Received July 21, 2021, accepted August 5, 2021, date of publication August 31, 2021, date of current version September 15, 2021.
Digital Object Identifier 10.1109/ACCESS.2021.3109338

IoT for Global Development to Achieve the United Nations Sustainable Development Goals: The New Scenario After the COVID-19 Pandemic

ASCENSIÓN LÓPEZ-VARGAS[1], AGAPITO LEDEZMA[1], (Member, IEEE), JACK BOTT[2], AND ARACELI SANCHIS[1], (Member, IEEE)
[1]Department of Computer Sciences, Control Learning and Optimization Group, University Carlos III of Madrid, Leganes, 28911 Madrid, Spain
[2]The Earth Institute, Columbia University, New York City, NY 10027, USA

Corresponding author: Ascensión López-Vargas (asuvargas@gmail.com)

This work was supported by the European Commission through Urban Innovative Actions of the EPIU Getafe Project under Grant UIA04-212. The work of Ascensión López-Vargas was supported by the University of Jaén, "Ayudas de la EDUJA para la realización de estancias para la obtención de Mención Internacional," in 2019. The work of Agapito Ledezma was supported by the Agencia Estatal de Investigación (AEI) under Grant RTI2018-096036-B-C22/AEI/10.13039/501100011033. The work of Araceli Sanchis was supported by the Agencia Estatal de Investigación (AEI) under Grant PID2019-104793RB-C31/AEI/10.13039/501100011033.

ABSTRACT COVID-19 has not affected all countries equally: developing countries have been more disadvantaged by the pandemic. Regarding global development, the COVID-19 pandemic has forced a step back in the path to attaining the Sustainable Development Goals (SDGs). The SDGs most negatively affected by the pandemic are identified here: education, health, and work. Then using the SDGs as a reference, this research explores the new challenges faced by developing countries and the impact of the Internet of Things (IoT) after COVID-19's emergence. IoT solutions carried out in developing countries during the pandemic have been identified and reviewed. Successful Internet of Things for Development (IoT4D) projects, in relation to the SDGs, are highlighted. New social and technical challenges that have emerged for the IoT4D as a consequence of the pandemic are then studied. This work concludes that the future of IoT4D in the wake of COVID-19 should focus on the use of low-cost IoT devices for the SDGs most affected by the pandemic. After an exhaustive study, the Intelligent Internet of Things (IIoT) has been determined to be a key actor in the pandemic's wake, with a leading role in the health sector. The proposed approach includes an extensive study of the new role of the IoT4D for achieving the SDGs in our forever changed world.

INDEX TERMS Internet of Things, artificial intelligence, Internet of Things for development, sustainable development goals, COVID-19, IoT4D, developing countries.

I. INTRODUCTION

COVID-19 is the most devastating pandemic so far in the 21st century: according to the European Centre for Disease Prevention and Control [1], since 31 December'19 and as of 15 July'21, 187,509,874 cases of COVID-19 have been reported in the world, including 4,043,003 deaths (in alignment with the applied regulations and testing strategies in the affected countries). The consequences of COVID-19 are immense. Not only has the healthcare sector been subjected to high pressure but the entire world economy has been massively impacted; the post-COVID-19 marketplace will be irrevocably different [2].

COVID-19 has especially affected developing countries [3], [4]. This is partly due to the absence of international support to ensure progress on the United Nations (UN) SDGs [5]. The success of the SDGs depends on two premises [6]: sustained economic growth and globalization, which the COVID-19 pandemic has torn apart. According to estimations, global growth contraction for 2020 was -3.5 percent because of the pandemic, and the expected recovery time frame is in years [7]. The UN Conference on Trade and Development's latest "Global Investment Trends Monitor" report released on 27 October'20 [8], announced that global Foreign Direct Investment (FDI) fell 49% in the first half of 2020 compared to 2019. Estimations reflect that overseas development aid could drop by 25 billion USD in 2021 [6].

The associate editor coordinating the review of this manuscript and approving it for publication was Ahmed A. Zaki Diab.

In the 17 years since SARS [9], a new digital era has emerged, and the IoT is now exhibited as a possible tool for containing new viruses such as COVID-19 within reasonable limits [10]. In 2019, before the outbreak of the pandemic, several studies with main objectives to avoid pandemics already included the use of new technologies such as IoT and AI [10]. The IoT is not only presented as a solution to avoid new pandemics, like the one we are currently experiencing, but also as an enabler of many sectors in the wake of COVID-19. So much so that, the global IoT market size is estimated to grow from USD 150 billion in 2019 to USD 243 billion by 2021 [11]. Increased demand for laptops, work-from-home monitoring devices, and smart payments that reduce personal contact, as seen in cash transactions, have fostered growth in the IoT market.

In early 2020 a work entitled "Challenges and Opportunities of the Internet of Things for Global Development to Achieve the United Nations Sustainable Development Goals" was published [12]. This work, based on literature published until 2019, focused on the challenges to successfully utilizing the IoT in developing countries. The weakness and strengths of using the IoT in the developing world to achieve the Global Goals by 2030 were highlighted. But in 2020, the COVID-19 pandemic turned the world upside down, and the scenario totally changed.

The ultimate goal of this work is to carry out an extensive study on the new situation after the global pandemic, to evaluate the new role of the IoT4D (as a complementary partial set of development policies that can improve human well-being sustainably) to achieve the SDGs, and to explain how the integration of the IoT4D in development programs could improve quality of life for the world's most vulnerable populations. Regarding the structure, Section II presents the scenario before the COVID-19 pandemic for the IoT4D to achieve the SDGs, then in Section III the impact of COVID-19 on the achievement of the UN SDGs is studied. Section IV presents the new scenario for the IoT4D after COVID-19, highlighting the challenges and potential for the application of the IoT in developing countries. The future of IoT4D in the wake of the COVID-19 pandemic is presented in Section V. The limitations of the study are discussed in Section VI. Finally, a summary of conclusions is included in Section VII.

II. IoT4D AND SDGs (BEFORE THE COVID-19 PANDEMIC)

During the UN Conference on Sustainable Development (Rio de Janeiro, 2012) the SDGs were designed and launched with the purpose of replacing the Millennium Development Goals (MDGs) to continue leading the fight against poverty beyond 2015 [13]. The SDGs have three main objectives [14]: to eradicate poverty, to protect the planet, and to ensure that all people enjoy peace and prosperity (all to be accomplished by 2030).

Before the COVID-19 pandemic, experts estimated [15] that IoT in developing countries would generate 40% of its possible value add by 2025. The World Economic Forum's IoT for Sustainable Development project aimed to encourage employment of the IoT to speed up progress on the 17 SDGs [15]. In 2018, the World Economic Forum [16] stated that around the 84% of IoT deployments addressed (or had the potential to address) SDGs. This report presented an IoT analytics database of 640+ IoT projects [15] for studying and understanding the potential of the IoT to support the SDGs achievement. It stated that 75% of the documented IoT projects were around only 5 SDGs; 25% of projects are focused on SDG9, 19% on SDG11, 19% on SDG7, 7% on SDG3, and 5% on SDG12. Based on the results, 95% of the projects could be categorized as small/medium sized and 70% of these IoT4D projects were devised by the private initiatives (80% of which originated in the Americas and Europe).

The work "Challenges and Opportunities of the Internet of Things for Global Development to Achieve the United Nations Sustainable Development Goals" [12], studied the context and identified the challenges for IoT4D to reach billions of people living in developing countries, to speed up economic growth and social development. As a result of this extensive study, the authors suggested combining cost-effective IoT and Pay-As-You-Go (PAYG) as the perfect duo to better disseminate IoT4D and achieve the SDGs. Open-Source Hardware (OSHW) platforms have been progressively used in the design of high performance and cost-effective projects. High initial costs are not required for developing these OSHW based projects, allowing for better dissemination. To combine IoT technologies, seamless digital payments, and PAYG was a pattern in the developing world that obtained excellent results. To integrate IoT systems into the requirements of developing countries employing open-source tools and novel financing models was presented as a key strategy in achieving the SDGs [12]. Now, one year later, the COVID-19 pandemic has touched each and every SDG in significant ways: the scenario has totally changed, the assumptions taken are no longer valid and the pandemic challenges the global commitment toward vision 2030 [17].

III. THE NEGATIVE IMPACT OF THE COVID-19 OUTBREAK ON THE SUCCESSFUL ACHIEVEMENT OF THE UN SDGs

The COVID-19 pandemic has caused great damage mainly to the economic and health sectors, leaving behind high economic losses and millions of deaths. The United Nations published in July 2020 the "Sustainable Development Goals Report 2020" [18] assessing progress on the 17 Goals. This report stated that COVID-19 does not affect everyone equally: the poorest and most vulnerable (children, the elderly, disabled people, immigrants, and refugees) are being the most negatively affected by the COVID-19 pandemic. In 2020, an estimated 71 million people fell into extreme poverty because of the pandemic: the first rise in global poverty since 1998 [18]. More families living in extreme poverty means that children living in poor and disadvantaged communities are at greater risk of child marriages, child labor, and child trafficking: child labor levels are expected to rise for the first time in 20 years [18]. Women are also a category disproportionately affected by the pandemic [18]. Key

TABLE 1. The most affected SDGS due to the COVID-19 pandemic according to the reviewed literature.

SDG negative affected	(18)	(19)	(5)	(20)	(6)
Goal 1 - No poverty	x		x	x	x
Goal 2 - Zero hunger	x		x	x	x
Goal 3 - Good health and well being	x	x	x	x	x
Goal 4 - Quality education	x	x	x	x	x
Goal 5 - Gender equality			x		x
Goal 6 - Clean water & sanitation			x		x
Goal 7 - Affordable & Clean Energy			x		x
Goal 8 - Decent work & economic growth	x	x	x	x	x
Goal 9 - Industry, innovation & infrastructure					x
Goal 10 - Reduced inequalities				x	x
Goal 11 - Sustainable cities & communities			x		x
Goal 12 - Responsible product & consumption					x
Goal 13 - Climate action	x		x		x
Goal 14 - Life below water					x
Goal 15 - Life on land					x
Goal 16 - Peace, justice, and strong institutions			x	x	x
Goal 17 - Partnerships for the goals			x		x

findings of these reports are focused mainly on the impact of COVID-19 on 6 SDGs: SDG1, SDG2, SDG8, SDG4, SDG3, and SDG13.

In May 2020, Gulseven *et al.* [19] studied the impact of the COVID-19 pandemic on the SDGs. According to the authors, the COVID-19 pandemic has radically transformed the current state of global development, including the achievements of the SDGs. They argued that, while the deteriorating economic conditions will negatively affect most aspects of development, some positive developments may be observed in the long term. For example, the reduction of carbon emissions due to a decrease in transportation (SDG13) and the cutback of waste due to people consuming more responsibly (SDG12). The authors point to three targets as those most affected by the pandemic: SDG3, as people are avoiding hospitals unless it is absolutely necessary to visit; SDG4, with billions of students out of school staying at home; SDG8, with millions of people expected to lose their jobs. In July 2020, Barbier and Burgess [5] studied sustainable development after the COVID-19 crisis, in alignment with the SDGs. They indicated that the pandemic is likely to adversely impact 12 of the 17 goals and identified affordable policies that could yield immediate progress, mainly towards SDG6, SDG7 and SDG13. In addition, they concluded that the weakest economies (low/middle income) will additionally suffer from the absence of international funding available for achieving the 17 SDGs, climate change mitigation and adaptation, and biodiversity conservation. In July 2020,

TABLE 2. SDGs divided by internet of things sector.

