Challenges and Opportunities of the Internet of Things for Global Development to Achieve the United Nations Sustainable Development Goals

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ABSTRACT Internet of Things (IoT) makes a significant contribution to development in economical, social and ecological terms. In this work, the current context to successfully apply IoT in developing countries to achieve the Sustainable Development Goals (SDGs) of United Nations is studied. Potential and opportunities of the IoT in the developing world as well as the current challenges of IoT in developing countries are reviewed. The research methodology is focused on the IoT context in the developing world as well as profitable IoT projects carried out in developing countries, using the SDGs as a reference. Key features as a technical challenges, environmental conditions or social differences are studied to contextualize IoT in developing countries. Finally, the combination of low-cost IoT and pay-as-you-go is presented as the best scenario to better disseminate the Internet of Things for Development (IoT4D) to achieve the Sustainable Development Goals by 2030.

INDEX TERMS Internet of things, developing countries, sustainable development goals, IoT4D.

I. INTRODUCTION

In 2017, at the 7th Internet of Things (IoT) Week held in Geneva, the IoT research and industry community, jointly with ITU and other stakeholders, expressed their support for researching, developing and leveraging IoT technologies for sustainable development and for building a brighter future for our planet and its inhabitants [1].

IoT should not be restricted only to the challenges of industrialized countries; in the developing world IoT can act as a key piece to achieve stronger and sustainable development. IoT is already making great efficiency and productivity gains in industrialized countries, but it is rather equality importance for the developing world. The IoT has the tremendous opportunity for the human and economical development; it would be a mistake to overlook the potential for an even bigger and more significant impact in developing countries [2]. Developing countries are ideal for IoT innovation: the problems faced by the developing world can open up diverse and unexplored areas to which IoT can be applied. Apart from supporting economic growth, IoT also makes a significant contribution to development in social, environmental, as well as cultural aspects [3].

In recent years, IoT projects have started to develop for their application in the developing world, mainly in sub-Saharan Africa and southern. For example, along with the installation of renewable energy system, IoT applications have been installed for the monitoring and management of energy, improving the access to electricity [4], [5]. In the health sector, IoT proposals such as the monitoring of cold chain for vaccines have been implemented [6]. Water is another sector with a great potential for IoT: projects focus on the provision of water for both sanitary and agriculture (irrigation) have been also developed in rural areas of developing countries [6]–[10]. Emergency situations are one of the potential applications of IoT in developing countries to prevent and face natural disasters [10] detecting earthquakes, tsunamis or typhoons [4]. In the developing world, lack of resources means that simpler, more cost-effective solutions may prove more effective in a developing country context [4].

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The ultimate goal of this work is to study the current context and challenges to successfully apply IoT in developing countries by highlighting the weaknesses and strengths of its application in the developing world, to achieve the Sustainable Development Goals (SDGs) of the United Nations. This work also studies the potential of combining IoT based on open-source tools and new financial models, and reviewing previous works conducted in developing countries using open-source hardware platforms and open cloud platforms.

II. IoT OPPORTUNITIES IN DEVELOPING COUNTRIES
A. POTENTIAL AND OPPORTUNITIES OF THE IoT IN THE DEVELOPING WORLD
SDGs were born during the 2012 United Nations Conference on Sustainable Development in Rio de Janeiro by replacing Millennium Development Goals (MDGs) to continue to face poverty beyond 2015 [11]. SDGs (listed in Table 1) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity [12], all to be accomplished by 2030.

By 2025, experts predict that the 40% of economic added value from IoT will be generated in the developing world (upwards trend), according to a KfW Group’s report (2016) [13]. The IoT generate economic growth and can also make an important contribution to socially and ecologically sustainable development.

The World Economic Forum’s IoT for Sustainable Development project aims to encourage the use of the Internet of Things to accelerate progress on the 17 SDGs [14]. In 2018, the analysis of the World Economic Forum [15] reported that 84% of IoT deployments currently address (or have the potential to address) SDGs. This project presented an IoT analytics database of 640+ IoT projects [14] for studying the potential of IoT to support the SDGs, stated that the 75% of these IoT projects focus on five SDGs; (25%) SDG9, (19%) SDG11, (19%) SDG7, (7%) SDG3 and (5%) SDG12. In addition, results showed that the 95% of projects studied are small/medium sized and the 70% of these Internet of Things for Development (IoT4D) projects are led by private sector (80% originate in the Americas and Europe). These IoT solutions could be replicated in the developing world generating new business opportunities; the lack of access to digital infrastructure could put both countries and individuals at risk of being left even further behind in economic terms [16]. SDGs are interconnected, and often the key to success of one goal involves tackling issues more commonly associated with another. The report “Harnessing the Internet of Things for Global Development” [4] written as a contribution to the ITU/UNESCO Broadband Commission for Sustainable Development mapped the SDGs in sectors (Table 2).

The review focuses on Sectors 1-5. These areas include the five SDGs with most potential to be addressed using IoT applications. The objectives Zero Hunger (SDG2), Clean Water & Sanitation (SDG6) and Affordable & Clean Energy (SDG7), very important goals that together form the water-energy-food nexus (an index commonly used to measure development) [17]-[19] are also included. The IoT context in the developing world as well as profitable IoT projects carried

### TABLE 1. List of Sustainable Development Goals [12].

| Goal | Description |
|------|-------------|
| Goal 1: No poverty | End poverty in all its forms everywhere. |
| Goal 2: Zero hunger | End hunger, achieve food security and improved nutrition and promote sustainable agriculture. |
| Goal 3: Good health and well being | Ensure healthy lives and promote well-being for all at all ages. |
| Goal 4: Quality education | Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. |
| Goal 5: Gender equality | Achieve gender equality and empower all women and girls. |
| Goal 6: Clean water & sanitation | Ensure availability and sustainable management of water and sanitation for all. |
| Goal 7: Affordable & Clean Energy | Ensure access to affordable, reliable, sustainable and modern energy for all. |
| Goal 8: Decent work & economic growth | Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. |
| Goal 9: Industry, innovation & infrastructure | Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. |
| Goal 10: Reduced inequalities | Reduce inequality within and among countries. |
| Goal 11: Sustainable cities & communities | Make cities and human settlements inclusive, safe, resilient and sustainable. |
| Goal 12: Responsible product & consumption | Ensure sustainable consumption and production patterns. |
| Goal 13: Climate action | Take urgent action to combat climate change and its impacts. |
| Goal 14: Life below water | Conserve and sustainably use the oceans, seas and marine resources for sustainable development. |
| Goal 15: Life on land | Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. |
| Goal 16: Peace, justice, and strong institutions | Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels. |
| Goal 17: Partnerships for the goals | Strengthen the means of implementation and revitalize the global partnership for sustainable development. |

### TABLE 2. Sustainable Development Goals grouped by IoT Sector [19].

| 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 |
out in developing countries using Sectors 1-5 as a reference are presented below. Fig. 1 shows the analysis scheme for the study of the IoT application in developing countries followed in this study.

