Benefits and Challenges of Industry 4.0 in African Emerging Economies

Mesfin Kebede Kassa[1(✉)] and Hana Demma Wube[2]

[1] Department of Mechanical Engineering, Kombolcha Institute of Technology, Wollo University, Kombolcha, Ethiopia
livemesfin@gmail.com
[2] Ethiopian Artificial Intelligence Institute, 40782 Addis Ababa, Ethiopia

Abstract. The fourth industrial revolution (Industry 4.0 or I4.0) originated in Germany and represents the next phase in the digitization of the manufacturing sector, driven by the Internet of Things (IoT), Cyber Physical System (CPS), computing, additive manufacturing, and smart factories. I4.0 offer an exciting opportunity for manufacturers, and small and medium enterprises of developed and developing nations to develop a novel business models and integrate into global value chains. However, implementing I4.0 will present many challenges. Much has been done in developed countries regarding the benefits and challenges of I4.0 compared to developing countries. Thus, it is important to study the challenges and benefits of I4.0 in the context of African emerging economies. In this vein, the purpose of this study is to explore the concept, key factors, national preparedness, benefits, and challenges of I4.0 using existing literature. A case study, challenge, and benefits analysis were then conducted to test the potential for I4.0 implementation in African emerging economies using various data sources. Finally, future study directions on the I4.0 phenomenon were presented. The implementation of I4.0 in African countries was discussed in terms of manufacturing capacity, R&D, human capital, and IT infrastructure. From the study, it was found that promoting innovative new technologies through spending on research and development, increasing the accumulation of intellectual property, and the necessary human capital, and developing the "Internet plus" industry are the main challenges to implement I4.0 in African countries with emerging economies.

Keywords: Industry 4.0 · Benefits · Challenges · African emerging economies

1 Introduction

The fourth industrial revolution (I4.0) was first introduced in 2011 and refers to the strategic plan developed by the German federal government for the high-tech manufacturing industry of tomorrow, describing a joint national strategy to improve the industry and a fundamental paradigm shift from centralized

T. Girma Debelee et al. (Eds.): PanAfriCon AI 2022, CCIS 1800, pp. 261–276, 2023.
https://doi.org/10.1007/978-3-031-31327-1_15

production to decentralized production and control [16]. I4.0 has the potential to transform optimized and cell production into a completely integrated, optimized, and automated workflow, leading to increased efficiency and reshaping traditional manufacturing relationships between customers, manufacturers, and suppliers, as well as between human and machine [40]. In general, I4.0 is mainly focused on automation, machine learning, and real-time interconnection. The concept of I4.0 is currently under research and will be the main strategic manufacturing plan for the development of the manufacturing sector in different parts of the world under various names such as "Smart Manufacturing" in the US and Korea and "Made in China 2025" in China. "Towards Industry 4.0" (Rumo à Indústria 4.0) and "La Nouvelle France Industrielle" in France and Brazil, respectively [11,27]. "Make in India" in India, "Society 5.0 or super smart society" in Japan, "Crafting the Future" in Mexico. I4.0 is also demonstrated in the digitization of production and service processes in Netherlands, Denmark, Finland, and Sweden with the most established digital economy in the EU, followed by Luxembourg, Belgium, the UK, Ireland, and Italy [21]. It can be seen from the above literature that the concepts and implementation status of I4.0 differ in each country and have an impact on the global economy and market competition. It is important to mention that the goal of all these programs, both in developed and developing nations, is to introduce I4.0 concepts and technologies to local businesses. However, as Hall et al. and Kumar et al. noted, the advent of cutting-edge technologies can present greater difficulties emerging economies [15,24]. In particular, companies in African emerging economies often lag behind compared to their counterparts in developed countries in terms of technology adoption, as developing countries' economies have traditionally been more focused on commercialization and resource extraction. In addition, since I4.0 is a new subject, there isn't much information accessible about it in the context of African emerging economies. Therefore, the objective of the current work is to explore the concept, key technologies, key factors for the realization, national preparedness, benefits, and challenges of implementing I4.0 using existing literature. Exploring the potential for I4.0 implementation using a challenges and benefits analysis in selected African countries with emerging economies using indicators.

2 Background

In this section, the key technologies, concepts, key enablers, national preparedness, benefits, and challenges of I4.0 have been explored and presented from existing literature. For this purpose, text mining was used to download papers from the Google Scholar database. The search for published articles is carried out using queries containing the keywords "Challenges", "Benefits", "Advantages", "Africa", and "Industry 4.0".

