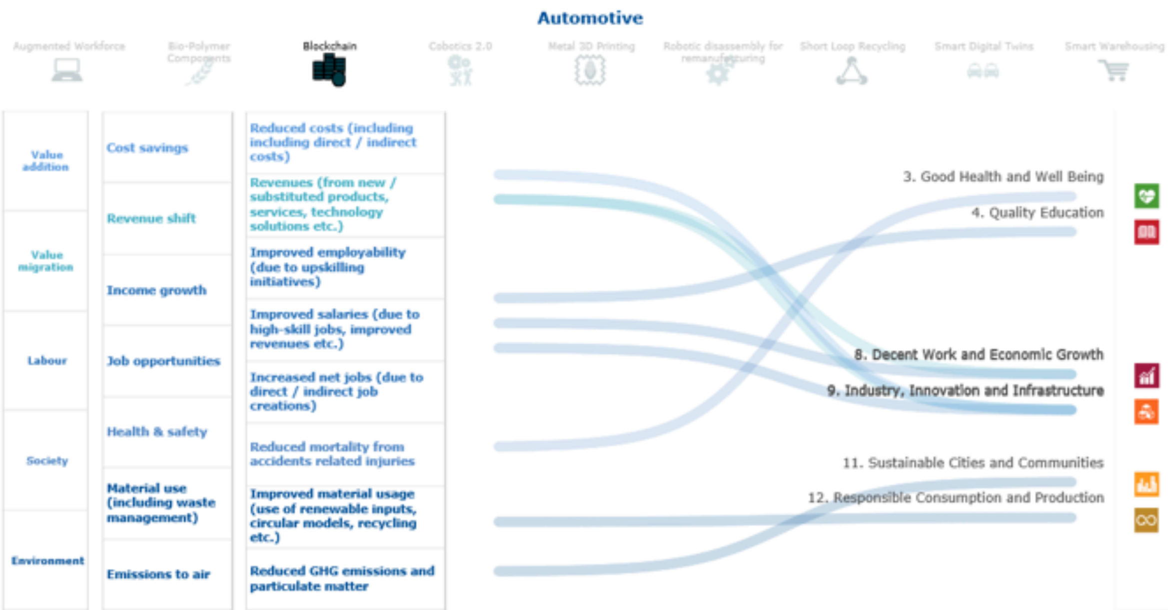
The next step in this project will be to apply the model with partner countries and organizations to quantify the value and contribution to the SDGs.

Figure 17: Accelerating Sustainable Production framework tool – mapping value drivers to SDG indicators in the automotive industry (screenshot)



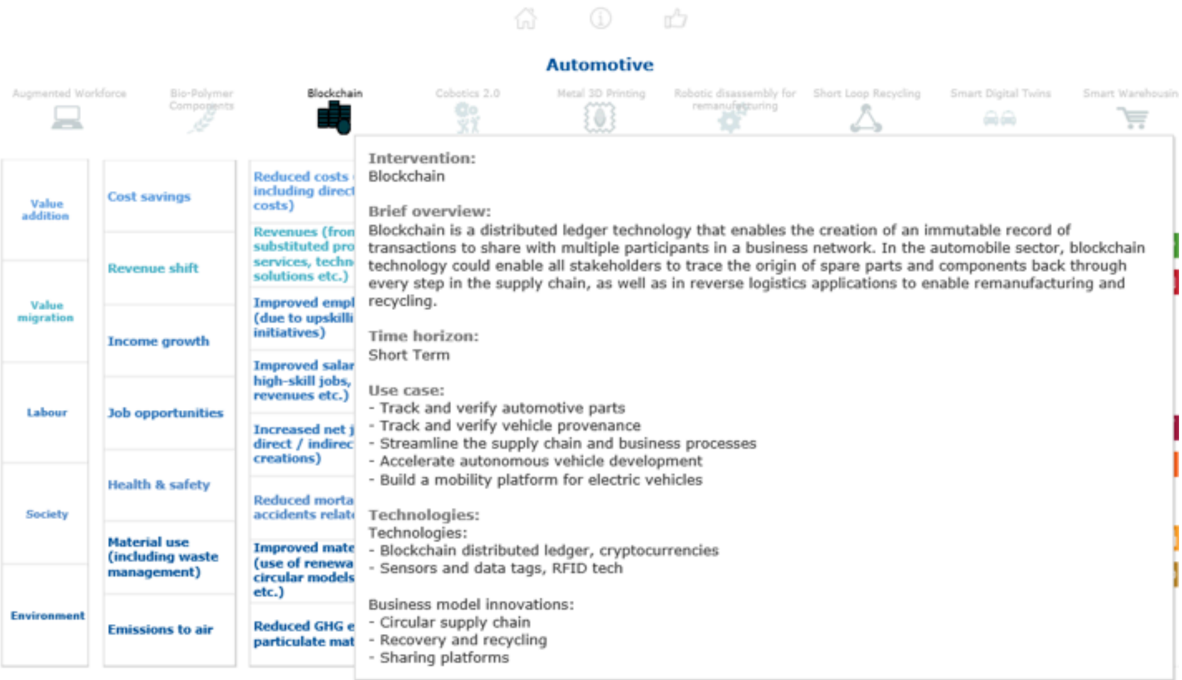
Source: Accenture Strategy

Figure 18: Accelerating Sustainable Production framework – mapping value drivers to SDG indicators for a selected Fourth Industrial Revolution development (blockchain) in the automotive industry (screenshot)



Source: Accenture Strategy

Figure 19: Accelerating Sustainable Production framework – detail of a selected Fourth Industrial Revolution development (blockchain) in the automotive industry (screenshot)



Source: Accenture Strategy

Appendices

Appendix 1: Details of Fourth Industrial Revolution sustainable production developments

Automotive

Figure 20: Sustainable production technological developments and descriptions in the automotive industry