1) HEALTH, WATER, AND SANITATION

More than 2 billion people live without access to safe drinking water and more than twice that number lack access to safe sanitation [20]. Additionally, 850 million people from rural regions in developing countries also have no access to water for agricultural production, which is often their primary source of income [21]. Millions of women and children spend endless hours fetching water from long distances, and water sources are often unclean or unaffordable. So the Clean Water & Sanitation Goal (SDG 6) is a precursor to other SDGs, such as health care (SDG3), education (SDG4), gender equality (SDG5) and jobs (SDG8) [22].

The application of IoT helps to achieve the SDG6 providing objective information about the state of water resources, their use and management, and also about wastewater generation and treatment [22]. For example, in rural regions of Africa, an evaluation showed that 30-40% of pumps were nonfunctional and communities have no access to clean water up to 1 month after fixing pumps [23]. GSM enabled water meters to enhance water pump monitoring, especially in cases like India where 85% of drinking water is groundwater-dependent [23]. Several projects based on the application of IoT to Water have been successfully implemented. In Bangladesh, 48 arsenic sensors were installed to monitor the quality of clean water and water pollution prevention. In the JiangSu province in China, water supply quality is also monitored with a wide range of IoT sensors located at key points of the distribution network [6]. A clever low-cost reverse osmosis system, coupled to smart controllers, allows clean water to be efficiently distributed to rural areas of India, and to monitor and guarantee the quality and quantity of water supplied in real time [7].

In developing countries the mortality rate of children before 5 years old is 15 times higher than in high income countries. In 2017, 5.4 million children under-five died; the access to simple and affordable interventions could be prevented more than half of these early child deaths [24]. In 2015, an estimated 303,000 women around died due to complications of pregnancy and childbirth [25]. A major part of these deaths were in developing countries; 2/3 of those occurred in sub-Saharan Africa [26]. With an improvement of management and care in developing countries this number of deaths could be reduced [25]: lifetime risk of dying from maternal causes in Africa was 1 in 37, in Europe was 1 in 3300 [26]. The application of the IoT in healthcare allows remote monitoring and personal healthcare, medical device integration and even treatments of diseases [8], accelerating the attaining of SDG3. As an example, one of the main IoT applications in developing countries is the monitoring of the vaccine cold chain. In Haiti, healthcare professionals are using smart thermometers to better track vaccine delivery and storage [5]. IoT technologies are also being used to address immediate challenges in humanitarian response, such as the Ebola outbreak in West Africa [4].

2) AGRICULTURE AND LIVELIHOODS

In 2017, the number of hungry people in the world reached 821 million [27]. Children are the most vulnerable victims of malnutrition. About 3 million young lives a year, nearly half of all deaths in children aged less than 5 years old are attributable to malnutrition [28]. The Zero Hunger Goal (SDG2) pledges to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture [27]. In 2050, the world population is estimated at about 9.7 billion; thus the demand for food will be very high [29]. To nourish the 821 million people who are hungry today and the additional 2 billion expected people, a profound change is needed in both agriculture and the current system to obtain food [12]. As estimated, agriculture will need to produce 60% more food globally and 100% more in developing countries [22].

The promotion of sustainable agriculture reduces poverty (SDG1) and enables sustained, inclusive and sustainable economic growth (SDG8). The application of IoT to agriculture allows resources to be optimized, production costs to lower and crop losses to be avoided [31]. In developing countries, the challenges of IoT in agriculture are the cost of equipment and the need for wider internet coverage. These two prerequisites prevent many farmers in developing countries to enjoy this technology [32]. Specifically in the monitoring area, its adoption in small- and medium-scale farms is very much limited due to lack of awareness and deployment costs. So the potential to develop cost-effective agricultural-based IoT solutions remains a very open area [29]. Every year, 1/3 of the food produced in the world for human consumption—an estimated 1.3 billion tonnes — is wasted. Food losses and
Fisheries and aquaculture offer ample opportunities to reduce use of marine resources as well as terrestrial ecosystems. Another key element is the conservation and sustainably population affected by disasters lived in developing countries around 90% of deaths as a result of disasters and 98% of the take place in the developing world: between 1991 and 2005, majority of deaths and people affected by natural disasters changing climate, 26 are least developed countries. The vast the 30 countries most vulnerable to natural disasters and a poor communities with the fewest resources to adapt. A changing climate will impact poverty by 2030 (without measures to protect poor fami-

3) EDUCATION
Globally, 264 million children and adolescents do not have the opportunity to enter or complete school. In 2017, the highest levels of illiteracy between young people (youth aged 15 to 24) were found in Sub-Saharan Africa (more than 50% of the youth population in countries such as Mali, Niger or Chad) and Southeast Asia. IoT application accelerates towards attaining the SDG4. Kim et al. stated that low-cost, mobile learning technology has the potential to facilitate personalised and exploratory learning through a child-centred model in underprivileged areas. An example of IoT applied to education is the Higher Education Support Project, launched in Burkina Faso, that established a new Virtual University with the aim to diversify higher education delivery models. In China, the Guangdong Compulsory Education Project supports the installation and use of ICT equipment and the development of digital educational content for students.

4) ENVIRONMENT AND CONSERVATION
The World Bank estimates that, climate change could result in more than 100 million additional people living in extreme poverty by 2030 (without measures to protect poor families from its impacts). A changing climate will impact everyone, but it is already having the highest impact on poor communities with the fewest resources to adapt. The poor are disproportionately affected by disasters: of the 30 countries most vulnerable to natural disasters and a changing climate, 26 are least developed countries. The vast majority of deaths and people affected by natural disasters take place in the developing world: between 1991 and 2005, around 90% of deaths as a result of disasters and 98% of the population affected by disasters lived in developing countries. Another key element is the conservation and sustainably use of marine resources as well as terrestrial ecosystems. Fisheries and aquaculture offer ample opportunities to reduce hunger and alleviate poverty, generating economic growth. Overfishing threatens a valuable source of food; unmanaged aquaculture can be the driver of pollution contributing to the ocean acidification. The IoT application has the potential to reduce greenhouse emissions and helps slow the rise of global temperatures; in addition, IoT allows to mitigate the effect of natural disasters. An example of IoT application in this area is the initiative developed by IBM’s China Research Lab and the Beijing Environmental Protection Bureau to scale-up its air quality forecasting system. A network of sensors spread throughout Beijing returns increasingly precise forecasts of air pollution levels in different neighborhoods. Very interesting IoT applications are the Tsunami Early Warning Systems installed in India, Islamic Republic of Iran, Pakistan, and Oman. The tsunami detection using IoT is extremely helpful to spread early warning messages as compared to normal detection systems and hence it avoids more destruction. Adoption of IoT could reduce the chances of losing human lives as well as damage to large-scale infrastructures due to disasters.