2.1 Industry 4.0 Key Technologies

The main driving forces behind the application of I4.0 are the Internet of Things (IoT) and Cyber-Physical Systems (CPS) in terms of interconnected smart grids, smart cities, logistics, and smart factories. It has been reported that IOT is the basis for building CPS by integrating the real world and digital world of CPS, and the smart factory is seen as a vision for I4.0 [28]. Cloud computing, big data, 3D printing, holograms, energy conservation, smart sensors, horizontal and vertical system integration, mobile computing, blockchain, cloud computing, and big data services for integrating industrial IoT networks are some of the key technologies needed for I4.0 implementation [19,34]. The main I4.0 pillars, which are commonly linked to the I4.0 concept, are depicted in Fig. 1.

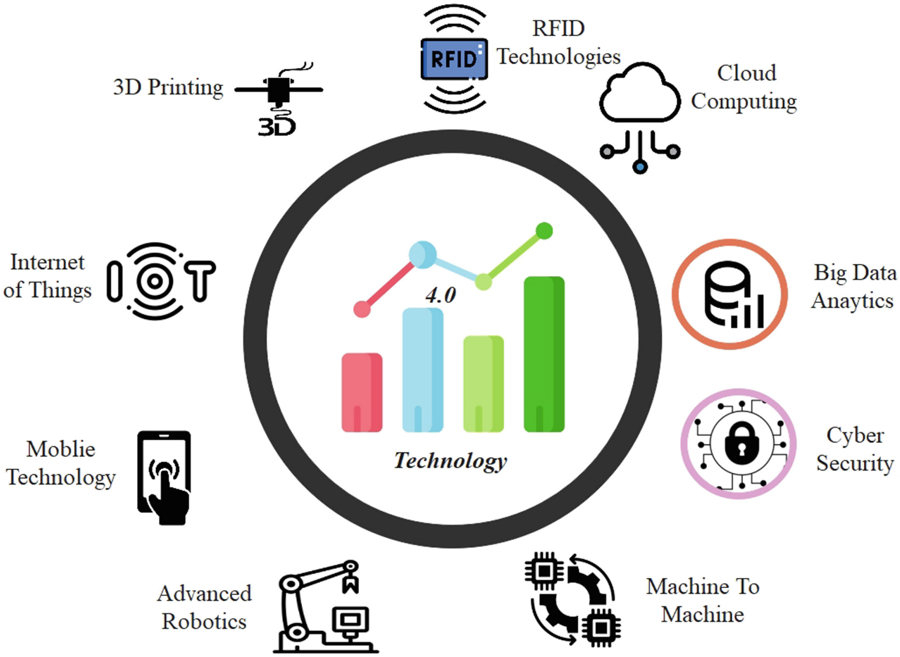

Fig. 1. Pillars of Industry 4.0.

In terms of the application of I4.0 key technologies, Radio frequency identification (RFID) & cloud computing are the most frequently used essential technologies for the realization of I4.0. These technologies are used to detect abnormalities and introduce gold nano-rods into the input materials for the polymer-based biomedical device's [32]. I4.0 also finds application in intelligent manufacturing systems such as multi-agent technology, cloud-based solutions, and different manufacturing plants [5,23,47]. In addition, I4.0 is also being used in autonomous robots such as in the healthcare sector for elderly care and in surgery, surveillance systems used for monitoring, spying, and performing dangerous tasks, and used as assistants for guidance and control. In the agricultural sector, the IoT is being used to predict and improve the efficiency of farming by managing the breeding and cultivation process using intelligent agricultural tools [7,42]. Further, blockchain technologies can transform the energy sector, supply chain management, distribution system, secure healthcare system, smart city development, business, manufacturing, and agricultural sector [8]. Furthermore, robot welding, workforce training, demand forecasting, physical layer authentication, predictive maintenance, and energy optimization are some of the industrial AI applications [35]. Other areas of application of the key technologies of I4.0 are summarized and presented in Table 1.

Table 1. Industry 4.0 key technologies with their applications.