No of sector	IoT Sector	Goal
1	Health, Water and Sanitation	SDG3, SDG6
2	Agriculture and livelihoods	SDG1, SDG8, SDG2
3	Education	SDG4
4	Environment and conservation	SDG12, SDG13, SDG14, SDG15
5	Resiliency, Infrastructure and Energy	SDG7, SDG9, SDG11
6	Governance and Human Rights	SDG10, SDG16
7	Cross-cutting	SDG5, SDG17

Filho *et al.* [20] identified the SDGs most directly affected by COVID-19, where there is a pressing need for urgent action. This is the case for SDG1, SDG2, SDG3, SDG4, SDG5, SDG8, SDG10, and SDG16. In July 2020, Robin Naidoo and Brendan Fisher published a study in the Nature website entitled "Reset Sustainable Development Goals for a pandemic world" [6]. The authors studied the impact of COVID-19 using the SDGs as a reference. For classifying the impact, they used 4 levels: a) most targets are unachievable, b) to achieve some targets would have helped prevent pandemic impacts, c) some targets affected and d) to achieve target would have made pandemic impacts worse. Results showed that 66% of the total SDGs targets (169) are either under threat because of the COVID-19 pandemic or not well-placed to mitigate its impacts. Some may get worse: 10% of the SDG targets could amplify the impacts of future pandemics. All SDGs are affected by COVID-19 according to the study. The authors place SDG1 as the target most affected by the pandemic being the only target cataloged as "most targets unachievable". Table 1 summarizes the most affected SDGs due to the COVID-19 pandemic according to the literature reviewed. All reviewed studies agree that the achievement of SDG3, SDG4 and SDG8 is negatively affected by COVID-19.

IV. THE NEW SCENARIO FOR THE IoT4D AFTER COVID-19

A. NEW CONTEXT AND POTENTIAL OF THE IoT4D AFTER THE COVID-19 OUTBREAK

SDGs are often interlinked; frequently by addressing the problems of one objective issues associated with a different objective are solved. The report "Harnessing the Internet of Things for Global Development" [21] was a joint effort by the ITU and the UNESCO Broadband Commission for Sustainable Development that mapped the UN Global Goals to IoT sectors (Table 2).

In "Challenges and Opportunities of the Internet of Things for Global Development to Achieve the United Nations Sustainable Development Goals" [12] IoT Sectors 1-5 (Table 2) were used for their study because they were the five sectors with the most potential to be addressed using the IoT [16]. In addition, these five sectors included SDG2, SDG6, and SDG7, three influential goals that together form the water-energy-food nexus (an indicator very often used for measuring development) [22]. Most SDGs affected by

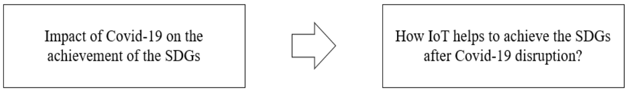

FIGURE 1. Analysis diagram for studying the IoT uses, in the developing world, followed in this work.

TABLE 3. Search results by keyword using the most popular repositories of research works (from 2020).

Keyword	Results by database			
	Google Scholar	ScienceDirect	Scopus	IEEE Xplore
Internet of things for development covid	24,800	1,669	2519	71
Internet of things for development coronavirus	19,800	754	1382	22
IoT Sustainable development Goals covid	9,620	292	202	5
IoT Sustainable development Goals coronavirus	9,620	125	102	2
IoT developing countries covid	7,990	534	356	10

the COVID-19 pandemic are included in these sectors (see Section II). Thus, to facilitate comparison, this work highlights Sectors 1-5 too (Table 2), as a reference for the analysis. The new IoT context in the developing world after the start of the COVID-19 pandemic is presented below (subsections 4.1.1. - 4.1.5.). This includes reference to profitable IoT projects in this period. Fig. 1. shows the methodology followed in this Section for studying the IoT application in developing countries.

Four databases were used for the review of the research works: Google Scholar, ScienceDirect, Scopus, and IEEE Xplore. Reports were identified by using various keywords. Table 3 shows the results of the searching process listed by keywords.

1) HEALTH, WATER AND SANITATION

The "Health, water, and sanitation" IoT sector includes two SDGs intimately linked to the COVID-19 pandemic: SDG3 ("Good health and well-being") and SDG6 ("Clean water and sanitation"). Although the studies reviewed differ on some aspects of the objectives most negatively affected by the COVID-19 pandemic (See Section III), all agree that the SDG most severely impacted by the pandemic is SDG3. The most immediate effects of the COVID-19 pandemic are evident in health centers, representing a threat to SDG3 [20]. In many countries, health centers such as hospitals have reached capacity, becoming unable to provide medical care to all people. In addition, people who need medical care try to avoid going to medical centers for fear of being infected by the virus. The lack of equipment and infrastructure in weak health systems means that the level of mortality may be high. According to the UN "Sustainable Development Goals Report 2020" [18] women and children are among the most affected by COVID-19. Disruption of health and vaccination services as well as limited access to diet and nutrition resources have the potential to generate hundreds of thousands of additional deaths in children under the age of 5 and tens of thousands of unexpected maternal deaths in 2020. Childhood vaccination services have not been spared from the ravages of the COVID-19 pandemic: about 70 countries reported moderate to severe disruptions, even the total suspension of this service during March and April of 2020 [18]. In many countries, there has been an increase in reports of domestic violence against women and children [18]. The COVID-19 pandemic has demonstrated that sanitation, adequate access to clean water, and hygiene (SDG6) is vital for avoiding the spread of diseases. The lack of safe access to sanitation and clean water makes developing countries extremely vulnerable to pandemic events. With some exceptions, the COVID-19 outbreak is expected to slow down investments in the water sector worldwide [23].

In April'20, the World Bank's Board approved an initial 25 projects to help countries respond to the coronavirus and shorten the time to recovery. This financing is intended to provide medical personnel and patients with access to water and sanitation at health centers. To fight infectious diseases, it is essential to ensure that health facilities have a supply of clean water and soap. In addition, having clean and well-maintained protective equipment allows for safe medical care and protects the well-being of medical staff. More than half of the health centers in the Democratic Republic of the Congo lack access to clean water and basic sanitation. More than one billion slum dwellers are vulnerable to the negative effects of the pandemic. Risks are aggravated by a lack of adequate housing, the absence of running water in the home, or shared toilets which can increase the spread of the virus. The absence of waste management systems, overcrowded public transport, and limited access to formal health care facilities also increases the risk of infection [18].

The application of the IoT in the health sector allows for remote monitoring in personal healthcare, medical device integration, and even the treatments of diseases, amongst other applications that move us closer to attaining SDG3. Table 4 includes a review of published works that use the IoT for fighting epidemic outbreaks in developing countries (2015-2020). The principal application for IoT technology to help achieve SDG3 after the COVID-19 pandemic is for controlling similar events. The detection of symptoms as well as the monitoring of patients are main uses of the IoT in this area [25]–[29], [37]. IoT can also be used for detecting and controlling mosquito-borne diseases. In the case of COVID-19, the examples found are focused on enforcing social distancing and real time monitoring of infected patients [34]–[36] (for ensuring quarantine time in many cases). There are several wireless standards on the market, usually operating in different frequency bands, and with differing communication protocols,

TABLE 4. Review of projects that apply the IoT on epidemic issues.

YEAR	AUTHOR	TITLE	TECHNOLOGIES	COMMUNICATIONS	APPLICATION DOMAIN	COUNTRY	DISEASE
2015	Sandhu et al. (24)	An intelligent system for predicting and preventing MERS-CoV infection outbreak	IoT/ Cloud computing	Mobile communications	Prediction of infected patients and control of the outbreaks	NF*	MERS-CoV
2016	S. Sareen et al. (25)	IoT-based cloud framework to control Ebola virus outbreak.	IoT/ Cloud computing	Bluetooth/ Wi-Fi	Detection and monitoring of infected patients	NF*	Ebola
2017	Lakshmi and Karthik (26)	Dengue Identification and Patient Care Monitoring Using Internet of Medical Things.	IoT/ Cloud computing (Rpi*)	Wi-Fi	Detection of early symptoms and monitoring of patients	India	Dengue
2017	S. Sareen et al. (27)	An intelligent and secure system for predicting and preventing Zika virus outbreak using Fog Computing.	IoT/ Fog computing	Wi-Fi / 4G	Monitoring and detection	India	Zika
2017	S. Sareen et al. (28)	Secure Internet of Things-based cloud framework to control Zika virus outbreak	IoT/ Cloud based system	4G	Detecting and controlling	India	Zika
2017	S. K. Sood et al. (29)	Wearable IoT sensor-based healthcare system for identifying and controlling chikungunya virus.	IoT/ Fog computing	Wireless	Detecting and controlling	India	Chikungunya
2017	S. Sood and I. Mahajan (30)	Fog-Cloud Based Cyber-Physical System for Distinguishing, Detecting and Preventing Mosquito Borne Diseases.	IoT/ Fog computing	RFID	Differentiating, diagnosing, and preventing MBDs	NF*	Mosquito Borne Diseases
2018	J.B. Kangbai et al (31)	Tracking Ebola through cellphone, internet of things and Blockchain Technology	IoT/Blockchain	RFID	Contact tracing, transmission pattern surveillance and vaccine delivery	Democratic Republic of Congo	Ebola
2018	N.H Hassan et al. (32)	Proposed Conceptual Iot-Based Patient Monitoring Sensor for Predicting and Controlling Dengue	IoT/ Cloud computing	ZigBee, Wi-Fi and Bluetooth	Predicting and controlling outbreak	Malaysia	Dengue
2020	Fatima Syyada Abeer et al (33)	IoT enabled Smart Monitoring of Coronavirus empowered with Fuzzy Inference System	IoT/ Cloud computing	Wireless	Monitoring and prediction	NF*	COVID-19
2020	Li Bai et al. (34)	Chinese experts' consensus on the Internet of Things-aided diagnosis and treatment of coronavirus disease 2019 (COVID-19)	IoT/ Cloud computing	5G	Epidemic prevention and control	China	COVID-19
2020	V. K. Singh et al. (35)	IoT-Q-Band: A low-cost internet of things based wearable band to detect and track absconding COVID-19 quarantine subjects	IoT/ Cloud computing	WiFi/LTE/GPRS	Detection of the absconding quarantine subjects in real-time	India	COVID-19
2020	M.Gupta et al. (36)	Enabling and Enforcing Social Distancing Measures using Smart City and ITS Infrastructures: A COVID-19 Use Case	IoT/Artificial Intelligence	LTE, Wi-Fi, 5G or Dedicated Short Range Communication (DSRC)	Enabling and enforcing social distancing	NF*	COVID-19
2020	M. N. Mohammed et al. (37)	Toward a novel design for coronavirus detection and diagnosis system using IoT based drone technology	IoT/Drones (*Arduino)	GSM	Detection and diagnosis	NF*	COVID-19

NOTE: NF* is Not Found

so the selection of the most suitable connectivity technology for an IoT system can be challenging. IoT wireless technologies, especially mobile communications technologies [24], [27], [28], [34]–[37], have been widely used for fighting pandemic events. The IoT is utilized by combining other technologies; the most popular technologies are cloud and fog computing [24]–[26], [28], [32]–[35]. Some of the reviewed projects also use OSHW [26], [37].