5) RESILIENCY, INFRASTRUCTURE, AND ENERGY
Today 1.06 billion people still have no access to electricity and 3.04 billion people still rely on solid fuels and kerosene for cooking and heating. Income levels and no having access to modern energy and good infrastructures are well correlated: countries with the highest ratio of the population living on an income of less than $1.90 per day tend to have low electrification rates and a high proportion of the population relies on traditional biomass use for cooking. A majority of the people with no access to electricity live in sub-Saharan Africa and Southeast Asia, and, to a lesser extent, in the Middle East, Central Asia and Latin America. Likewise, most people with no clean cooking means live in Southeast Asia (1.9 billion), followed by sub-Saharan Africa (850 million).

IoT4D aids in providing power solutions by enabling clean energy technologies, creating smarter energy markets and by optimizing the implementation of existing products. In Kenya, M-Kopa (IoT Microsoft award) was designed to provide everyone with high-quality energy at an affordable rate, especially off-grid people. After installing Solar Home Systems, customers are able to utilize the electricity generated by solar cells to power home appliances, and M-Kopa remotely monitors system uses and failures. In example, the monitoring of Solar Home Systems allows the early detection of failures extending the long-life of the photovoltaic system. In 2014, Project Surya launched a solution to enable extremely low-income women in Odisha, India, to afford clean cooking stoves. Sensors installed on forced draft stoves detected and uploaded data about cooking events on clean cook stoves.

These projects have improved the lives of many people in developing countries. IoT applications in agriculture are focused on water management, providing mechanisms for avoiding water stress (under-irrigation and over-irrigation).
The outcome of this IoT projects is to reduce the waste of water and energy. On the other hand, effectiveness and productivity increase, and consequently, the economy of the families improve. Additionally, in most developing countries women are disproportionately affected because their access to resources and energy benefits is further limited by gender disparities as the role of the woman in developing countries is to collect wood and water. This situation has negative consequences such as the physical effects of drudgery in traveling long distances to obtain fuel wood and water, the health effects of indoor air pollution and reduced school attendance. IoT projects focused on energy and water also improve other aspects such as gender equality, health or education. However, some of these initiatives required large initial investments or the use of previously installed infrastructures. As indicated in Section 2.2., in developing countries, infrastructures are often very poor or nonexistent. To achieve high IoT dissemination in developing countries, one of the main requirements is to use simple inexpensive technology.

B. CHALLENGES OF IOT IN DEVELOPING COUNTRIES
With the emergence of IoT, several works [2], [34], [49] have analyzed the expansion of this technology in the developing world by highlighting the challenges for IoT to reach billions of people living in developing countries to accelerate income growth and social development as a result. This section summarizes the key features to contextualize IoT in developing countries.

1) TECHNICAL CHALLENGES
1. Design requirements [49]: In 2013, Karim et al. [50] reported that information requirements in developing countries differ from those in industrialized countries. So IoT systems for developing countries generally have different design requirements and technological frameworks. As reported by the World economic Forum’s report [15] “Internet of Things Guidelines for Sustainability” (2018), the full potential of IoT acting as a catalyst to sustainable development is achieved when sustainability is integrated at the design phase of the IoT initiatives.
2. Lack of Research: In 2013, only 7 publications were published in peer-reviewed journals for every 1 million people in African Least Developed Countries. However, in the member countries of the Organisation for Economic Co-operation and Development, about 1,100 scientific and technical journal articles were published for every 1 million people [51].
3. Simple and cost-effective technology: As resources are lacking, simpler and cost-effective [52] solutions may prove more suitable in a developing country context [4].
4. Lack of modern Infrastructure [13], [52]: Stable and reliable power supply systems are more limited in developing countries. The same happens with the availability of data centers. [13]
5. Connectivity: The International Telecommunication Union (ITU) [53] estimated in 2016 that approximately seven billion persons, the 95% of the global population, live in an area that is covered by a mobile network. According to a Groupe Speciale Mobile Association (GSMA) report [54], 63% of Africans had access to improved water supply and 32% to electricity in 2014, compared to 82 % who had access to GSM coverage. In 2008, United Nations research in India [55] showed that nearly 366 million people (31% of the population) had access to improved sanitation, while, 545 million mobile phones were connected to service.
6. Internet connectivity: Internet connectivity is a prime issue for enabling IoT. Internet penetration in developing countries is increasing [34]. In most developing countries, mobile broadband is more affordable than fixed broadband services [53]. Figure 2 shows the growth of mobile broadband subscriptions during the period from 2012 to 2017. In industrialized countries, 94% of young people aged 15-24 use the Internet compared with 67% in developing countries and only 30% in Least Developed Countries (LDCs) [53]. However, overall figures reveal that of the 830 million young people who are online worldwide, 320 million (39%) live in China and India [53].
7. Power supply: As things move around and they are not connected to a power supply, their smartness needs to be powered from a self-sufficient energy source [56]. On the other hand, Miazi et al. [49] reported that reliable power supply is a big challenge for enabling IoT in most of the developing countries, being solar and wind the effective solutions.
8. Lacking local IoT expertise [13]: In developing countries, one main challenge is lack of technically knowledgeable personnel [57] due to IoT systems requiring regular maintenance, updates and function testing.

2) ENVIRONMENTAL CONDITIONS
1. Harsh environmental conditions: The “Global Climate Risk Index 2018” [58] report studies to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.) [59].
During the 1997-2016 period, nine of the ten most affected countries were developing countries [58]. This means that the IoT systems installed in developing countries must be prepared to operate under extreme climatic conditions (heat, humidity, etc.).

3) SOCIAL DIFFERENCES
1. Rural-Urban differences: In developing countries, the differences between rural and urban areas are vast: 85% of poor people live in rural areas [63]. These differences affect to infrastructure used by IoT deployment such as telecommunications networks or electricity grid.