Technologies	Applications	Source
Big Data and Analytics	Earlier industry threat detection in various production operations Predict new problems arise using data analysis previously recorded industry data	[4]
Autonomous Robots	To perform field work where are the human workers limited in work Use in the healthcare sector, emotional and social companionship, educational fields, surveillance, agriculture, and assistants for administration	[42]
Simulation	Use to mirror real processes and optimize decision making	[41]
System Integration: Horizontal and Vertical System Integration	Automation communication and cooperation especially along standardized processes	[13]
The Industrial IoT	Smart planning & machine control	[45]
Cyber security and CPS	Failure detection in machines and automatically prepare for troubleshooting actions on CPS	[22]
Cloud	Data Sharing	[40]
Additive Manufacturing	To manufacture small batches of customized products	[40]
Augmented Reality	For part selection in a warehouse and sending repair instructions over mobile devices	[40]

2.2 Key Factors for the Realization and National Preparedness of Industry 4.0

Following the above section, this section discusses the conceptual and technical studies related to I4.0. It primarily includes information on the key factors and national readiness for I4.0 to establish the study's key parameters. Li et al. explained that human resource development is a crucial human resource practice to create a suitable work environment and foster the innovation and creativity of human capital needed for I4.0 [25]. Kang et al. noted that infrastructure such as information and communication technology is a key technology to support smart manufacturing [19]. Strozzi et al. indicated that public policy, funding, and research in the field of I4.0 are key factors for the implementation of I4.0 [44]. Kim J. explained that machinery investment efficiency, total capital efficiency, research budgeting, research collaboration, IT security issues, and digital technologies are the main factors for I4.0 realization [21]. Li et al. indicated that manufacturing capability, R& D, and human capital are the main factors for the realization of I4.0 [25]. The key factors identified from the literature for the implementation of I4.0 are summarized and presented in Table 2. Further, in the literature, the realization of I4.0 in African countries is evidenced by the launch of I4.0 initiatives, including Smart Africa, the European Union-African Union Digital Task Force, and the African One Network [9]. However, it is also mentioned that the lack of electricity and internet infrastructure negatively affects the realization of I4.0. Despite the aforementioned negative effects of I4.0 realization, there are many benefits to be gained with its acceptance. For example, the productivity, profitability, and competitiveness of manufacturing sectors can be improved by adopting I4.0. In summary, it is clear from the aforementioned articles that the major variables listed above play a role in determining the national readiness of the African countries with emerging economies to implement I4.0.

Table 2. Key factors for the realization of Industry 4.0 identified from the literature.

No.	Key factors	Source
1	Human resource development	[26]
2	Government policy and funding	[44]
3	Infra system of manufacturing sites	[19]
4	Studies focusing on industry 4.0	[44]
5	IT security issues and Digital Technologies	[21]
6	Machinery investment efficiency and total capital efficiency, research budgeting and research collaboration	[21]

2.3 Benefits of Industry 4.0

Once the key factors for the realization of I4.0 have been identified, the benefits of implementing I4.0 need to be discussed. Kamble et al. indicated that I4.0 brought a new paradigm shift to the manufacturing sector by integrating new technologies to maximize productivity while using resources efficiently [18]. Erboz noted that the use of big data analytics in industries can lead to lower operating costs, faster decision making, and new product development. Further, big data analytics leads to a decisive advantage over competitors [12]. Alcacer and Cruz- Machado noted that the advantage of cloud computing is to lower cost of information, handle data effectively, and improve flexibility and efficiency [1]. According to Rghioui and Oumnad, the IoT can increase a company's level of efficiency by allowing data to be transferred between devices in real-time [39]. Anitah et al. reported that I4.0 is having a positive impact on operational performance such as product quality, flexibility, production lead times, delivery times, delivery reliability, and productivity levels of Kenyan fast-growing consumer goods manufacturers [2]. In summary, it can be concluded from the cited articles that companies can use I4.0 to increase efficiency and achieve significant cost savings. Based on this, I4.0 can be defined as the basis for the future competitiveness of manufacturing companies. The benefits of I4.0 identified from literature are summarized and depicted in Table 3.

Table 3. Benefits of Industry 4.0 identified from the literature.

Benefits	Source
Maximum performance with efficient use of resources	[1]
Lower operating costs, faster decision-making, and new product development	[39]
Real-time transmission of data between devices	[6]
Positive impact on operational performance	[31]
Lower cost of information	[2]

2.4 Challenges of Industry 4.0

The previous section highlights the benefits of implementing I4.0. However, to reap the benefits of I4.0, numerous hurdles must be overcome. This section outlines some of the challenges for successfully implementing I4.0. Many researchers report that the successful implementation of I4.0 at the micro and macro levels has been significantly influenced by the relevant skills and abilities of the country's technologically competent workforce. Moreover, the quality of the workforce's abilities and qualifications will be crucial in fostering innovation and competitiveness [6,31]. According to Pradhan and Agwa-Ejon, there is a severe lack of professionals with the I4.0 skill set in developing nations [37]. In addition, one of the biggest unresolved issues regardinf the implementation of I4.0