Development	Brief overview
Short loop recycling	Short loops, in which all recycling processes remain in the automotive sector, are set up to recover and recycle materials for (re)manufacturing leveraging multiple partnerships enabled by digital platforms and geo proximity. Current examples of such short loops are set up to recycle raw materials such as steel, copper, textiles, and plastics, keeping them as much as possible in the local automotive industry.
Bio-based plastics and composites	Replacing heavier metal and plastic components with engineering-grade biopolymers and/ or lighter natural-fibre-reinforced plastics created partially or wholly by using plant feedstock. For example, structures can use flax fibres and bio-epoxy resin intermingled with carbon fibres in hybrid composites, which are lighter, cheaper and more environmentally sustainable than conventional polymers. These materials and parts are suitable for multiple vehicle systems, including powertrain applications.
Smart Digital Twins	The convergence of existing digital twin technology with the industrial internet of things and machine learning technologies, providing a near real-time updates and digital asset representation created by sensors deployed on the machines. The digital twin paradigm enables manufacturers to operate factories efficiently and gain timely insights into product performance.
Cobotics 2.0	A cobotic system includes a robot and a human collaborating to perform a task to achieve higher productivity and also protecting human workers from potentially hazardous jobs (i.e. jobs with higher incidence of accidents). A lighter weight, mobile plug and play generation is arriving on the factory floor to collaborate safely with human workers thanks to advances in sensor and vision technology, and computing power.
Metal 3D printing	A shift toward metal-printing to allow more flexibility in general and application-specific materials. Applications in the auto industry are characterized by the broad adoption of additive for production tooling, spare and custom parts, and increased industrial uptake to print components of end products. Building objects from the bottom up and using the material only where needed reduces waste, enables weight reduction, and has a cost advantage, especially when using materials like titanium and nickel-alloy steels.
Blockchain	Blockchain is a distributed ledger technology that enables the creation of an immutable record of transactions to share with multiple participants in a business network. In the automobile sector, blockchain technology could enable all stakeholders to trace the origin of components back through every step in the supply chain, as well as in reverse logistics applications to enable remanufacturing and recycling.
Smart Warehousing	Advances in Autonomous Mobile Robotics (AMR) technology now allow robots to be used in warehouses, where they support high volumes of small, multi-line orders, often in collaboration with warehouse workers. This leads to productivity gains, decrease in accidents and injuries amongst workers, as well as opportunities for skills development and retraining. Current research is focusing on incorporating machine learning into AMR solutions.
Augmented workforce	The use of augmented reality tech (AR) in various stages of the vehicle production process. AR can support complex assembly, machine maintenance, expert support needs and quality assurance processes in the automotive industry. It is a collaborative tool that facilitates automation on the shop floor, enables productivity gains, resource efficiency and drives health and safety improvement.
Robotic disassembly for remanufacturing	Robots are widely used in automotive manufacturing but not in remanufacturing, particularly at the critical stage of disassembly. Advances in this sphere could mean that end-of-life product disassembly for remanufacture will become easier, faster and more cost-effective, driving efficient resource use and enabling the circular economy in the industry.

Source: Accenture Strategy research

Figure 21: Sustainable production technological developments in the automotive industry – time horizons, key technologies and business considerations

Development	Impact Time Horizon	Key technology & innovation characteristics (non-exhaustive)	Key business considerations
Short-loop recycling	**Short-term (present to 5 years)**	• **Physical tech:** Advanced material sorting, Robotic disassembly • **Digital tech:** Track and trace technologies, Machine vision, Cloud; Big data • **Other:** Business model innovation (recovery and recycling, circular supply chains)	• Vertical integration • Reverse logistics • Ecosystem adaptation
Bio-based plastics and composites	**Short-term (present to 5 years)**	• **Physical tech:** Nanotechnology (refers to the use of nanoparticles in lightweight materials), Advanced scientific instrumentation, Microfibre technologies e.g. for cellulose microfibre-enabled composites • **Digital tech:** Smart lab technologies for R&D, Big data, Cloud • **Biological tech**: Advanced green chemistry and chemical engineering	• Regulatory approvals required • R&D investments • Recyclability
Smart Digital Twins	**Medium-term (5 – 10 years)**	• **Physical tech:** Sensors and actuators, computing technologies • **Digital tech:** IIoT, Simulation software, Machine learning/ AI for predictive analytics and simulation, Big data, Cloud • **Other:** Real time simulation and diagnostics on the factory floor	• Data storage capabilities and cybersecurity • Capital investments • Connected products and services
Cobotics 2.0	**Short-term (present to 5 years)**	• **Physical tech:** Machine 3D sensing, Sensors and actuators, Electromechanical design tools • **Digital tech:** Advanced software for industrial robots, IIoT • **Other:** New safety solutions based on sensors and machine sensing	• Employee training • Process changes • Capital investments
Metal 3D printing	**Short-term (present to 5 years)**	• **Physical tech:** 3D printers and printing methods, New materials e.g. metal additive manufacturing • **Digital tech:** Advances in CAD design, cybersecurity improvements • **Other:** Advances in material science	• IP and cybersecurity • Stakeholder readiness • Recyclability
Blockchain	**Medium-term (5 – 10 years)**	• **Physical tech:** Sensors and data tags, RFID technology • **Digital tech**: Blockchain-distributed ledger, Cryptocurrencies • **Other:** Business model innovation (circular supply chains, sharing platforms)	• Cybersecurity • Transparency and traceability • Talent acquisition/Capability development
Smart Warehousing	**Long-term (>10 years)**	• **Physical tech:** Autonomous mobile robotics • **Digital tech:** Machine learning, Vision sensing, Software technology • **Other:** Effectively supports the start of an assembly line working in logistics	• Capital investments • Employee training • Process changes
Augmented workforce	**Medium-term (5 – 10 years)**	• **Physical tech:** Display technology, mobile devices • **Digital tech:** IIoT, Cloud, Data and analytics, Software technology • **Other:** Process innovation for machine maintenance, quality control, complex assembly	• Capital investments • Talent acquisition (Designers) • Employee training
Robotic disassembly for remanufacturing	**Medium-term (5 – 10 years)**	• **Physical tech:** Robotic and cobotic technologies, Machine 3D sensing and Machine Vision, Sensors and actuators, Electromechanical design • **Digital tech**: IIoT, Cloud, Data and analytics • **Other:** Other: Business model innovation (recovery and recycling, circular supply chains)	• Capital investments • Employee training • Process changes

