Industry 4.0 in Sustainable Industrial Areas in Emerging and Developing Countries

Applicability of Technologies and the Role of the Park Management

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CONTENT

1 INTRODUCTION

The Fourth Industrial Revolution, commonly known as Industry 4.0 describes a vision of the future of production. The physical and virtual spheres are deeply interconnected and recent technological developments (e.g. artificial intelligence, the internet of things) are fully used to optimize economic value creation. Due to the technological developments, profound, revolutionary change is expected. This change is likely to happen on all levels of societal analysis: the global allocation of economic activities will be affected (macro-level), industrial value chains will be reshuffled (meso-level), and the organization of a company, of an individual task and the necessary skills of a worker in a highly digitalized work environment will be questioned (micro-level).

Under this designation, modern Information and Communication Technology (ICT) will digitally connect all value creation activities (along and across value chains) allowing for a 24/7 monitoring and optimization of these processes. Modern ICT may further be used for a low-cost steering of production processes. Production processes may become self-organizing and more autonomous ("individualized mass products at low costs"). And finally, the available data may drive the creation of new services and innovative business models ("Data is the new oil"). The current way of value creation is thus severely questioned.

The term Industry 4.0 captures not only the result of the full connection of the physical and digital sphere, but also processes related to the integration of modern ICT into value creation systems (pathway towards Industry 4.0). It is always underlined that the Fourth Industrial Revolution should not only be discussed in its technological and economic dimensions, but also in its implications for the environment and the society. Decisions of policy makers, managers, and researchers are always reflected with regard to their impact on the design of a socially responsible and environmental conscious Fourth Industrial Revolution. If resources (e.g., materials, energy and water) are used more wisely, the negative impact of industrial production on the environment can be reduced and if working conditions increasingly reflect social standards and human needs, then the Fourth Industrial Revolution can be a step forward to a more sustainable development.

The road towards Industry 4.0 in a specific region depends on a variety of factors, e.g. on the existing manufacturing base and infrastructure, the relevant institutional frameworks, a country's innovation capacity, and the qualifications of the labor force.

The Fourth Industrial Revolution has gained a lot of attention by practitioners and researchers in industrialized countries (e.g. Germany, USA, and Japan). Less has been published on the applicability of this concept in developing and emerging countries. Thus, the goal of this study is to answer the following questions:

a. What are relevant Industry 4.0 technologies and applications for emerging and developing countries?

b. Which prerequisites are necessary to realize Industry 4.0 technologies and applications in developing and emerging countries and their potential with regard to sustainability?

c. What is the role of the industrial park management concerning the Industry 4.0 technologies and applications identified?

d. How may the deployment of Industry 4.0 technologies and applications be supported in developing and emerging countries?

To answer these questions, a desk research on Industry 4.0 technologies and applications was conducted. Based on this, a questionnaire for expert interviews was developed and 12 expert interviews with producers of Industry 4.0 technologies and international companies interested in investing in Industry 4.0 applications in developing and emerging countries were carried out. The industrial park in Höchst, a chemical and pharmaceutical site in Frankfurt a.M., was analyzed as a benchmark for Industry 4.0 and sustainability in Germany. Site visits in China, India and Egypt were part of the analysis, too. In addition, the outcomes of two workshops on Industry 4.0 and related technologies and applications as well as an exhibition on smart and digital automation are included in this study (see Annex A, Annex B).

The following Section 2 gives the theoretical background of Industry 4.0, describes relevant technologies and applications and evaluates their sustainability potential. Section 3 takes a country specific perspective: The challenges for Industry 4.0 are described for Germany as a representative of industrialized countries as well as for India, China and Egypt as examples for developing and emerging economies. Section 4 summarizes the implementation of Industry 4.0 in the analyzed Industrial Areas (IA). Special attention will be given to the role of the park management in IA as a potential catalyst of the Fourth Industrial Revolution. Section 5 gives an outlook on potential pathways for Industry 4.0 in developing and emerging countries and highlights opportunities to support the deployment of Industry 4.0 in these countries. Section 6 summarizes the key findings.

2 INDUSTRY 4.0 AND SUSTAINABLE INDUSTRIAL PRODUCTION

In the following, technological developments that enable the Fourth Industrial Revolution are briefly described, relevant applications of these technologies are highlighted and links to different aspects of sustainability will be created.

2.1 Underlying technologies and practical applications

Three interconnected technological developments are responsible for the Fourth Industrial Revolution[1]:

1. The first development is the internet. Due to the internet technology and the decreasing size of transistors, it is possible to connect all elements in a value chain via the internet (horizontal connection - machines, customer; **internet of things**).

2. The second development is the technological update of machines. Machines become so called **cyber-physical systems**, which are characterized by modern computer technology and the connection of these machines via the internet.

3. The third development is modern ICT's increased **data analysis capacity**. Large amounts of structured and unstructured data ('big data') can be analyzed in real time. This allows to optimize complex value chain activities and to predict future developments. The analysis of this data has not to be performed physically at the location of a specific machine but can be transferred via the internet to the "cloud".

The combination of these three technological developments (internet of things; cyber-physical systems; data analysis) enables to revolutionize the existing pattern of manufacturing. The production system becomes more flexible, more adaptive and, due to the increased analysis of data, more intelligent[2].

The application of these technological developments is manifold. In the practice oriented literature, digital twins, predictive maintenance and augmented reality applications receive the highest attention.[3] A **digital twin** is a virtual model of an element, such as a machine, a factory, a product or a value chain, which allows modeling, monitoring and predicting the performance of this element.[4] Using digital twins may for instance help to construct low-cost prototypes and to modify them in a short period of time. In innovation processes, costs may be reduced, and development times may be reduced.

An example of the power of modern data analysis is the capacity of modern algorithms to detect patterns in the functioning of machines. If the functioning of a machine can be better understood, more informed decisions on the use of the machine may be taken. One field of application is the so-called **predictive maintenance**. It uses measurement and production data to derivate maintenance information and aims to maintain machinery and equipment in a proactive way to avoid long downtimes. In the best case, the disturbance can be predicted before it actually happens.[5]

[1] Bauernhansl, T., et al. (2016). Standpunktpapier Industrie 4.0, Wissenschaftliche Gesellschaft für Produktionstechnik WGP e.V., Darmstadt.

[2] The World Economic Forum subsumes under the term "Industry 4.0" in addition to ICT aspects as well changes in the fields of biotechnology and neurotechnology (Schwab, K., Davis, N. (2018). Shaping the future of the fourth industrial revolution. A guide to building a better world. Portfolio Penguin. November 2018) In order to keep our focus on ICT developments, we do not include developments in these fields into our analysis.

[3] Lu, Y. (2017). Industry 4.0: A Survey on Technologies, Applications and Open Research Issues. Journal of Industrial Information Integration 6: 1–10.

[4] Zhong, R. Y. et al (2017). Intelligent Manufacturing in the Context of Industry 4.0: A Review. Engineering 3.5 (2017): 616–630.

[5] Manavalan E., Jayakrishna K (2018). A review of Internet of Things (IoT) embedded sustainable supply chain for Industry 4.0 requirements. Computer and Industrial Engineering. *https://doi.org/10.1016/j.cie.2018.11.030*

Another example for a technical application of Industry 4.0 is augmented reality (AR). Here the physical reality is "augmented" with current information from the virtual sphere. Workers wearing AR-glasses may receive instruction via the internet, such as selecting parts in a warehouse or receiving repair instructions.[6] Augmented reality devices may thus support local decision-making leading to higher product quality and faster processes.[7]

2.2 Application Cases

The described technologies may be used to optimize all parts of economic activity. In order to characterize the field of application, the practice-oriented literature distinguishes different application cases.[8; 9]

Manufacturing

- **Flexible Production**
  To manufacture a product, many companies and productions steps are involved. Digital networking improves the communication between companies and supports the coordination of production steps as well as the planning of the machine load.

- **Convertible factory**
  Future production lines can be built in modules and be quickly assembled for tasks. Productivity and efficiency would be improved; individualized products can be produced in small quantities at affordable prices.

Product design

- **Customer-oriented solutions**
  Consumers and producers will move closer together. The customers themselves could design products according to their wishes—for example, sneakers designed and tailored to the customer's unique foot shape. At the same time, smart products, that are already being delivered and in use, can send data to the manufacturer. With this usage data, the manufacturer can improve his or her products and offer the customer novel services.

- **Resource-efficient circular economy**
  The entire life cycle of a product can be analyzed from a resource efficiency perspective. Product design and production processes can be optimized via modern ICT.[10]

Supply Chain Optimization

Optimized logistics: Algorithms can calculate ideal delivery routes, machines may independently report when they need new materials—smart networking enables an optimal flow of goods.

[6] Vaidya, S., Ambad, P. Bhosle, S. (2018). Industry 4.0 – A Glimpse. Procedia Manufacturing. Volume 20, 2018, Pages 233-238. 2nd International Conference on Materials, Manufacturing and Design Engineering (iCMMD2017), 11-12 December 2017, MIT Aurangabad, Maharashtra, INDIA.

[7] Paelke, V. (2014). Augmented reality in the smart factory: Supporting workers in an Industry 4.0. environment. In: Emerging Technology and Factory Automation (ETFA), 2014 IEEE. IEEE, pp. 1–4.

[8] BMWI (2018). Plattform Industrie 4.0. *https://www.plattform-i40.de/I40/Navigation/DE/Industrie40/WasIndustrie40/was-ist-industrie-40.html*, accessed 2018/12/02.

[9] Lu, Yang. (2017). Industry 4.0: A Survey on Technologies, Applications and Open Research Issues. Journal of Industrial Information Integration 6: 1–10.

[10] Xiangab, P., Yuan, T. (2019). A collaboration-driven mode for improving sustainable cooperation in smart industrial parks. Resources, Conservation and Recycling. Volume 141, February 2019, Pages 273-283.

The cost saving potential of these technologies has been estimated by Fraunhofer Institute. They conclude that the cost saving potential through Industry 4.0 applications may be up to 70% in specific fields of application, illustrated in Table 1.

Table 1: Economic Potential of Industry 4.0[11]

Costs	Effects	Potential
Inventory costs	Reduction of buffers Avoidance of Bullwhip- and Burbidge-Effect (optimization of supply chain: less buffers; improved grouping of orders	-30 to -40%
Production costs	Process control loop Improved vertical and horizontal flexibility of personnel Use of Smart Wearables (e.g. augmented reality glasses)	-10 to -30%
Cost of logistics	Higher level of automation (milk run, picking, …) Smart Wearables	-10 to -30%
Complexity costs	Higher span of control Reduced trouble shooting Prosumer Model	-60 to -70%
Quality costs	Everything as a Service (XaaS) Realtime quality control	-10 to -20%
Maintenance costs	Optimized inventory for repair parts Optimized maintenance (process data, real time data)	-20 to -30%

The far-reaching use of these applications may have a severe impact on the configuration of value chains, the organization of companies, individual tasks, and necessary job skills.