2) AGRICULTURE AND LIVELIHOODS

The "Agriculture and Livelihoods" IoT sector includes three Global Goals adversely affected by COVID-19: SDG1 ("No poverty"), SDG2 ("Zero hunger"), and SDG8 ("Decent work & economic growth"). The UN "Sustainable Development Goals Report 2020" [18] estimated that 71 million people were expected to fall into extreme poverty in 2020 (the first rise in global poverty since 1998). A total increase of 150 million is expected by 2021 [38], directly affecting the achievement of the SDG1 [39]. The World Bank's "Poverty and Shared Prosperity 2020" report [40] has identified the three problems that are affecting world poverty most severely today and that threaten to continue to do so in the future: COVID-19, armed conflict, and climate change. This report estimated that, in 2020, between 88 million and 115 million people could fall back into extreme poverty because of the pandemic, with an additional increase of 23-35 million in 2021, potentially bringing the total number of new people living in extreme poverty to between 110 and 150 million. Figure 2 shows the global extreme poverty estimates before-after the COVID-19 pandemic. After the COVID-19 pandemic, lost incomes, limited social protection, and rising prices could change the situation of those who were previously secure. Now they could find themselves at risk of poverty and hunger [18]. The 2020 edition of "The Global Report on Food Crises" [41] describes the scale of acute hunger in the world. It is a study of the impact of COVID-19 on different aspects of life, such as health and nutrition, food availability or food access, estimating that 135 million people in 55 countries currently face acute hunger. The "UN World Food Programme" [42] has just doubled the estimated number of people who are likely to face critical food shortages this year, to 265 million, impairing the achievement of the SDG2. Regarding SDG8, the increase of underemployment and unemployment because of the COVID-19 crisis means some 1.6 billion already vulnerable workers in the informal or gig economy –around the half of the total workforce worldwide– may be significantly affected. Their incomes are estimated to have fallen by 60 percent in the first month of the crisis [18]. The COVID-19 pandemic has also positively affected the gig economy: the number of average daily tasks/jobs posted has increased since the start of the COVID-19 outbreak [43].

The IoT could play a key role in avoiding this new "hunger pandemic" [44], giving support for ensuring food safety, food security and reducing losses and waste of food [45]. The "United Nations World Food Programme" [42] has put out an urgent call to action for improving data analytics to avoid hunger and poverty. Collaborators in humanitarian and development projects must come together to address existing problems with data collection systems, establish data analysis standards in places where they are non-existent, and commit to additional data collection efforts in countries where there is limited data or consistent divergences in data interpretation. All types of food supply chains have been severely affected during the COVID-19 pandemic [46]. In 2020, Yadav *et al.* [47] identified the Agri-Food Supply chain as one of the weak points during the COVID-19 outbreak in India. They modelled a sustainable Agri-Food Supply Chain managed with different emerging IoT technologies (Blockchain, Robotics, Big data analysis, and Cloud computing). The consequences of COVID-19 on the food production chain are enormous. The "Internet of Food & Farm 2020" (IoF2020) project [48] explores the potential for IoT technologies in the

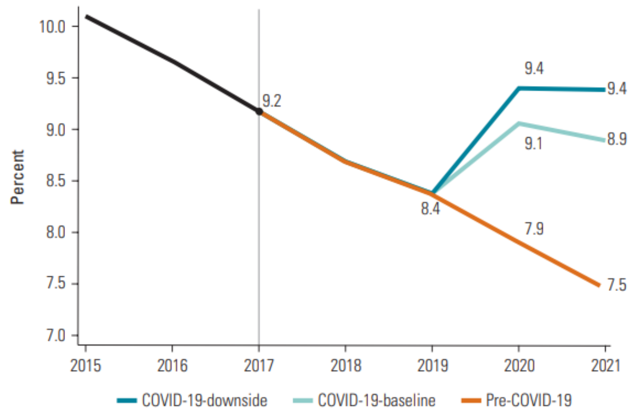

FIGURE 2. Impact of COVID-19 on Global extreme poverty: Poverty rate (%). Extreme poverty was measured as the number of people living with less than $1.90 per day. Note: There are three growth scenarios: [1] the pre-COVID-19 scenario using the January 2020 global economic prospects growth rate projections, before the COVID-19 crisis; [2] the COVID-19-downside scenario and [3] the COVID19-baseline using the June 2020 global economic prospects growth rates which project a contraction in global growth for 2020 of 8 percent and 5 percent, respectively. Source: World bank [40].

European food and farming industry. IoF2020 use Case 3.4, Intelligent Fruit Logistics, was created to fight against various COVID-19 related challenges. First, seasonal workers were unable to support harvest activities because of border closures and the travel restrictions. Crops could not be harvested so they remained on the land much longer than usual, increasing food waste. Second, difficulties arose in transporting crops: many truck drivers were in COVID high risk groups and were unable to work. The driver shortage affected delivery times and transport capacity was reduced. Third, customer demands changed [49]: when the lockdown started the demand for non-perishable products increased [50].

3) EDUCATION

The COVID-19 pandemic caused the largest disruption of education systems in history, affecting around 1.6 billion students in more than 190 countries and every continent [51]. The closure of schools and educational centers has impacted 94% of the students in the world, up to 99% of whom are located in low and lower-middle income countries [51]. In 2020, 370 million children missed out on school meals they depend on. Lack of access to computers and the internet at home means that education is out of reach for many students who before the COVID-19 pandemic were in school [52]. Before the onset of COVID-19, between 2015 and 2020, the cumulative financing needed to achieve SDG4 by 2030 in developing countries remained unchanged. Now, the annual financing needed to attain SDG4 by 2030 has increased from 340 billion USD to 504 billion USD [53].

The IoT offers unique opportunities for the education system, helping students to attend courses without being physically present, avoiding the spread of COVID-19. The IoT provides more and more information for students to access,

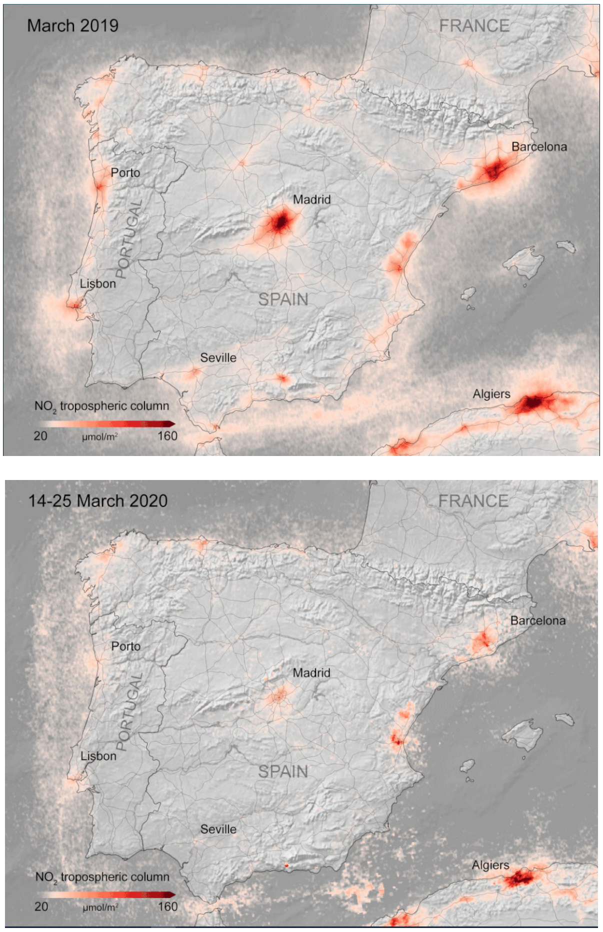

FIGURE 3. Average nitrogen dioxide concentrations in Spain from 14 to 25 March 2020 (Spanish lockdown) compared to the monthly average concentrations from 2019. Data captured by Copernicus Sentinel-5P satellite [58].

anytime and anywhere. The IoT for education applications is segmented as Learning Management Systems, Administration Management, Surveillance, and Other. The Learning Management area is expected to grow at a fast rate as IoT in Education is helping students by making learning easier and more effective [54]. The GSMA Report "Education for All in the Time of COVID-19: How EdTech can be Part of the Solution" [55] presented the use of EdTech as a solution for education after the COVID disruption (focusing on developing countries). In Lebanon, "The International School of Innovation" [56] has smart school infrastructure that includes sensors and cameras to enhance learning and the overall school experience. The IoT was used for a) finding patterns that affect student performance in specific subjects, b) providing learning analytics, including a learning objectives matrix for underperforming students and c) emotion detection and monitoring. Happiness can be tracked throughout the day as students attend different subjects.

4) ENVIRONMENT AND CONSERVATION

The "Environment and conservation" IoT sector includes four SDGs: SDG12 ("Responsible product & consumption"), SDG13 ("Climate action"), SDG14 ("Life below water"), and SDG15 ("Life on land"). The UN Conference on Trade and Development [57] estimates that the COVID-19 pandemic lockdowns around the globe have led to a dramatic 5% drop in greenhouse gas emissions. Figure 3 shows the average nitrogen dioxide concentrations from 14 to 25 March 2020 (coinciding with the total Spanish lockdown) compared to the monthly average concentrations from 2019, using data from the Copernicus Sentinel-5P satellite [58]. Not all measures to stem the pandemic have had a positive impact on the environment. In 2020, Zambrano-Monserrate *et al.* [59] studied the effects of COVID-19 on the environment (both, positive and negative) and concluded that the increased waste and the reduction of recycling are negative consequences of COVID-19. Due to quarantine policies, consumers have increased their demand for online shopping and home delivery, increasing organic waste generated by households as well as inorganic waste (shipping materials). Medical waste is also on the rise. Streets, beaches, and oceans have been hit by COVID-19 waste: plastic face masks, gloves, and hand sanitizer bottles [60]. In Wuhan (China), hospitals generated six times as much medical waste, at the peak of the outbreak, an average of 240 metric tons of medical waste per day, as they did before the crisis began [61]. Also, although there is no evidence on the survival of COVID-19 in drinking water or wastewater [62], the treatment plants of several countries have strengthened their disinfection routines (mainly by increasing chlorine additives) to prevent COVID-19 from spreading through wastewater [63].

Various initiatives based on the IoT have emerged to mitigate the effects of COVID-19 on the environment, mainly in the area of waste management. In 2020, Indian Scientists at the Sree Chitra Tirunal Institute for Medical Sciences and Technology (SCTIMST) Trivandrum, developed a novel disinfection gateway and a UV-based facemask disposal bin to fight COVID-19 [64]. The disposal device, called BIN-19, for collecting and disinfecting used facemasks was subjected to a series of successful microbiological tests to evaluate its efficiency. To avoid spread of the virus, China used the IoT for COVID-19 waste management in Wuhan, making processes automatic and using the minimum number of workers for infectious waste handling. This was realized through IoT technologies, including internet enabled sensing equipment, locating systems, scanning devices, and video surveillance tools [65].

5) RESILIENCY, INFRASTRUCTURE AND ENERGY

The "Resiliency, Infrastructure and Energy" IoT sector is linked to the following SDGs: SDG7 ("Affordable & Clean Energy"), SDG9 ("Industry, Innovation & Infrastructure"), and SDG11 ("Sustainable Cities & Commun ities"). The COVID-19 pandemic has spotlighted the need for reliable and affordable electricity (SDG7). It is required for hospital and health facilities to treat patients, for communities to pump clean water, for access to vital information, and for out-of-school children to learn remotely [18]. Manufacturing jobs are a vital source of income and are key for reducing poverty in developing regions; the effects of the COVID-19 outbreak have been highly destabilizing to industry, threatening to halt and even to reverse progress towards SDG9 [18]. The COVID-19 pandemic has highlighted the importance of increased investment in R&D, mainly in the pharmaceutical industry and in emerging technologies such as artificial intelligence or the IoT. COVID-19 has impacted business, speeding up the remote working revolution [66]. Over 90% of COVID-19 cases have occurred in urban areas so SDG11 has been hard impacted [67]. For many cities, the COVID-19 pandemic has expanded to a crisis of several aspects: urban access, urban equity, urban finance, safety, joblessness, public services, infrastructure, and transport; all of which are disproportionately affecting the most vulnerable in society [68].

After the COVID-19 pandemic, one of the main applications of the IoT sector is around smart cities. Cities will emerge from the pandemic, but how prepared for the next crisis they are will depend on how much they promote inclusive and sustainable urban development projects based on data [18]. In 2020, Costa and Peixoto [69] identified several smart cities initiatives to face new outbreaks. There are a lot of examples of using the IoT for maintaining social distancing [70]. In several countries, drones with loudspeakers were used for reminding people to stay at home [71] and for thermal imaging purposes. In 2020, De Vito *et al.* [72] deployed high-resolution air quality monitoring multisensor devices for mitigating new pandemic events by following the correlation of COVID-19 pandemic outbursts and air pollution levels. Automatic human body temperature sensing machines have been installed in many countries. Cameras are integrated with temperature sensors and send real time information to a central server [73]. Regarding energy, experts stated that COVID-19 has created an immediate need for remote, perpetual electricity grid monitoring [74]. Innovative projects such as EPIU Getafe [75] use IoT for attaining smart cities objectives, ensuring affordable energy for all. The monitoring of critical parameters in a remote way limits physical contact, avoiding new disease transmission. The IoT has a key role in industry, by integrating IoT devices into the supply chain in manufacturing plants teams can remotely access information, monitor, and manage the performance of their assets without being physically present [76].