Source: Accenture Strategy research

Electronics

Figure 22: Sustainable production technological developments and descriptions in the electronics industry

Development	Brief overview
Digital Traceability of Minerals	Blockchain-enabled software for precious and industrial metals markets to prevent "conflict minerals" from entering electronic products value chains. Private permissioned blockchain tech can chronologically and permanently log information that is copied across a computer network accessed by multiple collaborating parties. Transactions involving the source of ore can be linked back to previous sales transactions.
Semiconductor Fab 4.0	Refers to the application of advanced manufacturing techniques to the production of electronic components such as silicon wafer fabrication, semiconductors and microchips, which is very energy and resource intensive. Optimising operations can help improve sustainability significantly with a focus on the adoption of IIoT, big data, advanced analytics, machine learning and cobotics in both front and back-end fabs, especially in emerging markets where there is a considerable opportunity for energy and resource efficiency gains.
Advanced Electronic Design Automation	EDA, a simulation technology in the field of electronics design, calculates and predicts materials and components performance to create the optimum configuration for products. Used in chip design, it is now extending to the entire development process for an electronic device in combination with machine learning to increase the efficiency and accuracy of both design and production, resulting in faster time to market with accelerated prototyping, fewer batch defects and product recalls.
Near-dark Factories	Automated factories with robotic systems manufacture electronic products with limited or no human intervention. Though true lights-out production is still rare, more processes are running with limited human interaction. This results in considerable productivity gains, increased throughput and total capacity, whilst minimising errors and waste.
Autonomous disassembly for electronics	Refers to the disassembly of electronic products for component reuse and recycling, reducing the demand for virgin material and enabling closed material loops and Circular Economy business models. This development is enabled by modular design technology and advanced robotics and automation within mini disassembly factories. It decreases supply chain risk, mitigates reputation risk in the case of electronics and conflict minerals, and ensures the continuous reuse and valorisation of raw materials.
3D printed electronics	The use of 3D printing for the production of electronic products hardware components. By 3D-printing printed circuit boards (PCBs), designers can obtain faster prototypes, thereby accelerating time to market and ensuring efficient use of resources. This application of 3D printing is very new and limited to prototyping at present but companies are already experimenting with a focus on conductive inks to match the properties of the traditional metals used for electronics.
Green Electronic Materials	Synthetic biological materials from organic sources like bacteria and microbes can help meet the increasing demand for making smaller and more powerful devices. Currently functioning as wires, transistors and capacitators, these materials can decrease the dependence on non-renewable resources and the use of toxic components in electronics in a cost-efficient way. Proposed applications include biocompatible sensors, computing devices and as components of solar panels.
Advanced Green Packaging	Material science innovation has allowed lead electronic product companies to incorporate sustainable packaging in the products leaving the factory gates, such as mycelium-based protective foam, use of AirCarbon®, and leftover wheat straw processed by enzymes. Benefits include increased reputation for companies and reduced carbon footprint.

Source: Accenture Strategy research

Figure 23: Sustainable production technological developments in the electronics industry – time horizons, key technologies and business considerations

Development	Impact Time Horizon	Key technology & innovation characteristics (non-exhaustive)	Key business considerations
Digital Traceability of Minerals	**Medium-term (5 – 10 years)**	• **Digital tech:** Blockchain, Cloud computing, Online platforms • **Physical tech:** RFID, Mobile • **Other:** Business model innovation (sharing platforms, circular supplies, recovery and recycling)	• Cybersecurity • Reputation • Talent acquisition/capability development/ collaboration
Semiconductor Fab 4.0	**Short-term (present to 5 years)**	• **Digital tech:** Cloud computing and Big data, Advanced analytics, Cobotic systems and Machine learning • **Other:** Lean programmes	• Capital investments • Long term competitiveness
Advanced Electronic Design Automation	**Medium-term (5 – 10 years)**	• **Digital tech:** Electronic Design Automation tools, Cloud computing, Big data, IIoT, Machine learning • **Other:** R&D process re-design	• Cybersecurity • Capital investments • Talent acquisition/capability development
Near-dark Factories	**Medium-term (5 – 10 years)**	• **Physical tech:** Robotics and intelligent automation, Sensors and actuators • **Digital tech:** Factory floor planning tools, IIoT, Cloud computing and storage, Analytics	• Cybersecurity • Capital investments • Stakeholder readiness
Autonomous disassembly for electronics	**Medium-term (5 – 10 years)**	• **Physical tech:** Advanced robotics and automation, Sensors and actuators, Mobile devices • **Digital tech:** Digitally enabled return logistics, Cloud computing • **Other:** Business model innovation (circular supplies), Process design	• Employee training • R&D • Capital investments
3D printed electronics	**Medium-term (5 – 10 years)**	• **Physical tech:** Printers and printing methods/ inks, nanotechnology • **Digital tech:** CAD software, Electronic Design Automation tools • **Other:** Materials science, Mechanical engineering, Proprietary processes for Printed Circuit Boards printing and conductive inks	• Capital investments • Internal capabilities • Innovation driver
Green Electronic Materials	**Long – term (>10 years)**	• **Physical tech:** Nanotechnology, Advanced scientific instrumentation • **Biological:** Bio-hybrid systems/Synthetic biology and bioengineering, advanced green chemistry • **Other:** Materials science	• Collaboration opportunities • Innovation driver • Links to bioscience and biotech
Advanced Green Packaging	**Short – term (present to 5 years)**	• **Physical tech:** Advanced scientific instrumentation • **Biological tech:** Advanced green chemistry, Enzyme solutions • **Other:** Materials science	• Collaboration opportunities • Cost absorption • Supply chain readiness

Source: Accenture Strategy research

Food and beverage

Figure 24: Sustainable production technological developments and descriptions in the food and beverage industry