The potential economic benefits depend on a variety of factors (e.g. industrial sector, task). Regarding production for example, the Boston Consulting Group has analyzed various industry sectors in Germany where "industrial-component manufacturers stand to achieve some of the biggest productivity improvements (20 to 30 percent), and automotive companies can expect increases of 10 to 20 percent."[12] Other industrial sectors, for instance the chemical industry, underline that they have already integrated ICT in their processes and expect less improvements.

2.3 Industry 4.0 and Sustainability

Applying Industry 4.0 technologies and applications can be a step forward to more sustainable industrial value creation. A variety of sustainability indicators for Sustainable Industrial Areas have been defined by GIZ, UNIDO and World Bank.[13] In the following, we will briefly describe the potential of Industry 4.0 on selected indicators that have been identified as the most important ones during the interviews. In general, there is a potential that all dimensions of sustainability may be improved, if the Fourth Industrial Revolution is designed in a socially and environmentally responsible manner. The following examples may illustrate the potential (see Table 2)

Looking *at the environmental dimension* of sustainability, the allocation of materials, energy, water, and waste can be realized in a more efficient way[14]. The planning, running and control of industrial activities may be improved. Resource flows may be optimized and circular business models can be implemented; the multiple use of resources is supported. New markets for waste can be created; for solid waste a precise surveillance of the waste flow can be installed; for waste water an exact monitoring of the parameters can be realized in a 24/7 approach. The results may be immediately communicated via the internet and automated regulations may be applied in case of incidents. With regard to *social indicators*, Industry 4.0 may improve the working conditions of employees: jobs may be designed in an inclusive manner allowing persons with basic skills to perform more demanding tasks as they may receive support via augmented reality devices. Operators in factories may be guided through safe operating procedures avoiding major incidents with potential harm to human health.

[11] Bauernhansl, T., Krüger, J., Reinhart, G., Schuh, G. (2016). Standpunktpapier Industrie 4.0 Wissenschaftliche Gesellschaft für Produktionstechnik WGP e.V., Darmstadt.

[12] BCG (2015). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. *https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx*, accessed 2019/02/22.

[13] World Bank (2017). An international framework for eco-industrial parks (English). Washington, D.C.: World Bank Group. *http://documents.worldbank.org/curated/en/429091513840815462/An-international-framework-for-eco-industrial-parks*.

[14] Stock, T., & Seliger, G. (2016). Opportunities of Sustainable Manufacturing in Industry 4.0. In Procedia CIRP (Vol. 40, pp. 536–541). Elsevier B.V. *https://doi.org/10.1016/j.procir.2016.01.129*.

Table 2: Support possibilities of Industry 4.0 for different fields of sustainability

Environmental	Supply of resources / input factors	– avoid material losses, – high efficiency of all raw materials used, – avoid process interruptions which include material & energy waste.
	Waste Management	– Solid waste: analysis and monitoring of waste flows; automated waste handling – Fluid waste: clean all waste before releasing outside the IA according to governmental standards; automated transport and cleaning of waste ; avoid cleaning interruptions and discharge of non-cleaned wastes
	Energy Management	– avoid energy losses (media flows and caloric levels), – high efficiency of all supplied energies, – automated handling of the energy supply – avoid process interruptions
	Pollution Prevention	– 24/7 monitoring of GHG emissions and pollution control – avoid critical/hazardous incidents by preventing action – minimize effects of incidents by fire fighting and protecting the process equipment
Social	Qualification	– inclusive job design – guide operators to a safe and qualified working procedure – avoid non-completed handling of the equipment – avoid critical/hazardous incidents and injuries
Economic	Investments and business models	– be a nucleus for new investments – enable new business models – reduce the costs per unit and increase flexibility

The *economic dimension* of sustainability captures in this context the impact of Industry 4.0 technologies on the financial success of companies and the economic welfare of societies. Industry 4.0 may be a source for new business opportunities, if entrepreneurs realize the benefits that may be derived from the increased availability of data or the connection of value chain activities. New products and services may be created. Ecosystems of complementary actors (such as multinational companies on a specific site, local companies, academia, training institutions etc.) may be creating stimulating business ideas that will be brought to market by ambitious entrepreneurs.

While the Fourth Industrial Revolution has the potential to fundamentally alter economic activities around the world, it depends on the decisions of a variety of stakeholders (policy makers, managers, researchers, citizens), how the exact transformation process will unfold. In the following, we will analyze the impact of country-specific variables on the development of the Fourth Industrial Revolution.

3 INDUSTRY 4.0 IN INDUSTRIALIZED AND EMERGING COUNTRIES

In the following, the challenges and opportunities of industrialized and emerging countries with regard to the Fourth Industrial Revolution are briefly characterized. To do this, we use data provided by the World Economic Forum. A look at this context is necessary as the investment of companies in new technologies is highly dependent upon the national context. As a COO of a leading European pharmaceutical company points out:

"We have a huge Industry 4.0 initiative in our company on a global level. But we select the participants in this initiative very carefully. We experiment with new technologies in industrialized companies. But I don't see why we should include for instance India in our efforts. Labor is cheap there. We don't need to optimize there today."

It is thus of utmost importance to understand how decision makers see the Industry 4.0 readiness of specific countries in a given industry. The initial situation of the four countries analyzed for this study varies significantly.[15] There are – as Table 3 shows – noteworthy differences regarding key economic and key production indicators.

Table 3: Key Economic Indicators and key production indicators (2016)[16]

		GERMANY	CHINA	INDIA	EGYPT
Key Economic Indicators	Population (millions)	82.7	1,382.7	1,309.3	90.2
	GDP per capita (US$)	41,902.3	8,113.3	1,723.3	3,684.6
	Unemployment rate (%)	4.2	4.0	3.51[17]	12.7
Key Production Indicators	Manufacturing value added (2010 million US$)	774,149.7	2,999,885.2	423,721.9	41,659.5
	Manufacturing employment (% working population)	19.3	n.a.	11.4	11.2
	Manufacturing value added growth (annual %)	1.7	6.5	8.4	4.3
	Medium and hi-tech industries (% manufact. value added)	61.4	41.4	37.9	14.2
	CO_2 emission per unit of value added (kg/US$)	0.1	1.1	1.5	0.7

[15] The data included in this section represents the best available values from various sources at the time the report was prepared. Some data may have been revised or updated by the sources after publication. Nevertheless, the findings and underlying data needs to be treated carefully, as reliable data is often one of the bottlenecks for Industry 4.0 in emerging and developing countries. More information on the used indicators and how missing values have been estimated for section 3 can be found in Appendix C: Technical Notes and Sources on page 43 in the Readiness for the Future of Production Report 2018 from the World economic Forum: *http://www3.weforum.org/docs/FOP_Readiness_Report_2018.pdf*.

[16] Own illustration. Data based on WEF (2018). Readiness for the Future of Production Report 2018. Published by World Economic Forum's System Initiative on Shaping the Future of Production. *http://wef.ch/fopreadiness18*.

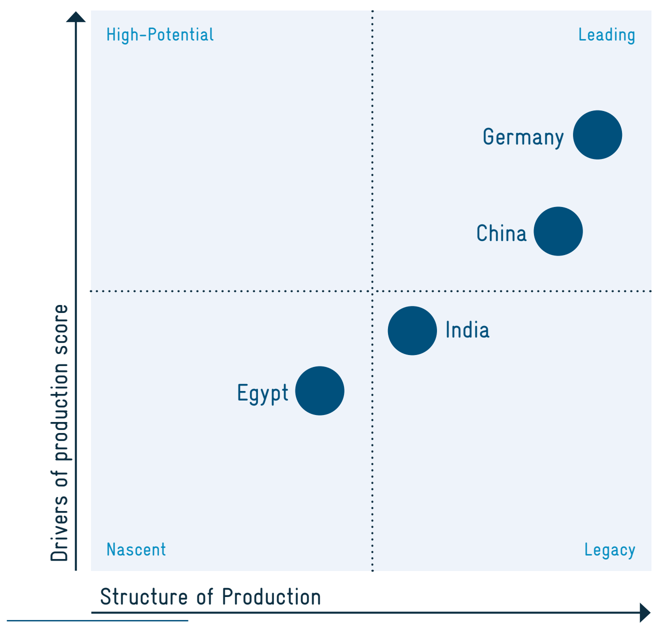
[17] Word Bank Data Base (2019). *https://data.worldbank.org/indicator/SL.UEM.TOTL.ZS?end=2018&start=2016. accessed 2019/02/27.*

In a recent study, the World Economic Forum has analyzed the readiness of 100 countries for Industry 4.0. The used data set is the most encompassing and up-to-date data set to describe the status quo of different countries – industrialized and developing countries – with regard to Industry 4.0.[18]

The framework is based on two dimensions, the (1) structure of production as a baseline for current production, and (2) the drivers of production which present key enablers in order to transform the production system and adopt Industry 4.0 technologies. In total, 59 indicators have been analyzed in these two dimensions and have been aggregated to two scores (Structure of Production Score and Driver of Production Score). The results for the focus countries are summarized in Figure 1.

Based on their Structure of Production and Driver of Production scores the countries are assigned to one of the four archetypes, illustrated in Figure 1 below.

Figure 1: Industry 4.0 Readiness of different countries[19]



The analyzed countries are positioned in different quadrants and characterized by different challenges[20]:

- **Leading countries**: **Germany** and **China** are both categorized as leading countries with a strong production base today, who exhibit a high level of readiness for the future through strong performance across the drivers of production components. These countries also have the most current economic value at stake for future disruptions. Both countries need to convert readiness into actual transformation and push the frontier of Industry 4.0 by designing, testing and pioneering emerging technologies.

- **Legacy countries**, represented by **India**, need to avoid getting squeezed between more advanced leading countries, which can offer more advanced manufacturing, and nascent countries that can offer

[18] WEF (2018). Readiness for the Future of Production Report 2018. Published by World Economic Forum's System Initiative on Shaping the Future of Production. *http://wef.ch/fopreadiness18*.

[19] For more information on the different country archetypes and underlying methodology, please see *http://www3.weforum.org/docs/FOP_Readiness_Report_2018.pdf*, pp. 8 (Readiness for the Future of Production report 2018 by the World Economic Forum).

[20] For the sake of simplicity, we will not focus on High-Potential countries that have strong capabilities to develop their structure of production, as these countries were not part of the study.

lower-cost labor. This calls for an improvement of the institutional framework, investing in human capital and supporting technology platforms and innovation capacity.

– **Nascent countries** are a group of countries with varying levels of industrial development. **Egypt** is part of this group. The key challenge for nascent countries is to determine whether to pursue advanced manufacturing or traditional manufacturing, and to what extent as part of their overall economic strategy. In addition, there is a need for improvement of the performance across all drivers of production, especially by enhancing the institutional framework, attracting global investments in order to improve the knowledge and technology transfer.

Country-Specific Challenges for Industry 4.0

In the following, the current national policies supporting Industry 4.0 will be briefly characterized and the most important drivers of future production[21] will be analyzed for China, India and Egypt to identify country-specific challenges for enhancing Industry 4.0 and sustainability. Our analysis is based on the World Economic Forum data set but a smaller subset out of the 59 indicators with higher relevance to our thematic focus has been selected. This selection is based on the guidance provided by GIZ in the terms of reference for this report and the results of the expert interviews. The detailed score of our selected indicators as well as their definition by the World Economic Forum can be found in the tables in Annex C and Annex D.