in developing nations is unemployment due to factors such as the mismatch between the available skills and the skills required by the industry, high rates of unskilled labor, and inadequate education [29]. Shvetsova and Kuzmina revealed that a fuzzy understanding of the skills that meet the requirements of I4.0 is also a serious problem in the implementation of I4.0 [43]. According to Raj et al., the introduction of new technologies will make it challenging to adopt I4.0 in the future because of worries about the secure handling of sensitive data and information [38]. Numerous sources also contend that a significant barrier to implementation of I4.0 is a lack of funding. The implementation of I4.0 may also be hampered by poor understanding of integration, lack of standardization, and concerns about secured infrastructure [3]. Further, socio-economic challenges such as non-inclusive economic growth are also factors hindering the implementation of I4.0 [30]. In summary, the aforementioned factors pose challenges for I4.0 implementation. In order to address them, national governments must place a high priority on the development of human resources, which includes improving the quality of education and acquiring the competencies needed to implement I4.0, which aims to combat poverty, inequality, and unemployment as well as create an inclusive economy. Table 4 provides an overview of I4.0 challenges identified in the cited literature.

Table 4. Challenges of Industry 4.0 identified from the literature.

Challenges	Source
Relevant skills and abilities of the country's workforce	[6,29,31,37,43]
Financial resources	[3]
Secured infrastructure	[38]
Socio-economic challenges	[30]

2.5 Industry 4.0 in Africa

Industry 4.0 is getting popular in various parts of the world, as discussed in the introductory part of this study. However, despite claims that I4.0 has the highest penetration rate in the world, I4.0 is gaining slow momentum in African countries. In these countries, the IoT, blockchain, 3D printing, big data, drones, and artificial intelligence (AI) are some of the breakthrough technologies of I4.0 in African countries [14]. The above technologies are used in industry, regional integration, energy, agriculture, education, and healthcare sectors. In this regard, the current research examined and presented the adoption of I4.0 in African nations with emerging economies.

3 Case Study - Analysis of the Challenges and Benefits of Implementing Industry 4.0

In the above sections, key technologies, key factors, challenges, and benefits of I4.0 were identified and highlighted. This section presents a case study to analyze the challenges and benefits of implementing I4.0 to check the potential of African emerging economies using a total of four key indicators: (i) Manufacturing capability, (ii) Research and development, (iii) Human capital, and (iv) ICT infrastructure. The indicators along with subcategories along with their data source are presented in Table 5. The case study begins by selecting the top five African countries with the high gross domestic product (GDP) (i.e. Ethiopia, Benin, Niger, Egypt, and Uganda) as depicted in Table 6, based on the data obtained from World bank for the end of 2021. In this regard, GDP was used to select the countries for the case study, since GDP is a widely considered indicator of the performance of a national economy. Subsequently, a numerical analysis is carried out for each indicator and presented in the following subsections.

Table 5. Industry 4.0 key indicators with data sources.

Indicator	Indicators	Data source
Manufacturing Capability	High Technology Exports as percentage of Manufacturing Exports	The World Bank Data (2020)
Research and Development	Expenditure On R&D Number of patent application	UNESCO Institute for Statistics (2018) The World Bank Data (2020)
Human Capital	Human capital in R& D	UNESCO Institute for Statistics (2018)
IT Infrastructure	Fixed Mobile broadband Subscription	ITU World Telecommunication/ICT Indicators database (2020)

3.1 Manufacturing Capability

In order to implement I4.0, the nation's policymakers need to plan strategic turnarounds, leading to a global reconfiguration of manufacturing focused on high-tech products, low value-added, and low-profit margin productions [25]. The manufacturing capability can be used to demonstrate the country's industrial revolution, including I4.0, using a few indicators such as GDP, the percentage of GDP that comes from industry value added, foreign direct investment net flow, and high-technology exports. Among, in the current study, high-tech exports (% of manufactured goods) presented in Table 7 were only considered as an indicator to test the readiness of I4.0 implementation in African nations with emerging economies. High-tech exports include products such as computers, pharmaceuticals, aerospace, electrical equipment, and scientific instruments

Table 6. Top five African countries with high economic growth [*D*ata source: The World Bank Data (2021)].

Global rank	Country Name	Economic growth: the rate of change of real GDP
3	Ethiopia	6.06
7	Benin	3.85
8	Niger	3.58
9	Egypt	3.57
14	Uganda	2.95

with high R&D intensity. From Table 7, it can be observed that Ethiopia has the biggest high-technology exports as a % of manufactured goods, accounting for 13.1 % the smallest belongs to Uganda, accounting for 2.1 %. Ethiopia's largest high-technology exports as a % of manufactured exports can be attributed to an increase in foreign investment. In conclusion, these data demonstrate that while the GDP of five African emerging economies is growing, high technology exports are low. As a result, these countries should be able to spend more in the creation of high-tech goods with a significant R&D aspect.