Development	Brief overview
Precision Agriculture	Integrates data and analytics with crop science to enable scientific farming decisions. It leverages technologies such as GPS, soil sensors, weather data and IoT for decisions related to fertiliser, irrigation, harvesting time, seed spacing etc. It is applicable to the entire agricultural production system and drives substantial yield gains whilst optimising for resource use.
Advanced Bio Farming	The convergence of precision Ag-Tech and the use of biological solutions for agriculture developed via advanced green chemistry (e.g. bio-stimulants and bio-pesticides). They represent a broad spectrum of products based on naturally occurring micro-organisms for pre- and post- harvest application. The solutions reduce chemical pollution to land and water, help address biodiversity decline and mitigate risks to human health and wellbeing from conventional agri chemicals.
Genome Editing	A technique that enables scientists to hack into genomes, make precise incisions, and insert desired traits into plants. In contrast, traditional genetic modification alters DNA to include genes from other organisms to produce a desirable trait. Genome editing can promote drought tolerance, increase in yields and productivity from agri equipment.
Vertical Farming	Producing food indoors in vertically stacked layers with or without sunlight by deploying technologies that control all aspects of the agri environment, e.g. humidity, temperature, fertigation, angle of light exposure, etc. Technological and energy advances have helped accelerate this development in food production, increasing yields, reducing crop waste and logistics costs.
Automated Agriculture	Leverages mechatronics-based technologies (such as agri robots) to drive greater automation of upstream production activities, increasing operational efficiency and resource productivity. Examples include robotic harvesting, sowing/ spraying with agri drones, mechanized milking of cows, autonomous tractors etc. Benefits include but are not limited to productivity increases, resource efficiency and the mitigation of risks with respect to labour shortages in developed economies.
Agriculture 5.0	This development refers to the convergence of precision farming augmented by the next generation of agri robotic systems with machine learning and agri bioengineering to create the farm of the future, maximise productivity and yields, and minimise inputs. Currently in its experimental stage, this development is driven by academic and industry partnerships.
Cellular & Tissue Engineering	The use of biotechnologies to engineer tissues from cell culture for end-product application, such as meat, or the use of cells/ microorganisms as a "factory" to produce fats and/ or proteins that make up an end food product, such as eggs and milk. If scaled sufficiently, this development has potential to decrease land and water use, reduce GHG emissions, and address antibiotic resistance in humans.
3D Food Printing	Machines that print, cook, and serve foods on a mass scale. 3D food printing can manufacture complex foods by combining nozzle technology with robotics and fresh ingredient handling. The technology can improve the nutritional value of processed foods, extend shelf life and decrease food waste.
Supply-side Advanced Packaging	Packaging which interacts with or reacts to changes in the internal environment to maintain its contents within optimal parameters for as long as possible, or communicate information to value chain participants. Uses biotechnologies, and digital sensor systems, such as time temperature indicators, knock indicators and RFID labels. It could work with distributed ledgers and help decrease upstream food production waste.
Supply Chain Traceability & Control	Distributed ledger-enabled solutions to enhance traceability and transparency along the food value chain enhanced by track and trace technology, cryptocurrencies and digital, which converge together to disintermediate the value chain, indicate provenance and increase livelihoods for farmers via increased incomes.
Advanced Organic Wastewater Treatment	Leverages wastewater-to-energy biochemical processes, advanced membrane solutions and biological catalysts used to speed up the bio-degradation of organic waste whilst harvesting energy. The technology removes >99% of the contaminants, enabling water reuse whilst generating renewable energy from biogas for use by the processing facility.

Source: Accenture Strategy research

Figure 25: Sustainable production technological developments in the food and beverage industry – time horizons, key technologies and business considerations

Development	Impact Time Horizon	Key technology & innovation characteristics (non-exhaustive)	Key business considerations
Precision Agriculture	**Short-term (present to 5 years)**	• **Physical tech:** GPS, Sensors, Drones, Mobile • **Digital tech:** IoT, Big data and Analytics, Cloud • **Other:** Crop science	• Affordability/ Need for low cost solutions/ Access to finance • Need for skills/ capacity building
Advanced Bio Farming	**Short-term (present to 5 years)**	• **Physical tech:** GPS, Sensors, Drones, Mobile, Adv. Green Chemistry • **Digital tech:** IoT, Big data and Analytics, Cloud • **Biological tech:** Biocatalysis, bioremediation, microbiome technologies	• Growth of the market • Product premium • Economies of scale
Genome Editing	**Medium term (5 – 10 years)**	• **Physical tech:** Genome sequencing chips, 3-D printed tooling • **Digital tech:** Big data, analytics, simulation modelling, AI (in some experimental cases) • **Biological tech:** CRISP-R/Cas9 gene editing tool	• Policy and regulation • Consumer awareness • Early stage innovation (gene targets are somewhat limited)
Vertical Farming	**Short-term (present to 5 years)**	• Physical tech: Sensors and actuators, Agri engineering • Digital tech: Big data, Cloud, Analytics, Mobile • Biological tech: Hydroponics, Aeroponics, Aquaponics • Other: Circular Economy business models	• Energy intensity • Skills / capacity building
Automated Agriculture	**Medium term (5 – 10 years)**	• **Physical tech:** GPS, Drones, Agri robotics, Sensors and actuators • **Digital tech:** Big data, Cloud, Analytics, Mobile, Machine sensing and machine vision	• Affordability/ Access to finance • Growth of the market
Agriculture 5.0	**Long-term (>10 years)**	• **Physical tech:** GPS, Drones, Agri robotics, Sensors and actuators • **Digital tech:** Big data, Cloud, Advanced analytics, Mobile, Machine sensing and machine vision, Machine learning • **Biological tech:** Genome editing	• Affordability/ Access to finance • Need for skills/ capacity building • Stakeholder readiness
Cellular & Tissue Engineering	**Medium term (5 – 10 years)**	• **Physical tech:** Advanced scientific instrumentation, 3-D printed tooling • **Digital tech:** Big data, Analytics, Cloud • **Biological tech:** Bio-fabrication, Bio-catalysis, Genome editing	• Growing market and decreasing costs • Partnerships for scaling • Consumer readiness
3D Food Printing	**Long-term (>10 years)**	• **Physical tech:** 3D printers and printing methods, New materials e.g. food cartridges and edible binding cement • **Digital tech:** Advances in CAD design • **Other:** Food & Nutrition sciences, Hydrocolloids	• High-end and low-cost solutions • Consumer awareness • Early stage innovation
Supply-side Advanced Packaging	**Short-term (present to 5 years)**	• **Physical tech:** New packaging materials • **Digital tech:** Chips, data tags, RFID, Blockchain, Sensors, Data, Could • **Biological tech:** Bioactive technologies	• Upstream applicability • Affordability/ Need for low cost solutions • Supply chain integration
Supply Chain Traceability & Control	**Medium term (5 – 10 years)**	• **Physical tech:** GPS • **Digital tech:** Blockchain/ distributed ledger solutions, cryptocurrencies (in some cases), RFID and data tags, Digital platforms • **Other:** Circular Economy business models	• R&D investments • Partnerships for scaling • Supply chain integration
Advanced Organic Wastewater Treatment	**Short-term (present to 5 years)**	• **Physical tech:** Effluent treatment plants/ Bioreactors, Membrane solutions, Energy harvesting • **Digital tech:** Control dashboards, Data, Analytics, Cloud • **Biological tech:** Biocatalysts, Electromicrobiology, Anaerobic & Aerobic treatments	• Waste stream applicability • Capital investments • Economies of scale

