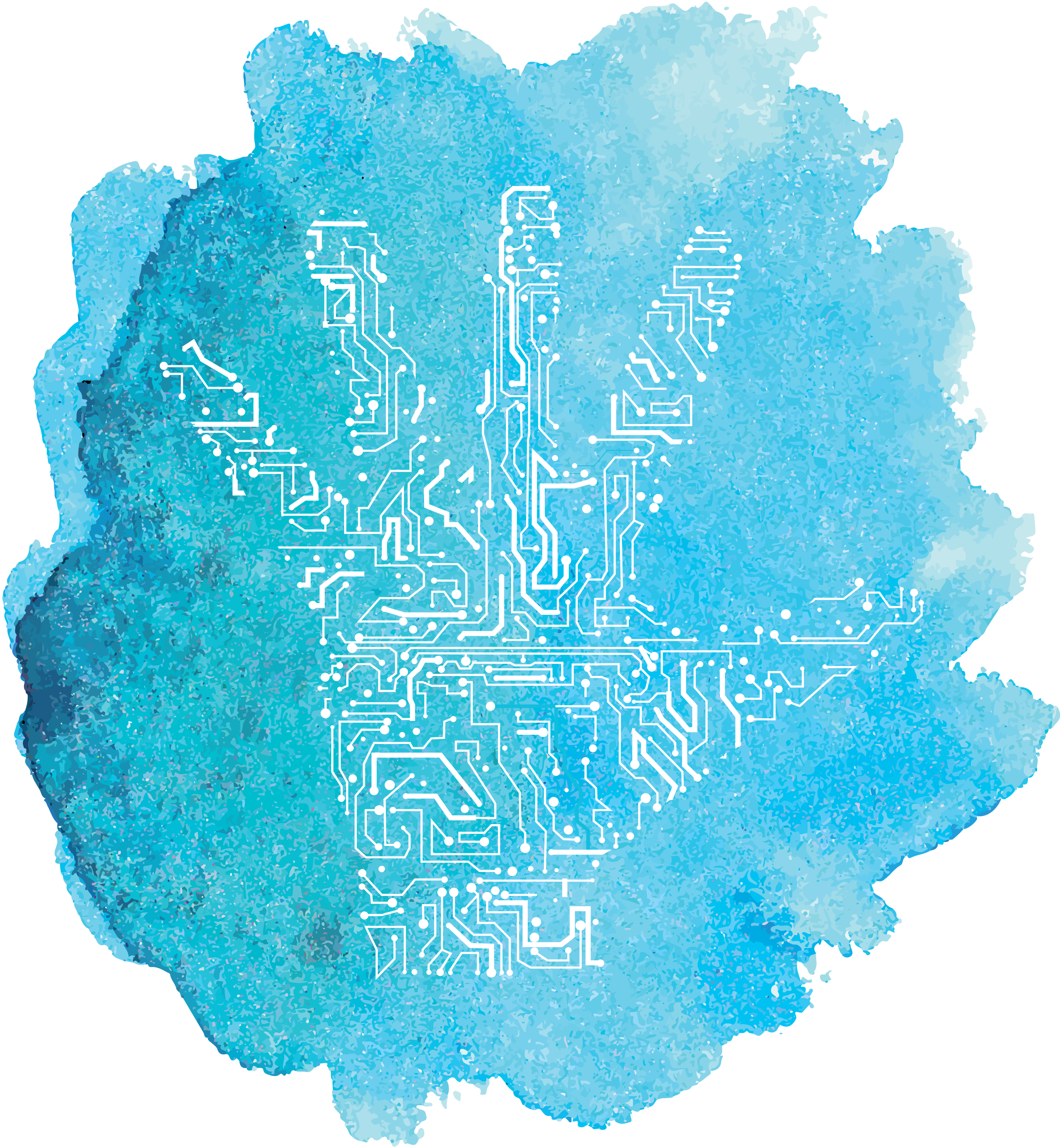
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Accelerating clean energy through Industry 4.0

Manufacturing the next revolution



INCLUSIVE AND SUSTAINABLE INDUSTRIAL DEVELOPMENT

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Executive Summary

Industry 4.0 could contribute to finding new ways of dealing with major global challenges, such as climate change, lack of clean energy access, economic stagnation and reducing the digital divide

However, understanding the potential opportunities and also challenges that Industry 4.0 may pose on countries with various levels of industrialization is necessary to outline the limits, barriers and risks it may pose to inclusive and sustainable industrial development. For instance, industrial production is undergoing a fundamental transformation. This process is informed by a vision where the physical world of industrial production merges with the digital world of information technology – in other words, the creation of a digitized and interconnected industrial production, also known as *cyber-physical systems*. These new state-of-the-art technologies offer increased deployment of renewable energy in manufacturing, reduced carbon emissions, optimized energy-use, heightened productivity and cost savings at an unprecedented scale.

The SDGs are not to be approached in an isolated way. There are numerous interlinkages between them, which indicates that their implementation should mutually support each other

One of the targets of SDG 9 specifically highlights the promotion of inclusive and sustainable industrial development and to raise the share of employment in manufacturing and the proportion of manufacturing value added to gross domestic product. Besides, SDG 9 sets increased access to information and communications technology (ICT) and affordable access to the Internet in least developed countries by 2020 as a specific target. Achieving these targets through the use of ICT and increased internet access could also help tackle SDG 7 and 13 in an integrated manner. This could trickle down and contribute significantly to sustainability and decarbonization in economic and industrial development.

Numerous opportunities with high economic and energy saving potentials are associated with digital and interconnected manufacturing

Among them is the ability to cost-effectively produce customized products due to the higher degree of flexibility. This means that the cost of producing one customized product is meant not to be significantly higher than mass production in the current manufacturing scenario. Another opportunity is to develop completely new business models based on the huge amount of data generated along the entire life cycle, starting from production, usage phase (including customer feedback), up to the end of life phase (e.g. recycling). Other than that, it is estimated that only 1% of existing data is analysed. Big Data could support sustainability, for instance by helping produce relevant statistics that enable better informed decision making as much on economic, environmental or societal issues.

The sustainable energy transition and Industry 4.0 share important characteristics that can be interconnected to pursue a sustainable energy transition. Such integrated approaches could be guided by the SDGs, which provide important target setting for energy, climate action and beyond.

For instance, both are highly influenced by technological innovation, dependent on the development of new suitable infrastructures and regulations as well as are potential enablers for new business models. These commonalities have not yet been translated into substantial policies to foster the transition to more sustainable energy systems and digital production at the same time and in an integrated manner. One concrete opportunity is that, industries account for a major share of electricity consumption – amounting in 2014 to 42.5 % worldwide (IEA 2016d) – and energy networks need to accommodate electricity demand from industrial consumers. This could be enough reason to think how the transition towards more sustainable energy systems and the digital transformation of industries could mutually benefit from each other.

A comprehensive shift in manufacturing, production, energy efficiency, and renewable energy can be captured through two development pathways: Transforming and Leapfrogging.

The transformation towards Industry 4.0 will involve retrofitting existing industrialized systems with Industry 4.0 technologies that could provide more sustainable solutions. Standardization, partnerships, and responsible policy design are all ways that lead up to maximizing the economic, social and environmental potentials of Industry 4.0. On the other hand, leapfrogging will provide developing countries with an opportunity to increase their share of industrialization without repeating the mistakes of traditional development pathways. Regions that are less developed can become candidates for the development of smart factories, decentralized micro-grids, etc. To support such a development, the challenges and opportunities associated with Industry 4.0 for countries with different stages of industrial development should be explored in more detail.

Policy recommendations

- **Maneuvering the innovation race:** The vast and increasing speed of technology development could lead to a first-mover advantage for pioneering countries or companies. This would give the few top runners large economic influence and – if regulations are weak – the power to lever out social and environmental standards. Countries should therefore not only be increasingly challenged to provide suitable framework conditions for innovation, but also to protect existing standards and to expand them to newly developing digital branches.

- **Increasing the agility of governments:** Digitization and Industry 4.0 are largely driven by actors from the economic sphere. Their pace often exceeds the speed at which policies and regulations can be formulated to govern digital and technology developments. In this way, policy making could become ineffective in impeding potential adverse effects, e.g. on privacy and data security, labor rights and safeguarding environment. Governments need to be more agile in adopting policies fast enough to ensure its citizens and countries will be protected from these adverse impacts.

- **Preventing the deepening of global inequalities:** Related to the previous point, inequalities between the economic development of industrialized, emerging economies and developing countries could further deepen if countries of the Global South cannot tap into digital development benefits. Developing and least developed countries should be enabled to use the possibilities of ICT and Industry 4.0 to achieve their development priorities. The creation of policies on the national, regional and global scales that ensure equal access and distribution of ICT and Industry 4.0 technologies is needed to prevent the deepening of global inequalities.

What can UNIDO offer?

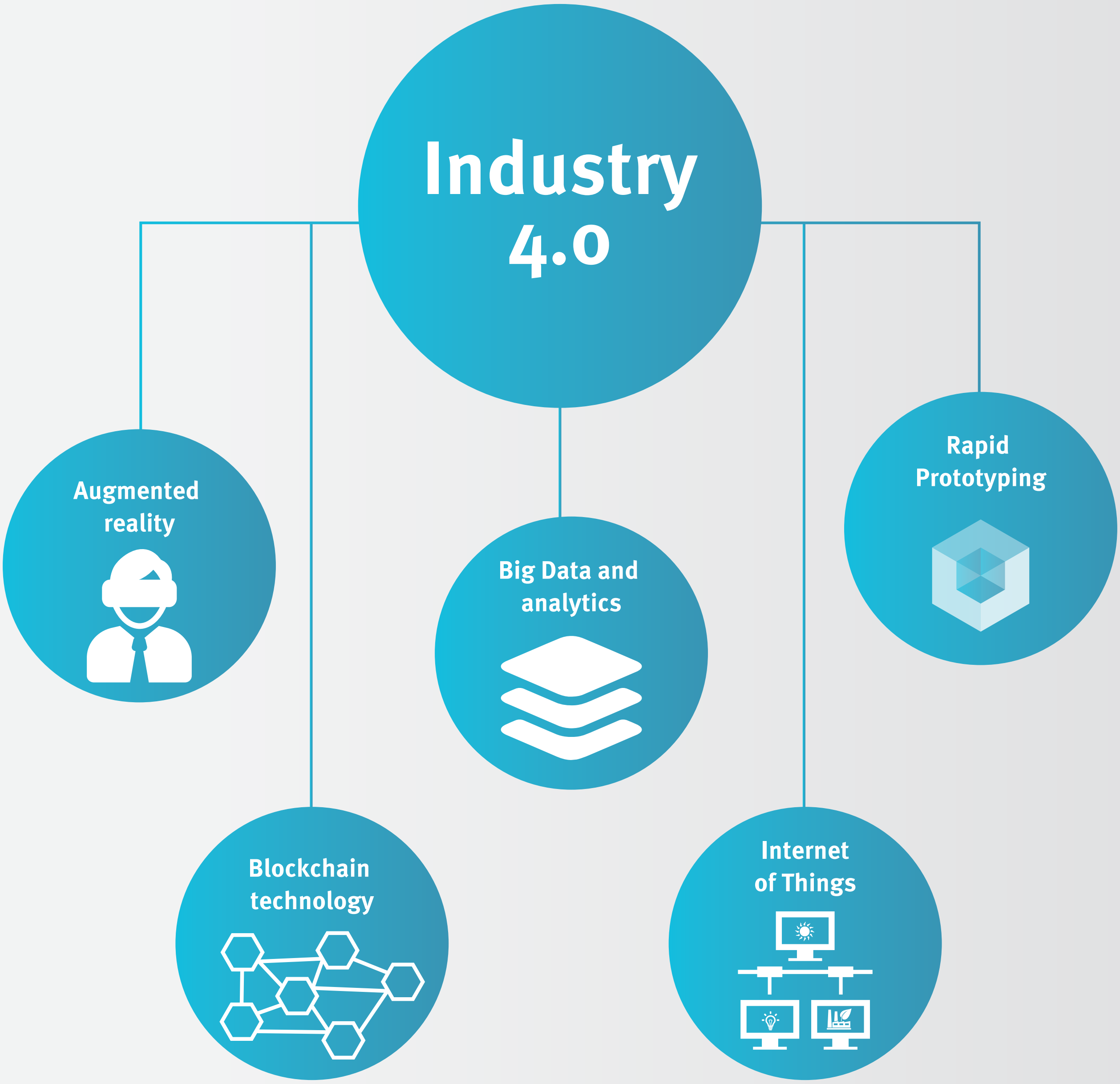
UNIDO has the capability and relevant portfolio to foster Industry 4.0 across all stages of industrial development. The mandate of UNIDO is to promote ISID that reinforces economic growth and diversification in a socially inclusive and environmentally sound manner.

- **UNIDO as a knowledge-sharing and project development platform:** UNIDO is capable of setting in motion the necessary programs. UNIDO's capacity to collect and analyze relevant data will provide major insights for facilitating Industry 4.0. Examples include evaluation of country preparedness and identification of resource gaps. Also, setting up knowledge and financial platforms can open the discussion between innovators, policy makers, and other key stakeholders to synchronize the trends of Industry 4.0 with the SDGs and ISID.

- **Retrofitting established industrial systems and leapfrogging technology waves with Industry 4.0:** Within this context, Industry 4.0 technologies could particularly enable **a)** developed countries to transform established industries and infrastructures in achieving ISID. This can be done by assisting in the coordination of financing mechanisms that will improve industrial energy efficiency in heavy industries. And **b)** developing countries to capitalize on the sustainable energy aspects of Industry 4.0 and move more rapidly towards ISID. UNIDO can play an important role in education and fostering entrepreneurship in Industry 4.0 technologies that will reduce the digital divide in ICT literacy, skills and infrastructure whilst promoting the setup of distributed, renewable energy systems next to fostering a technology start-up culture.

- **Partnerships with the private sector:** Innovative collaborations between the public and private sector can help assist developing countries to successfully implement Industry 4.0 technologies in their manufacturing processes. For instance, the private sector plays a large role in driving technology standards, financial solutions and targeted incentives to accelerate improvements. The public sector instead is responsible for creating sensible policies so that society and business flourish under this paradigm shift. Through extensive networks within both the public and private sectors, UNIDO can mediate win-win solutions in accordance with the SDGs and the Paris Agreement.