Table 7. African Countries with high-technology exports as a percentage of manufactured exports [*D*ata source: The World Bank Data (2020); % of manufactured exports].

Global rank	Country Name	% of manufactured exports
36	Ethiopia	13.1
100	Uganda	2.1
92	Benin	2.68
40	Niger	12.23
93	Egypt	2.68

3.2 Research and Development

In this section, the R&D intensity of the considered African countries with emerging economies has been evaluated. For this purpose, two indicators such as the number of patent applications and expenditure on research and development have been used. An application for a product or process that offers a novel method of performing a task or suggests a novel technical solution for a problem and is submitted via a patent agency in order to acquire exclusive rights to an invention is referred to as a patent application. The research and development expenditure is shown in Table 8 as a percentage of GDP. It is important to mention that only two of the five chosen countries have the indicator data.

According to Table 8, Egypt spends more money on R&D than Ethiopia. In addition, Table 9 demonstrates that Egyptian citizens registered a higher number of patent applications than that of Ethiopian citizens. This shows that Ethiopia and Egypt rely on the production of low-tech content, and the country, need to do more to support the I4.0 goals such as high technology, innovation, and integration since R&D investment and activities are an important basis for the creation of their brands. It is important to note that the data in Table 9 are not organized according to the citizenship of the citizens; rather, the data only indicate the nation in which the patent is filed.

Table 8. Research and development expenditure as a proportion of GDP [*Data source*: The World Bank Data (2017); Expenditure on research and development].

Country Name	Expenditure on research and development (in percent)
Ethiopia	0.27
Egypt	0.68

Table 9. Number of patents filed by citizens [*D*ata source: The World Bank Data (2017); Number of patents].

Global Rank	Country Name	Number of patents
101	Ethiopia	6
93	Uganda	13
33	Egypt	978

3.3 Human Capital

Human resource development is crucial for achieving I4.0's objectives. The practice of working with personnel with a commitment to the cause helps to create an adequate working environment for enhancing the creativity and innovation of human capital. Human capital is essential to foster research practices [36]. Human talent are essential for research and innovation, so it is important to develop human capital through high-quality education. I4.0 employees working on I4.0 are required to be trained in order to be able to run the system. Revival through education is an essential first move toward further growth. Policymakers must guarantee that there are enough researchers in their nations in order to improve knowledge societies. [26]. In the current study, the distribution of researchers per 1 million inhabitants engaged in R&D has been used to evaluate the human capital for the implementation of I4.0, as presented in Table 10, where data is available. It can be seen from the table that both countries have fewer researchers per million inhabitants. This shows that policymakers in these countries should consider creating labor demand for I4.0. Further, educational institutions should concentrate on cultivating and teaching college graduates to contribute to the implementation of I4.0, since the availability and skill of the workforce are important factors that have added to the competitiveness of manufacturing. Besides education, training is a requirement for the implementation of I4.0 because it calls for a different group of skills from the workforce. Several nations initiated skill development programs to develop the I4.0-required skills, including India, which has started an I4.0 skills development initiative called Skill India [17]. Similar to this, a working group on the development of I4.0 skills exists as part of the BRICS partnership with the goal of fostering digital skills among member nations [9]. In order to develop the necessary skill set, the government and private sector of African nations should actively engage in outreach and training initiatives.

Table 10. Researchers' distribution per million inhabitants [*D*ata source: UNESCO Institute for Statistics (2017)].

Country	Researchers (in full-time equivalent) per million inhabitants
Ethiopia	90.5
Egypt	677.1