Source: Accenture Strategy research

Figure 26: Sustainable production technological developments and descriptions in the textiles, apparel and footwear industry

Development	Brief overview
Gen-Edited Fibre Crops	Leveraging CRISPR/Cas9 genome editing for fibre crop improvement, especially in relation to cotton. The technology has the potential to address issues of decreasing yields due to soil erosion, water intensity and overuse of agri chemicals, whilst presenting a value creation opportunity for industry leaders and major exporting countries of cotton, such as China, India and US.
Advanced Bio Farming	The convergence of precision Ag-Tech and the use of biological solutions for agriculture developed via advanced green chemistry, such as bio-stimulants and bio-pesticides. These represent a broad spectrum of products based on naturally occurring micro-organisms for pre- and post- harvest application, which reduce pollution to land and water and reduce negative impact on local biodiversity.
Precision Agriculture (for fibre crops)	Integrates data and analytics with crop science to enable scientific farming decisions. It leverages technologies such as GPS, soil sensors, weather data and IoT for decisions related to fertiliser, irrigation, harvesting time, seed spacing etc. It is applicable to the entire agricultural production system and drives substantial yield gains whilst optimising for resource use.
Upcycled Textile Fibres	Chemical technology has already produced upcycled cellulose from wood pulp producing fibres that are superior to commercially available viscose. The technology has recently become applicable to cotton fibres at commercial scale. The method uses less water and chemicals, emits less CO2 and prolongs the usage of raw inputs whilst offering a viable business solution for closing material loops in apparel. Building on this process, researches now have found ways to apply similar methods to cotton-polyester blends through chemical innovation.
Biofabricated Leather	The production of leather without the use of animal hides via lab-grown biofabricated tissue from in-house created collagen cells. The collagen is purified and finished utilizing a simplified process of tanning that uses fewer chemicals. There is no waste because size and shape are determined by design whilst physical properties, such as variable sheet topography, are customisable. The process is faster and cleaner, resulting in an ethical product with reduced environmental footprint.
Next gen Bio-Based Polyester	Bio-based monomers have long been used to produce high-performance chemicals and polymers with textile applicability. However, the latest innovations by Chemical Industry leaders have now resulted in novel high-performance bio-based polyester that is cost effective, 100% renewable and recyclable (from corn stock). Biodegradability and long-term viability of sourcing remain a challenge but the development has the potential to be part of the solution mix required to move away from petroleum-derived products.
Alternative Natural Fibres	Textile fibres made from non-edible plants or parts of plants that are high in cellulose (e.g. pineapple leaves, coconut husks, banana stems). The source of fibre is farm residue that is often not of much commercial value. This also includes natural textile fibres that could be used as alternatives to cotton and petroleum-based textiles, pure or in textile blends, such as flax, hemp, bamboo and seaweed. These plants can provide fibres with superior properties that are renewable and biodegradable.
Footwear Factory 5.0	New type of shortened-supply-chain production micro-plants located in the demand markets. These are highly automated and use processes such as computerised knitting, robotic cutting and advanced additive manufacturing for mass production. At the same time, prototypes are designed and tested by computers using digital twin tech. Besides enabling mass customisation and faster time to market, the micro plants offer improved environmental performance based on increased resource productivity.
Nano-Tech Enhanced Fabrics	Nanoparticles-treated fabrics can repel stains and dirt, or even self-clean, to reduce washing, drying and ironing needs resulting in reduced energy and water footprint over the product life-cycle. This technological development enables differentiation and premiumisation opportunities for clothing manufacturers.
Blockchain for Fashion	Distributed ledger-enabled solutions to enhance traceability and transparency along the textile fibres value chain enhanced by mobile technologies and embedded electronics converging together to garner greater trust, reputation and brand loyalty throughout the product lifecycle. The technology could also be used to verify upstream origin of materials, workers conditions, fabric composition, chemicals used, etc.
Advanced Organic Wastewater Treatment	Leverages wastewater-to-energy biochemical processes, advanced membrane solutions and biological catalysts used to speed up the bio-degradation of organic waste whilst harvesting energy. The technology removes >99% of the contaminants, enabling water reuse and contributing to the renewable energy mix of individual processing facilities.
Automated Sewing	Advances in robotics, machine vision, as well as new process innovations have enabled novel approaches to the automation of sewing on the apparel shop floor, which has remained a largely manual activity to date. Currently available solutions are applicable but not limited to clothing and allow manufacturers to move supply chains closer to customers at a lower cost. Sustainability benefits include reduced transportation and waste.