FIGURE 1 | **TECHNOLOGIES THAT REVOLUTIONIZE MANUFACTURING WITH A SUSTAINABLE ENERGY RELEVANCE**



1

Introduction

"(...) the best prevention for conflict and the best prevention for other negative impacts on societies is, of course, sustainable and inclusive development."

António Guterres, United Nations Secretary General at the World Economic Forum 2017[1]

In the past few years, digital technologies have spread more and more into manufacturing and production processes. Rapid developments in the fields of Internet of Things, Big Data, robotics, blockchain technology, sensors, artificial intelligence, augmented reality and rapid prototyping technologies have noticeably transcended into the manufacturing industry. This unprecedented occurrence, often referred to as "the fourth industrial revolution" or "Industry 4.0", has gained considerable momentum. Industry 4.0 could fundamentally transform the way goods are developed, produced and consumed, and galvanize the development of new business models, services, and behaviors. While Industry 4.0 promises many opportunities for economic development, its further reaching impacts are largely uncertain. Industry 4.0 emerges against the backdrop of pressing global challenges such as climate change, food insecurity, lack of energy access, water scarcity, environmental degradation, loss of biodiversity and megatrends like population growth, urbanization and mass migration, as well as the new and ongoing conflicts and crises worldwide. This raises a valid question: if – and how – Industry 4.0 could contribute to finding new ways of dealing with some of these major social, economic, and environmental challenges.

The United Nations Industrial Development Organization (UNIDO) is the specialized agency of the United Nations whose mission is to promote and accelerate Inclusive and Sustainable Industrial Development (ISID, see Figure 1). UNIDO's mandate is fully recognized in the Sustainable Development Goal 9 (SDG 9), which demands to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation".

Consistent with this mandate, UNIDO's programmatic approach is guided by three interrelated thematic priorities: creating shared prosperity, advancing economic competitiveness and safeguarding the environment.

1 Source: Secretary-General's Remarks at the special session on „Cooperation for Peace: Tackling the Root Causes of Global Crises" (2017). Available at: https://www.un.org/sg/en/content/sg/statement/2017-01-19/secretary-generals-remarks-special-session-cooperation-peace, [Accessed 28 Apr. 2017].

BOX 1 | THE RELEVANCE OF THE SDGS FOR SUSTAINABLE ENERGY AND DIGITAL INDUSTRIAL DEVELOPMENT[1]

In September 2015, the UN Sustainable Development Summit adopted the 2030 agenda which is the key document guiding international efforts for sustainable development until 2030. The agenda spells out 17 goals – the so-called Sustainable Development Goals (SDGs, see Figure 2) – and 169 more specific targets in key development areas such as poverty, water, energy, education, gender equality, economy, biodiversity, climate action, and many more. In the context of this report, the SDGs 7, 9 and 13 are of particular relevance:

- **SDG 7** promotes affordable and clean energy. Its aim is to ensure access to affordable, reliable, sustainable and modern energy for all by 2030. This includes substantially increasing the share of renewable energies in the global energy mix as well as doubling the global rate of improvement in energy efficiency. SDG 7 especially aims at developing infrastructures and sustainable energy services for all in developing countries, with a particular focus on least developed countries, small island developing states, and land-locked developing countries.

- **SDG 9** relates to industry, innovation and infrastructure. It aims at building resilient infrastructures and promoting inclusive and sustainable industrialization as well as fostering innovation. One of the targets of SDG 9 specifically highlights the promotion of inclusive and sustainable industrialization and to raise the share of employment in manufacturing and the proportion of manufacturing value added to gross domestic product. Besides, SDG 9 sets increased access to information and communications technology and universal and affordable access to the Internet in least developed countries by 2020 as a specific target.

- **SDG 13** is dedicated to climate action: increasing efforts on mitigating climate change and on adapting to its impacts. The implementation of SDG 13 is strongly linked to the implementation of the Paris Agreement, which entered into force on 4 November 2016 and constitutes a major milestone for international climate change mitigation and adaptation efforts.

The SDGs are not to be approached in an isolated way. Rather they should create synergies and their implementation should mutually support each other. Exploiting the benefits of new technological developments in the energy sector as well as in the area of information and communication technologies (ICTs) could help to tackle SDG 7, 9 and 13 in an integrated manner, and contribute significantly to sustainability and decarbonization in economic and industrial development.

1 This box draws extensively on the Sustainable Development Knowledge Platform as source: https://sustainabledevelopment.un.org, [Accessed 30 Mar. 2017].

This report aims to start a conversation on how these priorities can be achieved, focusing particularly on the potential of Industry 4.0 to help achieve the UN Sustainable Development Goals (SDGs) related to affordable and clean energy (SDG 7), industry and infrastructure (SDG 9), and climate action (SDG 13) along with the implementation of the Paris Agreement (see Box 1).

Based on a review of the current literature and on interviews with experts, the report explores potential opportunities and also the challenges that Industry 4.0 may pose to countries at varying levels of industrialization. It analyzes the effects of Industry 4.0 along four country groups, namely industrialized, emerging industrial as well as developing and least developed countries (LDCs).[2] The report further discusses how Industry 4.0 could foster the implementation of sustainable energy and help curb greenhouse gas (GHG) emissions from the industrial sector. It also outlines potential limits, barriers and risks that Industry 4.0 may pose to sustainable and inclusive economic development.

2 For an overview of countries belonging to these categories, please see: UNIDO 2015. The list of least developed countries as of May 2016 can also be found here: http://www.un.org/en/development/desa/policy/cdp/ldc/ldc_list.pdf, [Accessed 28 Apr. 2017].

FIGURE 2 | **SUSTAINABLE DEVELOPMENT GOALS (SDGS)**

Source: United Nations (2015). Available at: http://www.un.org/sustainabledevelopment/sustainable-development-goals/ [Accessed 28 Apr. 2017].

Understanding the Concept of Industry 4.0

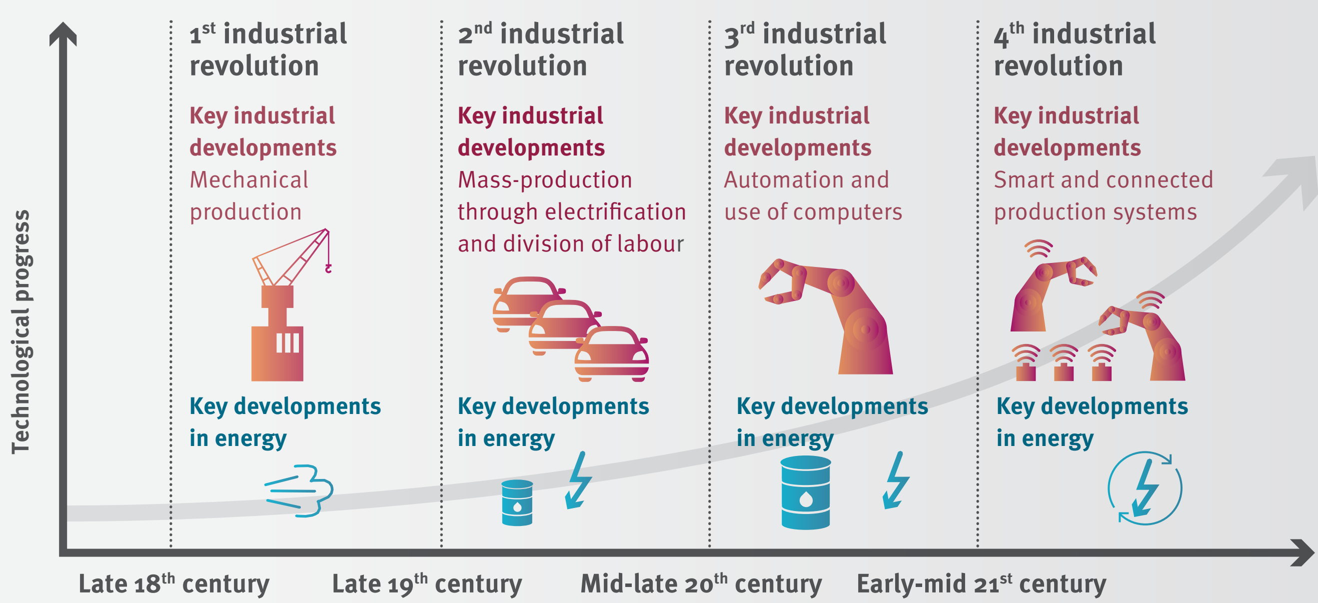
Looking at the past
the first three industrial revolutions

Manufacturing of products and goods has gone through disruptive changes three times in the past. The first so-called industrial revolution took place in the late 18th century, when steam engines entered the factories and enabled the further mechanization of the most physically demanding and highly repetitive tasks. This helped increase productivity and lower production costs, and in turn enabled an increase in living standards and the growth of cities around factories. Steam engines also enabled the development of press and printing, as well as railways. People and information could move more quickly than ever.

The second industrial revolution occurred in the late 19th century with the introduction of linear assembly-lines that could be powered with electrical energy from oil and gas - allowing for huge efficiency gains that would enable mass production.

The third industrial revolution- in the 1970's, the application of electronics, basic information and communication technology in manufacturing opened up new opportunities for automation and engineering, enabling new technological advances and further increased productivity (see Figure 3).

FIGURE 3 | THE FOUR INDUSTRIAL REVOLUTIONS



Source: Figure adapted by authors, based on Roser (2015) and Wahlster (2013).

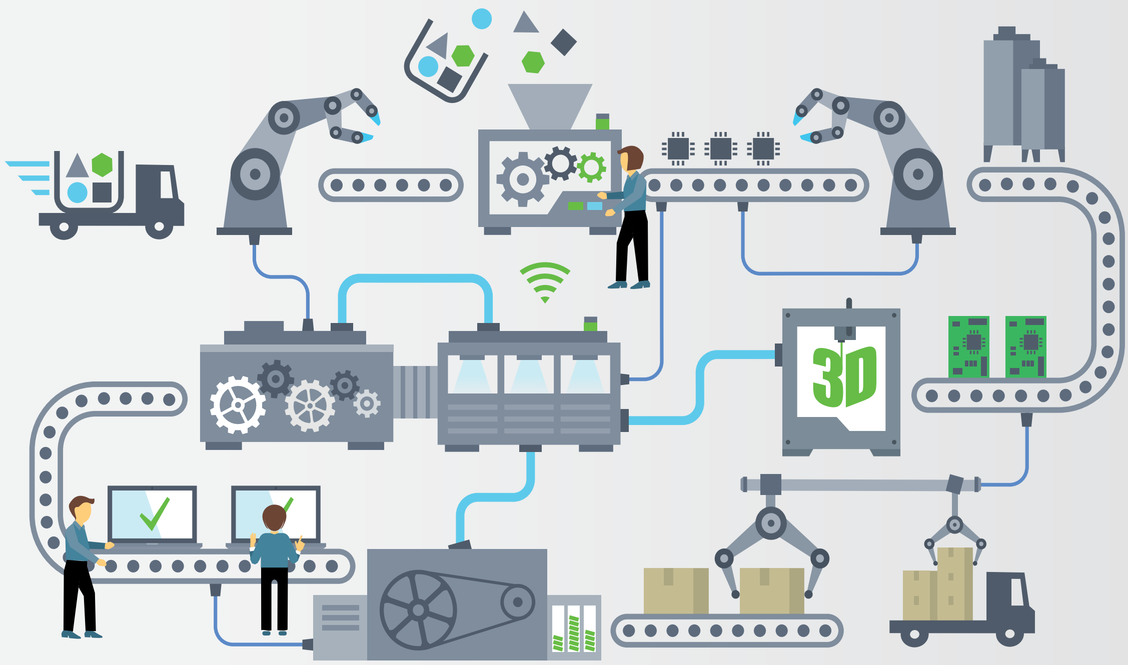
Looking at the future

a new industrial revolution is underway

Today, industrial production is undergoing another fundamental transformation (Herrmann et al. 2014; Kang et al. 2016). This process is informed by a vision where the physical world of industrial production merges with the digital world of information technology – in other words, the creation of a digitized and interconnected industrial production, also known as *cyber-physical systems* (see Figure 4). This vision of a digital and interconnected manufacturing sector has entered into public debate under different names in different regions: in Germany, where it first emerged, it is commonly referred to and promoted under the term "Industrie 4.0", whereas in the United States of America it is known as the Industrial Internet (of Things), Advanced Manufacturing or Digital Manufacturing.

At present, the path of a to-be-manufactured object is shaped by complex analysis and simulation tools used by production engineers, leading to well a defined manufacturing processes. These processes define the production technique, machine, chronology, (raw) materials and many other manufacturing parameters long before the to-be-manufactured object physically enters the factory.

FIGURE 4 | **INDUSTRY 4.0: DIGITAL AND INTERCONNECTED PRODUCTION**



In the future, connected supply-chains and digitized industrial production processes will connect workers, machine components, materials, to-be-manufactured objects and even logistics, with continuous exchange of data. The machines and objects will be given a digital identity, sensors and actuators, the ability to communicate and inform "intelligence". They will therefore be able to cooperate with each other, while the to-be-manufactured object can follow an algorithmically determined optimal path through the manufacturing system or, in case of a break-down, identify an alternative path so that production need not stop. In this manner, factories are to become mainly self-organizing and steering – even across factory borders – and a broader variety of products can be tailored even more to the wishes of customers.

Some of the opportunities with high economic potential associated with digital and interconnected manufacturing are:

- The aim to cost-effectively produce customized products due to the higher degree of flexibility. This means that the cost of producing one customized product is meant not to be significantly higher than mass production in the current manufacturing scenario.
- The opportunity to develop completely new business models based on the huge amount of data (also see Box 3) generated along the entire life cycle, starting from production, usage phase (incl. customer feedback), up to end of life phase (e. g. recycling).
- One sector that is often considered to be especially affected is logistics, as a number of digital trends such as e-mobility, autonomous driving and digital warehousing converge under the common term smart logistics (Sivamani et al. 2014; Qu et al. 2016).

(Inter-)National Industry 4.0 Initiatives

The notion of Industry 4.0 has gained wide attention worldwide, which can also be seen in the increasing number of national and regional initiatives that deal with smart manufacturing and digital production (see Figure 5). In the EU, there are more than 30 national and regional initiatives related to Industry 4.0, which are also supported and further connected by EU activities aiming at the creation of a Digital European Single market (BMWi 2017). In Germany, the "Plattform Industrie 4.0", steered and led by the Federal Ministries for Economic Affairs and Energy as well as for Education and Research, brings together high-ranking representatives

BOX 2 | INTERNET OF THINGS (IOT)

First coined by Kevin Ashton in 1999, the Internet of Things is a concept describing the next iteration of the internet, where information and data are no longer predominantly generated and processed by humans – which has been the case for most of the data created so far (Ashton 2009) – but by a network of interconnected so-called smart objects, embedded sensors and miniaturized computers, able to sense their environment, process data, and engage in machine-to-machine communication.