3.4 Information Technology Infrastructure

Information and Communication Technology (ICT) has been shown to be essential for success in the I4.0 arena as it enables quick responses to a dynamic market. ICT facilitates the use of information resources easier [20]. In the era of modern manufacturing, billions of digital devices have internet connectivity. This rapid growth has caused ICT to become the cornerstone of manufacturing systems, supported by modeling, simulation, and presentation tools, as well as digital and virtual production [10]. As a result of this rapid development, ICT has become the core of manufacturing systems, aided by tools for modeling, simulating, and presenting as well as digital and virtual production. Moreover, it has been reported that the impact of I4.0 technologies has led to a substantial increase in the availability of and delivery of digital economy services via digital media and mobile devices in developing nations like Africa [33]. Digital services include services offered by banks such as cell phone banking and new designs based on cloud-based computing such as mobile payments, digital platforms, and crypto assets [46], the African emerging economies can greatly benefit from this growth. In this study, the number of fixed-broadband subscriptions per 100 people at the end of 2020 has been used as an indicator to estimate the telecommunication/ICT infrastructure required for I4.0 implementation in the selected countries, as depicted in Table 11. From Table 11 it can be observed that Egypt has the highest rate of fixed-broadband subscriptions per 100 people compared to other countries. This indicates that Egypt has a better ICT readiness for the implementation of I4.0. However, the rest of the countries included in this study have the lowest readiness. Therefore, it is important that other countries focus on building ICT infrastructure for I4.0 implementation.

Table 11. Fixed broadband subscriptions per 100 people [*D*ata Source: ITU World Telecommunication/ICT Indicators database (2020)].

Global Rank	Country Name	Fixed broadband subscriptions per 100 people
170	Ethiopia	0.18
176	Uganda	0.13
164	Benin	0.25
186	Niger	0.05
106	Egypt	9.14

In general, it can be seen from the case study that for the African countries included in the study, despite their growing GDP, which is a promising picture for I4.0 implementation, there is a problem with defining goals and ideas for I4.0 implementation. The challenges for I4.0 implementation include promoting technologically advanced new technologies through investment in research and development, increasing the accumulation of intellectual property, and the necessary human capital, and developing the "Internet plus" industry. The study also identified four key crucial actors that will influence and support I4.0 implementation in African emerging economies; these are manufacturing capabilities, R&D, human capital, and ICT infrastructure. In addition, it was noted that the countries included in this study are in need of qualified professionals who could contribute their experience and creativity to the I4.0 blueprint to sustain their growth. Further, the country's policymakers should consider ambitious strategic plans for implementing I4.0 to effectively use digital technologies to build new industrial environments, fabricate new products, and enhance well-known brands.

Furthermore, technologies associated with I4.0 will replace the low-skilled workforce, which is plentiful in Africa and shown in the current study with a highly skilled workforce, so African governments should invest in I4.0 education and training programs so that technology complements rather than replaces the workforce. Moreover, to get the most out of I4.0, African governments and entrepreneurs must recognize new industry niches and use them to achieve sustainable, inclusive growth and take bold steps to close gaps in infrastructure, digital skills, and R&D. Also, the study shows that access to I4.0 in Africa is limited by infrastructure parameters such as broadband penetration, resulting in a low number of mobile phone and Internet users. Thus, new strategies are required to modernize the ICT infrastructure in Africa.

4 Conclusions

In this study, the concept, key technologies, key factors, national preparedness, benefits, and challenges of Industry 4.0 were explored and presented using existing literature. A case study was then presented to analyze the challenges and benefits of implementing I4.0 in African emerging economies by selecting five countries based on their GDP, such as Ethiopia, Benin, Niger, Egypt, and Uganda, using indicators from various data sources. The study found that while the GDP of five emerging African countries is growing, high-tech exports remain low. The number of patent applications filed by citizens of the selected countries is relatively low, indicating that the countries rely on low-tech content production. In addition, countries have fewer researchers per million inhabitants and low levels of fixed-broadband subscriptions per 100 people. In general, the study noted that empowering manufacturing capability through R&D driven manufacturing, creating the necessary infrastructure, green development, optimizing the national industry, and increasing the necessary human capital should be the guiding principles for successful I4.0 implementation. Further, for emerging economies in Africa, it can be concluded that more work needs to be done to meet I4.0 requirements beyond their GDP growth to remain globally competitive. Furthermore, future studies could be conducted using different sub-categories of indicators to test the capacity of African countries to implement I4.0 along with the implications. Moreover, with regard to geographic coverage, more research is needed in regions that have contributed to the global economy beyond the considered major African emerging economies. In addition, a study of women's participation in the digital economy could be carried out in the future.