B. CHALLENGES OF THE IoT4D IN THE WAKE OF THE COVID-19 PANDEMIC

In 2020, before the COVID-19 pandemic, [12] identified the challenges for the IoT4D to achieve the SDGs by 2030 (Table 5). The authors grouped challenges into 5 different categories: technical aspects, environmental conditions, social differences, policy, and financial conditions. These challenges remain and some of them have worsened. New challenges have emerged because of the effects of the COVID-19 pandemic. The following sections comprise new challenges identified for IoT4D that have surfaced as a consequence of the COVID-19 pandemic.

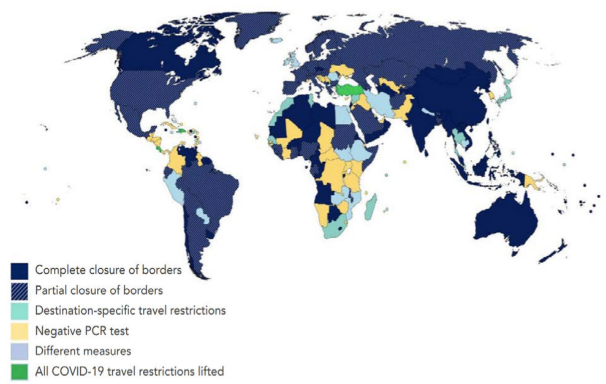

FIGURE 4. Destinations with travel restrictions as of 1 November 2020. Source: United nations world tourism organization [78].

1) POOR PEOPLE WITH NEW PROFILE

The World Bank's Report ''Poverty and Shared Prosperity '' [40] analyzed data from the Global Monitoring Database [77] showing how the COVID-19 pandemic is changing the profile of people living in poverty; the new poor who may have emerged as a result of the COVID-19 pandemic differ in ways that are important for policy. According to this report, much of the new poor will live in countries that are already struggling with high rates of poverty, but middle-income countries are expected to also be significantly affected, having more than 75% of the total new poor. As it was mentioned in Table 5, before COVID-19 large portions of the extreme poor were rural. However, there is a high probability that people who fall into poverty by COVID-19 live in highly populated urban environments that favor the transmission of the virus. Many of the new poor work in construction or factories, sectors that are severely affected by mobility restrictions and lockdowns caused by the pandemic.

2) TRAVELLING RESTRICTIONS

In 2020, international tourism will revert to levels seen 30 years ago as an effect of the COVID-19 pandemic [78]. According to the ''8th Travel Restrictions Report'' of the United Nations World Tourism Organization (UNWTO) [79] published in December'20, 118 destinations (54% of the total destinations worldwide) have completely or partially closed their borders due to the COVID-19 pandemic (1st November 2020). Figure 4 shows the distribution of destinations with travel restrictions. Travel restrictions are not only affecting tourism, but they are also impacting the delivery of humanitarian assistance [80], impeding the development of humanitarian works, and delaying cooperation projects.

3) DECREASE OF FINANCING FOR DEVELOPMENT

The United Nations' Report, ''Financing for Development in the Era of COVID-19 and Beyond'' [81] forecasts the decrease of financial flows by up to 45% in developing economies due to the COVID-19 pandemic. This threatens years of advancement made towards the achievement of the

TABLE 5. Challenges of the IoT in developing countries identified before COVID-19 outbreak.

Category	Challenge	Details
Technical	Design requirements	The design requirements of the IoT applications for developing countries commonly have different requirements and technological frameworks.
	Lack of research	Low publications rate in peer-reviewed journals.
	Simple and cost-effective technology	Solutions may prove more suitable in a developing country context.
	Lack of modern infrastructure	Lack of local cloud computing infrastructure.
	Internet connectivity	
	Power supply	-
	Lacking local IoT expertise	Availability of reliable power supplies.
Environmental conditions	Harsh environmental conditions.	-
Social differences	Rural-urban differences.	-
Policy	Security and privacy	There are enormous differences between rural and urban areas in the developing world with the 85% of poor people living in rural areas.
	Absence of standards	Need of including security in the design of the IoT projects.
	Government regulations	Developments with no standardization sometimes results as designed products that operate in disruptive ways on the Internet
Financial conditions	Lack of financial systems	Government regulations to protect data access and use increase the consumers trust in the IoT devices.

SDGs, including poverty descent, salary equality, nutrition, health improvements, and literacy rate progress.

4) SOCIAL ACCEPTANCE AND SECURITY DATA

In 2020, Ndiaye *et al.* [70] concluded that there is a need for social acceptance and security in data sharing for IoT management systems in the wake of COVID-19. A clear example: governments around the world have developed tracing applications for reducing and controlling the spread of COVID-19 based on the IoT. Although published studies support the use of tracing applications as an effective weapon in the fight against COVID-19 [82], the reality is that these types of smartphone applications are not being well accepted by society. Fears over privacy and the security of their data, resulted in download percentages of only 10% - 20% in many countries [83].

5) DATA INNOVATION

The UN SDGs Report [18] focuses on the importance of timely, quality, open, disaggregated data, and statistics as a key piece for fighting the COVID-19 crisis. Investments in data and innovation are essential to responding to the crisis and supporting SDG acceleration, and for the IoT expansion as well.

6) DIGITAL INFRASTRUCTURE

According to the World Bank, after the COVID-19 pandemic, the primary challenge facing the IoT is to integrate and streamline digital infrastructure at various stages of the public health response, especially in epidemic forecasting and decision-making areas [84]. The closure of workplaces as well as home quarantines has led to a spike in the usage of telecommunication networks with an increase in the use of the internet by approximately 30% [85]. During March and April, decreases in broadband speed were identified because of reflecting peaks in Internet access combined with changes in behavior and traffic flow. This was particularly evident and more intense in countries such as Ecuador, Chile, Morocco, South Africa, and Turkey (where the quality of broadband network is lower) [86]. Experts consider that the overall increase in traffic will become a fixture of the future [85].

7) 5G DEPLOYMENT

The post COVID-19 era has two main actors: the IoT and 5G. Their application in areas such as telehealth, contact tracing and self-isolation, online education, retail and supply chains, smart manufacturing and factory automation, e-government and media, and e-tourism and entertainment offer solutions for combating the pandemic. However, the lack of widely available 5G communication networks imposes a limitation for the rapid adoption of proposed technologies [87]. Figure 5 shows the global distribution of 5G deployments/investments in 2020; Sub-Saharan Africa, East-middle Asia and Latin America are the areas with a lower 5G deployment.

8) WORRIES ABOUT 5G TECHNOLOGY

The 5G network is required for the full expansion of the IoT. It promotes cellular operations, related to the security of the IoT and reduces network challenges [89]. During the COVID-19 pandemic false claims linking 5G to COVID-19 have been widely shared online. Prestigious institutions such as the International Telecommunications Union (ITU) and the Global System for Mobile Communications Association (GSMA) have been forced to issue official letters making clear that such claims linking 5G technology and the

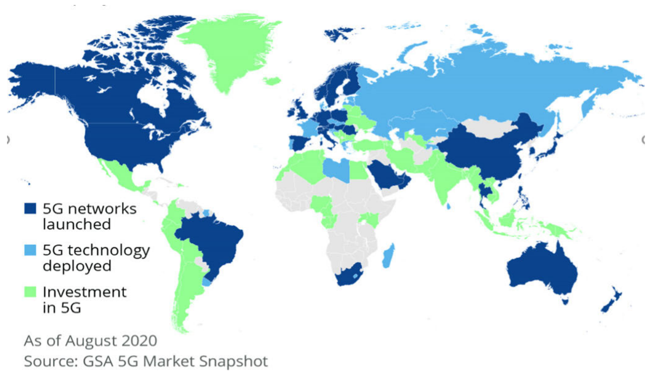

FIGURE 5. **Countries where 5G has been deployed and where investments have been made. As of August 2020. Source: [88].**

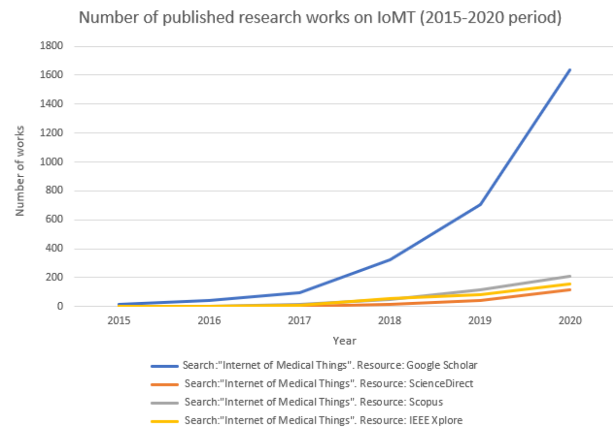

FIGURE 6. **Number of research works published in the last 5 years related to the "Internet of Medical Things" area using different scientific databases.**

spread of COVID-19 have no scientific basis whatsoever [90]. However, 5G-COVID-19 conspiracies have animated anti-vaccination, anti-5G protests, and acts of vandalism that have occurred during the pandemic [91]. Even impeding the installation and repair of mobile antennas due to the fear of 5G in rural areas of developing countries [92].

9) EDUCATION GAP

COVID-19 has revealed the need for the digital transformation of education [93]. The digital education gap is higher in the developing world: computer and mobile phone access opportunities are more limited in developing countries [94]. Students from underprivileged families do not all have laptops and smartphones, so policies should pay attention to this issue providing the technological tools required for studying; in addition, governments should ensure that the internet is available in remote areas, in order to reach remote populations for the learning process [95].

10) INTERNET WASTE

The dependence on ICT infrastructure and connectivity has been spotlighted by the COVID-19 pandemic and overall numbers of demand and use have increased. The massive expansion of the IoT has caused collateral damage to environment due to infrastructure equipment, such as energy consumption from production and use, carbon emissions from power supply equipment, water consumption for cooling systems, waste from electrical and electronic equipment, and raw material scarcity [96]. In developing countries, challenges for facing Internet Waste are higher than in industrialized countries, because of the lack of infrastructure for appropriate waste management, the absence of legislation dealing specifically with this new type of waste, and the absence of any framework for end-of-life product take-back or implementation of extended manufacturer responsibility [97].

V. THE FUTURE OF THE IoT4D IN THE COVID-19 PANDEMIC ERA

After studying the new scenario after the onset of COVID-19 and challenges for applying IoT in developing countries, the future of IoT4D is applying low-cost IoT on the most affected SDGs including those in IoT Sectors 1, 2, and 3 (See Section 4.1.). On the other hand, after the COVID-19 pandemic another application of the IoT4D, the Intelligent Internet of Things, has emerged as a key actor in the pandemic wake, especially in Sector 1 which includes pharmaceutical research.

A. IoT4D PROJECTS ON THE MOST AFFECTED SDGs BY THE COVID-19

As the SDGs most affected by the COVID-19 pandemic are the SDG3, SDG4, and SDG8, the promotion of the IoT4D focused on Sectors 1-3 (defined in Section IV.A.) could be the best solution to face the worst effects of the COVID-19 pandemic on the UN SDGs. Since the beginning of the pandemic the application of the IoT to Sector 1 has been a trend. In 2020, the development of applications focused on the Internet of Medical Things was multiplied. Figure 6 shows the number of research works published in the last 5 years related to the "Internet of Medical Things" area using different scientific databases. Upgraded wearable technology, combining Artificial Intelligence (AI) and IoT for Healthcare or Making Health Services More Accessible have been identified as promising research and development directions for healthcare IoT in the aftermath of the COVID-19 pandemic [98].