4) POLICY
1. Security and privacy [64]: In 2016, Ivașcu, T et al. stated that the two main obstacles to IoT are security and privacy. IoT devices are largely being designed without security in mind; in 2019, the African Academic Network on Internet Policy stated that urgent privacy/security regulation is required in Africa [65].

2. Absence of standards: Developments with no standardization sometimes results as designed products that operate in disruptive ways on the Internet [66]. In 2016, F.J. Ferrándiz-Pastor [67] argued that there are still several IT related issues that hinder further dissemination of IoT in agriculture. These include expensive the lack of established sensor network standards.

3. Government regulations [68]: In 2019, Abunohaiah and Al-Haija [69] reported that the IoT has broadly been unregulated so far. A clear regulatory framework could accelerate the expansion of IoT and make it more potential [69]. Large majority of IoT consumers lack trust in the IoT devices and favor more government regulations to protect data access and use, amongst other aspects [68]. Countries such as India [70] and Senegal [71] have just included IoT regulation as a priority. Concretely the Government of India has introduced policies and initiatives simplifying the licensing and regulatory frameworks whilst ensuring appropriate security frameworks, to leverage benefits of IoT in several sectors [72].

5) FINANCIAL CONDITIONS
1. Lack of financial systems [60] Access to basic banking services in developing countries is extremely limited [61]. This is the main reason why different business models, such as pay-as-you-go (PAYG), are emerging especially in developing countries and are combined with IoT initiatives [62].

III. THE FUTURE OF IoT4D

After studying the current context and the challenges for applying IoT in the developing world and reviewing successful projects in which IoT has been applied, the future of IoT4D is presented as a combination of two key aspects: low-cost IoT and PAYG. Today 1.7 billion people remain unbanked, but two thirds of them own a mobile phone [73]. It has been necessary to adopt different ways of doing business to reach these people with product and services to improve their livelihoods. In recent years in developing countries, the tendency is to combine IoT technologies with seamless digital payments and new business models like PAYG. The integration of open-source tools into the design of IoT projects considerably reduces technology costs. The use of this low-cost IoT allows consumers to be provided with previously inaccessible products that enhance their livelihood and also allow them to start on a path to financial inclusion [62].

A. LOW-COST IoT

In recent years, open-source tools have exponentially increased and have become a trend in the last decade. With the proliferation of open-source hardware-based (OSHW) projects, novel OSHW platforms have been progressively incorporated into the design of precise low-cost IoT systems. Table 2 shows initiatives that have been developed in the last 10 years in the IoT4D area. Most of the found projects have been designed around open-source tools. Of all the OSHW platforms available on the market, Arduino™ [73], [74], [76], [80], [82], [86], [88]–[90], [91], [92], [94]–[97], [100] and Raspberry PI [75], [77]–[79], [83], [87], [91] have been the most widely used platforms to be integrated into IoT4D projects. The most widespread open cloud platform was Thingspeak [84], [91], [93], [95], [100]. Table 3 shows the IoT4D projects linked to SDGs. Several projects focus on improving the water-energy-food index. In 2019, Fell et al. [99] presented a smart low-cost remote-monitoring flow sensor designed for the developing country context. The sensor used low-cost off-the-shelf sonar devices to gauge river height as a proxy for flow rates and operates via an IoT node based on mobile communications (GSM) to provide real-time data. The sensor was applied in Franschhoek, South Africa. In relation to the smart energy for developing, in 2019 López-Vargas et al. [100] presented a new low-cost datalogger designed specially to monitor Solar Home Systems installed in rural areas of developing countries. The datalogger used mobile communications to transmit data, and provided real-time remote monitoring to collaborate in the success of rural electrification programs [101], [102]. Along the same line, in 2018 Sanni et al. [97] applied the IoT concept to smart metering to measure key energy use data and to send instantaneous data to a web server to be accessed by permitted users. It was developed to be applied in Africa. Several projects work in line with the Zero Hunger objective throughout smart irrigation and smart farmer projects. In 2018, Abagissa et al. [95] presented a system composed of: a sensor network to assess temperature, humidity and water level adjustments; a sensor node needed for an optimal farming environment; monitoring management devices to collect and analyze the data from the collected sensor data, to store them in the management server and to alert an emergency. In 2017, Salvi et al. [86] presented a new framework for multilevel farming in urban areas with limited cultivation space; it was designed to be applied in India.
TABLE 3. IoT applications from the developing world and concerned SDGs.