References

1. Alcácer, V., Cruz-Machado, V.: Scanning the industry 4.0: a literature review on technologies for manufacturing systems. Eng. Sci. Technol. Int. J. **22**(3), 899–919 (2019)
2. Anitah, J.N., Nyamwange, S.O., Magutu, P.O., Chirchir, M., Mose, J.M., et al.: Industry 4.0 technologies and operational performance of unilever Kenya and l'oreal East Africa. Noble Int. J. Bus. Manage. Res. **3**(10), 125–134 (2019)
3. Bag, S., Yadav, G., Dhamija, P., Kataria, K.K.: Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: an empirical study. J. Clean. Prod. **281**, 125233 (2021)
4. Bagheri, B., Yang, S., Kao, H.A., Lee, J.: Cyber-physical systems architecture for self-aware machines in industry 4.0 environment. IFAC-PapersOnLine **48**(3), 1622–1627 (2015)
5. Barbosa, G., Aroca, R.: Advances of industry 4.0 concepts on aircraft construction: an overview of trends. J. Steel Struct. Constr. **3**, 125 (2017)
6. Benešová, A., Tupa, J.: Requirements for education and qualification of people in industry 4.0. Procedia Manuf. **11**, 2195–2202 (2017)
7. Bersani, C., Ruggiero, C., Sacile, R., Soussi, A., Zero, E.: Internet of things approaches for monitoring and control of smart greenhouses in industry 4.0. Energies **15**(10), 3834 (2022)

8. Bodkhe, U., et al.: Blockchain for industry 4.0: a comprehensive review. IEEE Access **8**, 79764–79800 (2020)
9. Bongomin, O., Nganyi, E.O., Abswaidi, M.R., Hitiyise, E., Tumusiime, G.: Sustainable and dynamic competitiveness towards technological leadership of industry 4.0: implications for East African community. J. Eng. **2020**, 1–22 (2020)
10. Colin, M., Galindo, R., Hernández, O.: Information and communication technology as a key strategy for efficient supply chain management in manufacturing smes. Procedia Comput. Sci. **55**, 833–842 (2015)
11. Dalenogare, L.S., Benitez, G.B., Ayala, N.F., Frank, A.G.: The expected contribution of industry 4.0 technologies for industrial performance. Int. J. Prod. Econ. **204**, 383–394 (2018)
12. Erboz, G.: How to define industry 4.0: main pillars of industry 4.0. Manage. Trends Dev. Enterp. Glob. Era **761**, 767 (2017)
13. Erol, S., Jäger, A., Hold, P., Ott, K., Sihn, W.: Tangible industry 4.0: a scenario-based approach to learning for the future of production. Procedia CiRp **54**, 13–18 (2016)
14. Gillwald, A., Calandro, E., Sadeski, F., Lacave, M.: Unlocking the potential of the fourth industrial revolution in Africa (2019)
15. Hall, B.H., Maffioli, A.: Evaluating the impact of technology development funds in emerging economies: evidence from Latin America. Eur. J. Dev. Res. **20**(2), 172–198 (2008)
16. Hermann, M., Pentek, T., Otto, B.: Design principles for industrie 4.0 scenarios. In: 2016 49th Hawaii International Conference on System Sciences (HICSS), pp. 3928–3937. IEEE (2016)
17. Jujjavarapu, G., et al.: AI and the manufacturing and services industry in India. The center for Internet and Society, India (2018). https://cisindia.org/internetgovernance/files/AIManufacturingandServices_Report_02.pdf. Accessed 06 Jan 2019
18. Kamble, S.S., Gunasekaran, A., Gawankar, S.A.: Sustainable industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives. Process Saf. Environ. Protect. **117**, 408–425 (2018)
19. Kang, H.S., et al.: Smart manufacturing: past research, present findings, and future directions. Int. J. Precis. Eng. Manuf.-Green Technol. **3**(1), 111–128 (2016). https://doi.org/10.1007/s40684-016-0015-5
20. Ketteni, E., Kottaridi, C., Mamuneas, T.P.: Information and communication technology and foreign direct investment: interactions and contributions to economic growth. Empir. Econ. **48**(4), 1525–1539 (2015)
21. Kim, J.: Are countries ready for the new meso revolution? Testing the waters for new industrial change in Korea. Technol. Forecast. Soc. Chang. **132**, 34–39 (2018)
22. Kolberg, D., Zühlke, D.: Lean automation enabled by industry 4.0 technologies. IFAC-PapersOnLine **48**(3), 1870–1875 (2015)
23. Kumar, A.: Methods and materials for smart manufacturing: additive manufacturing, internet of things, flexible sensors and soft robotics. Manuf. Lett. **15**, 122–125 (2018)
24. Kumar, N., Siddharthan, N.S.: Technology, Market Structure and Internationalization: Issues and Policies for Developing Countries. Routledge (2013)
25. Li, L.: The path to made-in-China: how this was done and future prospects. Int. J. Prod. Econ. **146**(1), 4–13 (2013)
26. Li, L.: China's manufacturing locus in 2025: with a comparison of "made-in-china 2025" and "industry 4.0". Technol. Forecast. Soc. Chang. **135**, 66–74 (2018)