Source: Accenture Strategy research

Figure 27: Sustainable production technological developments in the textiles, apparel and footwear industry – time horizons, key technologies and business considerations

Development	Impact Time Horizon	Key technology & innovation characteristics (non-exhaustive)	Key business considerations
Gen-Edited Fibre Crops	**Medium term (5 – 10 years)**	• **Physical tech:** Genome sequencing chips, 3-D printed tooling • **Digital tech:** Big data, analytics, simulation modelling, AI (in some experimental cases) • **Biological tech:** CRISP-R/Cas9 gene editing tool	• Policy and regulation • Consumer awareness • Early stage innovation (experimental evidence with cotton)
Advanced Bio Farming	**Short-term (present to 5 years)**	• **Physical tech:** GPS, Sensors, Drones, Mobile, Adv. Green Chemistry • **Digital tech:** IoT, Big data and Analytics, Cloud • **Biological tech:** Biocatalysis, bioremediation	• Growth of the market • Product premium • Economies of scale
Precision Agriculture (for fibre crops)	**Short-term (present to 5 years)**	• **Physical tech:** GPS, Sensors, Drones, Mobile • **Digital tech:** IoT, Big data and Analytics, Cloud • **Other:** Crop science	• Affordability/ Need for low cost solutions/ Access to finance • Need for skills/ capacity building
Upcycled Textile Fibres	**Short-term (present to 5 years)**	• **Physical tech:** Proprietary chemical solutions in closed loops, Mechanical engineering technologies • **Digital tech:** Digital platforms and supply chain tools • **Other:** Circular Economy business models	• Reverse logistics • Scale / Capacity building • Upstream integration
Biofabricated Leather	**Long-term (>10 years)**	• **Physical tech:** Advanced scientific instrumentation, 3-D printed tooling • **Digital tech:** Big data, Analytics, Cloud • **Biological tech:** Bio-fabrication and engineering, Genome editing	• Blue ocean market • Scale / Capacity building • Product premiumisation opportunity
Next gen Bio-Based Polyester	**Short-term (present to 5 years)**	• **Physical tech:** Advanced green chemistry & industrial bioscience • **Digital tech:** Big data, Analytics, Cloud • **Other:** Circular Economy business models	• Upstream integration • Scale / Capacity building • Farmer empowerment
Alternative Natural Fibres	**Short-term (present to 5 years)**	• **Physical tech:** Advanced green chemistry & industrial bioscience • **Digital tech:** Big data, Analytics, Cloud • **Other:** Circular Economy business models	• Upstream integration • Scale / Capacity building • Raw material aggregation • Farmer empowerment
Footwear Factory 5.0	**Medium term (5 – 10 years)**	• **Physical tech:** IIoT, Sensors and actuators, 3D printing, robotics, New materials • **Digital tech:** Cloud, Supply chain digitalization, Digital Twin • **Other:** Reshoring of production	• Capital investments • Need for new skills/ capacity building
Nano-Tech Enhanced Fabrics	**Medium term (5 – 10 years)**	• **Physical tech**: Nanotechnology-based coatings for fabrics, New materials • **Digital tech:** Cloud, Big data	• R&D investments • Regulatory environment • Supply chain integration
Blockchain for Fashion	**Medium term (5 – 10 years)**	• **Physical tech:** GPS, microchips/ wearable electronics • **Digital tech:** Blockchain/ distributed ledger solutions, cryptocurrencies (in some cases), Digital platforms • **Other:** Circular Economy business models	• R&D investments • Partnerships for scaling • Supply chain integration
Advanced Organic Wastewater Treatment	**Short-term (present to 5 years)**	• **Physical tech:** Effluent treatment plants/ Bioreactors, Membrane solutions, Energy harvesting • **Digital tech:** Control dashboards, Data, Analytics, Cloud • **Biological tech:** Biocatalysts, Electromicrobiology, Anaerobic & Aerobic treatments	• Waste stream applicability • Capital investments • Economies of scale
Automated Sewing	**Medium term (5 – 10 years)**	• **Physical tech:** Sensors and actuators, Robotics • **Digital tech:** Machine vision, Machine sensing, M2M communication • **Other:** Chemical science	• R&D Investment (early stage development) • Capital investments • Process redesign

Source: Accenture Strategy research

Appendix 2: Scope, terms, definitions and methodologies

Scope

The research scope for Fourth Industrial Revolution technologies applicable to sustainable production was based on the following criteria:

- Energy and raw materials extraction assumed to be out of scope for this analysis
- Time to mainstream adoption: from present day to 10 or more years
- Upstream value chain applicability (cradle-to-factory-gate scope)
- Production focus including but not limited to manufacturing activities
- Potential to drive positive effect on sustainability towards achieving one or more of the SDGs
- Advanced Fourth Industrial Revolution-enabled technologies in the innovation or early adoption stages, based on Rogers' theory of diffusion of innovations

Countries were selected based on their developing market focus, the relative economic importance of in-scope industries for the national economy, data from the United Nations Industrial Development Organization (UNIDO) on the share of manufacturing value added (MVA) in GDP, as well as the country's impact on world MVA and manufacturing trade.

The manufacturing industries were selected by examining the UNIDO classification system, focusing on those that supply end products to consumers. Data on the economic, social and environmental importance of industries to the global economy was also considered. A "basket" of low- and high-tech industries was then selected to reflect UNIDO's finding that such industries typically have higher environmental productivity (they generate fewer emissions when producing $1 of value added). The underlying assumption in this approach was to select the industries most susceptible to sustainable technology interventions. Finally, the interest of the project community was also considered when arriving at the final four industries.