| Year | Authors | Details | Low-cost IoT | Connectivity | Goal | Country/Region |
|------|---------|---------|-------------|-------------|------|----------------|
| 2012 | N. Gupta et al. [73] | Learning by creating: Interactive programming for Indian high schools | Arduino | NF | SDG4 | India |
| 2013 | Mukundhan Srivathan, Aravind B et al. [74] | GreenITComp: Low cost green computing system for education in Rural India: A scheme for sustainable development through education | Arduino | wired | SDG4 | India |
| 2013 | M. Ali [75] | Technical development and socio-economic implications of the Raspberry Pi as a learning tool in developing countries | Raspberry Pi | NF | SDG4 | Uganda |
| 2014 | Prajakta A. Pawar [76] | Heart Rate Monitoring System using IR base Sensor & Arduino Uno | Arduino UNO | IR | SDG3 | India |
| 2014 | S.S. Laga et al. [77] | Raspberry Pi for automation of water treatment plant | Raspberry Pi | wired | SDG6 | India |
| 2014 | S. Madhura [78] | Towards ubiquitous learning tools for computer aided classroom in developing regions | Raspberry Pi | NF | SDG4 | Bangladesh |
| 2015 | P. Pruet et al. [79] | Exploring the Internet of “Educational Things”(IoET) in rural underprivileged areas | Raspberry Pi | Wi-Fi | SDG4 | Thailand |
| 2015 | B.S. Boutola et al. [80] | Arduino based supervision of banana ripening stages | Arduino | GSM | SDG2 | India |
| 2016 | Bharathi, S. [81] | Smart Portable IOT Vaccine Monitor | Intel Galileo Gen 2 | Wi-Fi | SDG3 | NF |
| 2016 | N. S. Kumar et al. [82] | IOT Based Smart Garbage alert system using Arduino-UNO | Arduino UNO | GPRS module | SDG1 | India |
| 2016 | Rohini Shahi and Sushama Agrawal [83] | IoT Based Urban Climate Monitoring using Raspberry Pi | RPi | Wi-Fi module | SDG13 | Aamrehabad, India |
| 2017 | M. S. Mokala and P. Vweimana [84] | A Novel Technology for Smart Agriculture based on IoT with Cloud Computing | Thingspeak | IEE | SDG2 | India |
| 2017 | Amandeep et al. [85] | Smart Farming Using IOT | NF | wireless Zigbee modules | SDG2 | India |
| 2017 | S. Salvi et al. [86] | Cloud Based Data Analysis and Monitoring of Smart Multi-level Irrigation System using IoT | Arduino | Bluetooth modules | SDG2 | India |
| 2017 | Md. Shoebul Arefin et al. [87] | Smart Health Care System for Underdeveloped Countries | Raspberry Pi | wireless technologies | SDG3 | Bangladesh |
| 2017 | Ashish.B [88] | Temperature measured IoT based smart incubator | Arduino, RPi | ESP8266 (Wi-Fi) | SDG3 | NF |
| 2017 | Arison [89] | Vital sensor kit for use with telemedicine in developing countries | Arduino Uno | via Wi-Fi or SMS | SDG3 | NF |
| 2017 | C. Raj et al. [90] | HEMAN: Health Monitoring and Nous An IoT based e-Health Care System for Remote Telemedicine | Atmega 328P, Arduino, Amazon AWS | NF | SDG3 | India |
| 2017 | S. Ramesh [91] | An IoT architecture for financial services in developing countries | ATmega328P | Near Field Communication (NFC) | SDG8 | Sub-Saharan Africa |
| 2017 | A. Mohan et al. [91] | A Waste Collection Mechanism based on IoT | Raspberry Pi, Arduino, ThinkSpeak | GSM | SDG11 | India |
| 2017 | T. Tsikovk et al [92] | IoT Platform for Control of Carbon Emissions | Arduino Uno and Raspberry Pi | 802.11a wireless network | SDG12 | NF |
| 2017 | A. Cervasquilla-Barrion et al. [93] | IoT applications: On the path of Costa Rica’s commitment to becoming carbon-neutral | ThinkSpeak | GSM/GPRS | SDG13 | Costa Rica |
| 2017 | Abhinav Kumar Sharma [94] | IoT enabled forest fire detection and online monitoring system | Arduino | Wi-Fi | SDG15 | NF |
| 2017 | A. T. Ahatgina et al. [95] | IoT Based Smart Agricultural Device Controlling System | Arduino, ThingSpeak | Wi-Fi | SDG2 | India |
| 2017 | Sai Sreekar Siddula et al. [96] | Water Level Monitoring and Management of Data using IoT | Arduino | Bluetooth modules | SDG6 | India |
| 2018 | Saez [97] et al. | Smart Metering System: A Solution for Adoption in Developing Countries | Arduino | Wi-Fi module | SDG7 | Nigeria |
| 2018 | R. S. Cabrera and A. P. de la Cruz [98] | Public Transport Vehicle Tracking Service for Intermediate Cities of Developing Countries, based on ITS Architecture using Internet of Things (IoT) | ESP8266 12E | Wi-Fi | SDG9 | Popayan, Colombia |
| 2019 | J. Fell et al. [99] | Low-Cost Flow Sensors: Making Smart Water Monitoring Technology Affordable | Particle Electron | GSM | SDG6 | Franschhoek, South Africa |
| 2019 | A. Lopez-Vargas et al. [100] | IoT application for real-time monitoring of Solar Home Systems based on Arduino™ with 3G connectivity | Arduino, Thingspeak | 3G | SDG7 | Mexico |

Abbreviation: NF is “Not Found”.

Cloud-based data analysis and monitoring allowed the user to analyze and monitor the irrigation system over the Internet by providing ubiquitous access via Bluetooth modules. Their experimental results showed reduced water use and better power use.

One of the main challenges for expanding IoT in developing countries is connectivity. Among all the different standards deployed on the market [103], usually distributed in different frequency bands and using multiple communication protocols, selecting the most suitable connectivity technology
for an IoT application can be challenging. Wireless technologies have been widely used for decentralized systems, although Ethernet cable is an alternative for centralized systems [104]. The connectivity requirements of different types of IoT networks vastly vary depending on their purpose and resource constraints. Most of the reviewed projects use WLAN [79], [81], [83], [88], [89], [92], [94], [95], [98], [97] technologies for connectivity systems, mainly Wi-Fi. Another interesting solution implemented into some studied projects is the creation of low-power wide-area networks (LPWAN) [84], [96], [105]. The network sends data to a central node that usually acts as a gateway by sending information to the cloud via WWAN technologies (mobile communications in many cases). Mobile communications [72], [80], [91], [93], [99] also offer a good solution in areas deprived of traditional telecommunications (wired) networks. After reviewing, Southern Asia was identified as the region with more IoT4D projects based on low cost technology.

**B. PAY-AS-YOU-GO AND DEVELOPING COUNTRIES**

Pay-as-you-go refers to a business model which helps low-income customers to access to basic services. Commonly, companies offer a product for which a customer makes a down payment. This first payment is followed by regular payments for a term ranging (usually 6 months-8 years). Payments are typically made using mobile money; other methods used include scratch cards, mobile airtime or cash [106].

Of all the industries leveraging PAYG models in developing countries, the market for PAYG solar home systems (PAYG solar) is the most mature, especially in Sub-Saharan Africa [62]. The global PAYG solar market is projected to grow to $6-7 billion in revenue and 20 million in unit sales annually by 2022.

Solar PAYG is taken as an example of PAYG application in the developing world that can be used as a test, and can help predict how the PAYG model can be applied to other development aspects in line with SDGs. Other industries beyond PAYG solar in which PAYG models are creating livelihood improvements are clean water, telecommunications, agriculture, cooking stoves and gas, sanitation or education [62]. All this makes the PAYG model most appropriate for IoT to expand in the developing world.

Some projects focused on different SDGs have included the PAYG model. eWaterPay [107] is a pre-payment water dispenser harnessing IoT. Awarded in 2018 with a GSMA’s Global Mobile Award in the category “Outstanding Mobile Contribution to the UN SDGs” this project works across Sub-Saharan Africa ensuring 24/7 accessibility to clean water in communities that need it most. This project uses the PAYG model of payment applied to water (“Pay as you drink”). This project has impacted in sub-Saharan communities—who previously had little or no access to a clean, reliable water source—and now have access through a low-cost, PAYG water model. eWATERtap is an example of how the combination of IoT and PAYG is providing livelihood essentials and helping drive inclusion [62]. The Hello Tractor initiative [108] allows farmers to request affordable tractor services using a mobile application. Hello tractor works in Nigeria and it uses the PAYG model. By accessing tractors through Hello Tractor, farmers can drastically increase their yields and enhance their incomes [62]. The Acacia Irrigation project [109] is an initiative by the Sustainable Engineering Lab, to provide solar powered irrigation for farmers in Senegal. The Acacia Irrigation project also uses the PAYG model. In 2017, the United Nations Capital Development Fund [110] and the Promoting Equality in African Schools [111] in Uganda investigate how digital finance can help to alleviate the school fees payment issues for parents, schools and students, using the “Pay-as-you-learn” (PAYL) as a payment model for schools in Uganda [112].