27. Liao, Y., Deschamps, F., Loures, E.D.F.R., Ramos, L.F.P.: Past, present and future of industry 4.0-a systematic literature review and research agenda proposal. Int. J. Prod. Res. **55**(12), 3609–3629 (2017)
28. Lu, Y.: Industry 4.0: a survey on technologies, applications and open research issues. J. Ind. Inf. Integr. **6**, 1–10 (2017)
29. Maisiri, W., Darwish, H., Van Dyk, L.: An investigation of industry 4.0 skills requirements. South Afr. J. Ind. Eng. **30**(3), 90–105 (2019)
30. Maisiri, W., van Dyk, L., Coeztee, R.: Factors that inhibit sustainable adoption of industry 4.0 in the South African manufacturing industry. Sustainability **13**(3), 1013 (2021)
31. Mavrikios, D., Georgoulias, K., Chryssolouris, G.: The teaching factory paradigm: developments and outlook. Procedia Manuf. **23**, 1–6 (2018)
32. Monostori, L., et al.: Cyber-physical systems in manufacturing. Cirp Ann. **65**(2), 621–641 (2016)
33. Mpofu, F.Y., Mhlanga, D.: Digital financial inclusion, digital financial services tax and financial inclusion in the fourth industrial revolution era in africa. Economies **10**(8), 184 (2022)
34. Mueller, E., Chen, X.L., Riedel, R.: Challenges and requirements for the application of industry 4.0: a special insight with the usage of cyber-physical system. Chin. J. Mech. Eng. **30**(5), 1050–1057 (2017)
35. Peres, R.S., Jia, X., Lee, J., Sun, K., Colombo, A.W., Barata, J.: Industrial artificial intelligence in industry 4.0-systematic review, challenges and outlook. IEEE Access **8**, 220121–220139 (2020)
36. Popa, S., Soto-Acosta, P., Martinez-Conesa, I.: Antecedents, moderators, and outcomes of innovation climate and open innovation: an empirical study in SMEs. Technol. Forecast. Soc. Chang. **118**, 134–142 (2017)
37. Pradhan, A., Agwa-Ejon, J.: Opportunities and challenges of embracing smart factory in South Africa. In: 2018 Portland International Conference on Management of Engineering and Technology (PICMET), pp. 1–8. IEEE (2018)
38. Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A.B.L., Rajak, S.: Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: an inter-country comparative perspective. Int. J. Prod. Econ. **224**, 107546 (2020)
39. Rghioui, A., Oumnad, A.: Internet of things: visions, technologies, and areas of application. Technology **6**(7) (2017)
40. Rüßmann, M., et al.: Industry 4.0: The future of productivity and growth in manufacturing industries. Boston Consult. Group **9**(1), 54–89 (2015)
41. Santos, C.H.D., de Queiroz, J.A., Leal, F., Montevechi, J.A.B.: Use of simulation in the industry 4.0 context: creation of a digital twin to optimise decision making on non-automated process. J. Simul. **16**(3), 284–297 (2022)
42. Shamout, M., Ben-Abdallah, R., Alshurideh, M., Alzoubi, H., Kurdi, B.A., Hamadneh, S.: A conceptual model for the adoption of autonomous robots in supply chain and logistics industry. Uncertain Supply Chain Manage. **10**(2), 577–592 (2022)
43. Shvetsova, O.A., Kuzmina, A.D.: Development of engineering personnel in the era of the fourth industrial revolution. In: 2018 Third International Conference on Human Factors in Complex Technical Systems and Environments (ERGO) and Environments (ERGO), pp. 45–48. IEEE (2018)
44. Strozzi, F., Colicchia, C., Creazza, A., Noè, C.: Literature review on the 'smart factory' concept using bibliometric tools. Int. J. Prod. Res. **55**(22), 6572–6591 (2017)

45. Valdeza, A.C., Braunera, P., Schaara, A.K., Holzingerb, A., Zieflea, M.: Reducing complexity with simplicity-usability methods for industry 4.0. In: Proceedings 19th Triennial Congress of the IEA, vol. 9, p. 14 (2015)
46. Wube, H.D., Esubalew, S.Z., Weldesellasie, F.F., Debelee, T.G.: Text-based chatbot in financial sector: a systematic literature review. Data Sci. Financ. Econ. **2**(3), 232–259 (2022)
47. Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T.: Intelligent manufacturing in the context of industry 4.0: a review. Engineering **3**(5), 616–630 (2017)