This is already exemplified in our everyday life by connected watches or cars, while industrial applications include Veolia's use of interconnected sensors in order to continuously monitor its water treatment processes (e.g. pH, temperature, etc.) and enable real-time or even pre-emptive maintenance, hence saving costs and enabling better quality and safety standards.

BOX 3 | BIG DATA

Big data is a term often used to describe sets of data characterized by high volume, high velocity, and high variety (De Mauro et al. 2015), and for which the use of advanced analytical tools is required in order to process data into actionable information by identifying patterns, trends, and relationships (Lycett 2013).

Big data is a consequence of the continuous and increasing production of data, spurred in particular by the vast deployment of digital platforms and applications in everyday life. Examples include, new analytical devices (e.g. in the medical sector), as well as the increased number of sensors and connected objects (the Internet of Things) which continuously generate large amounts of data. However, it is estimated that less than 1 % of all available data is currently analysed (Gantz & Reinsel 2012). Big data therefore creates important challenges and opportunities now and in the coming years.

Big data could support sustainability, for instance by helping produce relevant statistics that enable better informed decision making as much on economic, environmental or societal issues (UN Big Data Global Working Group Task Teams 2014).

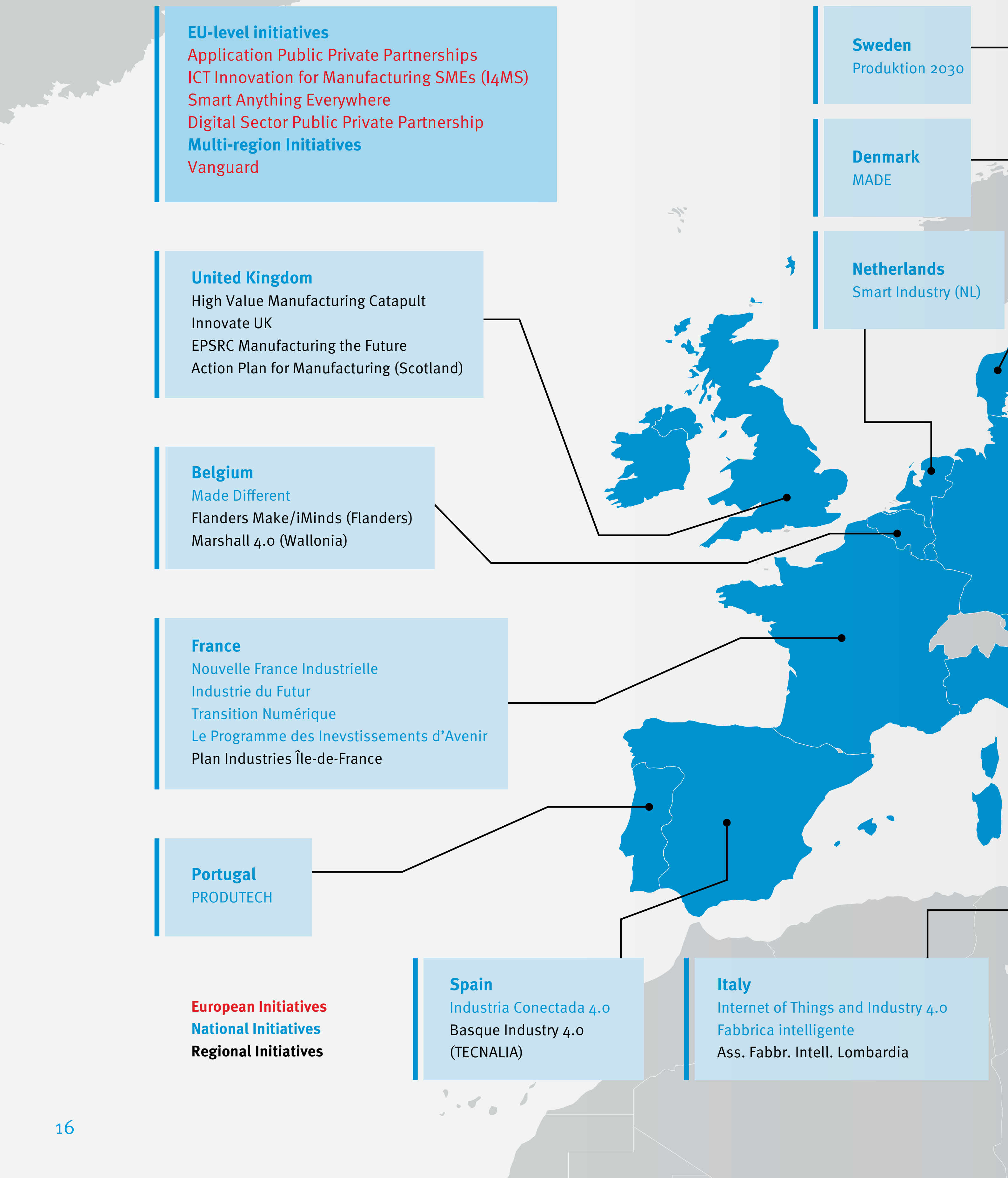
from industry, science and the trade unions, and aims to develop joint recommendations for all stakeholders (Plattform Industrie 4.0 2017). The “Industrial Internet Consortium”, founded in 2014 in the USA, links different organizations interested in developing, applying and testing technologies necessary to accelerate the growth of the Industrial Internet, thereby identifying, assembling and promoting best practices (The Industrial Internet Consortium 2017). It is also open to non-American companies. A lot of other countries offer similar initiatives such as “Made in China 2025” (China), “Industrial Value-Chain Initiative“(Japan) or “Usine du Futur” (France).

Digitization and Industry 4.0 have also become a major topic on the level of the G20, comprising 19 of the most important industrialized countries emerging economies and the European Union. Under the German G20 presidency in 2017, digitization is discussed with a particular focus on the creation and application of common norms and standards, the protection of data and privacy, transparency, as well as the opportunities for developing countries and potential risks from digital technologies and innovations (German Federal Government 2017).

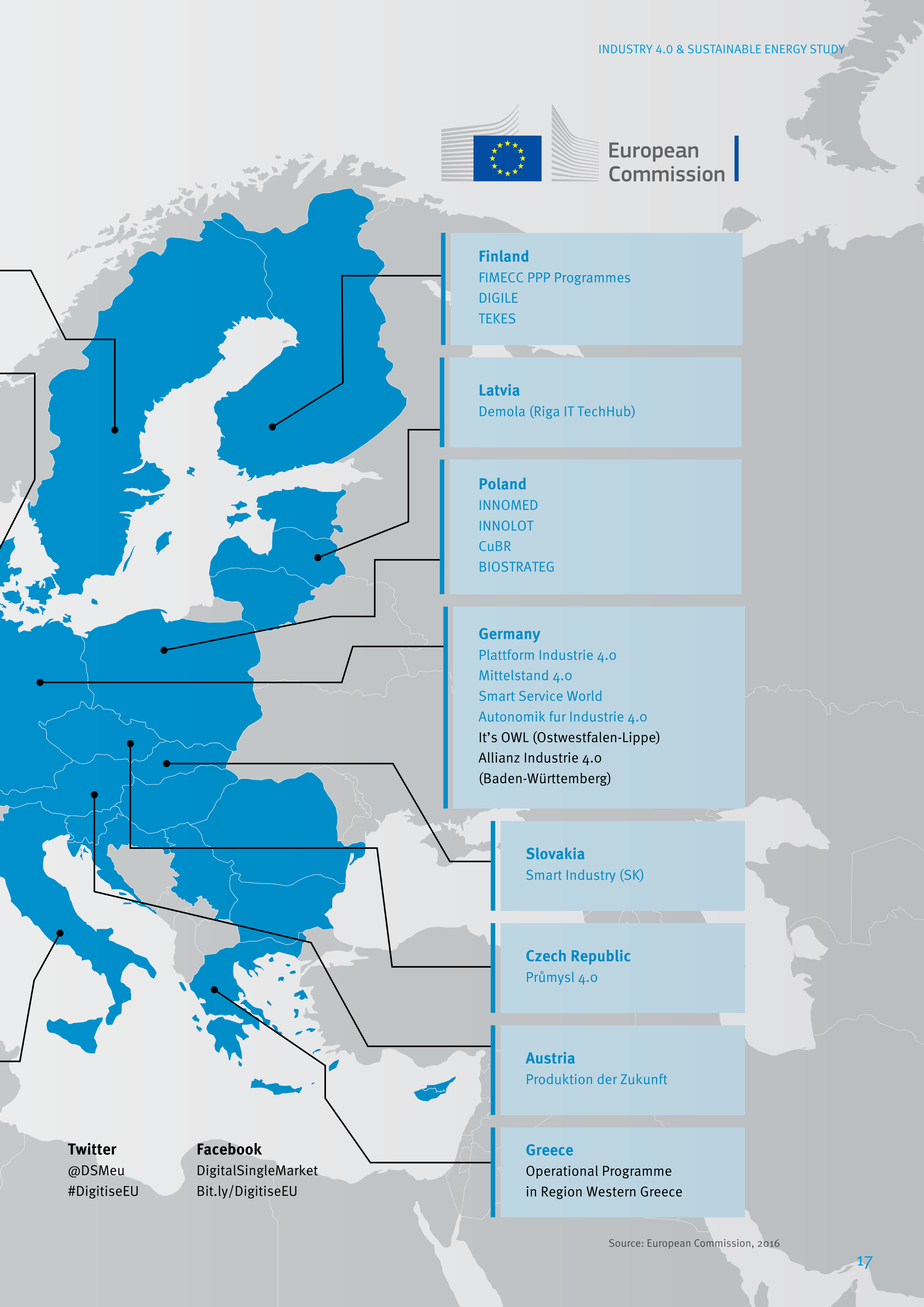
BOX 4 | AUGMENTED REALITY

One big potential for AR is seen in the service sector. Its application for maintenance purposes can help to connect staff on the customer location with service experts from the producing company, allowing them to jointly inspect the product under consideration and develop feasible maintenance solutions, without forcing experts to physically travel to the customer. The same approach can be applied when it comes to train local workforces in different regions. Through these approaches AR applications open up economic opportunities for small companies like start-ups, which want to sell their product around the globe and to offer decent services to their customers, but cannot afford to establish a global service network.

FIGURE 5 | **OVERVIEW OF EUROPEAN INITIATIVES ON DIGITIZING INDUSTRY**



European Commission



Finland
FIMECC PPP Programmes
DIGILE
TEKES

Latvia
Demola (Riga IT TechHub)

Poland
INNOMED
INNOLOT
CuBR
BIOSTRATEG

Germany
Plattform Industrie 4.0
Mittelstand 4.0
Smart Service World
Autonomik fur Industrie 4.0
It's OWL (Ostwestfalen-Lippe)
Allianz Industrie 4.0
(Baden-Württemberg)

Slovakia
Smart Industry (SK)

Czech Republic
Průmysl 4.0

Austria
Produktion der Zukunft

Greece
Operational Programme
in Region Western Greece

Twitter
@DSMeu
#DigitiseEU

Facebook
DigitalSingleMarket
Bit.ly/DigitiseEU

Source: European Commission, 2016

Challenges associated with Industry 4.0

The high potential of Industry 4.0 for transforming industrial processes and the economy do not come without challenges. Public discourse especially in early industrialized countries has particularly focused on the question of how digitization may affect the "future of work", meaning both quality and quantity of jobs (see expert opinion piece by Berger and Frey), but also the work relationship between humans and machines. An inherent conflict could for example arise in human-machine-interaction: if humans have to follow decisions of machines they cannot fully comprehend anymore, this could likely lead to frustration.

Besides, digitization could not only alter and reduce employment in some sectors, but also create new jobs – though not exclusively with positive effects. Some countries have witnessed the rise of a new industry of commercial content moderation (CCM) – for example the Philippines, India but also a range of industrialized countries (Roberts 2017). Commercial content moderators are people who screen user-generated content uploaded to internet sites and social media platforms for their appropriateness (Roberts 2016). They are therefore often confronted with disturbing images, e.g. displaying extreme violence or pornography that could have negative impacts on their psychological health (Chen 2014, Stone 2010, Roberts 2016).

Apart from effects on employment, the digitization of industry is likely to pose other challenges:

- **Resource demand:** Every digital device is based on hardware that requires raw materials for its original production. Due to the growing diffusion and application of digital technologies, the demand for raw materials is also likely to increase - opening up questions regarding their availability. The study "Raw materials for emerging technologies 2016" by the German Mineral Resources Agency (DERA) forecasts that in 2035 the most crucial materials are likely to be Lithium and Heavy Rare Earths (Marscheider-Weidemann et al. 2016).

- **Data security & privacy:** One of the biggest challenges most often expressed by companies in association with Industry 4.0 is data security (Brink et al. 2015; Littlefield 2016). They are afraid to become more vulnerable to hackers invading their intellectual property as they have digitized their processes and connected all devices and machines to the network. A less prominent challenge is to maintain and guarantee the privacy of employees, who will also contribute a lot of personal data, when constantly interacting with permanently connected devices.

- **Overstraining of governments** with the creation of suitable policy frameworks: Digitization and Industry 4.0 are largely driven by actors from the economic sphere. Their pace often exceeds the speed at which policies and regulations can be formulated to govern digital and technology developments. In this way, policy making could become ineffective in impeding potential adverse effects, e.g. on privacy and data security, labor rights and conditions and the environment.

- **Innovation race:** The vast and increasing speed of technology development could lead to a first-mover advantage for pioneering countries or companies. This would give the few top runners large economic influence and – if regulations are weak – power to lever out social and environmental standards. Countries will therefore not only be increasingly challenged to provide suitable framework conditions for innovation, but also to protect existing standards and to expand them to newly developing digital branches.

- **Deepening global inequalities:** Related to the previous point, inequalities between the economic development of industrialized, emerging economies and developing countries could further deepen if countries of the Global South cannot tap into digital development benefits. Developing and least developed countries should be enabled to use the possibilities of ICT and Industry 4.0 to achieve their development priorities.

