Chapter 1

Use-cases of Blockchain Technology for Humanitarian Engineering

Arvind W. Kiwelekar, Sanil Gandhi, Laxaman D. Netak[1]

Abstract

Humanitarian Engineers are always in search of innovative methods to make technological interventions to solve societal problems. The emerging Blockchain technology has the enormous potential to provide effective interventions in various developmental sectors including Agriculture, Education Health, and Transportation. In these sectors, mediators, either in the form of individuals or organizations, are seen as one of the impediments for developmental work. The Blockchain technology facilitates peer-to-peer business transactions without any mediators. Thus, the Blockchain technology is emerging as an alternative to conventional mediator-centric solutions adopting client-server based Internet technologies.

The Blockchain technology can be combined with other technologies to address domain specific challenges. For example, the combination of Blockchain technology and Internet-of-Thing (IoT) has the potential to monitor usage of scarce resources such as the level of ground-water and amount of energy consumption. The combination of RFID and Blockchain technology assists in ascertaining the provenance of agricultural and handicraft products thus avoiding the exploitation of original producers from the duplicate or hackneyed producer.

The aims of this chapter are threefold. Firstly, to describe the primary building blocks of Blockchain technology. Secondly, to illustrate various use-case scenarios of Blockchain technology combined with RFID, IoT and Artificial Intelligence in the field of Agriculture, Energy consumption, monitoring of usages of natural resources, the provenance of natural and handicrafts products. Thirdly, to evaluate the existing platforms supporting Blockchain-based application development.

1.1 Humanitarian Engineering: An Example

Helping underprivileged and marginalized people is the goal of Humanitarian Engineering. It does so by designing and implementing technology-based solutions to

[1]Department of Computer Engineering, Dr. Babasaheb Ambedkar Technological University Lonere-402103 Raigad(MS) India

address the challenges faced by such people. The *Jaipur foot* [1] is one of the best examples of humanitarian engineering products. The Jaipur foot is an artificial leg designed to help people with below-knee leg amputation. It uses a new material of that time called polyurethane to develop near-natural but artificial leg. Since the last fifty years, the Jaipur foot has been assisting thousands of physically challenged people to compete with ordinary people, bringing a smile on their faces. Innovative use of material technology which has brought durability, flexibility and convenience of use is a critical factor behind the successful and widespread use of Jaipur foot for overcoming leg disability.

The example of *Jaipur foot* illustrates two significant aspects of humanitarian engineering. First one is the use of technology, i.e. material technology in case of Jaipur foot and the second one is relieving pain or grief of underprivileged people. The focus of this chapter is on the Blockchain Technology, one of the emerging Information and Communication Technology. The objective of this chapter is to illustrate how Blockchain technology has promising applications to address diverse needs of underprivileged people.

1.2 A Framework for understanding Humanitarian Engineering

Before delving into details of technological alternatives for realizing humanitarian engineering let us develop a framework to understand the dynamics of humanitarian engineering as a discipline. The three main pillars of humanitarian engineering are: (1) Stakeholders (2) Goals (3) Sectors for humanitarian engineering.

1.2.1 Stakeholders for Humanitarian Engineering

The main stakeholders for humanitarian engineering projects are the people and organizations that play critical role in the development of underprivileged communities.These are also known as *development agencies*. These agencies operate at different geographical levels from global to local level.

The first kinds of development agencies are *international development agencies*. Their primary function is to address the problems faced by humankind. These agencies set the agenda for development programs, identify the problems faced by humankind, monitor and evaluate the performance of development programs, collect data and evidences to study the impact of development programs and to fund the developmental activities in various countries. The role three leading international development agencies are described in Table 1.2. Besides this, some of the other international development agencies sponsoring developmental projects are World Bank and Asian Development Banks (ADB).

Many countries in the world have development agencies at the national level to formulate country-specific development policies, align it with policies formulated by UNDP, and implement developmental projects. For example in India, National Initiative for Transforming India (NITI) Aayog, is one such organization.