Summarizing, in developing countries, to combine low-cost IoT technologies with seamless digital payments and new business models like PAYG provides consumers with previously inaccessible, capital-intensive products that enhance their everyday lives while simultaneously placing them on a path to financial inclusion [62]. In Table 4, key characteristic studied in this work are listed; they are presented as the optimal solution for the expansion of IoT4D.

**IV. CONCLUSION**

The potential of IoT in the developing world is to make an even greater and more significant impact than in industrialized countries. Problems faced by developing countries can open up new unexplored fields to apply IoT to. Around 85% of IoT deployments have the potential to address SDGs. The application of IoT between developed and developing countries differs. Infrastructures, connectivity, lack of personnel with technical knowledge, environmental conditions or financial systems are key aspects for implementing IoT into the developing world. One of the main challenges for expanding IoT in developing countries is connectivity. Most projects use wireless communications. In many cases the combination of low-range networks combined with mobile communications offers an excellent cost-effective solution.

With open-source hardware-based (OSHW) projects proliferating, novel OSHW platforms have been progressively incorporated into the design of precise low-cost IoT systems. Such projects do not generally require high initial costs, which allows greater dissemination and makes this area more appealing and affordable for the scientific community to...
achieve SDGs. To combine IoT technologies, seamless digital payments and pay-as-you-go are a tendency in the developing world that is obtaining excellent results. So the combination of Low-cost IoT and PAYG is presented as the perfect scenario to better disseminate IOT4D to achieve SDGs.

To adapt IoT projects to the needs of developing countries by integrating open source tools and new financing models to collaborate in achieving the SDGs is presented has a brilliant scenario to better disseminate IOT4D to achieve SDGs.

The world that is obtaining excellent results. So the combination of payments and pay-as-you-go is a tendency in the developing countries. The combination of payments and pay-as-you-go is a tendency in the developing countries.

What approach for africa? “EAI Endorsed Trans. Internet Things, vol. 4, no. 13, Sep. 2018, Art. no. 155481.

J. Garry, Harnessing the Internet of Things for Global Development, Geneva, Switzerland: International Telecommunication Union (ITU), 2015.

T. Ramanathan, N. Ramanathan, J. Mohanty, I. H. Rehman, E. Graham, and V. Ramanathan, “Wireless sensors linked to climate financing for globally affordable clean cooking,” Nature Climate Change, vol. 7, no. 1, pp. 44–47, Oct. 2016.

Path Website. Investing in Vaccines for the Developing World. Accessed: Feb. 2019. [Online]. Available: https://pathazureedge.net/media/documents/VAC_investing_fs_2015.pdf

World Bank Website. Jiangsu Water and Wastewater. Accessed: Feb. 5, 2020. [Online]. Available: http://projects.worldbank.org/P096926/jiangsu-water-wastewater?lang=en&tab=overview

A. Muhammad, B. Haider, and Z. Ahmad, “IoT enabled analysis of irrigation roosters in the indus basin irrigation system,” Procedia Eng., vol. 154, pp. 229–235, Jan. 2016.

N. Diolto and J. Kalezhi, “The Internet of things in agriculture for sustainable rural development,” in Proc. Int. Conf. Emerg. Trends Netw. Comput. Commun. (ETNCC), Windhoek, Namibia, May 2015, pp. 13–18.

M. Zorn, “Natural disasters and less developed countries,” in Nature, Tourism and Ethnicity as Drivers of (De)Marginalization (Perspectives on Geographical Marginality), vol. 3, S. Pelc and M. Koderman, Eds. Cham, Switzerland: Springer, 2018.

J. A. Leggett and N. T. Carter. (2012). Rio+20: The United Nations Conference on Sustainable Development. Accessed: Feb. 5, 2020. [Online]. Available: http://www.fao.org/docrep/019/i2672e/i2672e.htm

United Nations Development Programme Website. Accessed: Feb. 5, 2020. [Online]. Available: http://www.undp.org/content/undp/en/home/sustainable-development-goals.html

T. Scherf. (2016). Internet of Things—Hype or hope for developing countries? KfW Development Research. Accessed: Feb. 5, 2020. [Online]. Available: https://www.kfw-entwicklungsbank.de/PDF/Download-Center/PDF-Dokumente-Development-Research/Internet-of-Things-%E2%80%93-hype-or-hope-for-developing-countries.pdf

World Economic Forum Website. IoT for Sustainable Development Project. Accessed: Feb. 2, 2020. [Online]. Available: http://w3.org/sc/iot/sd/

World Economic Forum Website. Internet of Things: Guidelines for Sustainability. Accessed: Feb. 9, 2020. [Online]. Available: http://www3. woforum.org/docs/iotGuidelinesforSustainability.pdf

S. Lund and J. Manyika, “How digital trade is transforming globalisation,” The E15 Initiative, Int. Centre Trade Sustain. Develop. (ICTSD) World Econ. Forum, Geneva, Switzerland, Tech. Rep., 2016. [Online]. Available: http://www.e15initiative.org/ and http://e15initiative.org/publications/how-digital-trade-is-transforming-globalisation/

E. M. Biggs, E. Bruce, B. Bouffor, J. M. A. Duncan, J. Horsley, N. Paulli, K. McNell, A. Neef, F. Van Ogtrop, J. Curnow, B. Haworth, S. Duque, and Y. Imanari, “Sustainable development and the water–energy–food nexus: A perspective on livelihoods,” Environ. Sci. Policy, vol. 54, pp. 389–397, Dec. 2015.

Z. Zhang, X. Chen, Y. Li, W. Ding, and G. Fu, “Water-energy-food nexus: Concepts, questions and methodologies,” J. Cleaner Prod., vol. 195, pp. 625–639, 2018.

A. Smajgl, J. Ward, and L. Pluschke, “The water–food–energy nexus—Realising a new paradigm,” J. Hydroli., vol. 533, pp. 533–540, Feb. 2016.

Nature-Based Solutions for Water, the United Nations World Water Development Report 2018. Accessed: Feb. 6, 2020. [Online]. Available: https://wesdonc.unesco.org/ar/48223fpp0000231823

M. Namara, R. A. Hameed, G. E. Castillo, H. M. Ravnborg, L. Smith, and B. van Koppen, “Agricultural water management and poverty linkages,” Agric. Water Manage., vol. 97, no. 4, pp. 520–527, 2010.