Along this line, several initiatives are applying the IoT on Sector 2 (Education) in the wake of COVID-19. In 2020, at the onset of the COVID-19 outbreak, UNESCO launched an international multi-sector partnership called The Global Education Coalition (GEC) [99] to meet the urgent and unprecedented need for continuity of learning as the pandemic disrupted education systems across the world [100]. The Global Education Coalition was committed to equity and inclusion in access to quality education and lifelong learning for all, in line with the SDG4, integrating IoT as a key actor into its strategic planning. The coalition has prioritized Africa in its operations and at present 22 countries are benefiting from a wide range of support and actions such as setting up online learning platforms and developing teachers' capacities in Senegal, reinforcing TV and radio programmes in the Democratic Republic of Congo, or digitizing curricula in Ghana. Another example: in the Arab States region, the coalition is operating in 8 countries producing online education resources in Lebanon, supporting distance learning in Palestine, and offering digital skills training in Morocco. The IoT is a key piece in several initiatives promoted by GEC. Regarding the IoT Sector 3, with every industry affected by COVID-19, the number of potential effective applications designed to specific business areas is rising, and the IoT is leading this tech race. The main business segments that can reap most benefits from IoT systems in this time have been identified: Healthcare, Agriculture and Retail [101].

B. LOW COST IoT

The use of open-source SW/HW for designing IoT solutions reduces technology costs considerably allowing the installation of modern technology in unprivileged areas. During the last few years, the use of this type of technology in developing countries has been a trend and open HW platforms have been included in the design of precise low-cost IoT systems. The integration of these technologies also could be an optimal solution for fighting COVID-19 and encourage collaboration on the achievement of the SDGs in COVID-19's wake, while facing the lack of financing for development projects. Table 6 shows a literature review of low-cost IoT4D projects developed after COVID-19 disruption linked to SDGs.

In 2020, Tendolkar and Ramya [118] presented ''CareBro'', a solution for managing remotely an entire farm without requiring physical presence. The authors developed a solution that is always in touch with the farmer and, thought the cloud, provide monitoring in real time and decision making. The solution improves the productivity performance of farms, providing data for keeping plants safe, support in their productive growth and suggest improvements. CareBro was developed around Arduino and Node MCU microcontrollers. The connected sensors linked with the farm wide IoT network send data via the cloud all the way to the farmer's cell phone. In 2020, de Medeiros and Girão [106] presented the development of a device for accurately measuring the concentrations of the Particulate Material (PM2.5 and PM10), O3, C0, NO2, and NO3 by means of three sensors: PMSA003, MICS-6814, and MQ-131. The device was equipped with an ESP-WROOM-32 microcontroller that had Wi-Fi and Bluetooth wireless interfaces for sending data to a server in the cloud. In the IoT4D projects reviewed, the objective of low-cost hardware was achieved using Open Source HW. According to the literature review included in Table 6, the most popular platforms were ESP32 [122], Node MCU [123] and Arduino [124]. A key aspect of the IoT4D deployments is the communication technology. Most of the reviewed projects used Wi-Fi [102]–[104], [108], [109], [111]–[115], [117]–[121] for transmitting data. LoRa has emerged as the second alternative, for transmitting data, used in the reviewed works. Of the 20 works reviewed, 15 proposals were classified within the IoT Sector 1 [102], [103], [105]–[115], [119], [121]; 13 works aligned with the SDG3 [102], [103], [105]–[115]. Southern Asia was identified as the region with the most IoT4D projects based on low-cost technology deployed in the wake of COVID-19. A new a relevant aspect of the reviewed IoT4D works is the latest trend of deploying IoT in tandem with other technologies such as Blockchain or Artificial Intelligence to curb the spread of COVID-19; the integration of AI+IoT was the most popular combination [103], [107], [109]–[111], [117], [119], creating a new IoT application with a bright future: the Intelligent Internet of Things.

C. THE INTELLIGENT IoT

The Intelligent Internet of Things is the result of combining the Internet of Things and Artificial Intelligence. After the COVID-19 outbreak, the IIoT has so far grown in significance [125], [126]. As identified in Section IV, data innovation is essential in responding to the COVID-19 crisis and the IIoT helps to overcome new challenges by transforming data into smart data, wherein useful information could be obtained by applying cost-effective and new data processing methodologies [125]. The main expansion of this new combination of technologies is taking place in the medical area after the COVID-19 pandemic [127]. IIoT is employed for monitoring [128] and detecting [129] COVID-19 cases as well as for diagnosis [130], [131]; medical data analysis [132] is another key application of the IIoT for reducing time in data analysis (avoiding virus expansion). Table 7 comprises the IoT4D projects using the low-cost technology reviewed that included AI techniques (more than half of all projects reviewed are aligned to SDG3). In 2021, Mariammal *et al.* [119] proposed a system based on the IoT which included neural networks for prediction. It included various embedded sensors for measuring conductivity, pH, turbidity, and color. The measured sensor values were stored in the database and further directed for prediction analysis. The resulting neural network algorithm was used for forecasting the quality result. The system alerted the user when any of the measured parameters were less than defined fixed thresholds. In 2021, Biswas *et al.* [109] proposed an IoT based device for detecting the subsistence of COVID-19 based on a certain framework of body components. The presence of coronavirus was detected by measuring an individual's body temperature with the help of temperature sensors. RQ or respiratory quotient was used as another determining principle to detect coronavirus. Blood samples were also analyzed. Data was transmitted using Wi-Fi. The body parameters collected from the subject were compared with the data of normal non-infected humans using an Artificial Neural Network algorithm. Of the 6 works reviewed, Artificial Neural Network was the most used technique [109]–[111], [119], followed by Support Vector Machines [110], [111], [117].

TABLE 6. Projects based on low-cost IoT for development in the COVID-19 era.

Title	Low-cost IoT	Communications	Goal	Sector	Country	Combining Technology
Smart epidemic tunnel: IoT-based sensor-fusion assistive technology for COVID-19 disinfection (102)	Node MCU	Wi-Fi	SDG3	1 Health, Water and Sanitation	India	-
IoT-based System for COVID-19 Indoor Safety Monitoring (103)	Arduino, ESP8266, Raspberry	Wi-Fi	SDG3	1 Health, Water and Sanitation	NF	AI
Development of educational kit for IoT online learning (104)	Arduino WEMOS D1 ESP8266 /Thingspeak	Wi-Fi	SDG4	3 Education	Malaysia	-
IoT as an Alternative Way to Improve the Telemedicine Methods Against COVID-19 in Vulnerable Zones (105)	ESP 32	LoRa	SDG3	1 Health, Water and Sanitation	Ecuador	-
An IoT-based Air Quality Monitoring Platform (106)	ESP-WROOM-32	ESP32 Bluetooth	SDG3	1 Health, Water and Sanitation	Brazil	-
Role of IoT to avoid spreading of COVID-19 (107)	Node MCU	NF*	SDG3	1 Health, Water and Sanitation	China	AI
A home hospitalization system based on the Internet of things, Fog computing and cloud computing (108)	Node MCU/ Arduino	Wi-Fi	SDG3	1 Health, Water and Sanitation	Tunisia	-
IoT Based Scanner For Corona Detection (109)	Arduino and Node MCU	Wi-Fi /4G GSM GPRS	SDG3	1 Health, Water and Sanitation	India	AI
An Intelligent and Energy-Efficient Wireless Body Area Network to Control Coronavirus Outbreak (110)	Arduino	LoRa	SDG3	1 Health, Water and Sanitation	NF*	AI
Internet of Things (IoT) Based Indoor Air Quality Sensing and Predictive Analytic—A COVID-19 Perspective (111)	ATmega328P Node MCU	Wi-Fi	SDG3	1 Health, Water and Sanitation	Pakistan	AI
Monitoring Air Quality of Dhaka using IoT: Effects of COVID-19 (112)	ESP32	Wi-Fi	SDG3	1 Health, Water and Sanitation	Bangladesh	-
Internet of Things versus Covid-19: Integrated Low-Cost Proposal for Oximetry Collection and Data Availability in Cloud for Strategic Management of Population in Isolation (113)	ESP32	Wi-Fi	SDG3	1 Health, Water and Sanitation	Brazil	-
Affordable Medical Ventilators providing Wireless Monitoring based on Internet of Things Technology in the Light of COVID-19 (114)	ESP32	Wi-Fi	SDG3	1 Health, Water and Sanitation	NF*	-
Suraksha: Low-Cost Device to Maintain Social Distancing during CoVID-19 (115)	Node MCU	Wi-Fi	SDG3	1 Health, Water and Sanitation	India	-
Development of Integrated IoT Trainer (LRioT) for Practical Work in Electrical Engineering Education Program Amid Pandemic (116)	ESP32	LoRa	SDG4	3 Education	Indonesia	-
A Novel IoT Enabled System for detection of Infected Leaf for Smart Agricultural (117)	ESP32	Wi-Fi	SDG2	2 Agriculture and livelihoods	China	AI
CareBro (Personal Farm Assistant):An IoT based Smart Agriculture with Edge Computing (118)	Node MCU Arduino Uno Thingspeak	Wi-Fi	SDG2	2 Agriculture and livelihoods	India	-
Efficient IOT based Water Quality Prediction Using Cat Swarm Optimized Neural Network classification (119)	Arduino	Wi-Fi	SDG6	1 Health, Water and Sanitation	India	AI
Adapting Internet of Things to Arduino-Based Devices for Low-Cost Remote Sensing in School Science Learning Environments (120)	Arduino UNO	Wi-Fi module ESP-01S	SDG4	3 Education	Korea	-
Smart Shoe Sanitizing Device (121)	Node MCU	Wi-Fi	SDG6	1 Health, Water and Sanitation	India	-

NOTE: NF* is Not Found

VI. DISCUSSION

The role of the IoT and its contribution in developing countries as a part of development programs has been discussed extensively. In 2021, Dalal [133] carried out a study on the role of the IoT as a driving force for sustainable development. In this research, around 300 online surveys among the IoT industry experts, researchers, faculty members and educationists working in IoT area, were done. The 84%

TABLE 7. **IIoT projects using low-cost technology reviewed.**

IoT4D Project	Goal	Sector	AI Algorithm
IoT-based System for COVID-19 Indoor Safety Monitoring (103)	SDG3	1- Health, Water and Sanitation	Haar Cascade Classifier
IoT Based Scanner For Corona Detection (109)	SDG3	1- Health, Water and Sanitation	Artificial Neural Network
An Intelligent and Energy-Efficient Wireless Body Area Network to Control Coronavirus Outbreak (110)	SDG3	1- Health, Water and Sanitation	Random Forest, Logistic Regression, Naive Bayes, Support Vector Machines and Artificial Neural Network
Internet of Things (IoT) Based Indoor Air Quality Sensing and Predictive Analytic—A COVID-19 Perspective (111)	SDG3	1- Health, Water and Sanitation	Support Vector Machines, K-Nearest Neighbors, Naive Bayes, Artificial Neural Network
A Novel IoT Enabled System for detection of Infected Leaf for Smart Agricultural (117)	SDG2	2 - Agriculture and livelihoods	Support Vector Machines
Efficient IOT based Water Quality Prediction Using Cat Swarm Optimized Neural Network classification (119)	SDG6	1- Health, Water and Sanitation	Artificial Neural Network

of respondents concluded that IoT can play an enormous and phenomenal role in achieving the SDGs. On the other side, 96% were agree that IoT applications is essential and indispensable to achieve the target of sustainable growth, but this is only possible if global/national and regional efforts are streamlined to accomplish sustainable development. Islam *et al.* [134] found that IoT technologies do not address all the problems of SDGs in developing countries; they concluded that the achievement of the SDGs also requires (in addition to IoT applications deployment) equitable legislation, regulatory outlines, and financial enablers. The IoT can make a difference in the achievement of the SDGs [135] but only if it is accompanied by adequate legislation, investment, education, and the modernization of the technological infrastructure. Two main limitations have been found carrying out this work. First, the lack of data and information on IoT4D projects in developing countries makes it difficult to find specific details such as the number of people impacted by the IoT4D solutions, or the results achieved. In addition to this limitation, due to the recent appearance of COVID-19 in December 2019 [136], many of the IoT4D projects developed for facing the pandemic are in an initial stage and there are no post-implantation studies published. Reference [134] studied the relationship between the IoT and SDGs but they considered the 17 SDGs as a single group. Other works studied the relationship between IoT and sustainability focused on an specific SDG [47]. The presented work aimed to conduct the study in depth on the IoT4D application for achieving each SDG in the wake of the COVID-19. SDGs were grouped by IoT sector (see Section IV). 2 IoT sectors were left outside this study [4] SDGs): the Governance and Human Rights sector (SDG10 and SDG16) and the Cross-cutting sector (SDG5 and SDG17).