China

China has integrated Industry 4.0 as part of its "Made in China" national economic development plan.[22] The country invests heavily into the modernization of its manufacturing industry. The "Made-in-China 2025" guiding principles are to enhance industrial capability through innovation-driven manufacturing, emphasize quality over quantity, achieve green development, optimize the structure of Chinese industry, and nurture human talent. The development schedule targets virtually all high-tech industries that strongly contribute to economic growth in advanced economies: automotive, aviation, machinery, robotics, high-tech maritime and railway equipment, energy-saving vehicles, medical devices, and information technology to name only a few.[23] The political push for industrial modernization in China creates an enormous demand for smart manufacturing products like industrial robots, smart sensors, wireless sensor networks, and radio frequency identification chips. With regard to the drivers of future production, China is ranked 25th of 100 countries. The analysis shows the following opportunities and challenges.

– Technology & Innovation: China is ranked 25th of 100 countries. The high investments, the political backing of the modernization as well as the innovation orientation of decision makers are important assets for creating an Industry 4.0. The weak absorptive capacity of companies and employees in those modernization processes is a relevant challenge.

– Human Capital: China is ranked 40th of 100 countries. The current workforce does not have the right skill set with regard to Industry 4.0. Universities are seen as a strong asset for developing the necessary skills on an academic level, but vocational training and further education are seen as a weakness.

– Global Trade & Investment: China is ranked 9th of 100 countries. The very high investments into the modernization and in greenfield developments are a very relevant means for developing the good infrastructure (ranked 16/100).

– Institutional Framework: China is ranked 61st of 100 countries. While the future orientation of the government is very positive, the regulatory efficiency and the rule of law constitute major barriers for rapid and free learning on Industry 4.0 developments in China.

India

While India's service sector has grown strongly over the last decades, most manufacturing sectors are still stuck with technology, equipment, and processes from the past, such as manual inputs, lack of ICT integration in manufacturing, and critical gaps in capability. The development of the national manufacturing industry is supported by the government program "Made in India".

[21] In total, 59 indicators have been analyzed by the World Economic Forum with regard to the drivers of future production. In the following, we will present the relative position of the analyzed countries on selected indicators. We chose to focus on the ranking – instead of the absolute values - (a) for the sake of simplicity and (b) to highlight the country's competitive, thus relative, position. The driver "*Technology & Innovation*" captures a country's ability to foster and commercialize innovations that have an application in production. In addition, a country's ICT infrastructure is analyzed. The indicator set "*Human Capital*" captures to what degree the workforce of a country is ready to realize the opportunities and manage the challenges related to Industry 4.0. Here, the skill set of the existing as well as of the future labor force is captured. The indicator set "*Global Trade & Investment*" assesses a country's participation in international trade to facilitate the exchange of products, knowledge and technology, and to establish global linkages. In addition, the availability of financial resources to invest in production-related developments as well as the quality of infrastructure to enable production-related activities is measured. The field "*Institutional Framework*" assesses how effective government institutions, rules and regulations contribute towards shepherding technological development, novel businesses and advanced manufacturing.

[22] Li, Ling, 2018. "China's manufacturing focus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0"," Technological Forecasting and Social Change, Elsevier, vol. 135(C), pages 66-74.

[23] Wübbeke, J., Meissner, M., Zenglein Jaqueline Ives, M.J., Conrad, B. (2016). Made in China 2025: The making of a high-tech superpower and consequences for industrial countries. Merics - Mercator Institute for China Studies, No.2. 2016.

The aims of the program are to increase the share of manufacturing in the country's Gross Domestic Product to 25% by 2022 and to create 100 million additional jobs by 2022 in the manufacturing sector. Further goals are to develop the appropriate skill sets among rural migrants and the urban poor for inclusive growth. The domestic value creation and the technological depth in manufacturing are to be increased. All this should be enabled by an increased global competitiveness of the Indian manufacturing sector. The strong national IT sector is an additional asset for the future of manufacturing in India. As a result, India can step forward to produce high-tech products for the domestic and the international market to a higher degree than today. With regard to the drivers of future production, India is ranked 44th of 100 countries.

– Technology & Innovation: India is ranked 34th of 100. The willingness to innovate is seen as an asset to build on, but existing technologies in the manufacturing sector and companies' absorptive capacities are seen as weaknesses.

– Human Capital: India is ranked 63rd of 100 countries. Especially the current labor forces show weaknesses with regard to Industry 4.0 related skills (80/100). Ranking of vocational training and on-the-job training show room for improvement.

– Global Trade & Investment: India is ranked 55th of 100. High trade barriers hinder free and fair-trade relations. The weak electricity infrastructure (rank 89/100) can be seen as another significant barrier towards Industry 4.0.

– Institutional Framework: India ranks 54th of 100 countries. While the future orientation of the government is very positive, the regulatory efficiency (rank 96/100) and the rule of law (59/100) constitute major barriers for rapid and free learning on Industry 4.0 developments.

Egypt

Egypt has identified the manufacturing sector as a relevant field for its economic development. Its "Industrial Development Strategy" intends to develop the technological and industrial base for manufacturing activity in Egypt. It is the stated goal to achieve a gradual shift in the industrial structure from resource-based and low-tech activities to medium and high-tech industries[24].

With regard to the drivers of future production, Egypt is currently ranked on position number 68 out of 100 countries. The country is characterized by a relatively small manufacturing sector mainly focusing on products with little complexity.

– Technology & Innovation: Egypt is ranked 53rd of 100 countries. With weak R&D expenditure and a very weak position in companies' absorptive capacities.

– Human Capital: Egypt is ranked 85th of 100 countries. The labor forces show weaknesses with regard to Industry 4.0 related skills. Vocational training and on-the-job training rank on last positions and show significant room for further improvement.

– Global Trade & Investment: Egypt ranks 75th of 100. High trade barriers hinder large-scale knowledge transfer with regard to Industry 4.0. However, Greenfield investments can be a lever for modernizing Egypt's manufacturing industry.

– Institutional Framework: Egypt ranks 78th of 100 countries. The performance of all relevant aspects (future orientation of the government; regulatory efficiency; rule of law) is ranked on position 50 or higher.

[24] Ministry of Trade and Industry Egypt (2016). Industry and Trade Development Strategy 2016 – 2020. *http://www.mti.gov.eg/English/MediaCenter/News/PublishingImages/Pages/2017-Strategy/2017%20Strategy.pdf*

Summary

For the investigated emerging and developing countries, the following opportunities and challenges for enhancing Industry 4.0 and sustainability have been identified:

- Technology & Innovation: Activate (China & India) or develop (Egypt) the necessary ecosystem for creating and implementing Industry 4.0 technologies and business models that enhance sustainability. Especially in China and India, high amounts of public money are foreseen to modernize the manufacturing sectors in the light of Industry 4.0. Increasing the countries' absorptive and innovative capacities seem to be key for further development.

- Human Capital: One core challenge lies in integrating Industry 4.0 and sustainability topics into the existing non-academic and academic curricula. Here, China and India are, due to a stronger educational system, in a much better starting position than Egypt.

- Global Trade & Invest: Countries may use global trade and investments as a field for technological development with regard to Industry 4.0. China's infrastructure (especially electricity) is rated much higher than India's and Egypt's and offers thus a more favorable context for investments in Industry 4.0 technologies. Especially China seems not to believe in the value of free global trade with regard to its domestic market. India and Egypt are characterized by high trade barriers as well. Nevertheless, high greenfield investments can be seen as a lever to increase sustainability in production activities in all countries.

- Institutional Framework: All investigated countries may analyze the impact of their institutional and policy frameworks with regard to the development and implementation of Industry 4.0 technologies and business models.

These findings show that some of the important prerequisites for the Fourth Industrial Revolution are not fulfilled by developing and emerging countries. Countries need to work on their technical expertise, innovation capacity, and human capital, and to invest or attract significant financial resources to benefit from the Fourth Industrial Revolution. Otherwise, they risk falling behind in global competition. In the light of the Fourth Industrial Revolution, a national roadmap for Industry 4.0 is needed which builds on the existing strengths, and works on the most important weaknesses.

4 SUSTAINABLE INDUSTRIAL AREAS AND THE USE OF INDUSTRY 4.0

The concept of Sustainable Industrial Areas (SIA) underlines the necessity that in successful industrial areas economic, environmental and social aspects need to be balanced. Sustainable Industrial Areas install management structures which focus on resource and energy efficiency, environmental protection and social compatibility as well as on economic value added.

GIZ has been working for many years with the concept of SIA around the world. In the following and as indicated in table 2, we describe how Industry 4.0 may be used to enhance sustainability in all mentioned dimensions. In addition to the description of the Industry 4.0 potential, the status quo of Industry 4.0 implementation in six industrial areas is described. The information and data gathered from the analyzed industrial areas needs to take into account that all industrial parks have their own specificities and cannot be seen as being representative for the entire country.

4.1 Characteristics of the analyzed parks

The analyzed industrial areas host different industries on site: process industry in Germany and India - process and discrete industries in China and Egypt. They are characterized by different business models which are pursued by the operator of the industrial area (private-profit oriented company in Germany versus government agencies in India and China). Egypt has both; parks which are operated by private companies as well as publicly operated ones. The services offered by the industrial park operator vary: in Germany, a broad range of services are offered (e.g. central energy supply, central waste management, central pollution prevention, and central responsibility for identifying local synergies across companies on site and beyond); in India, the site operator focusses on the planning and renting of the land as it is for the visited public park in Egypt. The realization of synergies on site is not the main focus of activities. In China, the management of the industrial park includes mainly estate management, and the provision and maintenance of infrastructure functions (like traffic facilities and clear water discharge). In that sense, it is equal to the private park in Egypt. Nevertheless, the Egyptian private park also controls a part of material flows and provides electricity, internet and other infrastructure. The main characteristics and activities of the parks are summarized in Table 4 below.

Before starting with the detailed description of the results, an overall impression with regard to the readiness of the analyzed industrial areas for Industry 4.0 will be shared. One conclusion is, that the analyzed German and Chinese industrial areas have a medium to high readiness for Industry 4.0. They have at least an implicit Industry 4.0 strategy, they screen the relevant developments, and experiment selectively with relevant technologies. The industrial areas in India and Egypt are characterized by a lower readiness with significant knowledge deficits and without a defined Industry 4.0 strategy. While especially international enterprises in the industrial areas in Egypt already started to think about strategies moving from automatization towards an Industry 4.0 implementation, national companies still have a low level of digitalization of production. Park management does not provide any Industry 4.0 related assistance so far.