EXPERT OPINION PIECE

Robots and the return of the "machinery question"

Thor Berger and Carl Benedikt Frey

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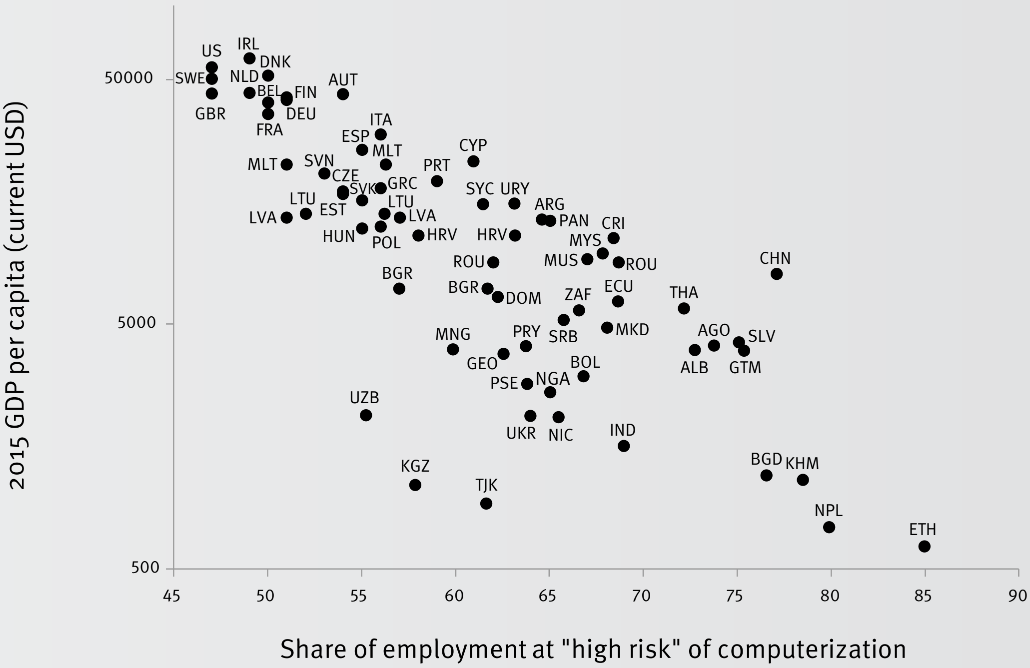
Carl Benedikt Frey, *Oxford Martin Citi Fellow & Co-Director of the Oxford Martin Program on Technology and Employment, University of Oxford.*

For more than two centuries, contemporaries have from time to time worried about machines reducing the demand for jobs. The "machinery question", as it was called during the Industrial Revolution, has witnessed a recent revival. Since the Computer Revolution of the 1980s, workers have been displaced from repetitive and rule-based work activities, which can easily be codified and thus carried out by industrial robots or software. The effects on employment have been pervasive: labor markets have "hollowed out" in response, as middle-skill jobs have been automated away, with employment growth concentrated at both extremes of the skill spectrum (see Goos et al. 2009, 2014 and Autor & Dorn 2013). This process of job polarization has been evident among industrialized economies for quite some time, and has more recently been documented for a host of emerging industrial countries as well. Yet, the future impact of technology on jobs is likely to be even greater. A number of studies have shown that a new generation of digital technologies are making inroads into jobs and tasks that were deemed non-automatable only a decade ago (Frey & Osborne 2017). In particular, advances in machine learning and mobile robotics aided by the increased availability of big data, due to the proliferation of connected devices and digital sensors, has allowed computer technology to displace workers in a wider set of more complex tasks in both the cognitive and manual skill domains. A wide variety of jobs that long were thought to be resilient to computerization has consequently seen increased threat from automation in recent years including those of drivers, medical doctors, and journalists.

No country is immune to the expanding scope of automation, yet two facts suggest that it poses more significant challenges for emerging industrial economies and the least developed countries. First, a defining feature of the development path of today's industrialized countries was a sizable manufacturing sector that offered well-paid jobs for a large share of the population. As emerging economies are undergoing that same process of structural transformation, however, the ability of the manufacturing sector to absorb workers is much more limited. Whereas manufacturing typically employed more than a third of the population at its peak in developed countries, this share peaked well below half that in many emerging industrial economies, which has become known as "premature deindustrialization": countries substituting away from manufacturing before fully industrializing (Rodrik 2015). Second, a limited ability of the secondary sector to absorb labor is further exacerbated by global trends in the exposure to automation: Figure 6 graphs the share of jobs at "high risk" of automation in the industrialized, emerging industrial, and least developed economies, which shows the striking negative correlation between a country's income level and the share of jobs that are feasible to automate. Thus, while automation will be a challenge everywhere—with about half of employment falling in the "high risk" category even in countries such as the United Kingdom and the United States—the limited scope for extensive industrial growth and a higher share of jobs at risk poses a twin challenge for maintaining employment in emerging economies over the next decades.

FIGURE 6 | JOBS AT "HIGH RISK" OF AUTOMATION



Notes: This figure shows the share of aggregate employment that is at "high risk" of automation based on the definition derived in Frey & Osborne (2017) with additional data drawn from the World Bank (2016a) and Bowles (2016). GDP per capita in 2015 in current USD was obtained from the World Bank.

Although the scope of automation is widening, we caution against the widespread belief of a jobless future since the evidence that new technologies have led to a permanent reduction in employment is mixed. A recent study suggests that each industrial robot implemented in the United States has reduced employment by 6.2 workers, which has translated into permanently lower labor force participation and depressed wages.[3] Yet, another recent cross-country study finds that industrial robots have only reduced employment within certain skill groups (Graetz & Michaels 2015). This has also been the case in the past. While technology destroys old work, it also creates new employment opportunities in, for example, the digital and energy-related sectors (Berger & Frey 2016b). However, transitions into new jobs are often painful, as it requires the acquisition of new skills, meaning that rapid technological change imposes high adaptation costs for individual workers.

As technology is making inroads into an expanding set of human skill domains, the key question facing policy makers is: what skills will be in demand in the future of work? A robust trend in recent decades has been the increased demand for highly educated workers, which has manifested itself in dramatically rising returns to skills. Mainly, these changes reflect the increased importance of technical and problem-solving skills, which is also mirrored in a striking geographical correlation between endowments of complex abstract skills and the creation of new types of jobs and industries (Berger & Frey 2016a, 2017a). While the scope of automation is invariably widening, there exists certain skills where humans are likely to retain a comparative advantage. In particular, jobs that revolve around creativity, complex social interactions, and manipulation of physical objects in uncontrolled environments are likely to remain outside of the domain of digital technology. A higher share of jobs at risk of automation in emerging industrial economies and the least developed countries partly reflect the lower endowments of these skillsets, which highlights the more general implication that how well countries meet the challenges of automation boils down to whether they manage to facilitate the acquisition and diffusion of these skills that remain valuable also in the future of work.

3 See Berger & Frey (2016a, 2017a) and Berger et al. (2017b) regarding the limited employment impacts of new technologies and Acemoglu & Restrepo (2017) concerning the adverse employment impacts of industrial robots in the United States.

Sustainable Energy

Renewable energy and energy efficiency are the two central components of sustainable energy systems (Lemaire 2004, revised 2010) and play pivotal roles in achieving international climate mitigation and sustainable development targets.

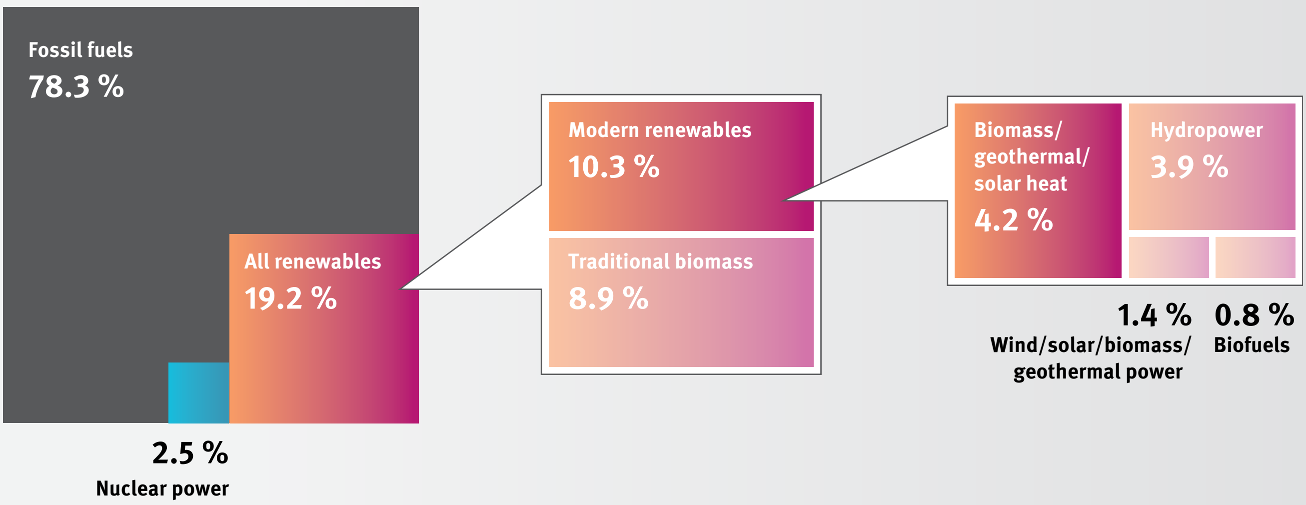
Renewable energy

Looking at the role of renewables in the global energy system today, there is still a long way to go to achieve more sustainable energy systems: In 2014, more than 78 % of global final energy consumption was covered by fossil fuels; renewable energies, not including traditional biomass[4], contributed a share of 10.3 % with solar and wind power accounting only for a fraction of global final energy consumption (REN21 2016, see Figure 7). Consequently, the energy sector still remains the major emitter of harmful climate gases accounting for approximately two thirds of global greenhouse gas emissions (OECD/IEA 2015).

However, renewable energy capacities have witnessed a vast development over the past decade. Growth rates of renewable energies were particularly high for solar photovoltaics (at an average rate of 46.2 % since 1990) and wind energy (at an average rate of 24.3 % since 1990) (IEA 2016a).

4 Traditional biomass is defined by the IEA as "the use of wood, charcoal, agricultural resides and animal dung for cooking and heating in the residential sector. It tends to have very low conversion efficiency (10 % to 20 %) and often unsustainable supply". Definition retrieved from: https://www.iea.org/topics/renewables/subtopics/bioenergy/, [Accessed 26 Apr. 2017].

FIGURE 7 | **ESTIMATED RENEWABLE ENERGY SHARE OF GLOBAL FINAL ENERGY CONSUMPTION, 2014**



Source: REN21 2016; source thereof according to REN21: IEA, Energy and Climate Change, World Energy Outlook Special Report, Climate Transparency.

In 2015, renewable energies contributed more than 50 % of the world's additional electricity capacity (IEA 2016b) turning them into an increasingly important source for electricity supply. Developing countries, emerging economies and industrialized countries alike, such as China, Chile, India, the US, Spain, Australia and many North African and Middle Eastern countries, have forwarded the development and construction of large-scale[5] solar energy and wind farms in recent years. This development is driven by a multitude of factors, among others decreasing prices for renewable energy technologies, rising energy demand as well as countries' desire to diversify their national energy mix and to decrease their dependency on energy imports. In addition, the development of renewable energy capacities was fostered by and increased awareness for the necessity to reduce GHG emissions from the energy sector to combat global climate change. Worldwide, the number of countries implementing more favorable policy and regulatory conditions for renewable energies has increased, rising from 43 in 2005 to 164 countries in mid-2015 (IRENA 2015).

Yet, the integration of renewable energy into electrical power systems does not come without challenges, particularly with regard to grid load balance and the management of the complexity of a system that instead of a few large conventional power plants includes a multitude of decentralized, renewable power generation units (Brand 2017). Digital technologies can play a major role in order to cope with these challenges (Brand 2017).

Energy efficiency

Similarly to renewable energies, energy efficiency has advanced over the past years. Worldwide, energy intensity has decreased – despite declining oil prices (IEA 2016c). Emerging economies have shown higher energy intensity improvements than industrialized countries, with China leading the way by decreasing its energy intensity by 5.6 % from 2014 to 2015 (IEA 2016c).

However, as the IEA points out, energy efficiency needs to be stepped up significantly in order to achieve the international climate change mitigation targets. The industrial sector – which accounts for approximately one third of global final energy use and 40 % of global energy-related CO_2 emissions (OECD/IEA 2009) – could make a significant contribution in this regard. New technologies and technological developments are pivotal for this purpose. The IEA estimates, that energy use could be decreased by 13 % to 29 % in five energy-intensive industrial sectors[6] by implementing the current best available technologies (OECD/IEA 2009). Thereby, global energy use and global CO_2 emissions could be reduced by 4 % (OECD/IEA 2009). However, the IEA also points out, that achieving these savings will not happen instantly and that the application of best available technologies depends on several factors, such as energy costs, return on investments, and regulations.

5 Large-scale is here understood as a capacity of more than 1 MW.

6 For its study, the IEA assessed the following sectors: chemicals, iron and steel, cement, pulp and paper, aluminum.

BOX 5 | MINI-GRIDS AS AN APPROACH FOR ENABLING SUSTAINABLE ENERGY FOR ALL

Approximately 1.1 billion people worldwide do not have access to electricity, and 2.9 billion use polluting, inefficient and unhealthy fuels for cooking (SE4All 2016). Much of the increased energy demand in developing countries is currently met by using fossil fuels or traditional biomass such as firewood, dung, and charcoal. A successful sustainable energy transition therefore encompasses tackling the challenge of energy security which means the availability of stable, secure and affordable energy where ever and whenever needed (Roehrkasten & Westphal 2016).

The global Sustainable Energy for All (SE4All) initiative, launched in 2010 by the former UN Secretary-General Ban Ki-moon, integrates energy transition and energy security and aims to ensure universal access to modern energy services, to double the global rate of improvement in energy efficiency, and to double the share of renewable energy in the global energy mix (SE4All 2016). One important building block of the initiative for providing energy access in remote areas is clean energy mini-grids[1] (SE4All). They could serve as a bridge until grid connection is achieved or provide an alternative to grid-connection in areas with very low population density, rough terrain and high distances from the main grid making the expansion of grid connection very costly (OECD/IEA 2016). Yet, the renewable mini-grid sector is still in an early stage of development and currently accounts for only a marginal share of renewable energy capacity. It faces many challenges, such as a lack of economic viability, inadequate regulations and tariff structures and high costs and uncertainties about grid expansion plans (OECD/IEA 2016). In future, however, mini-grids could benefit from innovative technological, socio-political developments and new approaches to regulate and finance energy and become a valid opportunity for the development of alternative approaches to supplying electricity (IRENA 2016).