VII. CONCLUSION

COVID-19 is the most devastating pandemic so far of this century and the developing world is highly vulnerable to the outbreaks of COVID-19 because of the lack of international support to ensure progress towards SDGs of the United Nations. Progress towards the SDGs is now threatened by the consequences of the COVID-19 pandemic. All SDGs have been affected by COVID-19; after an exhaustive literature revision, the reviewed studies agreed that SDG3, SDG4 and SDG8 were the most negatively affected by COVID-19. The potential of IoT in the developing world for fighting against COVID-19 is to make an even greater and more significant impact than in industrialized countries. New challenges have emerged because of COVID-19. On the one hand, new social challenges have been identified: there is a new profile of poor population, countries have reduced their financial support for development, travel restrictions have affected millions of trips and citizens are worried about the 5G deployment and the security of IoT data. On the other hand, often, technical challenges such as the lack of digital infrastructure impedes the fast deployment of IoT4D projects. The future of IoT4D in the wake of the COVID-19 is presented by applying low-cost IoT on the most affected SDGs: education, health, and work. OSHW platforms have been integrated into the design of high performance and low-cost IoT systems for fighting against the COVID-19 pandemic in the developing world. Another application of the IoT4D, the Intelligent Internet of Things which applies IoT jointly with Artificial Intelligence, has emerged as a key actor in the pandemic wake, especially in the health sector.

REFERENCES

[1] European Centre for Disease Prevention and Control Website. Accessed: Jul. 21, 2021. [Online]. Available: https://www.ecdc.europa.eu/en
[2] N. Donthu and A. Gustafsson, "Effects of COVID-19 on business and research," *J. Bus. Res.*, vol. 117, pp. 284–289, Sep. 2020.
[3] A. Sumner, C. Hoy, and E. Ortiz-Juarez, *Estimates of the Impact of COVID-19 on Global Poverty*. Tokyo, Japan: United Nations Univ., 2020.
[4] F. Ahmed, N. Ahmed, C. Pissarides, and J. Stiglitz, "Why inequality could spread COVID-19," *Lancet Public Health*, vol. 5, no. 5, p. e240, 2020, doi: 10.1016/S2468-2667(20)30085-2.
[5] E. B. Barbier and J. C. Burgess, "Sustainability and development after COVID-19," *World Develop.*, vol. 135, Nov. 2020 Art. no. 105082, doi: 10.1016/j.worlddev.2020.105082.
[6] *Reset Sustainable Development Goals for a Pandemic World*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.nature.com/articles/d41586-020-01999-x
[7] *COVID-19 to Plunge Global Economy Into Worst Recession Since World War II*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.worldbank.org/en/news/press-release/2020/06/08/covid-19-to-plunge-global-economy-into-worst-recession-since-world-war-ii

[8] Accessed: Jul. 21, 2021. [Online]. Available: https://unctad.org/system/files/official-document/diaeiainf2020d4_en.pdf
[9] World Health Organization Website, SARS Topic. Accessed: Jul. 21, 2021. [Online]. Available: https://www.who.int/topics/sars/es/
[10] Strategy. *Global Influenza*. Accessed: Jul. 21, 2021. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/311184/9789241515320-eng.pdf?ua=1
[11] *Covid-19 Impact on Internet of Things (IoT) Market*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/covid-19-impact-on-iot-market-212332561.html
[12] A. Làpez-Vargas, M. Fuentes, and M. Vivar, "Challenges and opportunities of the Internet of Things for global development to achieve the united nations sustainable development goals," *IEEE Access*, vol. 8, pp. 37202–37213, 2020.
[13] J. A. Leggett. (2012). *Rio+20: The United Nations Conference on Sustainable Development*. Accessed: Feb. 5, 2020. [Online]. Available: https://www.fas.org/sgp/crs/row/R42573.pdf
[14] *United Nations Development Programme Website*. Accessed: Feb. 5, 2020. [Online]. Available: https://www.undp.org/content/undp/en/home/sustainable-development-goals.html
[15] World Economic Forum Website. *IoT for Sustainable Development Project*. Accessed: Feb. 2, 2020. [Online]. Available: https://widgets.weforum.org/iot4d/
[16] World Economic Forum Website. *Internet of Things: Guidelines for Sustainability*. Accessed: Feb. 9, 2020. [Online]. Available: https://www3.weforum.org/docs/IoTGuidelinesforSustainability.pdf
[17] H. S. Rifai, "The sustainable development goals in a bioremediation journal context: What a difference a year makes in a post COVID-19 world!" *Bioremed. J.*, vol. 24, nos. 2–3, pp. 91–94, 2020, doi: 10.1080/10889868.2020.1761066.
[18] (2020). *The SDG Report*. [Online]. Available: https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf
[19] O. Gulseven, F. A. Harmoodi, M, A. Falasi, and I. ALshomali. *How the COVID-19 Pandemic Will Affect the UN Sustainable Development Goals*. Accessed: May 4, 2020. [Online]. Available: https://ssrn.com/abstract=3592933
[20] W. L. Filho, L. L. Brandli, A. L. Salvia, L. Rayman-Bacchus, and J. Platje, "COVID-19 and the UN sustainable development goals: Threat to solidarity or an opportunity?" *Sustainability*, vol. 12, no. 13, p. 5343, 2020, doi: 10.3390/su12135343.
[21] *Harnessing-IoT-Global-Development*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.itu.int/en/action/broadband/Documents/Harnessing-IoT-Global-Development.pdf
[22] E. M. Biggs, E. Bruce, B. Boruff, J. M. A. Duncan, J. Horsley, N. Pauli, K. McNeill, A. Neef, F. van Ogtrop, J. Curnow, B. Haworth, S. Duce, and Y. Imanari, "Sustainable development and the water–energy–food nexus: A perspective on livelihoods," *Environ. Sci. Policy*, vol. 54, pp. 389–397, Dec. 2018.
[23] *The Impact of COVID-19 on the Water and Sanitation Sector*. Accessed: Sep. 7, 2021. [Online]. Available: https://www.ifc.org/wps/wcm/connect/126b1a18-23d9-46f3-beb7-047c20885bf6/The+Impact+of+COVID_Water%26Sanitation_final_web.pdf?MOD=AJPERES&CVID=ncaG-hA
[24] R. Sandhu, S. K. Sood, and G. Kaur, "An intelligent system for predicting and preventing MERS-CoV infection outbreak," *J. Supercomput.*, vol. 72, no. 8, pp. 3033–3056, 2016, doi: 10.1007/s11227-015-1474-0.
[25] S. Sareen, S. K. Sood, and S. K. Gupta, "IoT-based cloud framework to control Ebola virus outbreak," *J. Ambient Intell. Hum. Comput.*, vol. 9, pp. 459–476, Oct. 2018.
[26] K. S. Lakshmi and S. Karthik, "Dengue identification and patient care monitoring using internet of medical things," *J. Health Inform. Manage.* vol. 1, p. 2, Oct. 2012.
[27] S. Sareen, S. K. Gupta, and S. K. Sood, "An intelligent and secure system for predicting and preventing Zika virus outbreak using fog computing," *Enterprise Inf. Syst.*, vol. 11, pp. 1436–1456, Jan. 2017, doi: 10.1080/17517575.2016.1277558.
[28] S. Sareen, S. K. Sood, and S. K. Gupta, "Secure Internet of Things-based cloud framework to control Zika virus outbreak," *Int. J. Technol. Assess Health Care*, vol. 33, no. 1, pp. 11–18, Jan. 2017 doi: 10.1017/S0266462317000113.
[29] S. K. Sood and I. Mahajan, "Wearable IoT sensor based healthcare system for identifying and controlling chikungunya virus," *Comput. Ind.*, vol. 91, pp. 33–44, Oct. 2017.
[30] S. K. Sood and I. Mahajan, "Fog-cloud based cyber-physical system for distinguishing, detecting and preventing mosquito borne diseases," *Future Gener. Comput. Syst.*, vol. 88, pp. 764–775, Nov. 2018.
[31] J. B. Kangbai, S. L. Mandoh, and A. B. Fofanah, "Tracking Ebola through cellphone, Internet of Things and blockchain technology," *Current Res., Integr. Med.*, vol. 1, no. 12, pp. 13–15, 2018.
[32] N. Hassan, E. Salwana, S. Drus, N. Maarop, N. Narayana, and A. Ganthan, "Proposed conceptual IoT-based patient monitoring sensor for predicting and controlling dengue," *Int. J. Grid Distrib.*, vol. 11, no. 4, pp. 127–134, 2018.
[33] S. A. Fatima, N. Hussain, A. Balouch, I. Rustam, M. Saleem, and M. Asif, "IoT enabled smart monitoring of coronavirus empowered with fuzzy inference system," *Int. J. Adv. Res., Ideas Innov. Technol.*, vol. 6, pp. 188–194, 2020.
[34] L. Bai, D. Yang, X. Wang, L. Tong, X. Zhu, N. Zhong, C. Bai, C. A. Powell, and R. Chen, "Chinese experts' consensus on the Internet of Things-aided diagnosis and treatment of coronavirus disease 2019 (COVID-19)," *Clin. e-Health*, vol. 3, pp. 7–15, Jan. 2020.
[35] V. Singh, H. Chandna, A. Kumar, S. Kumar, N. Upadhyay, and K. Utkarsh, "IoT-Q-band: A low cost Internet of Things based wearable band to detect and track absconding COVID-19 quarantine subjects," *EAI Endorsed Trans. Internet Things*, vol. 6, no. 12, pp. 1–9, Jun. 2020.
[36] M. Gupta, M. Abdelsalam, and S. Mittal, "Enabling and enforcing social distancing measures using smart city and its infrastructures: A COVID-19 use case," 2020, *arXiv:2004.09246*. [Online]. Available: https://arxiv.org/abs/2004.09246
[37] M. Mohammed, N. Hazairin, S. Al-Zubaidi, S. Ak, S. Mustapha, and E. Yusuf, "Toward a novel design for coronavirus detection and diagnosis system using IoT based drone technology," *Int. J. Psychosocial Rehabil.*, vol. 24, no. 7, pp. 2287–2295, Jan. 2020.
[38] (2021). *COVID-19 to Add as Many as 150 Million Extreme Poor*. [Online]. Available: https://www.worldbank.org/en/news/press-release/2020/10/07/covid-19-to-add-as-many-as-150-million-extreme-poor-by-2021
[39] *The Impact of COVID-19 on Global Extreme Poverty*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.brookings.edu/blog/future-development/2020/10/21/the-impact-of-covid-19-on-global-extreme-poverty/#:~:text=Compared%20to%202019%2C%20poverty%20
[40] (2020). *Poverty and Shared Prosperity*. Accessed: Jul. 21, 2021. [Online]. Available: https://openknowledge.worldbank.org/bitstream/handle/10986/34496/9781464816024.pdf
[41] *The Global Report on Food Crises*. Accessed: Jul. 21, 2021 [Online]. Available: https://dss-prod-017575727556.s3.amazonaws.com/0/0/0/GRFC_2020_ONLINE_200420.pdf
[42] UN World Food Programme Website. Accessed: Jul. 21, 2021. [Online]. Available: https://es.wfp.org/
[43] M. Umar, Y. Xu, and S. S. Mirza, "The impact of COVID-19 on Gig economy," *Econ. Res.-Ekonomska Istraživanja*, vol. 34, no. 1, pp. 2284–2296, Dec. 2020, doi: 10.1080/1331677X.2020.1862688.
[44] (2020). *World on the Brink of a 'Hunger Pandemic': Coronavirus Threatens to Push Millions Into Starvation*. [Online]. Available: https://www.oxfam.org/en/world-brink-hunger-pandemic-coronavirus-threatens-push-millions-starvation
[45] G. M. Galanakis, "'The food systems in the era of the coronavirus (COVID-19) pandemic crisis," *Foods*, vol. 9, p. 523, Apr. 2020.
[46] D. Ivanov and A. Dolgui, "A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0," *Prod. Planning Control*, vol. 32, pp. 775–788, May 2020, doi: 10.1080/09537287.2020.1768450.
[47] S. Yadav, S. Luthra, and D. Garg, "Modelling Internet of Things (IoT)-driven global sustainability in multi-tier agri-food supply chain under natural epidemic outbreaks," *Environ. Sci. Pollution Res.*, vol. 28, no. 13, pp. 1663–16654, Apr. 2020, doi: 10.21203/rs.3.rs-84820/v1.
[48] (2020). *Nternet Of Food & Farm*. [Online]. Available: https://www.iof2020.eu/
[49] T. Ben Hassen, H. El Bilali, and M. S. Allahyari, "Impact of COVID-19 on food behavior and consumption in Qatar," *Sustainability*, vol. 12, p. 6973, Jan. 2020, doi: 10.3390/su12176973.
[50] *Smart Food Trays Have Become Even More Important During the COVID-19 Pandemic*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.iof2020.eu/covid-19/2020/smart-food-trays
[51] *Policy Brief: Education During COVID-19 and Beyond*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2020/08/sg_policy_brief_covid-19_and_education_august_2020.pdf
[52] UNICEF Data Website. *Education and COVID-19*. Accessed: Jul. 21, 2021. [Online]. Available: https://data.unicef.org/topic/education/covid-19/
[53] *Policy Paper*. Accessed: Jul. 21, 2021. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000374163