Key terms and definitions

- **Production:** The full spectrum of value-adding activities in the cradle-to-factory-gate part of a given industry value chain, excluding those that are assumed to be out of scope for this analysis
- **Sustainable production:** The manufacturing of products and product inputs, and the creation of related services, which respond to consumer and market needs and bring a better quality of life while minimizing the use of natural resources and toxic materials. In the process, emissions of waste and pollutants are also minimized to avoid jeopardizing the needs of further generations (based on the definition of sustainable consumption and production from the Oslo Symposium in 1994)
- **Fourth Industrial Revolution sustainable production development:** A set of digital, physical and/or biological Fourth Industrial Revolution technologies converging together to change manufacturing inputs, processes and outputs, and enable new business models, with the potential to increase value creation across the triple bottom line (economic, social and environmental)
- **Fourth Industrial Revolution developments time horizons:** Expected time to full technology maturity and mainstream adoption, based on Accenture analysis, industry interviews of small and medium-sized enterprises, and press searches (short term: 0-5 years; medium term: 5-10 years; long term: 10+ years)
- **Circular economy:** According to the Waste and Resources Action Programme, "an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them while in use, then recover and regenerate products and materials at the end of each service life"

Methodologies

Fourth Industrial Revolution industry developments and the UN Sustainable Development Goals

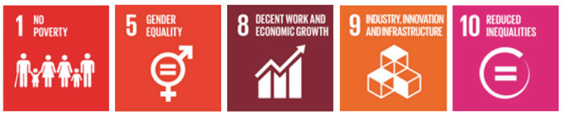
The United Nations Sustainable Development Goals (SDGs) serve as the basis of the framework for identifying the Fourth Industrial Revolution developments with the greatest potential to drive positive economic, social and environmental effects in sustainability. Fourteen of the 17 SDGs were selected and grouped to make up the three sustainability assessment areas, and the full list of the related targets and indicators was narrowed down to those relevant to production systems in the in-scope industries. The identified technological developments were evaluated for their link (or lack thereof) with each of the 14 SDGs, based on evidence from primary and secondary research. Where a direct link could be documented, further research determined an aggregate score for the given development across all the linked SDGs and in terms of upside potential and downside risks.

The SDGs selected and grouped along the economic, social and environmental dimensions are shown in Figure 28.

Our research then identified 40 technological developments across value chain segments – from "cradle to gate" (raw material extraction to downstream manufacturing) – and across our four target industries. Each development was then scored to determine more precisely the expected effect on accelerating sustainable production. The basis for our scoring included a review of literature coupled with interviews of industry and academic leaders. A range of scores was given to account for factors such as affordability, the rate of adopting technology and technological development paths. The scale has five positions, from -2 to +2.

Figure 28: Sustainable Development Goals linked to production activities and grouped by the three assessment areas

Economic impact:



Social impact:

Environmental impact:

Source: Accenture Strategy research

Regional opportunities

The regional assessment of opportunities for accelerating sustainable production is based on the World Economic Forum Country Readiness Index framework (Figure 29), which concerns factors related to:

– The structure of production – These factors capture the current baseline of production and measure the economic complexity and manufacturing value added as a percentage of GDP
– The drivers of production – These factors capture the country's preparedness to capitalize on emerging technologies to transform its production systems

In all, the framework includes levers that may determine how well a country is positioned to embrace Fourth Industrial Revolution developments, and may help identify the necessary actions to accelerate them.

Figure 29: Country Readiness Index framework used to identify regional opportunities

Structure of production	Structure of production	Complexity	Economic complexity
		Scale	Manufacturing value added
Drivers of production	Technology & innovation	Technology platform	Availability of ICT
			Use of ICT
			Digital security & data privacy
		Ability to innovate	Industry activity
			Research intensity
			Available financing
	Human capital	Current labour force	Labour force capabilities
		Future labour force	Migration
			Education outcomes
			Agility & adaptability
	Global trade & investment	Trade	Trade openness
			Trade facilitation & market access
		Investment	Investment & financing
		Infrastructure	Transportation & electricity
	Institutional framework	Government	Efficiency & effectiveness
			Rule of law
	Sustainable resources	Sustainability	Energy
			Emissions
			Water
	Demand environment	Demand	Market size
		Consumer base	Consumer sophistication

Source: A.T. Kearney/World Economic Forum analysis

In conducting the regional assessment, the steps outlined below were followed:

– As a first step, the World Economic Forum Country Readiness Index framework was used to understand the regional context. This step helped in understanding the regional nuances that could influence how well a particular Fourth Industrial Revolution development can be adopted in a region.
– Thereafter, innovative case studies were gathered to capture the key Fourth Industrial Revolution developments identified in the analysis. The choice of case studies was made to cover the four industrial sectors in the scope of this study and across the key thematic developments identified through the study.
– Regional opportunities were then identified based on the understanding of the regional context (as obtained from the framework) and an understanding of the critical success factors for the identified case studies.
– Lastly, the potential actions and implications for the businesses and policy-makers were identified to facilitate accelerated adoption of the short-listed regional opportunities.

The Accelerating Sustainable Production framework

The framework builds on the value at stake approach developed as part of the World Economic Forum Digital Transformation of Industries (DTI) project. The scope is extended to cover physical and biological technologies as well as digital technologies.

The original framework has been adjusted to address the specificity of the manufacturing sector. In particular, Environment was separated from Society to emphasize its importance and include several new non-financial impact areas.

The framework has a twofold purpose: (1) to measure the total value from implementing a development in the production system, and (2) to identify the sources of impact on SDGs and the underlying SDG indicators.To construct the framework and select the indicators, we used the following methodology:

1. Verification of the value levers used in the DTI's value at stake framework
2. Comprehensive literature review to identify indicators that capture missing socio-economic and environmental impacts
3. Review of the SDG indicators – detailed review of all SDG indicators, and the methodology developed by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDG)
4. Creation of a preliminary framework, which was used to map the potential effects of our in-scope Fourth Industrial Revolution developments. The framework was refined as part of this process.