Table 4: Characteristics of the analyzed industrial areas

	GERMANY	INDIA	EGYPT[25]	CHINA
Selected example	Industrial Park Frankfurt Höchst	Industrial Area Haridwar	Engineering Square (e2) in 6th of Oct. City (private)	China-Singapore Suzhou Industrial Park China Wujin high-tech industrial development zone
Relevant industries on Site	Process industries (chemical; pharmaceutical)	Process industries (chemical; cosmetics)	Process and concrete industries (majority are engineering and chemical industries)	Machine & electronic productions, automotive & automation facilities, medicine & nanotechnological laboratories with mainly discrete processes
Operator of Sustainable Industrial Area	Private company Infraserv Höchst	Government agency; SIIDCUL - State Industrial Infrastructure Corporation of Uttarakhand Limited	Private Company S.A.E. Owner Industrial Development Group - IDG	Government related companies (SIPAC & WPM)
Activities of site operator for companies on site				
Logistics/ Media Supply	Yes	No	No	No
Energy Supply	Yes	No	Yes	No
Waste Management	Yes	Partly	Yes	No
Pollution (measure waste emissions; report to authorities)	Yes	Yes	n.a.	Yes
Identification of synergies				
within park	Yes	No	No	No
with other actors (local economy; pot. new tenants)	Yes	No	No	No
Industry 4.0 readiness None; low; medium; high; very high	Medium to high	Low	Low to medium	Medium to high

4.2 Level of Digitalization

Even if we investigate the potential of Industry 4.0 and thus the potential of state-of-the-art ICT, it is important to underline that not all manufacturing processes are currently performed on the basis of modern ICT. Often, machines that are in use on the shop floor are more than 50 years old and are not handled or steered by ICT. Modern ICT is only used if the cost-benefit relation justifies the specific investment.

Referring to a study of the National Academy of Science and Engineering (Acatec) in Germany[26], we distinguish between four levels of ICT use: On level 1, an activity is done without ICT support. On level 2, a single activity is supported via current ICT (e.g. excel program). On level 3, different workplaces and production processes are interconnected. On level 4, ICT further supports decision making through big data analytics, predictive maintenance or automated decision making based on a defined if-then pattern (Industry 4.0).

4.3 Management of Sustainable Industrial Areas

The GIZ SIA Guidelines (*https://www.sia-toolbox.net/solution/sia-guidelines*) intend to guide industrial areas to become more sustainable in the phases of introducing, designing and operating SIAs. ICT may support in those phases of development and implementation of Sustainable Industrial Areas around the globe: In the first phase – introducing SIAs – ICT may support the analysis of the status quo in a specific region as well as the communication about potential developments to various stakeholders. In the second phase – designing SIAs – the master planning may be supported e.g. by creating a digital twin of the area that is to be developed. To foster sustainability, all aspects of infrastructure and logistics, supply of energy, water and goods, collection and treatment of effluents and waste as well as provision of communication networks and social services need to be taken into account. In the third phase – operating Sustainable Industrial Areas – systematic sharing of information with all relevant stakeholders is of importance. Ongoing environmental monitoring and climate risk management ensure smooth production processes and minimize possible negative impacts on environment and local communities.[27]

In Germany, all planning activities are based on current ICT. All resource flows are documented in the relevant databases and can – if necessary – be visualized. Different departments of the industrial park operation may access and use the relevant data. The results from planning are used for the optimization of the industrial areas as well. Nevertheless, the creation of a "100% digital twin" of a whole industrial area is currently not seen as a realistic option as too much data from different sources would need to be integrated.

"The technology providers are not ready to provide a fully functioning IT tool for creating a Digital Twin at low cost", underlines one interview partner at Infraserv Höchst.

In India and China, the planning of new industrial parks is done with ICT support as well. In India, it is underlined that different departments are responsible for planning and running the industrial area. Data is not stored in one single data base and, thus, access to data cannot be provided to different departments or government agencies. In China, the design of industrial area´s is done in cooperation between local or regional authorities, engineering companies, and the future industrial area management entity. The whole planning process is digitally supported. This is also the case for Egypt regarding private operating firms managing the industrial area activities and running parks within the whole country. Nevertheless, in Egypt, this is mainly concentrated at the economic hot spots in the Cairo area and the Suez delta. According to the introduced level of digitalization at the beginning of this chapter, the levels regarding the park management are summarized in the following Table 5.

Table 5: Level of Digitalization - Management of Sustainable Industrial Areas

	Level 1 Activity done manually	Level 2 Single Activity with ICT support (e.g. Excel)	Level 3 Multiple activities via ICT connected	Level 4 Intelligent decision support with Industry 4.0 technologies
Introducing Sustainable Industrial Areas		India	China, Egypt	Germany
Designing Sustainable Industrial Areas		India, China	Germany, Egypt	
Operating Sustainable Industrial Areas		India, Egypt	Germany, China	

4.4 Logistics

Industry 4.0 encompasses the digitalization of the value chain for reducing logistical costs, increasing logistical flexibility and improving the environmental performance.[28;29] In Germany, most of the material handling is facilitated electronically. The activities are automated, but not fully interconnected. Pilot projects for digital waiting lines for trucks are in a test phase where cyber-physical systems are under development. Besides, there are first initiatives in place on how to support and steer workers in warehouses and support them through augmented reality.

In India and China, logistical issues are organized by the companies on site and not by the operator of the industrial area. Synergy potentials are therefore left unused. In Egypt, the private park organisation is aware of material flows. The park operator measures only the number of trucks entering the park and the kind of materials transported, but not the quantity. There is no automated system for waiting lines or traffic organization for the whole park, but companies try to organize their logistics more efficiently by using forecasting models and digital support to organize their material flows. The cases which are applicable for a digitalization level are illustrated in Table 6 below.

[25] During the site visit in Cairo, Egypt, a public as well as a private Industrial Area have been analyzed. Nevertheless, the analysis will focus on the private park as the operating structure seems to be more applicable and further improvements and collaborations seem to be of higher probability.

[26] Schuh, G., Anderl, R., Gausemeier, J., Hompel, M.T., & Wahlster, W. (2017). Industrie 4.0 Maturity Index, Managing the Digital Transformation of Companies. Deutsche Akademie der Technikwissenschaften e.V. -acatech-.

[27] Xiangab, P., Yuan, T. (2019). A collaboration-driven mode for improving sustainable cooperation in smart industrial parks. Resources, Conservation and Recycling. Volume 141, February 2019, Pages 273-283.

[28] Li, D. (2016) Perspective for smart factory in petrochemical industry. Comput Chem Eng 91:136– 148. *https://doi.org/10.1016/j.compchemeng.2016.03.006*.

[29] Zhong, R.Y., Xun, X., Klotz, E. and Newman, S.T. (2017). Intelligent Manufacturing in the Context of Industry 4.0: A Review. Engineering 3: 616–30.

Table 6: Level of Digitalization – Logistics

	Level 1 Activity done manually	Level 2 Single Activity with ICT support (e.g. Excel)	Level 3 Multiple activities via ICT connected	Level 4 Intelligent decision support with Industry 4.0 technologies	Examples for used Industry 4.0 technologies
Inbound/ outbound logistics		Egypt	Germany, China	Germany	Germany: Digital waiting lines for trucks in test phase
On site logistics		Egypt		Germany, China	Germany: Steer workers in warehouse with augmented reality glasses

4.5 Energy Supply

For process industries, e.g. chemical industry, paper industry, or steel industry, energy costs are of very high importance. In some industrial areas, e.g. in Frankfurt/ Germany, electrical energy, heat and cold are produced for all companies on site. Thereby, energy costs may be reduced, and synergies may be used if steam is used in closed loops and multiple times.[30] In other areas, energy is not provided by the local manager of the industrial area, but by the national energy provider (e.g. India and China). Due to its high importance for the cost position, Infraserv Höchst explores options of Industry 4.0 in the field of energy management very carefully.

- All energy producing units have all relevant sensors and are digitally connected. Steering of the different facilities is centrally coordinated. If electricity may be bought cheaply from the (external) national grid, Infraserv changes its internal energy production plan within 15 minutes and uses externally purchased instead of internally produced energy. This is only possible due to a high degree of digitalization in all process steps (cyber-physical system).
- Artificial intelligence for detecting patterns in the energy production process as well as predictive maintenance is seen as interesting applications of Industry 4.0. Infraserv screens the market here.
- To support workers in their decision making, Infraserv Höchst runs tests with Augmented Reality glasses.

The visited industrial areas in Egypt, China and India have not yet explored the potential benefits of a local energy production network within the area. The topic was not on the agenda when the industrial area was planned. The industrial park in Egypt uses sensors for the storage of energy in the park and has a feed in tariff. Incentives are given to companies who install photovoltaic systems on their company site or building. In China, factories have installed photovoltaic systems on the roof of their buildings as well. But the produced energy coming from the onside renewable sources is rather small compared to the overall used energy (see Table 7 for digitalization levels).

Table 7: Level of Digitalization – Energy Supply

	Level 1 Activity done manually	Level 2 Single Activity with ICT support (e.g. Excel)	Level 3 Multiple activities via ICT connected	Level 4 Intelligent decision support with Industry 4.0 technologies	Examples for used Industry 4.0 technologies
Energy production: steering				Germany	Cyber physical system for connecting the industrial area with the national grid
Energy production: predictive maintenance			Egypt	Germany	Market screening ongoing

[30] Stock, T., & Seliger, G. (2016). Opportunities of Sustainable Manufacturing in Industry 4.0. In Procedia CIRP (Vol. 40, pp. 536–541). Elsevier B.V. *https://doi.org/10.1016/j.procir.2016.01.129*.

4.6 Waste Management

The target of Industry 4.0 processes regarding sustainability is to monitor waste flows, clean all waste before releasing it outside the industrial park according to governance standards, to transport waste in an automated way, and to avoid cleaning interruptions and discharge of non-cleaned waste. For solid waste, the analysis of the waste (quantity; quality) and the monitoring of its handling is of utmost importance. For wastewater, the 24/7 analysis and monitoring of the wastewater is an additional challenge as a higher concentration of waste may directly affect the cleaning capacities of installed machines and may lead to environmental incidents. To avoid these, a 24/7 monitoring and reporting are necessary.[31;32]

In Germany, sensors at different stages of the waste management process monitor the quality and quantity of the fluid waste. Simulations are made with regard to the "optimal" mix of waste to guarantee a low-cost cleaning process and to optimize recycling options. Automated procedures are in place, if incidents occur in the cleaning process.

In India and China, sensors are installed to measure the wastewater quality as well. But there is no automated handling of incidents, and in India it cannot be guaranteed that only fully cleaned waste water leaves the production facilities as the capacity for capturing all waste water is insufficient. In case of an incident, the excess wastewater pours into the nearby river.

In Egypt, there are no data measurements included in the process equipment; waste is not pre-treated at the site. Every company within the park is responsible for its own waste disposal; the waste quantity is not measured by a central unit. The park management is not aware of waste flows. Nevertheless, the park management sees a high potential of digitalization (improved process interfaces; improved recycling or reuse of media). An increased cooperation with surrounding communities & landscape is a future vision and will be applied during the introductory and designing phase of a new industrial park at the Suez delta. The results of the observation for India, China and Germany are outlined in Table 8 on the next page (Egypt not applicable).