1 IRENA defines mini-/micro-grids as follows: “Distributed energy sources (including generators and energy storage appliances) and interconnected loads integrating an energy infrastructure, which can operate in parallel with the main grid, off-grid or in islanding mode.” Source: IRENA 2016.

Combining Industry 4.0 and Sustainable Energy

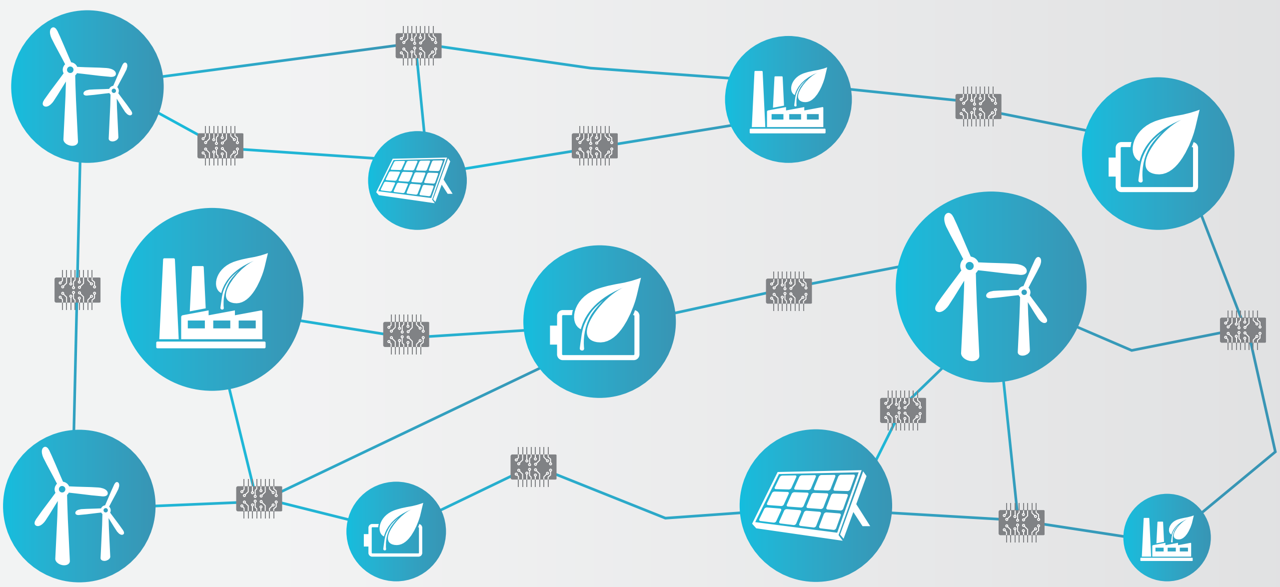
4

Why link the two systems?

The transformation of the energy sector through the deployment of more sustainable energy systems and digital transformation of the industry will substantially alter the way people live, consume, produce and trade. These two major transformations are concurrent and interconnected, but are pursued in different political arenas and with different paces and priorities across the globe.

The sustainable energy transition and Industry 4.0 share important characteristics: both are highly influenced by technological innovations, dependent on the development of new suitable infrastructures and regulations as well as are potential enablers for new business models. These commonalities have not yet translated into substantial policies to foster the transition to more sustainable energy systems and digital production *at the same time* and in an *integrated way* (Figure 8). Industries account for a major share of electricity consumption – amounting in 2014 to 42.5 % worldwide (IEA 2016d) – and energy networks need to accommodate electricity demand from industrial consumers. This could be reason enough to think how the transition towards more sustainable energy systems and the digital transformation of industries could mutually benefit from each other. Such an approach could also help to avoid the development of new path dependencies that potentially lead either sector – energy or industry – into a less sustainable, more carbon intensive future. Such integrated approaches could be guided by the SDGs, which provide important target setting for energy, climate action and beyond.

FIGURE 8 | **MAKING SMART FACTORIES PART OF THE ENERGY SYSTEMS**



Digitization of the energy sector

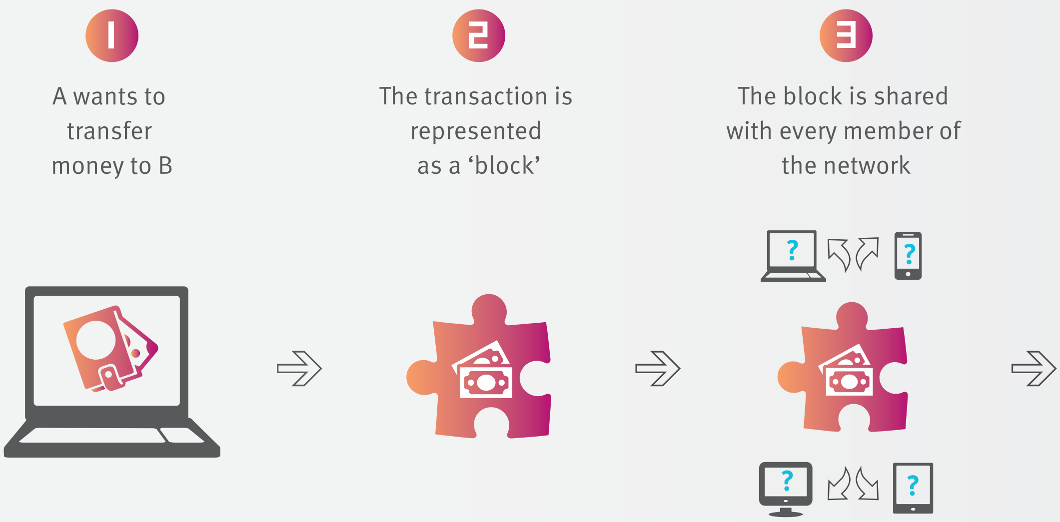
Over the past few years, the digitization of energy systems has received wide attention. Developments in information and communication technologies, the spread of internet access and mobile devices such as smartphones, and the development of the blockchain technology (see Box 5) open opportunities for new approaches and business models that could significantly impact the energy sector.

Digital technologies could offer solutions to the challenges of integrating renewable energy sources into small and large power grids which require new approaches to grid management (IRENA 2013). So-called *smart grids* serving that end have received wide attention in the past years. The term refers to grids that draw on the potentials of information and communication technologies in order to monitor and efficiently manage the generation, delivery, and consumption of electricity from different – potentially decentralized – sources of electricity to meet the varying electricity demands of end-users (OECD/IEA 2011). Such grids could provide the flexibility necessary to integrated renewable energies such as wind and solar into electricity

BOX 6 | BLOCKCHAINS, AND WHAT THEY COULD MEAN FOR SUSTAINABLE ENERGY

Blockchains are distributed databases and ledgers made of blocks stored on a large number of machines, so that any changes made to the database are permanently recorded, and any record is made publicly available thanks to the distributed design (Crosby et al. 2016). Blockchains are expected to bring about unprecedented changes in traceability and data robustness. This opens up new opportunities for reducing or eliminating the need for a trusted middleman in many operations, be it a supply of certified renewable electricity coming from distributed energy generation, the verification of legal provisions, the establishment of a patent, or a simple payment (see Figure 9).

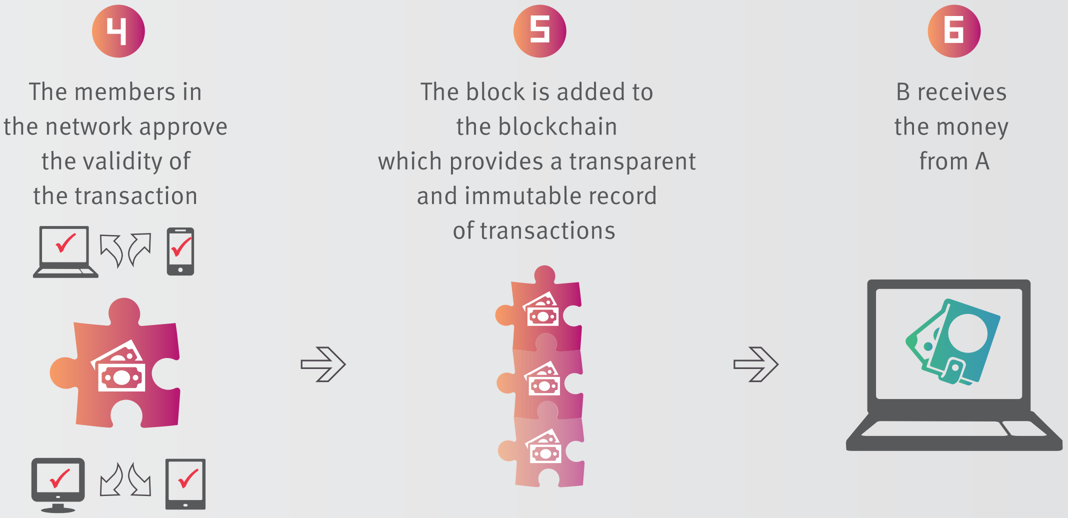
FIGURE 9 | HOW A BLOCKCHAIN WORKS



networks on a large scale. However, there are still many technical and regulatory barriers to smart grids and the complexity of electrical systems makes it rather unlikely that the implementation of smart grids will be provided by the market alone (OECD/IEA 2011).

Another digital approach related to distributed energy generation is Virtual Power Plants (VPP). VPP are heterogeneous coalitions of distributed energy resources, generally composed of intermittent renewable sources, storage systems, flexible loads, and small conventional power plants that need to negotiate some bilateral contracts in advance prior to participating in the day-ahead market (Shabanzadeh et al. 2015). VPP usually have a cloud-based central or distributed control center and make use of the Internet of Things devices and other digital technologies. An analysis and simulation conducted by German scientists show that combining virtual power plants with renewable energy will allow for the exclusive use of renewable energy sources in the future (Knorr et al. 2014). Big industry players have already taken up the development of solutions for virtual power plants, such as the cloud-based energy management system DEMS of Siemens' Smart Grid division.

According to a recent study, German energy executives see a wide range of possible applications for blockchains in the energy sector and believe the technology could have the potential to reduce costs and spur new business models in the energy sector (Burger et al. 2016). However, the blockchain technology faces many challenges, in particular privacy and data security issues, but also technical issues such as the currently still rather long time needed to conduct a transaction. Besides, services based on blockchain have to prove competitive with existing solutions and need to convince users of their attractiveness (Burger et al. 2016). However, there are already a number of start-ups, working on solving these challenges and on providing blockchain solutions for the energy sector (Brand 2017).



Source: Figure based on Wild et al. (2015) for the Financial Times

Saving energy in the manufacturing sector

One of the key characteristics of Industry 4.0 is the digitization of manufacturing processes. This transformation can offer opportunities for energy saving – for example, through the optimization or replacement of specific technologies, the application of new software tools that also offer energy optimization functionality, or adaptations in the business processes. The following paragraphs will elaborate how these approaches can support energy savings.

An example for the optimization of a specific technology can be found in the control of the behavior of a large number of interconnected robots by an algorithm that reduces their energy consumption. By minimizing the acceleration of robots, their energy consumption can be reduced by up to 30 % without increasing the overall production time (Lennartson & Bengtsson 2016). Many players from science and industry currently develop such optimization algorithms (such as in the EU-project AREUS[7]). But innovative digital technologies also offer the chance for the replacement of conventional, often more energy-intensive manufacturing procedures. For the production of prototypes or products with low lot sizes, Rapid Prototyping technologies can be a much cheaper, quicker and more energy-efficient alternative compared to the sequence of conventional ablative procedures which would conventionally be used to manufacture them.

A more disruptive approach is to transform a range of business processes. The digitization of the entire value creation network also opens the way to directly connect to the customer and integrate their user experience e. g. in the development of future products or additional services. In that manner, on-demand customized products become technologically feasible, providing the opportunity for eliminating unnecessary functionality (e. g. omit a gearshift for people who only want to cycle through flat terrain). The physical realization of every function requires resources (material for physical or energy for digital solutions), the reduction to customer-requested functionalities will help save resources compared to “all-inclusive” default solutions.

7 For further information see http://www.areus-project.eu/.

BOX 7 | RAPID PROTOTYPING

Rapid prototyping is a group of complementary technologies such as computer-aided design and additive-layers manufacturing, also known as 3D-printing, used to rapidly produce parts and prototypes, as opposed to the more traditional material forming and removal techniques (Kruth et al. 1998).

The cost and time savings enabled by rapid prototyping can help to ease mass-customisation and are considered an enabler for innovation, as innovative designs are becoming easier, quicker, and less expensive to test. Beyond prototyping, technologies such as additive-layer manufacturing also provide benefits to serial or mass manufacturing processes, as exemplified by General Electric’s LEAP engine where 3D-printed fuel nozzles have enabled to go from 18 sub-parts to only 1. This not only multiplied the durability of the component by 5 and reduced its weight by 25 %, but also enabled a better optimised geometry to achieve higher combustion efficiency (Ford & Despeisse 2016), leading to fuel savings throughout the life of the engine and reducing its CO_2 emissions.

Sustainable energy in the manufacturing sector

Combining the two trends, sustainable energy and Industry 4.0, is a rather new approach which has not attracted very much attention in research yet. However, there are a number of opportunities on how sustainable energy concepts can be incorporated into a digital factory. All of the concepts presented in the following require a data connection of the factory with the energy system to detect the current level of renewable energy in it or the market price respectively, so that energy generation and energy consumption can be converged.

Some of these approaches can be subsumed under the category of energy storage. Energy storage capacities are very important for volatile energy systems - both for security of supply and grid flexibility. Storage also allows for a more effective use of existing infrastructure e. g. by reducing peak loads.

For some industries with high thermal capacities or steam-based processes in their production, the Power-to-Heat concept might be of special relevance. Power-to-Heat basically means that a surplus of renewable and therefore reasonably priced energy is converted into thermal energy (e. g. steam) that can be stored or directly used (typically temporarily substituting gas heating processes). It can also be applied on a smaller scale in private homes.

A similar approach, which is currently developing quickly in Europe, is Power-to-Gas. Here the surplus of renewable energy is used to produce gas – most commonly methane or hydrogen. Generally the efficiency of Power-to-Heat is higher compared to Power-to-Gas, but the latter has two big advantages: it can be used for large scale storage, and the gas can easily be re-turned into electricity at a later point. The Power-to-Gas concept can be an especially relevant option for the few factories with an existing hydrogen infrastructure.