[54] "Global IoT in education market size by hardware, by solution, by service, by application, by end-user industry, by geographic scope and forecast," Elect. Verified Market Res., Tech. Rep. 6547, Jan. 2021, p. 202. Accessed: Sep. 7, 2021. [Online]. Available: https://www.verifiedmarketresearch.com/product/global-iot-in-education-market-size-and-forecast-to-2026/
[55] *Education for All in the Time of COVID-19: How Ed-Tech Can be Part of the Solution*. Accessed: Sep. 7, 2021. [Online]. Available: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2020/09/Education-For-All-in-the-Time-of-COVID-19-How-EdTech-can-be-Part-of-the-Solution.pdf
[56] Innovation International School Website. Accessed: Jul. 21, 2021. [Online]. Available: http://www.innovation-schools.com/
[57] Accessed: Jul. 21, 2021. [Online]. Available: https://unctad.org/
[58] European Space Agency Website. *Nitrogen Dioxide Concentrations Over Spain*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.esa.int/ESA_Multimedia/Images/2020/03/Nitrogen_dioxide_concentrations_over_Spain
[59] M. A. Zambrano-Monserrate, M. A. Ruano, and L. Sanchez-Alcalde, "Indirect effects of COVID-19 on the environment," *Sci. Total Environ.*, vol. 728, Aug. 2020, Art. no. 138813.
[60] *Growing Plastic Pollution in Wake of COVID-19: How Trade Policy Can Help*. Accessed: Jul. 21, 2021. [Online]. Available: https://unctad.org/news/growing-plastic-pollution-wake-covid-19-how-trade-policy-can-help
[61] *The COVID-19 Pandemic is Generating Tons of Medical Waste*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.theverge.com/2020/3/26/21194647/the-covid-19-pandemic-is-generating-tons-of-medical-waste
[62] *Water, Sanitation, Hygiene, and Waste Management for SARS-CoV-2, Virus That Causes COVID-19*. Accessed: Sep. 7, 2021. [Online]. Available: https://www.who.int/publications/i/item/WHO-2019-nCoV-IPC-WASH-2020.4
[63] F. García-Ávila, L. Valdiviezo-Gonzales, M. Cadme-Galabay, and H. Gutiírrez-Ortega, and L. Altamirano-Cárdenas, "Considerations on water quality and the use of chlorine in times of SARS-CoV-2 (COVID-19) pandemic in the community," *Case Stud. Chem. Environ. Eng.*, vol. 2, Sep. 2020, Art. no. 100049.
[64] Open Gov Asia Website. *Kerala, India Launches IoT-Based Mask Disposal Smart Bin*. Accessed: Jul. 21, 2021. [Online]. Available: https://opengovasia.com/kerala-india-launches-iot-based-mask-disposal-smart-bin/
[65] *COVID-19 Waste Management: Effective and Successful Measures in Wuhan, China*. Accessed: Sep. 7, 2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7383137/pdf/main.pdf
[66] News Letter Webisite. *Covid and the Remote Working Revolution: The End of the Office?* Accessed: Jul. 21, 2021. [Online]. Available: https://www.newsletter.co.uk/health/coronavirus/covid-and-remote-working-revolution-end-office-2966441
[67] United Nations Human Settlements Programme (UN-Habitat). *Opinion: COVID-19 Demonstrates Urgent Need for Cities to Prepare for Pandemics*. Accessed: Jun. 15, 2020. [Online]. Available: https://unhabitat.org/opinion-covid-19-demonstrates-urgent-need-for-cities-to-prepare-for
[68] *Policy Brief: COVID-19 in an Urban World*. Accessed: Jul. 21, 2021. [Online]. Available: https://reliefweb.int/sites/reliefweb.int/files/resources/COVIDANDCITIES.pdf
[69] D. Costa and J. Peixoto, "COVID-19 pandemic: A review of smart cities initiatives to face new outbreaks," *IET Smart Cities*, vol. 2, pp. 64–73, Aug. 2020, doi: 10.1049/iet-smc.2020.0044.
[70] M. Ndiaye, S. S. Oyewobi, A. M. Abu-Mahfouz, G. P. Hancke, A. M. Kurien, and K. Djouani, "IoT in the wake of COVID-19: A survey on contributions, challenges and evolution," *IEEE Access*, vol. 8, pp. 186821–186839, 2020, doi: 10.1109/ACCESS.2020.3030090.
[71] Insider Website. *Spain's Police are Flying Drones With Speakers Around Public Places to Warn Citizens on Coronavirus Lockdown to Get Inside*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.businessinsider.com/spanish-police-using-drones-to-ask-people-stay-at-home-2020-3
[72] S. De Vito, E. Esposito, G. D'Elia, A. Del Giudice, G. Fattoruso, S. Ferlito, P. D'Auria, F. Intini, G. Di Francia, and E. Terzini, "High resolution air quality monitoring with IoT intelligent multisensor devices during COVID-19 pandemic phase 2 in Italy," in *Proc. AEIT Int. Annu. Conf. (AEIT)*, Catania, Italy, Sep. 2020, pp. 1–6, doi: 10.23919/AEIT50178.2020.9241144.
[73] M. Kamal, A. Aljohani, and E. Alanazi, "IoT meets COVID-19: Status, challenges, and opportunities," 2020, *arXiv:2007.12268*. [Online]. Available: https://arxiv.org/abs/2007.12268
[74] Intrado Website. *COVID-19 Spawns Remote Electric Grid Monitoring*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.globenewswire.com/news-release/2020/03/30/2008267/0/en/COVID-19-SPAWNS-REMOTE-ELECTRIC-GRID-MONITORING.html
[75] Accessed: Jul. 21, 2021. [Online]. Available: https://hogaressaludables.getafe.es/
[76] Accessed: Jul. 21, 2021. [Online]. Available: https://iotbusinessnews.com/2020/06/23/52494-the-role-of-iot-in-the-remote-work-revolution/
[77] Accessed: Jul. 21, 2021. [Online]. Available: https://www.worldbank.org/en/topic/poverty/brief/global-database-of-shared-prosperity
[78] UN World Tourism Organization Website. *COVID-19 and Tourism*. Accessed: Jul. 21, 2021. [Online]. Available: https://webunwto.s3.eu-west-1.amazonaws.com/s3fs-public/2020-12/2020_Year_in_Review_0.pdf
[79] *COVID-19 Related Travel Restrictions a Global Review for Tourism*. Accessed: Sep. 7, 2021. [Online]. Available: https://webunwto.s3.eu-west-1.amazonaws.com/s3fs-public/2020-12/201202-Travel-Restrictions.pdf
[80] *COVID-19 in Developing Countries: Multilateral Cooperation is Vital*. Accessed: Jul. 21, 2021. [Online]. Available: https://ideas4development.org/en/covid-19-developping-countries-vital-multilateral-cooperation/
[81] *Financing for Development in the Era of COVID-19 and Beyond*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.un.org/sites/un2.un.org/files/part_ii-_detailed_menu_of_options_financing_for_development_covid19.pdf
[82] A. Barrat, C. Cattuto, M. Kivel, S. Lehmann, and J. Saramáki, "Effect of manual and digital contact tracing on COVID-19 outbreaks: A study on empirical contact data," *J. Roy. Soc. Interface*, vol. 18, no. 178, pp. 1–11, May 2020, doi: 10.1098/rsif.2020.1000.
[83] ElDiario Website. Accessed: Jul. 21, 2021. [Online]. Available: https://www.eldiario.es/tecnologia/descargas-logrando-apps-rastreo-covid-europa_1_6303188.html
[84] World Economic Forum Website. *How Digital Infrastructure Can Help us Through the COVID-19 Crisis*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.weforum.org/agenda/2020/04/digital-infrastructure-public-health-crisis-covid-19/
[85] *Economic Impact of COVID-19 on Digital Infrastructure*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.itu.int/en/myitu/Publications/2020/10/16/08/59/Economic-impact-of-COVID-19-on-digital-infrastructure
[86] R. L. Katz, F. Callorda, J. Martin, and C. Juan, "Digitization mitigate COVID-19 damages? Evidence from developing countries," May 2020. [Online]. Available: https://ssrn.com/abstract=3600829
[87] Y. Siriwardhana, C. De Alwis, G. Gür, M. Ylianttila, and M. Liyanage, "The fight against the COVID-19 pandemic with 5G technologies," *IEEE Eng. Manag. Rev.*, vol. 48, no. 3, pp. 72–84, Sep. 2020, doi: 10.1109/EMR.2020.3017451.
[88] Global mobile Suppliers Association Website. Accessed: Jul. 21, 2021. [Online]. Available: https://gsacom.com/
[89] S. Li, L. D. Xu, and S. Zhao, "5G Internet of Things: A survey," *J. Ind. Inf. Integr.*, vol. 10, pp. 1–9, Oct. 2018.
[90] ITU Website. Accessed: Jul. 21, 2021. [Online]. Available: https://www.itu.int/en/Pages/COVID-19/5g-covid-19-statement.aspx
[91] J. Meese, J. Frith, and R. Wilken, "COVID-19, 5G conspiracies and infrastructural futures," *Media Int. Australia*, vol. 177, no. 1, pp. 30–46, 2020, doi: 10.1177/1329878X20952165.
[92] BBC Website. Accessed: Jul. 21, 2021. [Online]. Available: https://www.bbc.com/news/world-latin-america-53021239
[93] *The Digital Transformation of Education: Connecting Schools, Empowering Learners*. Accessed: Jul. 21, 2021. [Online]. Available: https://www.itu.int/en/myitu/Publications/2020/10/16/08/37/The-digital-transformation-of-education
[94] J. Lopez-Sintas, G. Lamberti, and J. Sukphan, "The social structuring of the digital gap in a developing country. The impact of computer and internet access opportunities on internet use in Thailand," *Technol. Soc.*, vol. 63, Nov. 2020, Art. no. 101433.
[95] D. C. Darma, Z. Ilmi, S. Darma, and Y. Syaharuddin, "COVID-19 and its impact on education: Challenges from industry 4.0," *Aquademia*, vol. 4, no. 2, Jul. 2020, Art. no. ep20025, doi: 10.29333/aquademia/8453.
[96] Internet Waste, ITU White Report. Accessed: Jul. 21, 2021. [Online]. Available: https://www.itu.int/en/ITU-D/Environment/Documents/Publications/2020/Internet-Waste%202020.pdf?csf=1&e=iQq5Zi