Table 8: Level of Digitalization – Waste Management

	Level 1 Activity done manually	Level 2 Single Activity with ICT support (e.g. Excel)	Level 3 Multiple activities via ICT connected	Level 4 Intelligent decision support with Industry 4.0 technologies	Examples for used Industry 4.0 technologies
Monitoring of waste flows: incoming / outgoing waste			India, China, Germany	Germany (partly)	Germany: Simulations of ideal blend of waste for recycling
Automated handling of incidents			China	Germany	Germany: Fully automated process with shutdown if legally binding specifications are not met

4.7 Pollution Prevention and Environmental Management System

ICT may be used to prevent pollution by systematically monitoring the current pollution and insuring that all relevant standards are met. The different levels for the observed case study region in the countries are shown in below (if applicable).

[31] Tamás, P., Illés, B. Dobos, P. (2016). Waste reduction possibilities for manufacturing systems in the Industry 4.0. IOP Conf. Series: Materials Science and Engineering 161 (2016) 012074 doi:10.1088/1757-899X/161/1/012074.

[32] WEF (2018). World Economic Forum White Paper: Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation.

Table 9: Level of Digitalization – Pollution Prevention

	Level 1 Activity done manually	Level 2 Single Activity with ICT support (e.g. Excel)	Level 3 Multiple activities via ICT connected	Level 4 Intelligent decision support with Industry 4.0 technologies	Examples for used Industry 4.0 technologies
24/7 monitoring and reporting of environmental data			India, China	Germany	Simulations of ideal blend of waste for recycling
Simulation of environmental impact			China	Germany	Germany: Fully automated process with shutdown if legally binding specifications are not met

In Germany, ICT is used in the planning of the industrial area to simulate the expected pollution before a new plant is built. In the operating phase, the environmental parameters are monitored and in case of incidents, emergency plans are in place to prevent environmental damages. In India, less environmental parameters are monitored on the level of the individual site, as the site operator is not responsible for the ongoing business on site.

In China, the limit of pollution is defined when a new production plan is approved by the public authority. In the operation phase the real output of pollution is under control of the local authorities. In modern industrial areas, the pollution is controlled on a 24/7 basis. The Suzhou Industry Park Administration has created a division to disseminate knowledge about industry 4.0 to companies in the park.

In Egypt, there is no ICT-based pollution prevention or environmental management system in place. Companies based in the industrial park have to report their emissions to the Egyptian environmental affairs agency; park management facilitates the governmental control.

4.8 Reasoning behind the observed level of digitalization

The reasons why Industry 4.0 potentials are not fully exploited in emerging and developing countries are manifold. Recent studies investigated the challenges of the Fourth Industrial Revolution on a large scale[33;34]. We report here a few impressions from our personal interviews.

1. Technological options are unknown

Industry 4.0 is not a top priority on the agenda of decision makers in developing and emerging countries. Especially for small and medium sized companies operating in a low-tech environment, technological options are unknown. Furthermore, decision makers do not have the necessary resources to survey upcoming developments and to reflect on the implications of these developments on their business models.

2. Financial resources are seen as a limiting factor

Updating existing industrial areas with regard to advanced ICT in the described fields of logistics, energy management or waste management requires significant financial resources. Unless the regulatory requirements change or the market demands immediate action, decision makers are reluctant to invest the necessary resources into Industry 4.0 projects as the perceived benefits are partly unclear and the organizational barriers are significant.

3. Workforce lacks necessary skills

The interviewed partners identified their workers' qualifications as a severe barrier for a systematic use of Industry 4.0. "*If we would have these great new technologies - who should handle them? I don't have access to workers with the necessary skills*", formulated one interview partner in Haridwar/India.

4. Industry 4.0 Centre of Gravity is not in emerging and developing countries

The interview partners in companies have not seen their local environments in India, China or Egypt as hotspots for the Fourth Industrial Revolution. "*In our area here, we make use of existing technologies or apply technologies developed somewhere else*", said one interview partner in Delhi, India. "*Even if we have great IT-specialists in India, to my knowledge, they don't work on Industry 4.0 issues. The dots are not connected,*" continued the interview partner.

5. Legal challenges receive little attention

Surprisingly, the interview partners did not mention legal challenges as main barriers. These issues (e.g. data security issues, legal issues counteracting cyber criminality) receive in contrast a lot of attention in Germany.

During the workshop "Industry 4.0 – One Click towards the Future", which was held on the 13th of November 2018 in the German Chamber of Commerce and Industry in Berlin, one main issue was about legal barriers, that the representatives from medium-size companies in Germany, Industry 4.0 Experts (e.g. Siemens) and startups discussed.

"*Due to the legal uncertainty specifically in the field of augmented reality and virtual glass, it is difficult and resource intense for startups and small and medium-sized companies to focus on the business model and the development of innovation. As they do not have as much financial resource for a legal department as big players do, they lack behind even though they have a valuable and sustainable product or service to sell,*" an entrepreneur stated.

33 Luthra, S.; Mangla, S.K. (2018). Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. Process Safety and Environmental Protection. 2018. P. 168-179.

34 Glass, R. et al. (2018). Identifying the barriers to Industrie 4.0. Procedia CIRP Volume 72, 2018, Pages 985-988. 51st CIRP Conference on Manufacturing Systems. https://doi.org/10.1016/j.procir.2018.03.187.

5 PATHWAYS FOR EMERGING AND DEVELOPING COUNTRIES

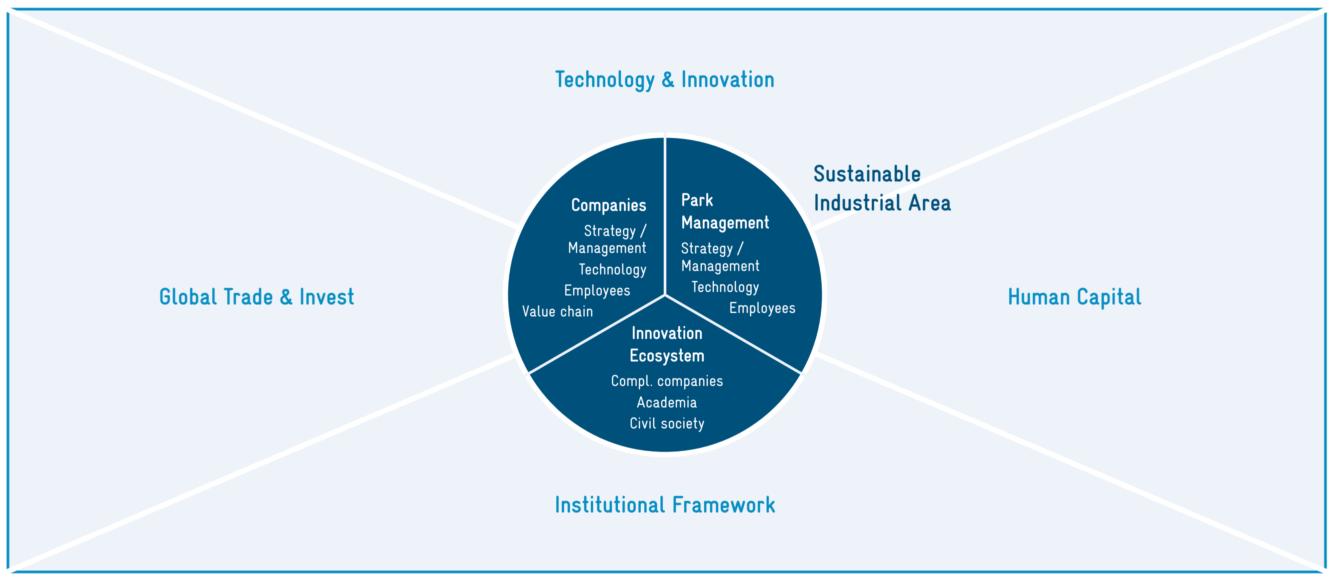
The impact of Industry 4.0 on the development of emerging and developing countries cannot be predicted today. Too many variables – such as international trade policies, international market and technology developments – influence the international allocation of value chain activities. It thus remains unclear whether the Fourth Industrial Revolution will support or endanger the economic development of emerging and developing countries. Will it support the competitiveness of an emerging country and its production systems? Or, will advanced countries re-integrate activities formerly performed in emerging countries in their home country once advanced automation allows a low-cost production even in high-wage countries?[35] These developments set – of course – the boundary conditions for national development.

The pathway of an individual Sustainable Industrial Area towards Industry 4.0 is further influenced by the national context in the fields of technology and innovation, human capital, institutional framework, global trade, and investments (see section 3). On a regional level, the status quo of the companies on site (and their strategy/management, technology, and their integration in value chains), the park management (with its strategy/management, technology and employees) and the regional ecosystem (with the existing cooperation between companies, academia, public authorities and civil society) have to be taken into account. A "one size fits all approach" seems thus inadequate for enhancing Industry 4.0 in emerging and developing countries. The analysis of the situation in developing countries has shown that the labor force is not sufficiently equipped with the right skill set for Industry 4.0. It is – further – an option for enhancing the economic ecosystem around the industrial area.

In the following, we briefly (1) highlight the importance that decision makers observe Industry 4.0 developments carefully. We (2) outline a process model on how a specific regional entity (e.g. the management entity of an Industrial Area) may develop its specific Industry 4.0 development strategy. We then (3) describe how Industry 4.0 related skills may be developed. Afterwards, we (4) describe how Industry 4.0 may be used to strengthen the regional ecosystem. Finally, we (5) propose to develop international entrepreneurship programs supporting entrepreneurship in Industrial Areas.

[35] Schwab, K., Davis, N. (2018). Shaping the future of the fourth industrial revolution. Crown Publishing Group, p. 54.

Figure 2: Pathways of IA towards Industry 4.0: National & regional context factors



5.1 Ensure access to state of the art Industry 4.0 knowledge

"*What is Industry 4.0? I haven't heard of this before. […] That's an interesting and important topic – but I don't know who would have more knowledge about Industry 4.0 in my area*", stated one CEO of a medium sized company in India.