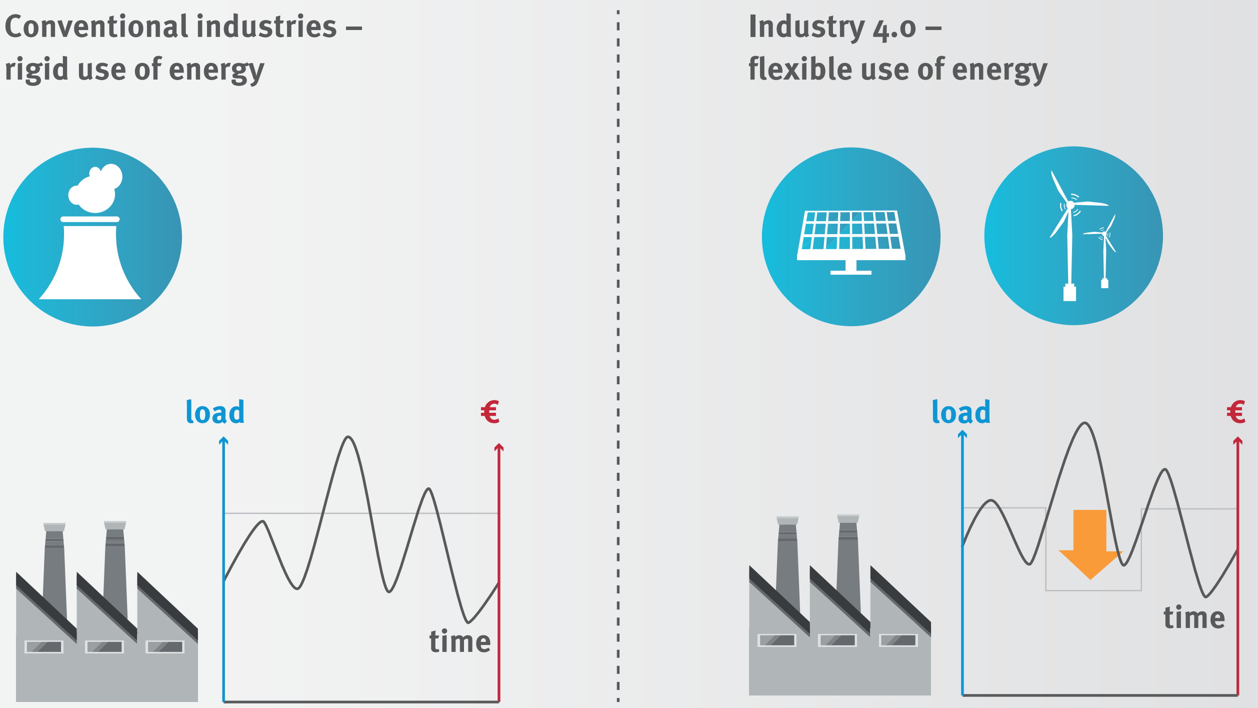
Demand response is a concept that addresses the temporal flexibility of energy consumption, which is why Power-to-Heat is also considered as a demand response approach. Demand response may be characterized as load curtailment, load increase and load shifting. In the industrial context it is especially relevant for time-flexible but energy intense production processes (such as chemical electrolysis). There the general aim is to time production phases according to the availability of cheap electricity in the energy market (due to surplus of renewable energy) whenever possible (see Figure 10).

All of the approaches mentioned above can help to foster Sustainable Energy in the manufacturing sector. A highly industrialized country that is also pursuing ambitious goals for renewable energy contribution like Germany, should seek to take advantage of these approaches. This is why the German Federal Ministry of Education and Research has launched a major research project addressing the energy transformation, called Kopernikus. Kopernikus focuses on two of the aforementioned approaches:

- SynErgie[8] on the synchronization of industrial processes with renewable energy generation
- Power to X[9] on the storage of renewable energy in different forms.

8 For further information see: https://www.kopernikus-projekte.de/projekte/industrieprozesse
9 For further information see: https://www.kopernikus-projekte.de/projekte/power-to-x

FIGURE 10 | **PRODUCING IN SMART FACTORIES WHEN ELECTRICITY IS CHEAP**



Source: Figure based on Sauer 2015.

5

Country Perspectives: Industry 4.0 and Sustainable Energy

This chapter explores the opportunities and challenges of Industry 4.0 and its potential synergies with more sustainable energy systems against the background of countries with different levels of industrialization. For that purpose, the analysis applies the country categories developed by UNIDO for its Industrial Development Reports. The UNIDO country classification is primarily based on the manufacturing value added (MVA) per capita as an indicator to assess a country's level of industrial production deflated to its population size (Upadhyaya 2013). The choice of MVA per capita as a key indicator to classify countries reflects the primary mandate and focus of UNIDO to promote industrial development worldwide (Upadhyaya 2013). This approach leads to the following country categories (see Figure 11, Annex 1 provides a full list of countries in each category) [10]:

- **Industrialized countries**: countries with an adjusted MVA per capita of more than 2.500 international dollars as well as all countries with a GDP per capita above 20.000 international dollars.

- **Emerging industrial economies**: countries that reached an adjusted MVA per capita of more than 1.000 international dollars or contribute 0.5 % or more to global MVA.

- **Other developing countries:** all countries below the threshold of 1.000 international dollars per capita are classified as **other developing countries**.

- **Least developed countries (LDCs):** defined by the UN General Assembly are low-income countries confronting severe structural impediments to sustainable development. This report will dedicate a separate section to this country group to underscore the commitment of UNIDO to foster sustainable and inclusive industrialization especially in the least developed countries.

10 For a more detailed explanation of the method behind the UNIDO country classifications and the selection of the thresholds for the country grouping see Upadhyaya 2013.

FIGURE 11 | **NUMBER OF COUNTRIES ACCORDING TO LEVEL OF INDUSTRIALIZATION**

Countries grouped according to their MVA per capita often vary significantly in terms of their economic and industrial policies and profiles as well as with regard to many other aspects, be it their natural resource base, energy policies, level of infrastructure development or performance in a wide range of socio-economic indicators. However, it would go beyond the scope of this report to provide a detailed analysis at the level of different world regions or individual countries. It can therefore only provide a cursory look on some key issues in the different country classes.

Industrialized countries – exploiting sustainability potentials in industrial production

Countries in Europe and North America, Australia, Japan, Singapore, Taiwan and the Republic of Korea already have advanced infrastructures, regulations and skilled human resources bringing them into a good position to exploit the potentials of new information and communication technologies and to drive innovation and development in the area of Industry 4.0 (Baller et al. 2016). According to a survey among 559 industrial enterprises with more than 100 employees, the USA (28 % of respondents), Germany (25 % of respondents) and Japan (20 % of respondents) can be considered the leading countries in the field of Industry 4.0 (Bitkom Research 2016). These countries belong also to the frontrunners in terms of renewable energy development and energy efficiency. However, the economies of industrialized countries are still largely dependent on fossil fuels – turning them into major greenhouse gas emitters. In 2014, the 35 member states of the OECD alone accounted for 36.6 % of worldwide CO2 emissions from fuel combustion (IEA 2016d).

While the digitization in industrialized countries has gained wide momentum, it is currently driven mainly by the desire to improve competitiveness by optimizing as well as further automatizing production processes. Energy and resource efficiency gains are a welcomed side effect, but rarely a key objective of deploying Industry 4.0 technologies. Yet, some companies already take advantage from digital technologies to improve their energy efficiency. For example, a German car manufacturer has achieved a 30% energy efficiency gain for a robot system by (among other optimizations) using Industry 4.0 technologies (Daimler 2017), while a Canadian company reports to have saved up to 15% of energy by implementing them in their production processes (Thilmany 2017). However, there is very little data available on overall energy efficiency gains from digital technologies in the industrial sector. Companies hardly provide quantitative data. Yet, they often express that they were able to reduce their energy consumption because the digitization of manufacturing processes allowed them to gain better knowledge about the actual energy demand of their machines. Based on the lack of data on the exploitation of digital technologies for energy efficiency, however, there is reason to believe that much potential for increasing industrial energy efficiency remains untapped.

Smart applications in the production processes could help to exploit these potentials as they can provide transparency about energy consumption patterns and help to optimize a company's energy management. Besides, due to their automation-enabled temporal flexibility, smart factories and their energetic drains and sources could be part of a so-called smart grid and help stabilize the energy system by either consuming and storing energy (in case of energy surplus) or on the opposite by reducing their consumption (in case of energy shortage) on demand. A more conscious and targeted approach for linking Industry 4.0 and sustainable energy efforts could engender major opportunities for industrialized countries' economies to become more sustainable and to reduce their carbon footprint.

Emerging industrial economies – aiming for the right direction

The group of emerging industrial economies includes, among others, India, Indonesia, Thailand, China, most Central and Latin American countries, many Eastern and South Eastern European countries, as well as a few countries on the African continent like Tunisia and South Africa. This list already shows how diverse the group of emerging industrial economies is. Many of them have already developed or are in the process of developing strategies for the digitization of their societies and economies, usually comprising diverse measures for developing and upgrading infrastructures for the application of ICTs as well as regulations and incentives to foster the exploitation of digital technologies for social and economic development.

Among the emerging industrial economies there are many important suppliers for global production chains. The introduction of Industry 4.0 technologies into manufacturing processes in these countries is often driven by market demands as well as the need for compliance with the regulations or requirements of major commercial customers. These commercial customers could therefore play an important role in pushing digitalized, more energy and resource efficient production technologies forward in emerging industrialized countries.

Besides, the potential for the generation of energy and material savings through digital technologies could be significant: according to a recent study focusing on medium to large sized Chinese industrial companies, 83.5% of Chinese participants expect to see high or very high savings in energy consumption as a result of Industry 4.0. The potential for material savings is anticipated to be even larger, with 88.1% of Chinese participants forecasting very high or high savings potentials. However the link to renewable energy is not very obvious to these Chinese companies yet, as only 3% of them plan to set up their own facilities for generating renewable energy in the next five years (Beier et al. 2017).

In South Africa, as another example, companies use sensors and ICT to immediately react to changes in the energy quality, such as voltage imbalances, to avoid damage to their equipment. However, energy efficiency gains are rather side effects than the main objective of ICT-based adaptations to the respective energy management system. This could change when energy prices increase and become a major driver for the increase of production costs. There are also more and more examples of companies "defecting" from the grid and installing their own PV or biomass powered micro-grids. Some companies, e.g. in the pulp and paper sector, which produce energy as a by-product of their production processes, i.e. in form of heat, aim to become energy suppliers to the grid themselves. Both developments need smart technologies to efficiently steer the complex underlying processes. [11]

For the future development of Industry 4.0 and sustainable energy in emerging industrialized countries, the importance of local showcases cannot be overstated. Many best practices already exist in the Northern American and European context – however, they fail to provide convincing examples encouraging company leaders in emerging industrialized countries to invest in Industry 4.0 concepts.

11 This paragraph is based on an interview with Alf Hartzenburg, National Project Manager, Industrial Energy Efficiency Project, National Cleaner Production Centre of South Africa, on 19 Apr 2017.

Furthermore, local showcases could assist and inspire policy makers to develop suitable policies to spur the uptake of industry 4.0 and to foster research and innovation in this area. Such clear signals are much needed from companies to move forward with investments into digital technologies. Industry 4.0 policies, however, should also be linked with targets for resource efficiency, renewable energy integration, and the improvement of energy efficiency, in order to aim for more sustainable, less carbon intensive industrial development pathways.[12]

Other developing countries – aiming for sustainable and digital development

Over the past decade, many developing countries have made significant progress in the development of infrastructures and skills to connect their populations to mobile networks and the internet and to enable them to benefit from digital opportunities. The number of internet users and the number of smartphones have increased considerably. Today, ICT, in particular mobile phones, play a major role for businesses in developing countries. However, in particular in rural and remote areas, both access to modern ICT and electricity are often still not provided, costly or unreliable.

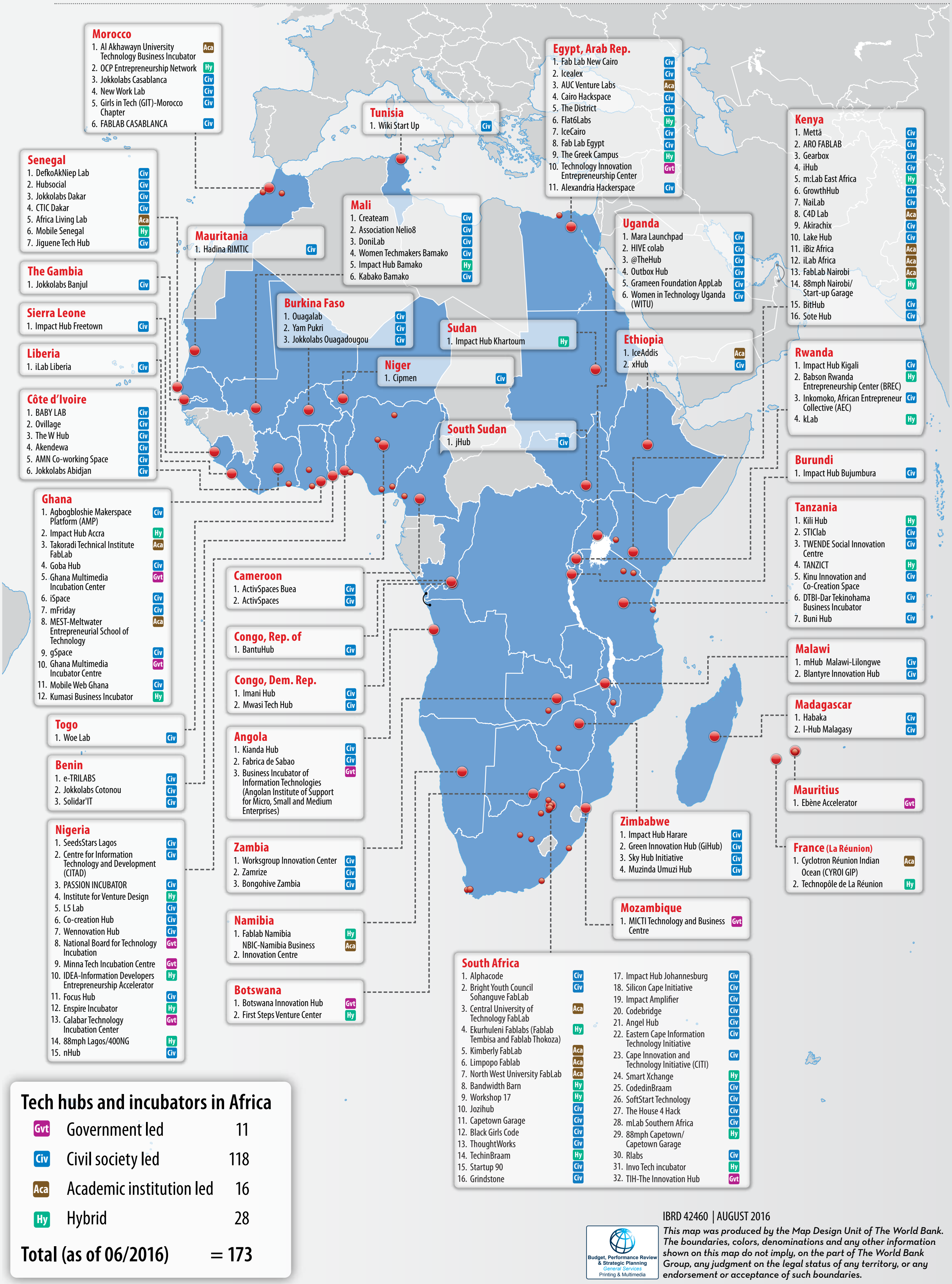
The industrial sector in many developing countries is often still weak and has a low level of automation. In combination with a lack of suitable framework conditions – whether with regard to infrastructures, regulations or related to human resources – this has so far led to a rather low impact and uptake of digital technologies in manufacturing (Deloitte 2016). This, however, should not obscure the fact that most developing countries have very well realized the potential of digital technologies for socio-economic development and have also started with the development and implementation of digital strategies and programs to foster the development of digital economies. Besides, the awareness of industry 4.0 technologies and their benefits is growing amongst industrial leaders and policy makers (Deloitte 2016). Moreover, new, often less costly technologies are also quickly picked up by individuals and small businesses in developing countries to provide services or to find solutions for everyday problems.