[97] O. Osibanjo and I. C. Nnorom, "The challenge of electronic waste (e-waste) management in developing countries," *Waste Manage. Res.*, vol. 25, no. 6, pp. 489–501, Dec. 2007, doi: 110.1177/0734242X07082028.
[98] A. H. M. Aman, W. H. Hassan, S. Sameen, Z. S. Attarbashi, M. Alizadeh, and L. A. Latiff, "IoMT amid COVID-19 pandemic: Application, architecture, technology, and security," *J. Netw. Comput. Appl.*, vol. 2020, Nov. 2021, Art. no. 102886, doi: 10.1016/j.jnca.2020.102886.
[99] Global Education Coalition Website. Accessed: Jul. 21, 2021. [Online]. Available: https://globaleducationcoalition.unesco.org/
[100] *Responding to COVID-19 and Beyond, the Global Education Coalition in Action*. Accessed: Sep. 7, 2021. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000374364
[101] Softengi Website. *IoT Solutions in the Post-COVID World*. Accessed: Sep. 7, 2021. [Online]. Available: https://softengi.com/blog/iot-in-the-time-of-covid-19/
[102] S. Pandya, A. Sur, and K. Kotecha, "Smart epidemic tunnel: IoT-based sensor-fusion assistive technology for COVID-19 disinfection," *Int. J. Pervasive Comput. Commun.*, 2020, doi: 10.1108/IJPCC-07-2020-0091.
[103] N. Petrović and D. Kocić, "IoT-based system for COVID-19 indoor safety monitoring," ICETRAN, 2020, pp. 1–6.
[104] N. A. Rahman, M. R. Idris, and K. S. Baharudin, "Development of educational kit for IoT online learning," *Int. J. Technol., Innov. Hum.*, vol. 1, no. 1, pp. 26–32, 2020, doi: 10.29210/881001.
[105] L. Pozo-Guzman and J. Berrezueta-Guzman, "IoT as an alternative way to improve the telemedicine methods against COVID-19 in vulnerable zones," in *Information and Communication Technologies*, vol. 1307, G. R. Morales, C. E. R. Fonseca, J. P. Salgado, P. Pérez-Gosende, M. O. Cordero, and S. Berrezueta, Eds. Commun. Comput. Inf. Sci., 2020, pp. 64–76.
[106] H. P. L. De Medeiros and G. Girão, "An IoT-based air quality monitoring platform," in *Proc. IEEE Int. Smart Cities Conf. (ISC)*, Piscataway, NJ, USA, Sep. 2020, pp. 1–6, doi: 10.1109/ISC251055.2020.9239070.
[107] K. Kumar, N. Kumar, and R. Shah, "Role of IoT to avoid spreading of COVID-19," *Int. J. Intell. Netw.*, vol. 1, pp. 32–35, Jan. 2020 .
[108] H. B. Hassen, N. Ayari, and B. Hamdi, "A home hospitalization system based on the Internet of Things, fog computing and cloud computing," *Inform. Med. Unlocked*, vol. 20, Jan. 2020, Art. no. 100368.
[109] P. Biswas, K. Ganguly, and S. Chatterjee, "IoT based scanner for corona detection," *J. Phys., Conf.*, vol. 1797, Feb. 2021, Art. no. 012022.
[110] N. Bilandi, H. K. Verma, and R. Dhir, "An intelligent and energy-efficient wireless body area network to control coronavirus outbreak," *Arab. J. Sci. Eng.*, vol. 2021, pp. 1–20, Feb. 2021.
[111] R. Mumtaz, S. M. H. Zaidi, M. Z. Shakir, U. Shafi, M. M. Malik, A. Haque, S. Mumtaz, and S. A. R. Zaidi, "Internet of Things (IoT) based indoor air quality sensing and predictive analytic—A COVID-19 perspective," *Electronics*, vol. 10, p. 184, 2021, doi: 10.3390/electronics10020184.
[112] R. Saha, S. N. M. A. Hoque, M. M. R. Manu, and A. Hoque, "Monitoring air quality of Dhaka using IoT: Effects of COVID-19," in *Proc. 2nd Int. Conf. Robot., Elect. Signal Process. Techn. (ICREST)*, DHAKA, Bangladesh, Jan. 2021, pp. 715–721.
[113] L. G. V. Fernandez, R. T. Gonçalves, J. C. dos Santos, T. C. P. Moreira, J. F. P. Nery, L. M. de Carvalho, and F. H. B. de Souza, "Internet of Things versus COVID-19: Integrated low-cost proposal for oximetry collection and data availability in cloud for strategic management of population in isolation," in *Proc. 3rd Int. Conf.*, Mar. 2021, pp. 1–11.
[114] H. Unke and M. Reinhard, "Affordable medical ventilators providing wireless monitoring based on Internet of Things technology in the light of COVID-19," 2020. [Online]. Available: https://www.researchgate.net/publication/340092010_Affordable_Medical_Ventilators_providing_Wireless_Monitoring_based_on_Internet_of_Things_Technology_in_the_Light_of_COVID-19
[115] S. Raghav, G. Vijay, P. S. Harika, A. V. Rao, A. Gopinath, N. B. S. Shibu, and G. Gayathri, "Suraksha: Low cost device to maintain social distancing during CoVID-19," in *Proc. 4th Int. Conf. Electron., Commun. Aerosp. Technol. (ICECA)*, Coimbatore, India, Nov. 2020, pp. 1476–1480, doi: 10.1109/ICECA49313.2020.9297503.
[116] T. P. Nugraha, R. Pratama, D. Wahyudin, and Y. Somantri, "Development of integrated IoT trainer (LRioT) for practical work in electrical engineering education program amid pandemic," in *Proc. 6th UPI Int. Conf. TVET*, Feb. 2021, pp. 244–247, doi: 10.2991/assehr.k.210203.126.
[117] A. Shukla and R. Miri, "A novel IoT enabled system for detection of infected leaf for smart agricultural," *J. Univ. Shanghai Sci. Technol.*, vol. 23, no. 2, p. 249, Feb. 2021, doi: 10.51201/jusst12612.
[118] A. Tendolkar and S. Ramya, "CareBro (personal farm assistant): An IoT based smart agriculture with edge computing," in *Proc. 3rd Int. Conf. Multimedia Process., Commun. Inf. Technol. (MPCIT)*, Shivamogga, India, Dec. 2020, p. 9.
[119] M. G. Mariammal, "Efficient IOT based water quality prediction using cat swarm optimized neural network classification," *Psychol. Educ. J.*, vol. 58, no. 1, pp. 4279–4282, 2021.
[120] S. Ga, H. J. Cha, and C. J. Kim, "Adapting Internet of Things to arduino-based devices for low-cost remote sensing in school science learning environments," *Int. J. Online Biomed. Eng.*, vol. 2021, pp. 4–18, Feb. 2021.
[121] P. K. Bhunia, P. Mondal, P. Biswas, and S. Chatterjee, "Smart shoe sanitizing device," *J. Phys., Conf.*, vol. 1797, Feb. 2021, Art. no. 012021.
[122] Espressif Website. Accessed: Jul. 21, 2021. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf
[123] NodeMcu Website. Accessed: Jul. 21, 2021. [Online]. Available: https://www.nodemcu.com/index_en.html
[124] Arduino Website. Accessed: Jul. 21, 2021. [Online]. Available: https://www.arduino.cc/
[125] V. Jahmunah, V. K. Sudarshan, S. L. Oh, R. Gururajan, R. Gururajan, X. Zhou, X. Tao, O. Faust, E. J. Ciaccio, K. H. Ng, and U. R. Acharya, "Future IoT tools for COVID-19 contact tracing and prediction: A review of the state-of-the-science," *Int. J. Imag. Syst. Technol.*, vol. 31, no. 2, pp. 455–471, 2021
[126] R. Scott, M. Poliak, J. Vrbka, and E. Nica, "COVID-19 response and recovery in smart sustainable city governance and management: Data-driven Internet of Things systems and machine learning-based analytics," *Geopolitics, History Int. Relations*, vol. 12, no. 2, pp. 16–22, 2020.
[127] H. Lin, S. Garg, J. Hu, X. Wang, M. J. Piran, and M. S. Hossain, "Privacy-enhanced data fusion for COVID-19 applications in intelligent Internet of Medical Things," *IEEE Internet Things J.*, early access, Oct. 22, 2020, doi: 10.1109/JIOT.2020.3033129.
[128] N. Sharma, M. Mangla, S. N. Mohanty, D. Gupta, P. Tiwari, M. Shorfuzzaman, and M. Rawashdeh, "A smart ontology-based IoT framework for remote patient monitoring and COVID-19 detection using 1D biomedical signals," *Biomed. Signal Process. Control*, vol. 68, Jul. 2021, Art. no. 102717.
[129] R. Mukherjee, A. Kundu, I. Mukherjee, D. Gupta, P. Tiwari, A. Khanna, and M. Shorfuzzaman, "IoT-cloud based healthcare model for COVID-19 detection: An enhanced K-nearest Neighbour classifier based approach," *Computing*, vol. 2021, pp. 1–21, Apr. 2021.
[130] K. H. Abdulkareem, M. A. Mohammed, A. Salim, M. Arif, O. Geman, D. Gupta, and A. Khanna, "Realizing an effective COVID-19 diagnosis system based on machine learning and IOT in smart hospital environment," *IEEE Internet Things J.*, early access, Jan. 11, 2021, doi: 10.1109/JIOT.2021.3050775.
[131] D. N. Le, V. S. Parvathy, D. Gupta, A. Khanna, J. J. P. C. Rodrigues, and K. Shankar, "IoT enabled depthwise separable convolution neural network with deep support vector machine for COVID-19 diagnosis and classification," *Int. J. Mach. Learn. Cybern.*, vol. 2021, pp. 1–14, Jan. 2021.
[132] R. Patan, G. S. P. Ghantasala, R. Sekaran, D. Gupta, and M. Ramachandran, "Smart healthcare and quality of service in IoT using grey filter convolutional based cyber physical system," *Sustain. Cities Soc.*, vol. 59, Aug. 2020, Art. no. 102141.
[133] S. Dalal, "Futuristic investigative study of IoT/green IoT as a driving force for sustainable development," *Indian J. Sci. Technol.*, vol. 14, no. 8, pp. 738–751, 2021, doi: 10.17485/IJST/v14i8.165.
[134] A. Islam, K. Anum, D. Dwidienawati, S. Wahab, and A. Abdul, "Building a post COVID-19 configuration between Internet of Things (IoT) and sustainable development goals (SDGs) for developing countries," *J. Arts Social Sci.*, vol. 4, no. 1, pp. 45–58, 2020.
[135] *Open Access Government Website*. Accessed: Sep. 7, 2021. [Online]. Available: https://www.openaccessgovernment.org/iot-can-make-a-difference-in-the-developing-world/87666>
[136] *COVId-19 Timeline, OMS Website*. Accessed: Sep. 7, 2021. [Online]. Available: https://www.who.int/news/item/27-04-2020-who-timeline—covid-19