Framework structure

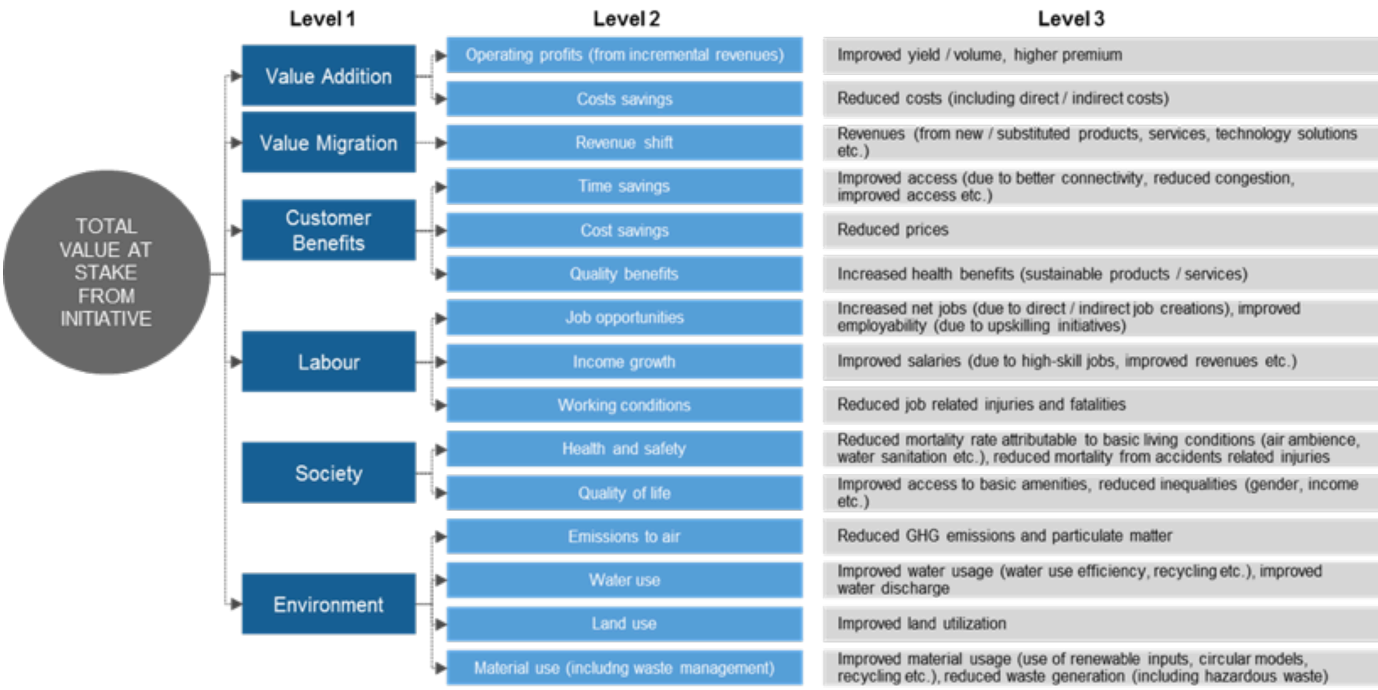
Value levers

The structure of the Accelerating Sustainable Production framework was developed starting with the original value at stake framework from the DTI initiative. Recognizing our sustainability focus, the original structure was modified by separating society from the environment and adding additional value levers, thus ensuring that all potentially negative effects were captured.

Our Accelerating Sustainable Production framework (Figure 30) differentiates between value to industry (value addition and migration) and value to society (customer benefits, labour, society and the environment):

– **Value addition** – benefits from implementing Fourth Industrial Revolution developments to the analysed industry, divided into two main groups: (1) improved operating profits from producing more from the same inputs or receiving higher premiums, and (2) reduced costs, both direct (such as input costs or labour) and indirect (such as utilities or equipment)
– **Value migration** – operating profits that will shift between different industries and that take two main forms: (1) increased revenue to providers of technologies, and (2) revenue loss to providers of substituted products and inputs. As a result, the replaced parts of the economy are taken into account
– Customer benefits – benefits from consumption of improved products as a result of the development, with three main categories: time, cost and quality
– **Labour** – a separate branch because of its significant role in the production process, and with three main sources of value: (1) job opportunities (either from changes in employment or from training), (2) remuneration and (3) working conditions
– **Society** – a category covering spin-off benefits to the communities affected by improvements to factories or changes from new products, with two main forms: (1) health and safety, which focuses on reduced mortality/improved life expectancy, and (2) quality of life from improved access to amenities (e.g. safe water, electricity) or reduced inequalities (from labour-related sources)
– **Environment** – an area grouped into four subcategories: (1) emissions to air (GHG emissions) and particulate matter, (2) water use (improved water usage and discharge), (3) land use (improved land utilization) and (4) material use, which includes waste management (Climate effects, other than water and those that are land-related, are assumed to be captured in the estimated cost of emissions.)

Figure 30: Framework for analysing value at stake for individual sustainable production technology developments



Source: Accenture Strategy analysis

Effects on SDGs

Finally, we established connections between the lowest-level value levers and SDG indicators. To do this, we performed a detailed analysis of SDG indicators and their definitions.

The SDG indicators were developed by the IAEG-SDG and agreed to by the United Nations Statistical Commission. The development process took one year and involved Member States, with regional and international agencies as observers. The list of indicators used was based on the latest developments from the IAEG-SDG in April 2017.

Our aim was to create causal links between value levers and SDG indicators, where changes to value levers contribute to the SDGs. In this way, once the computational element is added, how a particular development helps a region move closer to reaching a target can be quantified. We took the position of entire industries or large industry players, as many of the economic indicators (primarily under SDG 8 and 9) refer to macroeconomic changes.

This exercise will support policy and business leaders in designing their strategies, and will help to see the list of SDGs that different elements of investment opportunities contribute towards. As a result, leaders can have a comprehensive view of the effects when performing qualitative analysis. In the future, this exercise will form a foundation for detailed economic models to quantify the value creation potential of sustainable innovation in different markets.

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[2] Fourteen out of the 17 SDGs were selected and grouped to make up the three sustainability assessment areas (economic, social and environmental value). The full list of the related targets and indicators was narrowed down to those relevant to production systems in the in-scope industries. See the appendices for more details.

[3] Countries were selected based on their developing market focus, the relative economic importance of in-scope industries for the national economy, data from the United Nations Industrial Development Organization on the share of manufacturing value added (MVA) in gross domestic product, as well as the country's impact on world MVA and manufacturing trade.

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Acknowledgements

The World Economic Forum Accelerating Sustainable Production project team would like to thank the project community members below for their generous contribution, comments and insights in the creation of this report.
We would also like to express our gratitude to the members of the broader community of the System Initiative on Shaping the Future of Production for their ongoing commitment and support to the System Initiative and for addressing production issues globally.
Finally, our sincere thanks to our knowledge partners at Accenture Strategy and to all our Forum colleagues who provided support throughout the preparation of this publication.

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