Water for a Sustainable world. Report 2015. United Nations Report. Accessed: Feb. 5, 2020. [Online]. Available: https://unesdoc. unesco.org/ark:/48223/pp0000231823

GSMA Report. (2013). Sustainable Energy & Water Access through M2M Connectivity. Accessed: Feb. 6, 2020. [Online]. Available: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2013/01/Sustainable-Energy-and-Water-Access-through-M2M-Connectivity.pdf

World Health Organization. Accessed: Feb. 9, 2020. [Online]. Available: http://www.who.int

Sustainable Development Goal 3. Accessed: Feb. 9, 2020. [Online]. Available: https://sustainabledevelopment.un.org/sdg3

World Health Statistics Overview 2019. Accessed: Feb. 9, 2020. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/ 311696/WHO-DAAD-2019-1-eng.pdf?ua=1

United Nations Website. Zero Hunger: Why it Matters. Accessed: Feb. 9, 2020. [Online]. Available: https://www.un.org/sustainabledevelopment/wp-content/uploads/2018/09/Goal-2.pdf

UNICEF/WHO/World Bank Group Joint Child Malnutrition Estimates. Key Findings of the 2019 Edition. Levels and Trends in Child Malnutrition. Accessed: Feb. 9, 2020. [Online]. Available: https://www.who.int/nutgrowthdb/jme-2019-key-findings.pdf

O. Elijah, T. A. Rahman, I. Orikumhi, C. Y. Leow, and M. H. D. N. Hindia, “An overview of Internet of things (IoT) and data analytics in agriculture: Benefits and challenges,” IEEE Internet Things J., vol. 5, no. 5, pp. 3758–3773, Oct. 2018.

P. P. Ray, M. Mukherjee, and L. Shu, “Internet of things for disaster management: State-of-the-art and prospects,” IEEE Access, vol. 5, pp. 18818–18835, 2017.

Food and Agriculture Organization of the United Nations Website. The possibilities of Internet of Things (IoT) for Agriculture. Accessed: Feb. 9, 2020. [Online]. Available: http://www.fao.org/ agriculture/news/possibilities-internet-things-iot-agriculture

M. Stoices, C. P. Ditifem, J. Vaněk, J. Masner, and J. Pavlík, “Internet of things (IoT) in agriculture—Selected aspects,” Agris On-Line Papers Econ. Informat., vol. 8, no. 1, pp. 83–88, Mar. 2016.

Food and agriculture organization of the United Nations Website. SAVE FOOD: Global Initiative on Food Loss and Waste Reduction. Feb. 9, 2020. [Online]. Available: http://www.fao.org/savefood/resources/keyfindings/en/

G. Sylvester, Success Stories on Information and Communication Technologies for Agriculture and Rural Development, 2nd ed. Rome, Italy: Food and Agriculture Organization of the United Nations, 2015.

M. Yunus, A World of Three Zeros: The New Economics of Zero Poverty, Zero Unemployment, and Zero Net Carbon Emissions. New York, NY, USA: PublicAffairs, 2017.

UNICEF Website. GOAL AREA 2: Every Child Learns, Global Annual Results Report 2018. Accessed: Feb. 9, 2020. [Online]. Available: https://www.unicef.org/media/55331/file

UNESCO Website. Atlas of Literacy. Accessed: Feb. 9, 2020. [Online]. Available: https://www.tellmaps.com/la-tic/silac/svg/#?map= 1082895961
M. TASNIM, F. ZAMAN, H. S. FERDOUS, AND S. M. SAAD, “Towards ubiquitous learning tools for computer aided classroom in developing regions,” in Proc. 16th Int. Conf. Comput. Inf. Technol. (ICCIT), 2013, pp. 320–325.

P. PUET, C. S.ANG, D. FARZIN, AND N. CHAIWUT, “Exploring the Internet of ‘educational things’ (IoET) in rural underprivileged areas,” in Proc. 12th Int. Conf. Elect. Eng.Electron., Comput., Telecommun. Inf. Technol. (ECTI-CON), Jun. 2015, pp. 1–5.

B. S. BUTOLA, P. K. SHARMA, Y. SINGH, AND Y. AMIN, “Arduino based supervision of banana ripening stages,” in Proc. 1st Int. Conf. Next Gener. Comput. Technol. (NGCT), Dehradun, India, Sep. 2015, pp. 921–924.

S. BHARATH, “Smart portable IoT vaccine monitor,” Int. J. Eng. Tech. Res., vol. 5, no. 3, pp. 2454–4698, Jul. 2016.

N. S. KUMAR, B. VUAYALAKSHMI, R. J. PRANATHA, AND A. SHANKAR, “IoT based smart greenhouse alert system using arduino UNO,” in Proc. IEEE Region 10 Conf. (TENCON), Singapore, Nov. 2016, pp. 1028–1034.

R. Shete and S. Agrawal, “IoT based urban climate monitoring using raspberry pi,” in Proc. Int. Conf. Commun. Signal Process. (ICSSP), MELNARVARITTAM, India, Apr. 2016, pp. 2008–2012.

M. S. Mekala and P. Viswanathan, “A novel technology for Smart agriculture based on IoT with cloud computing,” in Proc. Int. Conf. I-SMAC (IoT Social, Mobile, Anal. Cloud) (I-SMAC), Palladam, India, Feb. 2017, pp. 75–82.

A. Channappa, A. Bhattacharjee, P. Das, D. Basu, S. Roy, S. Ghosh, S. Saha, S. Pain, S. Dey, and T. K. Rana, “Smart farming using IoT,” in Proc. 8th IEEE Annu. Inf. Technol., Electron. Mobile Commun. Conf. (EMCON), Vancouver, BC, Canada, Oct. 2017, pp. 278–280.

S. Salvi, S. A. Framed Jain, H. A. Sanjay, T. K. Harshita, M. Farhana, N. Jain, and M. V. Sahas, “Cloud based data analysis and monitoring of smart multi-level irrigation system using IoT,” in Proc. Int. Conf. I-SMAC (IoT Social, Mobile, Anal. Cloud) (I-SMAC), Palladam, India, Feb. 2017, pp. 752–757.

M. S. Arefin, T. H. Suruvi, N. N. Snigdha, M. F. Mridha, and M. A. Adnan, “Smart health care system for underdeveloped countries,” in Proc. IEEE Int. Conf. Telecommun. Photon. (ICTP), Dhaka, Bangladesh, Dec. 2017, pp. 28–32.