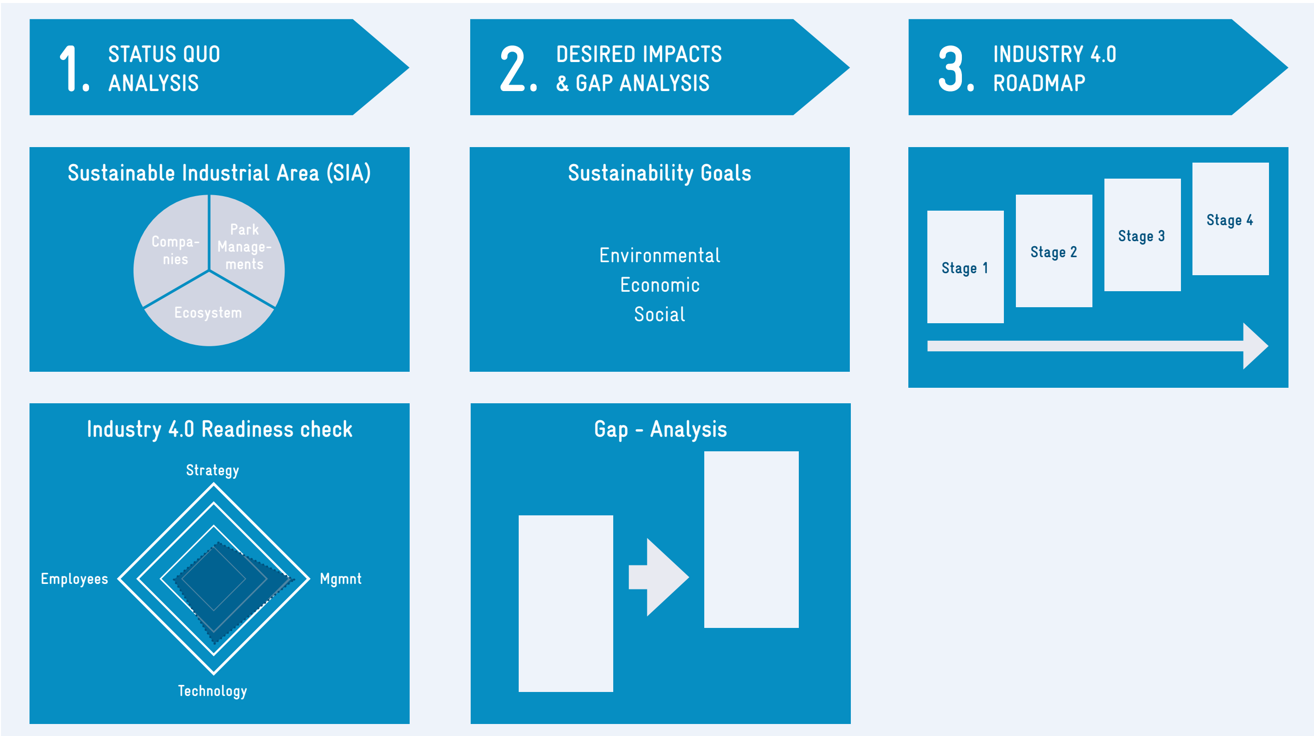
These sentences were typical comments mentioned during the interviews with practitioners in small and medium companies and regional entities in India and Egypt. In China, the knowledge seemed to be more advanced: Some industrial areas hosted workshops and small conferences on Industry 4.0 developments. The technologies themselves, their impact on future value creation and the global allocation of production activities as well as the potential for strengthening regional ecosystems are crucial topics each Sustainable Industrial Area needs to monitor. The implications of these developments have to be deducted for each IA by the local actors – based on state-of-the-art knowledge.

The GIZ SIA Working Group could support a forum that makes Industry 4.0 meaningful for industrial areas in emerging and developing countries. This forum could collect, interpret and disseminate relevant developments about Industry 4.0, especially those developments which have implications for a Sustainable Industrial Area. This forum – may it be organized internally by GIZ or in collaboration with knowledge partners - could serve as a knowledge hub (physical or virtual) where IA park management, technology providers, and users reflect on the Fourth Industrial Revolution, its implications for the development of IA, and the competitiveness of different areas. Applied research (e.g. surveys, technology reports, and case studies), workshops and other capacity building activities could be initiated and delivered by the forum.

5.2 Define a site-specific Industry 4.0 roadmap

Different Industry 4.0 readiness models have been published.[36;37] They try to capture to what degree a specific entity (e.g. company, region, or state) may make use of advanced ICT/Industry 4.0 technology. They are based on the assumption that several prerequisites need to be fulfilled to exploit Industry 4.0's potential; otherwise, the dimension with the lowest performance will be the bottleneck for the development.

Figure 3: Three-Stage-Model for Industry 4.0 Readiness



We propose a three-step approach for developing a site-specific Industry 4.0 roadmap as illustrated in Figure 3 above:

In the first step, the IA's readiness with regard to Industry 4.0 is analyzed in a variety of dimensions. The analysis should encompass the (a) IA park management, (b) the companies on site, and (c) the regional ecosystem (e.g. complementary businesses, training providers, academia, and civil society). A checklist operationalizing different levels of readiness may serve as a basis for this status-quo analysis.[38]

In a second step, the desired outcomes of a strategic use of Industry 4.0 should be defined, e.g. using the different sustainability dimensions identified by GIZ for Sustainable Industrial Areas.[39] On this basis, the degree of change, that is intended, may be described, and the gap between existing capabilities (status quo) and needed capabilities becomes obvious (gap analysis). In the light of the gap, the scope and ambition level of an Industry 4.0 project may be shaped:

– Scope: Is the use of ICT focused on one specific field of activity/position, on broader processes encompassing different work places (e.g. waste water management) or is the use of Industry 4.0 in the whole IA the goal (e.g. creation of a lighthouse project demonstrating Industry 4.0 potential)?

– Ambition level: Is the ambition level of a project the simple ICT support of an activity ("electrification" of activities done on a paper and pencil basis before), is the goal to create transparency, predict developments, or automated decisions? The broader the scope and the higher the ambition level, the more fundamental and the more complex is the Industry 4.0 transition process of a IA.

Based on these reflections, a regional Industry 4.0 roadmap may be developed integrating the interests of different stakeholders in step 3. We propose to use a multi-method approach for developing this Industry 4.0 roadmap: A questionnaire may be the basis for the status-quo analysis combined with workshops with regional stakeholders. The goals and projects should be developed in close collaboration with all actors responsible for the implementation.

[36] A. Schumacher, S. Erol, W. Sihna (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. Changeable, Agile, Reconfigurable & Virtual Production. Procedia CIRP 52 (2016) 161 – 166 (p. 162).

[37] Schuh, G., Anderl, R., Gausemeier, J., Hompel, M.T., & Wahlster, W. (2017). Industrie 4.0 Maturity Index, Managing the Digital Transformation of Companies. Deutsche Akademie der Technikwissenschaften e.V. -acatech-.

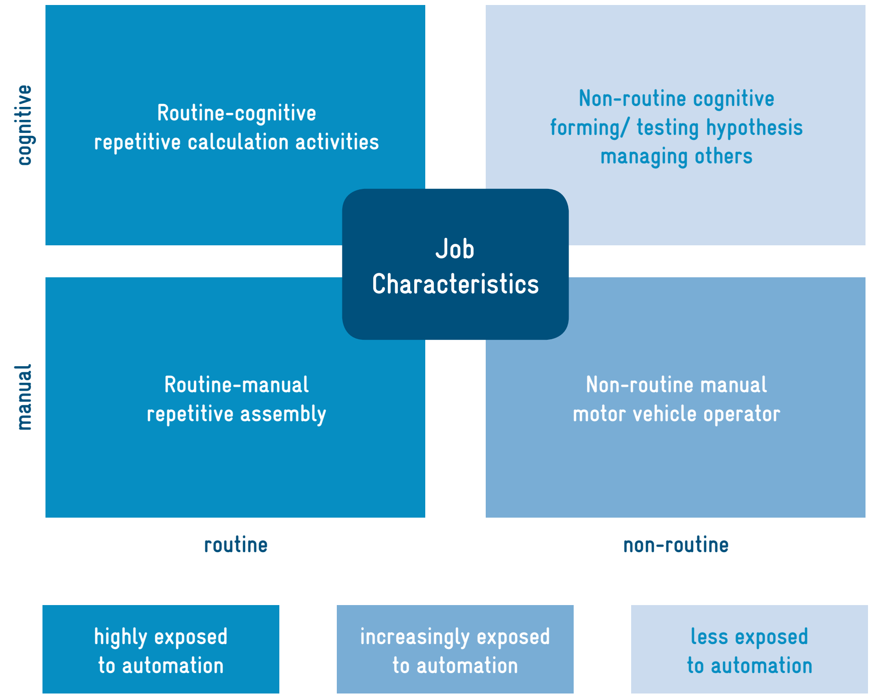
[38] A. Schumacher, S. Erol, W. Sihna (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. Changeable, Agile, Reconfigurable & Virtual Production. Procedia CIRP 52 (2016) 161 – 166 (p. 162).

[39] World Bank (2017). An international framework for eco-industrial parks (English). Washington, D.C.: World Bank Group. *http://documents.worldbank.org/curated/en/429091513840815462/An-international-framework-for-eco-industrial-parks*.

5.3 Invest in Skills

Another important topic is the impact on Industry 4.0 on employment. A wide range of jobs is at risk of automation. These encompass especially routine tasks and increasingly non-routine, manual tasks. Only non-routine, cognitive tasks are less exposed to automation, so far.[40] Emerging countries have thus to make sure that the necessary skill set is available in the countries to benefit from Industry 4.0. Otherwise, there is a noteworthy risk, that a lot of jobs will be lost to automation.[41] The skill content of recent technological change from D. Author et al. (2003) is illustrated in Figure 4.

Figure 4: Predictions of task model for impact of computerization on four categories of workplace tasks



Employees need to be able to handle or even develop innovative technologies and applications of the Fourth Industrial Revolution. Analytical thinking, active learning, creativity and complex problem-solving skills are – as the Future of Jobs Report of the World Economic Forum has shown – of increasing importance until the year 2022 (see following Table 10 for a detailed description). As the majority of jobs will be influenced by the Industry 4.0 technology, employees need to be re-skilled or upskilled to gain digital literacy.

[40] Author, D.; Levy, F.; Murnane, R. (2003): The Skill Content of Recent Technological Change: An Empirical Exploration. In: The Quarterly Journal of Economics, 118 (4): 1279-1334.

[41] There are a variety of scenarios describing the number of jobs that might be lost due to further automation, see especially the work of Frey and Osborne, *https://www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf* describing that more than 60% of jobs in China and India might be replaced by increased automation.

Table 10: The Future of Jobs - Comparing skills demand, 2018 vs. 2022 (top ten)[42]

Today (2018)	Analytical thinking and innovation Complex problem-solving Critical thinking and analysis Active learning and learning strategies Creativity, originality and initiative Attention to detail, trustworthiness Emotional intelligence Reasoning, problem-solving and ideation Leadership and social influence Coordination and time management
Trending (2022)	Analytical thinking and innovation Active learning and learning strategies Creativity, originality and initiative Technology design and programming Critical thinking and analysis Complex problem-solving Leadership and social influence Emotional intelligence Reasoning, problem-solving and ideation Systems analysis and evaluation
Declining (2022)	Manual dexterity, endurance and precision Memory, verbal, auditory and spatial abilities Management of financial, material resources Technology installation and maintenance Reading, writing, math and active listening Management of personnel Quality control and safety awareness Coordination and time management Visual, auditory and speech abilities Technology use, monitoring and control

Emerging countries face the challenge that the educational system – ranging from schools to vocational training and academic education – has to be enhanced to address these skill gaps. In Egypt, for instance, the analysis of the World Economic Forum has shown significant weaknesses in the field of vocational training and further education. In China and India, a noteworthy gap between research and education entities with a high reputation on the one hand, and numerous other actors with minor quality on the other hand was identified. Addressing the skill gaps in emerging countries requires therefore a site, industry, and topic specific analysis. Industry 4.0 related training depends on the hierarchical positioning of an employee. Taking the chemical industry as an example, the steps can be divided into (1) basic competencies, such as IT-Tools, collaboration tools and data security, and (2) task-specific competencies, e.g. smart factory, smart lab and wastewater management. Finally, level (3) relates to management competencies and can be linked to digital business models, leadership as well as disruption.