Against this background, many urban centers in African countries have seen the development of ICT-based startups and tech hubs led by government initiatives, private sector companies, civil society and/or academy (see Figure 12).

There is also a growing number of makerspaces in developing countries. Makerspaces are collaborative, often community-led working spaces equipped with a wide range of manufacturing tools, in many cases including technologies like 3D-printers and laser cutters, which provide a space for people to learn, to jointly explore technological applications and to develop new ideas and products that serve an individual purpose or that could even be commercialized. Makerspaces are very diverse. In the context of developing countries, they often provide spaces for the development of new of business models and could help to provide high-quality goods to areas that lack access to certain supply chains (Buchmann et al. 2017).

12 This paragraph is based on an interview with Aris Ika Nugrahanto, National Project Coordinator, UNIDO IEE Project Indonesia, on 18 Apr 2017.

FIGURE 12 | TECH HUBS AND INCUBATORS IN AFRICA (AS OF JUNE 2016)



Source: The World Bank 2016b, available at: http://pubdocs.worldbank.org/en/765531472059967675/AFC42460-081716.pdf [Accessed 28 Apr. 2017].

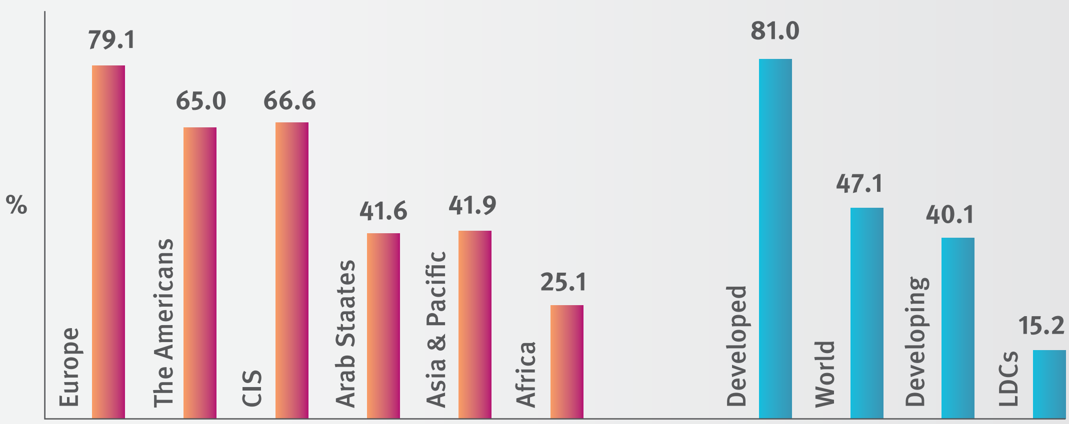
The interest of governments, corporations and organizations from the area of international development cooperation in startups, hubs and makerspaces in developing countries has increased over the past years, acknowledging the potentials of these spaces to spur a local, innovative and often technologically advanced economy. However, so far there is very little evidence that programs, incubators and accelerators fostering local startups in developing countries particularly address the aspect of sustainable energy. In order to strengthen interlinkages between digital manufacturing and sustainable energy, tailored regulations and incentives could help to encourage startups and other innovative businesses to understand energy efficiency and renewable energies as an essential part of a sustainable business model.

Least developed countries – setting digital development priorities

Least developed countries (LDCs)[13] face severe challenges with regard to sanitation infrastructure and public health, education as well as water and energy access. Many of the countries in this category have recently experienced or are still struggling with violent conflicts and share a high vulnerability to the adverse effects of climate change, be it natural disasters, sea level rise, droughts, soil erosion and loss of biodiversity, or other climate change impacts. Several LDCs belong to the group of landlocked countries facing particular difficult conditions for their integration into the global economy (Collier 2007). Besides, the group includes very resource scarce countries as well as those being endowed with large natural resources like Sierra Leone and the Democratic Republic of the Congo.

13 The category of the least developed countries is the only one defined by the UN General Assembly in order to target the most disadvantaged economies with special support measures (UN DESA 2015). As of June 2017, the UN had identified 47 countries considered as least developed (see Annex 1). Most of these countries are located on the African continent. The group also includes countries in Asia as well as several small island states. The definition of the least developed countries is based on a list of clear indicators and thresholds used to assess a countries income, human assets and economic vulnerability. For a detailed overview of the indicators and thresholds used to identify the least developed countries see: https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-criteria.html; [Accessed 28 Apr. 2017].

FIGURE 13 | **PERCENTAGE OF INDIVIDUALS USING THE INTERNET**



Source: ITU 2016.

Almost half of the world population is using the internet, but the percentage of internet users varies across world regions. In Europe, nearly eight out of ten people use the internet, in the Arab, Asian and Pacific countries four out of ten do so and less than three out of ten in Africa. However, in total numbers, the developing countries with 2.5 billion internet users surpass by far the developed countries with one billion users.

Over the past years, there has been an increase in the usage of information and communication technologies in the least developed countries. Yet, the gap between industrialized countries, other developing countries and LDCs remains large: only 15.2 % of the population in the LDCs is using the internet compared to the world average of 47.1 % (see Figure 13). Internet access – as electricity access – is often limited to urban areas and characterized by low speed and reliability.

However, many least developed countries have realized the potential of digital technologies to assist them in their development process and are determined to develop their infrastructures and human resources to benefit from digital technologies. In particular the Rwandan government has set high goals and shown strong commitment for connecting its people to high-speed internet and for turning the country into an IT hub.

Aside from providing access to education and essential information and fostering the development of local businesses, ICTs could also contribute to solving one of the most pressing challenges in the least developed countries: bringing electricity to remote, rural areas. For example, it is estimated that only 30 % of the 315 million people who will gain access to electricity in Africa's rural areas by 2040 will be connected to national grids. Most of the remaining 70 % will receive their electricity from off-grid household or mini-grid systems (African Progress Panel 2017). Here, decentralized solar-powered mini-grids are promising solutions (African Progress Panel 2017). Combining this development with the application of ICT to manage local mini- and micro-grids could help to tackle Africa's rural electrification challenge. Besides, small businesses and services could develop around small renewable and digital energy systems providing for new income opportunities.

Industry 4.0 in the classical sense of digitalized production plays a rather marginal role in least developed countries, in particular for those in Africa, and may only be relevant for companies manufacturing goods as part of global value chains, for example enterprises in the clothing and textile industry in Bangladesh and Cambodia. There exist already concepts of how to integrate Industry 4.0 technologies into the textile sector (Bullón Pérez et al. 2017, Chen & Mingjie 2015). Some authors forecast that Big Data and Internet of Things will play a big role in textile future (Choubey & Agrawal 2016) which could lead to a textile plant which will self-configure and self-optimize (Gloy et al. 2015). However, this flexibility would have the biggest impact on production lines with small lot sizes and increased product variations – typical characteristics of producers especially in high-wage countries (Saggiomo et al. 2016). For least developed countries it would be interesting to observe which of the applied technologies prove effective and therefore might also be adaptable for textile production with significantly higher lot sizes. Yet, the entailed social and economic implications of such a development and the potential loss of jobs would need to be carefully considered and strategies developed on how risks from technological developments could be mitigated or even turned into opportunities.

6

UNIDO's potential role in Industry 4.0

UNIDO and Industry 4.0

UNIDO has the capability and relevant portfolio to foster Industry 4.0 across all stages of industrial development. UNIDO promotes ISID through three programmatic fields of activity; creating shared prosperity, advancing economic competitiveness and safeguarding the environment.

As outlined in the previous chapters, Industry 4.0 has the potential to help accomplish UNIDO's vision that emphasizes ISID and address the integrated approach of the SDGs namely affordable and clean energy (SDG 7), industry, innovation, and infrastructure (SDG9) and climate action (SDG 13). These SDGs will be essential to promoting industrial energy efficiency, increasing renewable and decentralized energy systems, and designing climate policy. Industry 4.0 could help foster and achieve these targets.

UNIDO pursues a number of activities in the pursuit of ISID. Among them is the generation of data and statistics which provide the raw materials used by partners to explore, study, and develop industrial activities and facilitate platforms and partnerships for their collaboration. UNIDO's programs aim for industrial energy efficiency including policy and development standards (e.g. energy management systems based on ISO 50001), capacity building and awareness-raising, technology demonstration and upscaling. Other UNDO programmes act to increase demand for innovative partnerships, multi-level, and integrated solutions to promote industrial development that addresses energy, climate, and development challenges simultaneously (UNIDO, 2016a). UNIDO could assist in producing innovative partnerships with various stakeholders such as the private sector and organizations based in the countries considered as leaders for Industry 4.0. This collaboration can be done through knowledge sharing platforms for member states, such as the Vienna Energy Forum (VEF).

Additionally UNIDO contributes to industrial development directly, which includes structural changes for the growth and nature of the industrial sector, through assisting countries in the development of investment priorities, technology transfer, capacity building, and partnership arrangements. UNIDO also focuses on the development of renewable energy for the industrial sector. An illustration of this can be seen through the promotion of models for decentralized mini-grids based on renewable energy which could benefit rural and remote areas.

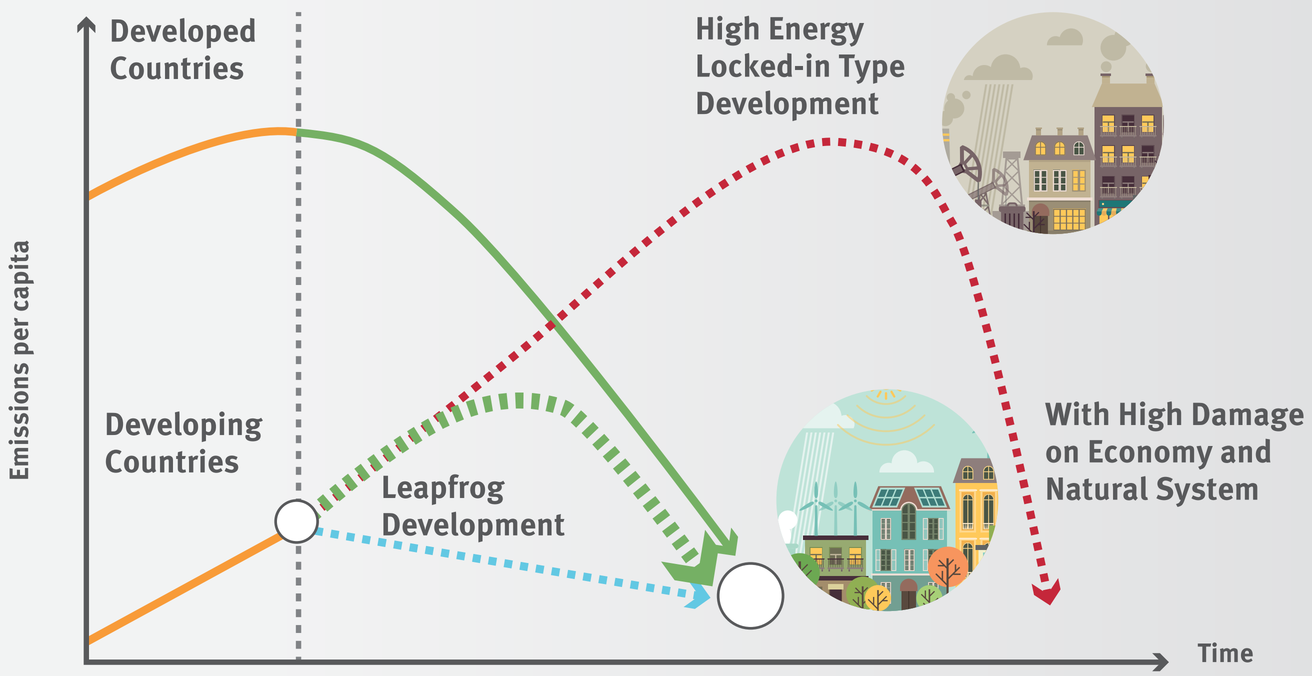
What can UNIDO offer?

Based on current levels of industrialization, countries can generally be associated with one of the two development paths as depicted in Figure 14. Within this context, Industry 4.0 technologies could particularly enable a) developed countries to transform established industries and infrastructures for potentially achieving ISID and b) developing countries to capitalize on the sustainable energy aspects of Industry 4.0 and move more rapidly towards ISID.