B. Ashish, “Temperature monitored IoT based smart incubator,” in Proc. Int. Conf. I-SMAC (IoT Social, Mobile, Anal. Cloud) (I-SMAC), Feb. 2017, pp. 497–501.

N. Arrizón, J. Hernandez, T. Ogunfunmi, A. Maldonado-Liu, A. Pacheco, and U. Kim, “Vital sensor kit for use with telemedicine in developing countries,” in Proc. IEEE Global Humanitarian Technol. Conf. (GHTC), Vancouver, BC, Canada, Oct. 2017, pp. 1–5.

C. Raj, C. Jain, and W. Arif, “HEMAN: Health monitoring and nous: An IoT based e-healthcare system for remote telemedicine,” in Proc. Int. Conf. Wireless Commun., Signal Process. Netw. (WiSNetP), Chennai, India, Mar. 2017, pp. 2115–2119.

A. Mohan, S. Johar, and S. Mini, “A waste collection mechanism based on IoT,” in Proc. 14th IEEE India Council Int. Conf. (INDICON), Roorkee, India, Dec. 2017, pp. 1–5.

T. Tsokov and D. Petrova-Antonova, “EcoLogic: IoT platform for control of carbon emissions,” in Proc. 12th Int. Conf. Softw. Technol., 2017, pp. 178–185.

A. Carasaquilla-Batista, A. Chacon-Rodriguez, M. Solorzano-Quintana, and M. Guerrero-Barrantes, “IoT applications: On the path of costa Rica’s commitment to becoming carbon-neutral,” in Proc. Int. Conf. Internet Things Global Community (IoTGC), Funchal, Portugal, Jul. 2017, pp. 1–6.

A. Sharma, M. Ansari, M. Siddiqui, and M. Baig, “IoT enabled forest fire detection and online monitoring system,” Int. J. Current Trends Eng. Res., vol. 3, no. 5, pp. 50–54, 2017.

A. T. ABAGISSA, A. BEHURA, AND S. K. PANI, “IoT based smart agricultural device controlling system,” in Proc. 2nd Int. Conf. Inventive Commun. Comput. Technol. (ICICCT), Coimbatore, India, Apr. 2018, pp. 26–30.

S. S. Siddulla, P. Babu, and P. C. Jain, “Water level monitoring and management of dams using IoT,” in Proc. 3rd Int. Conf. Internet Things, Smart Innov. Usages (IoT-SU), Bhimtal, India, Feb. 2018, pp. 1–5, doi: 10.1109/IoT-SU.2018.8519843.

T. SANNI, A. ADGOPHE, P. AMAIZE, AND C. D. AJAEGBU, “Smart metering system: A solution for adoption in developing countries,” IEEE PES/IAS PowerAfrica, Tech. Rep. 969, 2018, pp. 623–627.

R. S. Cabrera and A. D. de la Cruz, “Public transport vehicle tracking service for intermediate cities of developing countries, based on ITS architecture using Internet of things (IoT),” in Proc. 21st Int. Conf. Infell. Transp. Syst. (ITSC), Maui, HI, USA, Nov. 2018, pp. 2784–2789.

J. Fell, J. Pead, and K. Winter, “Low-cost flow sensors: Making smart water monitoring technology affordable,” IEEE Consumer. Electron. Mag., vol. 8, no. 1, pp. 72–77, Jan. 2019.

A. López-Vargas, M. Fuentes, and M. Vivar, “IoT application for real-time monitoring of solar home systems based on Arduino with 3G connectivity,” IEEE Sensors J., vol. 19, no. 2, pp. 679–691, Jan. 2019.

T. Urneze, D. Harries, and A. Schlaper, “Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific,” Renew. Energy, vol. 34, no. 2, pp. 354–357, Feb. 2009.

F. D. J. Nieuwenhout, A. V. A. V. Dijk, D. Hirsch, P. E. Lasschuit, and G. Van Rossum, “Monitoring and evaluation of experiences with applications of solar PV for households in developing countries,” Netherlands Energy Res. Found., Petten, The Netherlands, Tech. Rep. ECN-00-089, Sep. 2000.

N. Lethaby, “Wireless Connectivity for the Internet of Things: One Size Does Not Fit All,” Dallas, TX, USA: Texas Instruments, 2017.

R. I. S. Pereira, I. M. Dupont, P. C. M. Carvalho, and S. C. Jucá, “IoT embedded Linux system based on raspberry Pi applied to real-time cloud monitoring of a decentralized photovoltaic plant,” Measurement, vol. 114, pp. 286–297, Jan. 2018.

P. W. Lawrence, T. M. Phippard, G. S. Ramachandran, and D. Hughes, “Developing the IoT to support the health sector: A case study from Kikwit, DR Congo,” in Proc. Int. Conf. Emerg. Technol. Developing Countries, 2017, pp. 45–56, doi: 10.1007/978-3-319-67837-5_5.

International Finance Corporation, Advisors, Dalberg, and Lighting Global, Off-Grid Solar Market Trends Report 2018. Accessed: Feb. 6, 2020. [Online]. Available: https://www.lightingafrica.org/wp-content/uploads/2018/02/2018_Off_Grid_Solar_Market_Trends_Report_Full.pdf.

WaterPay Website. Accessed: Feb. 10, 2020. [Online]. Available: https://www.waterpay.com/.

Hello Tractor Project Website. Accessed: Feb. 10, 2020, [Online]. Available: https://www.hellotractor.com/home.

Quadraic Sustainable Engineering Lab Website. Acacia Irrigation Project. Accessed: Feb. 10, 2020. [Online]. Available: https://usel.columbia.edu/acacia-irrigation-project.

Unite Nations Capital Development Fund Website. Accessed: Feb. 10, 2020. [Online]. Available: https://www.uncdf.org/mns4hp/home.

Promoting Equality in African Schools (PEAS) Website. Accessed: Feb. 10, 2020. [Online]. Available: https://www.peas.org.uk/.

Unite Nations Capital Development Fund Website. Exploring the Prospects of Pay as You Learn in Uganda. Accessed: Feb. 10, 2020. [Online]. Available: https://www.uncdf.org/article/5481/exploring-the-prospects-of-pay-as-you-learn-in-uganda.

C. Dupont, T. Bures, M. Sheikhhasliah, C. Pham, and A. Rahim, “Low-cost IoT Big data, and cloud platform for developing countries,” in BT–Economics of Grids, Clouds, Systems, and Services. New York, NY, USA: UNCDF, 2017, pp. 285–299.
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