A variety of methods may be used to develop the necessary skills: The continuum ranges from purely face-to-face meetings (lectures, workshops, traineeships) to mainly digitally facilitated training (e.g. webinars, apps). Especially on the workers' level, the trainings need to have an immediate job-related benefit (e.g. cost reduction, revenue increase, process simplicity, compliance). Certificates for new jobs and skills may serve as another means to incentivize the participation in Industry 4.0-related training initiatives.

The manager of a Sustainable Industrial Area could act as the nucleus for the Industry 4.0 re-/upskilling initiative: This entity could – together with the companies on site – identify the necessary skill gaps and could develop with partners the necessary capacity development measures. At the industrial park Frankfurt-Höchst, this role is played by Provadis, who has devoted significant resources to analyzing job and skill related implications of the Fourth Industrial Revolution, and developing effective capacity building activities. The proposed GIZ SIA forum on Industry 4.0 could play this role as well: this entity could – together with the different IA - (a) identify the skill gaps, (b) develop the necessary training materials, and (c) create a community of research entities and training providers focusing on capacity building for IA around the world[43].

5.4 Create innovative ecosystems

This report has shown that Industry 4.0 will transform not only company internal production activities but as well the configuration of value creation networks. As value will be created in a network of different actors – including for instance manufacturing companies, suppliers, logistic companies, research institutions – all connected by modern ICT, it is important that in and around the IA, an effective innovative ecosystem is managed.

This innovative ecosystem may encompass an addition to the companies on site as well as research and training institutions, lead customers, infrastructure providers, public authorities, and members from civil society[44].

As members of the regional ecosystem learn from each other

[42] World Economic Forum (2018). The Future of Jobs Report 2018. *www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf*

[43] See for a more technology and governance driven approach: the World Economic Forum Center for the Fourth Industrial Revolution in San Francisco. Offices in India and China are in the process of being opened in 2019. *https://www.weforum.org/centre-for-the-fourth-industrial-revolution*.

[44] Moore, J. F. (1996). The Death of Competition: Leadership & Strategy in the Age of Business Ecosystems. New York: HarperBusiness.

and develop joint initiatives, the ecosystem strengthens the competitive position of all members. While this concept is well-known in Europe, interview partners for instance in India have not heard of this idea.

"We don't know what the other companies in our area are doing. If we want to identify collaboration potential, we have to go from door to door. That's why we founded an industry association, organizing a few events per year. It would be great if this could be done more systematically." (CEO Cello, Haridwar)

The manager of a Sustainable Industrial Area could manage the regional ecosystem as well. On this basis, synergies (e.g. by using the same energy networks, joint waste management facilities) could be identified and new fields for collaboration could be defined (e.g. activities to attract new workers, capacity building initiatives, or workshops on Industry 4.0). By increasing the actors' professionalism, the ecosystem may increase as well as the local value added.

"We learn a lot from our global Industry 4.0 initiatives. But we have problems in finding employees with the right skills in our area. There should be a joint initiative for qualifying employees for Industry 4.0 – we as a local entity of a multinational company are too small for creating our own training initiative. Having highly skilled employees is the prerequisite to play an active, high-value role in the global Unilever organization" (Unilever, Haridwar).

One example for a systematic ecosystem management from Germany may be of interest: Infraserv Höchst analyzed the resources within the industrial park and in the region to identify new business opportunities.[45] On this basis, new business opportunities – e.g. using hydrogen as an energy source for trains, using recycled phosphor for creating commercial fertilizer – have been identified.

5.5 Support Industry 4.0 entrepreneurship

Industry 4.0 creates a variety of new business opportunities for companies in emerging and developing countries. But one challenge in developing and emerging countries lies in creating high-tech or knowledge-intense startups. Often, startups in developing countries use established business models from industrialized countries and apply or adapt them to the local context. Local startups often focus on local/national "business-to-consumer" and not on "business-to-business markets". The developed solutions serve especially a local need, but they are not scalable to the global market. In this situation, a noteworthy opportunity for creating local value added is missed in emerging and developing countries.

In Europe, there are different initiatives fostering entrepreneurship as a topic for creating new jobs in the light of sustainability. Especially the European Institute of Technology with its different Knowledge Innovation Clusters (e.g. Climate KIC; InnoEnergyKIC; Digital KIC), systematically creates a network of institutions tackling societal challenges via entrepreneurship[46].

Several hundred entrepreneurs receive grants, training, and networking opportunities, and are the basis of a community of impactful entrepreneurs in Europe. International pitching sessions, European PR activity and collaboration with leading venture capitalists create successful entrepreneurs. Startups in small European countries thereby may be part of a strong European startup community. This approach could be transferred to Sustainable Industrial Areas as well. A dedicated and internationally coordinated entrepreneurship program could create a dynamic movement, which embraces the opportunities in the Fourth Industrial Revolution. Sustainable Industrial Areas could serve as a nucleus for creating high-impact, scalable entrepreneurship activities serving sustainability goals. Sustainable Industrial Areas could be transformed into hubs for Industry 4.0 entrepreneurship. Different IAs around the world could collaborate in order to analyze market needs, scale up successful solutions, and focus the attention of international investors on developing and emerging countries. The GIZ SIA Working Group could be the engine for these international entrepreneurship programs.

[45] For details about this project and the used methodology, see *www.be-circle.com*

[46] For details, see *www.eit.europa.eu*.

6 CONCLUSION

In the following, we briefly summarize the key findings of this study:

a) What are relevant Industry 4.0 technologies and applications for emerging and developing countries?

The combination of three technological developments (internet of things; cyber-physical systems; data analysis) revolutionizes existing patterns of manufacturing. Production systems become more flexible, more adaptive and, due to the increased analysis of data, more intelligent. Practically relevant applications of these developments are digital twins, predictive maintenance and augmented reality solutions. These applications may be introduced to a variety of working fields: production, logistics, energy supply and management of industrial sites. Industry 4.0 applications may be beneficial in all phases of the development of Sustainable Industrial Areas (Introducing, Designing and Operating Sustainable Industrial Areas). With regard to site management, the highest potential is seen in the fields of energy management, waste management, and logistics. Relevant technologies and applications need to be continuously observed. Test applications are necessary to identify the economic potential of new technology in real-life.

b) Which prerequisites are necessary to realize Industry 4.0 technologies and applications in developing and emerging countries and their potential with regard to sustainability?

Countries need to work on their technical expertise, their ability to innovate, on their human capital, and their ability to generate funds for the necessary modernization of their manufacturing sector. In addition, the institutional environment should be favorable for creating Industry 4.0 related learning processes. The analyzed developing and emerging countries face the following challenges:

- Technology & Innovation: Activate (China & India) or develop (Egypt) the necessary ecosystem for creating and implementing Industry 4.0 technologies and business models that enhance sustainability. Especially in China and India, high amounts of public money are foreseen to modernize the manufacturing sectors in the light of Industry 4.0. Increasing the countries' absorptive and innovative capacities seems to be key for further development.
- Human Capital: One core challenge lies in integrating Industry 4.0 and sustainability topics into the existing non-academic and academic curricula. Here, China and India are, due to a stronger educational system, in a much better starting position than Egypt.
- Global Trade & Invest: Countries may use global trade and investments as a field for technological development with regard to Industry 4.0. China's infrastructure (especially electricity) is rated much higher than India's and Egypt's and offers thus as better initial situation for investing in Industry 4.0 applications. Especially China seems not to believe in the value of free global trade with regard to its domestic market. India and Egypt are characterized by high trade barriers as well.

  Nevertheless, high greenfield investments can be seen as a lever to increase sustainability in production activities in all countries.
- Institutional Framework: All investigated countries may analyze the impact of their institutional framework with regard to the development and implementation of Industry 4.0 technologies and business models. The existing institutional regulations (rule of law, corruption) show weaknesses in developing and emerging countries.

c) What is the role of the industrial park management concerning the Industry 4.0 technologies and applications identified?

In Germany, the manager of the industrial park is a catalyst for the making the technological development of the Fourth Industrial Revolution meaningful for companies on site. Industry 4.0 is part of the site's strategic management processes. A task force with expertise in different fields (energy, waste, and logistics) analyzes Industry 4.0 related technological and business trends. The task force proposes joint experiments with Industry 4.0 applications to test their potential. In addition, the regional training institute Provadis works on relevant Industry 4.0 capacity building activities, park management acts as a knowledge hub and a catalyst for Industry 4.0 on site.

In India, Egypt or China, the role of park management with regard to Industry 4.0 is much weaker. There is no Industry 4.0 related strategy. In India and Egypt, park management does not actively foster Industry 4.0 initiatives. In China, workshops and conferences on Industry 4.0 topics are organized by the park management; but there are neither coordinated experiments nor a roadmap towards Industry 4.0.

d) How may the deployment of Industry 4.0 technologies and applications be supported in developing and emerging countries?

The following pathways are recommended to foster the deployment of Industry 4.0 technologies and applications.

We propose that GIZ supports:

1. the access to and awareness raising and provision of state-of-the-art knowledge for decision makers in emerging and developing countries,
2. development of site-specific Industry 4.0 roadmaps for IAs,
3. Capacity building initiatives closing the skill gaps related to the Fourth Industrial Revolution,
4. the development of regional innovation ecosystems,
5. and an international entrepreneurship program for promoting Industry 4.0 in IAs.