Retrofitting established industrial systems with Industry 4.0

Industrialized countries are frontrunners when it comes to technological leadership and innovation. Due to their key stake in former industrial revolutions, these countries are now operating within established industries and infrastructure that enabled considerable economic growth. At the same time, this considerable economic growth led to high energy consumption with detrimental effects to the environment. To ensure an increasingly inclusive and sustainable

FIGURE 14 | RETROFIT AND LEAPFROG PATHWAYS FOR ADOPTING LOW EMISSION INDUSTRIAL INFRASTRUCTURE OVER TIME



Source: http://gec.jp/citycoop/osaka-hcm-lcc/en/about/lcc.html. © avian / 123rf.com development path in industrialized countries, the potential of transforming and retrofitting existing industrial systems and infrastructure needs to be further tapped into. Connecting Industry 4.0 and sustainable energy initiatives could stimulate major opportunities for industrialized countries' economies, with most of potential found in carbon intensive industries via digitization, automation and optimization.

There are several ways that UNIDO can contribute to the adoption of energy-related Industry 4.0 technologies in industrialized countries. One of the foremost ways is the setup of platforms for ideation and transfer of Industry 4.0 technologies from a sustainable industry perspective. As large investments are needed for enterprises to make the move to Industry 4.0, UNIDO can play a facilitative role by securing financial support for SMEs to explore alternative technologies. This will assist the coordination of financing mechanisms of highly complex financial market transformation projects that will improve industrial energy efficiency in heavy industries. Furthermore, UNIDO can help in creating policy environments that enable and support sustainable adoption of energy efficient technologies and management as an integral part of industries' business practices.

Leapfrogging technology waves with Industry 4.0

Today's developing countries have access to energy technologies that did not exist when current industrialized countries were at similar stages of their own growth. This fact is at the centre which enables the notion of developing countries to leapfrog if industry 4.0 technologies are adopted. This could allow them to deploy mini-grids (as illustrated in Box5) which are significantly less carbon-intensive, without passing through a stage of high fossil fuel consumption for industrial development. The wealth of opportunities offered by deploying Industry 4.0 type technologies could provide pathways for more sustainable industrialization and the development of new business models. For the developing regions that have not participated in the past technology waves, this means that ICT and advanced technology in general, could hold large potentials for coping with some of the most pressing challenges like energy access and connectivity whilst avoiding carbon lock-ins.

A precondition for emerging industrial economies, other developing countries and least developed countries to tap into these potentials is the closure of the so-called digital divide through investments in the development of ICT literacy, skills and infrastructures, whilst promoting the setup of distributed, renewable energy systems next to fostering a technology start-up culture. UNIDO is distinctive in its ability to provide a transformative support to developing regions that are looking to capitalize on opportunities offered by Industry 4.0.

UNIDO can also play an important role in education and fostering entrepreneurship within the field of Industry 4.0. Promoting entrepreneurial attitudes, skills and knowledge on clean energy technology can support the development of sustainable and competitive entrepreneurship in developing countries.

Another way in which UNIDO can assist emerging industrial economies, other developing countries and least developed countries accelerate towards Industry 4.0 is through climate change related technology transfer and technical assistance. Demonstration and transfer of environmentally sound technology can increase the in-country capacity for safe and sustainable energy management practices. For example, local showcases of expertise and technical implementation of mini-grids, together with their financing and productive use, can prove to be pivotal for scaling up a decentralized and renewable energy systems.

In general, UNIDO can fortify momentum on digital development in developing regions through enabling favourable system conditions and increasing awareness of Industry 4.0 technologies and its benefits amongst industrial leaders and policy makers. In contrast to the Industry 4.0 course of industrialized and emerging industrialized countries, the course for the developing countries will involve much more investment in human capital and educating the next generation in information technologies.

Partnerships with the private sector – for both development paths

Due to accelerated growth of potentially disruptive Industry 4.0 technologies, collaboration between the private and public sector would need to grow stronger in both developing and developed economies. The private sector should play a large role in driving technology standards, financial solutions and targeted incentives to accelerate improvements. The public sector will be responsible for creating sensible policies so that society and business flourish under this paradigm shift. In addition, international organizations and governments enhance green business enabling policy environments, while financial institutions (both private and public, including IFIs) provide financial frameworks which can unlock large resource pools for high capital projects.

To support Industry 4.0 development globally, UNIDO has a unique role in collaborating with the private sector to facilitate transfers of knowledge and experience by plugging entrepreneurs into its network of member states. Creating fruitful partnerships between the private and public sector as early as possible will allow economies to grow in tandem with technological advancement. Collaborations between the private sector and UNIDO could serve as building blocks to achieve SDGs and country goals by invoking the technical expertise of the private sector related to Industry 4.0 and sustainable energy and by increasing awareness of and preparedness for Industry 4.0 in less developed regions.

Conclusions

7

The new wave of industrial revolution, often referred to as Industry 4.0 or the Fourth Industrial Revolution, is expected to have a major impact on industries, economies and lifestyle patterns across the world. This process encompasses the collision of the physical world of industrial production with the digital world of information technology, also known as *Cyber-Physical system*. Digitized and interconnected industrial manufacturing processes are created, where factories are becoming mainly self-organizing and steering – even across factory borders.

Industry 4.0 is expected to open up opportunities for producing customized products with very few additional costs. It is also expected to develop new business models based on the huge amount of data created along the product life cycle. The interconnectedness and flexibility of Industry 4.0 technologies could also entail several opportunities to support the transition to sustainable energy systems. Digital technologies could be used to optimize production processes and to enhance their energy efficiency. Furthermore, Industry 4.0 could open new opportunities for encouraging the deployment of renewable energies, e.g. when companies harmonize their production cycles with peak generation times to better match demand for power with the actual supply. In that manner, Industry 4.0 can help cope with the significant fluctuation of energy supplied by renewable energy sources – one of its big challenges. However, such possibilities of linking Industry 4.0 and sustainable energy systems are still in need of further exploration. Currently, sustainability is rarely the prime objective for optimizing industrial production processes, but rather a beneficial side-effect. A more conscious approach to creating synergies between Industry 4.0 and sustainable energy could foster tapping into yet unexploited benefits.

The opportunities for Industry 4.0, however, do not come without challenges: digitized and interconnected industries could fundamentally change working environments as well as the number and type of jobs created. The vast and quick changes in technology and their effects on economy and society could easily become a major challenge for policy makers to develop new, necessary regulations and to adjust existing ones to altered contexts. It is also still unclear how Industry 4.0 effects resource consumption and how companies will deal with major data security issues.

Framework conditions for exploiting the benefits of Industry 4.0 and for coping with its challenges vary significantly across the globe. Although digital technologies have spread into almost every corner of the planet, there is still a gap between industrialized, developing and especially least developed countries with regard to Internet access and to other digital technologies. In the industrial sector, the readiness of companies to include digital technologies and services into their manufacturing processes also varies significantly, often depending on location, size, sector and integration into global value chains. However, in particular for medium- to large-sized to large companies, digital technologies seem to be more and more adopted and integrated into manufacturing processes for optimization. Also, small enterprises explore the opportunities and benefits they can gain from digital technologies and services. In order to better evaluate the benefits and challenges when integrating Industry 4.0 technologies into manufacturing, in particular in emerging economies and in developing countries, local showcases are pivotal. They can also serve best as a testimony for the benefits created when linking Industry 4.0 together with renewable energies and energy efficiency.

UNIDO is in a unique position to usher in the fourth industrial revolution and integrate it as a force for achieving societal and environmental priorities. As a knowledge platform and project developer, UNIDO is capable of setting in motion the necessary programs. UNIDO's capacity to collect and analyze relevant data will provide major insights for facilitating Industry 4.0. Examples include evaluation of country preparedness and identification of resource gaps. Setting up knowledge and financial platforms can also open the discussion between innovators, policy makers, and other key stakeholders to synchronize the trends of Industry 4.0 with the SDGs and ISID. Innovative collaborations between the public and private sector can help assist developing countries to successfully implement Industry 4.0 technologies in their manufacturing processes. Through extensive networks within both the public and private sectors, UNIDO can mediate win-win solutions in accordance with the SDGs and the Paris Agreement.

Finally, a comprehensive shift in manufacturing, production processes and the uptake of sustainable energy can be captured through two development pathways: Transforming and Leapfrogging. The transformation towards Industry 4.0 will involve retrofitting existing industrialized systems with Industry 4.0 technologies that could provide more sustainable solutions for industrialized countries. Standardization, partnerships, and responsible policy advice are all ways in which UNIDO can serve. Policy challenges will require keen understanding of potential impacts of Industry 4.0 in the industrialized countries such as employment, financing, and innovation. Yet, the potential to empower industry 4.0 to become more sustainable than the status quo is there. On the other hand, leapfrogging will provide developing countries with an opportunity to increase their share of industrialization without repeating the mistakes of traditional development pathways taken by industry. Regions that are less developed can become candidates for the development of smart factories, smart and micro-grids, development of ICT based start-ups and optimization of companies that are part of the global value chain (i.e. textile). To support such a development, the challenges and opportunities associated with Industry 4.0 for countries with different stages of industrial development should be explored in more detail. Equally important is to showcase successful practical applications of Industry 4.0 technologies in different countries and to assess their impact on energy efficiency as well as other beneficial effects.

The implications of Industry 4.0 can either foster the advancement of human prosperity or potentially increase inequality if their use is inadequate, unequal or only a fraction of countries utilize these technologies efficiently. The real question about promoting Industry 4.0 technologies and its relevance for Sustainable Energy is not whether it should be a development priority. The question is what kind of technologies can be prioritized to maximize its potential to achieve the UN SDGs and the Paris Agreement. UNIDO embraces this challenge by starting the conversation on how working with partners and stakeholders can realize the benefits of this global vision for the next era of inclusive and sustainable industrial development.

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ANNEX 1
UNIDO Country Classification: Full List of Countries

ANNEX 1-1
Industrialized Countries (IC or IND)

- Andorra
- Aruba
- Australia
- Austria
- Bahrain
- Belgium
- Bermuda
- British Virgin Islands
- Canada
- Cayman Islands
- China, Hong Kong SAR
- China, Macao SAR
- China, Taiwan Province
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- French Polynesia
- Germany
- Greenland
- Hungary
- Iceland
- Ireland
- Israel
- Italy
- Japan
- Kuwait
- Liechtenstein
- Lithuania
- Luxembourg
- Malaysia
- Malta
- Monaco
- Netherlands
- New Caledonia
- New Zealand
- Norway
- Portugal
- Qatar
- Republic of Korea
- Russian Federation
- San Marino
- Singapore
- Slovakia
- Slovenia
- Spain
- Sweden
- Switzerland
- United Arab Emirates
- United Kingdom
- United States of America

ANNEX 1-2
Emerging Industrial Economies (EIEs)

- Argentina
- Belarus
- Brazil
- Brunei Darussalam
- Bulgaria
- Chile
- China
- Colombia
- Costa Rica
- Croatia
- Cyprus
- Greece
- India
- Indonesia
- Kazakhstan
- Latvia
- Mauritius
- Mexico
- Oman
- Poland
- Romania
- Saudi Arabia
- Serbia
- South Africa
- Suriname
- Thailand
- The former Yugoslavian Republic of Macedonia
- Tunisia
- Turkey
- Ukraine
- Uruguay
- Venezuela (Bolivarian Republic of)

ANNEX 1-3
Other Developing Countries (ODCs)

- Albania
- Algeria
- Angola
- Anguilla
- Antigua and Barbuda
- Armenia
- Azerbaijan

- Bahamas
- Barbados
- Belize
- Bolivia (Plurinational State of)
- Bosnia and Herzegovina
- Botswana

- Cabo Verde
- Cameroon
- Congo
- Cook Islands
- Cuba
- Côte d'Ivoire

- Democratic People's Republic of Korea
- Dominica
- Dominican Republic

- Ecuador
- Egypt
- El Salvador
- Equatorial Guinea

- Fiji

- Gabon
- Georgia
- Ghana
- Grenada
- Guatemala
- Guyana

- Honduras

- Iran (Islamic Republic of)
- Iraq

- Jamaica
- Jordan

- Kenya
- Kyrgyzstan

- Lebanon
- Libya

- Maldives
- Marshall Islands
- Mongolia
- Montenegro
- Montserrat
- Morocco

- Namibia
- Nicaragua
- Nigeria

- Pakistan
- Palau
- Panama
- Papua New Guinea
- Paraguay
- Peru
- Philippines

- Republic of Moldova

- Saint Kitts and Nevis
- Saint Lucia
- Saint Vincent and the Grenadines
- Seychelles
- Sri Lanka
- State of Palestine
- Swaziland
- Syrian Arab Republic

- Tajikistan
- Tonga
- Trinidad and Tobago
- Turkmenistan

- Uzbekistan

- Viet Nam

- Zimbabwe

ANNEX 1-4
Least Developed Countries (LDCs)

- Afghanistan

- Bangladesh
- Benin
- Bhutan
- Burkina Faso
- Burundi

- Cambodia
- Central African Republic
- Chad
- Comoros

- Democratic Rep. of the Congo
- Djibouti

- Eritrea
- Ethiopia

- Gambia
- Guinea
- Guinea-Bissau

- Haiti

- Kiribati

- Lao People's Democratic Rep.
- Lesotho
- Liberia

- Madagascar
- Malawi
- Mali
- Mauritania
- Mozambique
- Myanmar

- Nepal
- Niger

- Rwanda

- Samoa
- Sao Tome and Principe
- Senegal
- Sierra Leone
- Solomon Islands
- Somalia
- South Sudan
- Sudan

- Timor-Leste
- Togo
- Tuvalu

- Uganda
- United Republic of Tanzania

- Vanuatu

- Yemen

- Zambia

Abbreviations

AR	Augmented Reality
CCM	Commercial Content Moderation
CSP	Concentrated Solar Power
EIE	Emerging Industrial Economies
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNI	Gross National Income
HDR	Human Development Report
IC	Industrialized Countries (also: IND)
ICT	Information and Communication Technology
ITU	International Telecommunication Union
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISID	Inclusive and Sustainable Industrial Development
LDCs	Least Developed Countries
Mtoe	Million Tons of Oil Equivalent
MVA	Manufacturing Value Added
ODC	Other Developing Countries
OECD	Organisation for Economic Co-Operation and Development
PV	Photovoltaic
REEP	Renewable Energy and Energy Efficiency Partnership
REN21	Renewable Energy Policy Network for the 21st Century
SDGs	Sustainable Development Goals
TPES	Total Primary Energy Supply
UN	United Nations
UNIDO	United Nations Industrial Development Organization
USA	United States of America
VPP	Virtual Power Plants

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