ANNEX A
INTERVIEW PARTNERS IN GERMANY

Name	Company/ Organization	Position / Background	Date	Duration
Interviews in Germany				
Dr. Alexander Dietze	Infraserv Höchst	Industry 4.0 working group	24.10.2018	120 min
Dr. Jörg Klauer	Infraserv Höchst	Head of Engineering	25.10.2018	90 min
Thorsten Grom	Infraserv Logistics	Innovation Projects	25.10.2018	90 min
Jochen Schmidt	Infraserv Höchst	Head of strategy	25.10.2018	60 min
Dominik Rohrmus	Siemens AG	Senior Engineers, Industry 4.0	5.11.2018	60 min
Dr. Olaf Sieg	Detecon International GmbH	Management Board	12.12.2018	35 min
Moritz Böhmecke-Schwafert	IBM Germany	Senior Consultant in different areas: Watson AI and Data Platforms (currently); Big Data, Strategy and Analytics	7.11.2018	90 min
Bernd Müller	Volkswagen AG Wolfsburg	Industry 4.0 working group	4.12.2018	120 min
Dr. Matthias Baum	Sanofi	Process Optimization	7.12.2018	90 min
Jeannette Baumgarten	Fraunhofer IPK	Marketing Transfer-Center Industriy 4.0 Lab	12.11.2018	45 min
Claudia Koch	Technische Universität Berlin, Chair of Innovation Economics	Research Associate for Industry 4.0 Topics	23.10.2018	70 min
Andrea Kunwald	Deutsche Telekom AG/ Labs Network Industry 4.0 e.V.	Project Manager, Coordinator LN Industry 4.0	01.11.2018	75 min

ANNEX B
OVERVIEW STUDY VISITS AND EVENTS

Workshops and Exhibitions			
Workshop "Industrie 4.0 – Ein Klick in die Zukunft"	German Chamber of Commerce and Industry, representatives from medium-size companies in Germany, Industry 4.0 Experts (e.g. Siemens)	13.11.2018	240 min
Online Workshop "Deutsche digitale Industrie-plattformen – Effizienzgewinne durch Vernetzu-ng", Follow Up Industrie 4.0 Germany	Producers of Industry 4.0 technologies and applications	14.11.2018	180 min
SPS-IPC-Drive, Nürnberg	Exhibition for smart and digital automation	28./29.11.2018	2 days

ANNEX C
INDUSTRY 4.0 READINESS INDICATORS

Table 11: Selected Indicators for Industry 4.0 Readiness[47]

	Germany	India	Egypt	China
Drivers of Production				
Technology & Innovation	8	34	53	25
2.04 FDI and technology transfer 1–7 (best)	10	52	61	45
2.05 Firm-level technology absorption 1–7 (best)	10	63	84	51
2.06 Impact of ICTs on new services and products	11	72	57	49
2.07 Cybersecurity commitment 0–1 (best)	27	26	16	35
2.09 Company investment in emerging technology 1–7 (best)	7	28	74	25
Human Capital	7	63	85	40
3.06 Digital skills among population 1–7 (best)	17	50	64	34
Global Trade & Investment	8	55	75	9
4.09 Electricity infrastructure 0–100 (best)	5	89	56	17
Institutional Framework	14	54	78	61
5.04 Rule of Law (2.5)–2.0 (best)	15	59	79	64
Sustainable Resources	13	96	48	66
Demand Environment	4	5	36	2
Structure of Production				
Complexity	3	48	61	27
Scale	4	9	29	1

Table 12: Industry 4.0 Readiness - Indicator Definition[48]

2.04	Executive Opinion Survey: "To what extent does foreign direct investment (FDI) bring new technology into your country? (1 = not at all, 7 = to a great extent)" Unit of measure: 1–7 (best)
2.05	Executive Opinion Survey: "In your country, to what extent do businesses adopt the latest technologies? (1 = not at all, 7 = to a great extent)"
2.06	Executive Opinion Survey: "In your country, to what extent do ICTs enable new business models? (1=not at all, 7=to a great extent)"
2.07	Score from the 2017 Global Cybersecurity Index, which measures cybersecurity commitment across five pillars: **Legal:** Measured based on the existence of legal institutions and frameworks dealing with cybersecurity and cybercrime. **Technical:** Measured based on the existence of technical institutions and frameworks dealing with cybersecurity. **Organizational:** Measured based on the existence of policy coordination institutions and strategies for cybersecurity development at the national level. **Capacity Building:** Measured based on the existence of research and development, education and training programs; certified professionals and public sector agencies fostering capacity building. **Cooperation:** Measured based on the existence of partnerships, cooperative frameworks and information sharing networks.
2.09	Executive Opinion Survey: "In your country, to what extent do companies invest in emerging technologies (e.g. Internet of Things, advanced analytics and artificial intelligence, augmented virtual reality and wearables, advanced robotics, 3D printing)? (1=not at all, 7= to a great extent)"
3.06	Executive Opinion Survey: "In your country, to what extent does the active population possess sufficient digital skills (e.g. computer skills, basic coding, digital reading)? (1= not at all, 7= to a great extent)"
4.09	This indicator is calculated by the World Economic Forum by aggregating two indicators that measure the electrification rate and electric power transmission and distribution losses.
5.04	Score for the Rule of Law dimension in the Worldwide Governance Indicators report issued by the World Bank. Rule of law captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police and the courts, as well as the likelihood of crime and violence. For more information on the concepts measured, visit http://info.worldbank. org/governance/wgi/#doc

[47] Own illustration. Data based on WEF (2018). Readiness for the Future of Production Report 2018. Published by World Economic Forum's System Initiative on Shaping the Future of Production. *http://wef.ch/fopreadiness18*.

[48] Own illustration. Data based on WEF (2018). Readiness for the Future of Production Report 2018. Published by World Economic Forum's System Initiative on Shaping the Future of Production. *http://wef.ch/fopreadiness18*.

ANNEX D
INDUSTRY 4.0 READINESS INDICATORS[49]

China	Selected Key Facts	Key Opportunities and Challenge	Implication for I4.0/Sustainability
Technology & Innovation Ranks 25/100	Technology platform (43/100) with good LTE mobile network coverage (30/100); FDI and technology transfer (45/100); weak technology absorption on company level (51/100) Ability to innovate (20/100): venture capital deal flow (3/100); high R&D expenditure (ranks 18/100; Companies embrace disruptive ideas (20/100) "Made in China" plan from national government with significant funding to modernize the manufacturing industry	Modernization of manufacturing processes, e.g. through the integration of sensors and internet of things technologies Strong investments and innovation orientation as an opportunity for the digital transformation Need to increase the absorptive capacity of companies as a challenge	Very promising field with political backing Market opportunities for Industry 4.0 technology providers
Human Capital Ranks 40/100	Current labor force with mixed profile (48/100): still high number of unskilled workers, limited digital skills Future work force in a promising position (31/100): Quality of universities (6/100); Vocational training (31/100); On the job training (36/100)	Modernization of skillset as challenge Academic institutions in a good position Challenges in the field of vocational and on the job training	Integrate Industry 4.0 and sustainability topics into curriculum for academic and non-academic trainings
Global Trade & Investment Ranks 9/100	Trade (88/100): High trade barriers Investment (1/100): Highest greenfield investments (1/100); very high investment inflow (2/100) Good Infrastructure (16/100): electricity infrastructure (17/100); transport infrastructure (17/100)	Global trade is not used as a mean for enhancing learning on Industry 4.0 But high investments are a mean for knowledge transfer Infrastructure in a good position for further upgrades	Excellent opportunity to integrate sustainability aspects into new investments (greenfield investments and modernization of existing manufacturing processes)
Institutional framework (61/100)	Future orientation of government (21/100) Regulatory efficiency (73/100) Rule of law (67/100) Incidence of corruption (58/100)	Uncertainties with regard to the institutional framework may prevent deployment of Industry 4.0 technologies and limit willingness to experiment with new technologies	Factor has to be taken into account as a limiting factor for future development

India	Selected Key Facts	Key Opportunities and Challenge	Implication for I4.0/Sustainability
Technology & Innovation Ranks 34/100	Technology platform (59/100) with LTE mobile network coverage (61/100); FDI and technology transfer (52/100); weak technology absorption on company level (63/100) Ability to innovate (29/100): venture capital deal flow (8/100); R&D expenditure (ranks 43/100; Companies embrace disruptive ideas (12/100); scientific and technical publication (66/100)	Modernization of manufacturing processes, e.g. through the integration of sensors and internet of things technologies, as an opportunity Technological platforms as a challenge Need to increase the absorptive capacity of companies as a challenge Ability to innovate as an opportunity	Technology Platform as a topic for further consideration – to be analyzed more in-depth Linkage between ability to innovate and sustainability as a success factor
Human Capital Ranks 63/100	Current labor force with mixed profile (80/100): still very high number of unskilled workers, limited digital skills (50/100) Future labor force in a medium position (42/100): Quality of universities (14/100); Vocational training (39/100); On the job training (33/100); School life expectancy (88/100)	Upgrading and Modernization of skillset as major challenge Academic institutions in a good position Challenges in the fields of vocational and on the job training	Integrate Industry 4.0 and sustainability topics into curriculum for academic and non-academic trainings Making sustainability issues meaningful for unskilled workers
Global Trade & Investment Ranks 55/100	Trade (89/100): High trade barriers Investment (11/100): High greenfield investments (4/100); high investment inflow (11/100) poor infrastructure (72/100): electricity infrastructure (89/100); transport infrastructure (23/100)	Global trade is not systematically used as a mean for enhancing learning on Industry 4.0 high investments can be a mean for knowledge transfer Electricity infrastructure as a major challenge	Global trade and investment as a relevant field for improving sustainable economic development Electricity infrastructure as a potential bottleneck for enhancing Industry 4.0 applications
Institutional framework (54/100)	Future orientation of government (22/100) Regulatory efficiency (96/100) Rule of law (59/100) Incidence of corruption (58/100)	Uncertainties with regard to the institutional framework may prevent deployment of Industry 4.0 technologies and limit willingness to experiment with new technologies	Factor has to be taken into account as a limiting factor for future development

[49] Data source World Economic; Implications deducted by authors.

Egypt	Selected Key Facts	Key Opportunities and Challenge	Implication for I4.0/Sustainability
Technology & Innovation Ranks 53/100	Technology platform (42/100) with FDI and technology transfer (61/100); weak technology absorption on company level (84/100) Ability to innovate (72/100): venture capital deal flow (46/100); R&D expenditure (ranks 49/100; Companies embrace disruptive ideas (95/100); scientific and technical publication (57/100)	Building of manufacturing processes as a challenge; weak position in FDI and technology transfer and weak technology absorption capacity Weak ability to innovate Companies not embracing disruptive ideas	Potential for leapfrogging given – special attention has to be given to the question how the basic capabilities for generating and disseminating innovation can be fostered
Human Capital Ranks 85/100	Current labor force with weak profile (78/100): still very high number of unskilled workers: mean years of schooling (82/100), limited digital skills (64/100) Future labor force in a weak position (95/100): Quality of universities (45/100); Vocational training (100/100); On the job training (100/100); School life expectancy (71/100)	Upgrading of skillset as major challenge Low level out of school plus severe challenges in the fields of vocational and on the job training	Upskilling of workforce needed in order to have high tech manufacturing processes in Egypt Developing a vocational training and on the job training culture as major challenge Integrate Industry 4.0 and sustainability topics into curriculum for academic and non-academic trainings Making sustainability issues meaningful for unskilled workers
Global Trade & Investment Ranks 75/100	Trade (96/100): High trade barriers Investment (30/100): High greenfield investments (9/100); investment inflow (37/100) Infrastructure (54/100): electricity infrastructure (56/100); transport infrastructure (53/100)	Global trade is not systematically used as a mean for enhancing learning on Industry 4.0 high greenfield investments can be a mean for knowledge transfer Infrastructure as a challenge for Industry 4.0	Global trade and investment as a relevant field for improving sustainable economic development – but trade barriers as a major barrier Infrastructure as a field for further improvement
Institutional framework (78/100)	Future orientation of government (56/100) Regulatory efficiency (74/100) Rule of law (79/100) Incidence of corruption (75/100)	Uncertainties with regard to the institutional framework prevent deployment of Industry 4.0 technologies and limit willingness to experiment with new technologies	Factor has to be taken into account as a limiting factor for future development

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