Also, there are some regional development agencies whose primary role is to implement the developmental projects in coordination with national and international

Sr. No.	Development Agencies	Activities
1	UNDP	United Nations Development Program (UNDP) is one of the subunits of the United Nations headquartered in New York City. The primary role of the UNDP is to formulate policies, set priorities, and sponsor development programs to address the challenges faced by humanity. It does so by proactively working with all the member nations of United Nations Organizations (UNO). [2]
2	UNWFP	United Nations World Food Program (UNWFP) is a branch of UNO raising the war against hunger and malnutrition. It provides food assistance to member countries so that the nutritional needs of the people leaving in poverty. It aims to reduce child mortality, improve maternal health and to fight against diseases. [3]
3	WHO	World Health Organization (WHO) is a subsidiary of UNO dealing with matters of public health at the international level. It articulates policies for ensuring the highest possible health for individuals by identifying social and economic factors affecting health. It closely works with national government agencies and monitors the effective implementation of health policies. [4]

Table 1.1 **International Development Agencies and Their Role**

agencies. In a few countries, universities and academic Institutes are slowly emerging as a regional knowledge centre to provide information necessary to get insights about the local developmental needs [5].

1.2.2 Sustainable Development Goals

The Sustainable Development Goals (SDG) capture the expectations and aspirations of people to live in a prosperous society without compromising on the needs of future generations. These SDGs are a set of ambitious goals put forward by the UN in the Year 2015 for the entire development of humanity [6, 7]. These set of goals are linked to specific targets to be achieved by the end of the year 2030. Table 1.2 list out all seventeen goals categorized into five labels namely People, Prosperity, Peace, Partnership and Planet [8].

Achieving these goals is an enormous task. Development agencies need to devise social, legal, financial and technological interventions. A development engineer responsible for technological interventions should know these SDGs so that project objectives and outcomes can be aligned with the SDGs. Knowledge of these SDGs is also essential for any engineer to make conscious about societal needs and environmental responsibilities.

Category	SDGs	Description
People	(SDG1) No Poverty, (SDG2) Zero Hunger, (SDG3) Good Health and Well-being, (SDG4) Quality Education, (SDG5) Gender Equality	End poverty and hunger in all their forms and dimensions, ensure all human beings can fulfill their potential in dignity, equality and healthy environment.
Prosperity	(SDG8) Decent Work and Economic Growth,	Enjoy prosperous and fulfilling lives, economic, social, and technological harmonic progress
Peace	(SDG10) Reducing Inequality, (SDG16) Peace, Justice, and Strong Institutions	Foster peaceful, just and inclusive societies, free from fear and violence.
Partnership	(SDG17) Partnerships for the Goals.	Revitalized global Partnership, participation of all countries, stakeholders and people.
Planet	(SDG6) Clean Water and Sanitation, (SDG7) Affordable and Clean Energy, (SDG9) Industry, Innovation, and Infrastructure (SDG11) Sustainable Cities and Communities, (SDG12) Responsible Consumption and Production, (SDG13) Climate Action, (SDG14) Life Below Water, (SDG15) Life On Land	Protect degradation through sustainable consumption, production, natural resource management, stakeholders and people

Table 1.2 **Sustainable Development Goals**

1.2.3 Sectors for Humanitarian Engineering

The set of SDGs described in the last section aims for the overall development of humanity. The three main sectors which directly capture needs of human being responsible for achieving SDGs are Economical systems, Social systems and Environmental systems. However, some institutes and sectors are responsible to lay the operational and legal framework necessary for business transactions. This section reviews such business sectors responsible for achieving the target indicators set for each SDGs.

1. **Agriculture** The agriculture sector is the most essential sector for Sustainable development. The SDGs like *End Poverty* and *Zero Hunger* are directly related to agricultural production. Feeding the ever growing population with sufficient

Figure 1.1 Sustainable Development Goals

food and nutrient is a huge task. As most of the rural population depends on income from agricultural produce, the goal of ending poverty is also correlated with agriculture. The Sustainable agricultural production is constrained by factors like growing population, water shortages, declining soil fertility and climate change [8]. Recently scientists have been exploring technologies such as Wireless sensor technologies [9] and ICT [10] for Sustainable agricultural production.

2. **Banking and Finance** Banking and financial markets drive economic development. It provides capital to start new businesses. It provides various avenues for income growth and wealth accumulation [11]. The number of banks and non-banking financial institutes present in the community is one of the indicators of economic development. Trust in financial institutes, efficient of processing business transactions(e.g., remittances, payment made to farmers on selling upon crops) diversity of financial instruments (e.g., crop insurance, loans, micro-credits) are some of the factors necessary of decent work and economic growth. Emerging technologies such as cryptocurrencies have to play a significant role in making business transactions simpler.
3. **Education** Education brings changes in behavior. Education makes people more knowledgeable and skillful to get decent jobs. Education brings awareness about the environment, and once social responsibility. It also has an indirect impact on the health of an individual, reduction in the rate of population growth. The task providing education to all is becoming more challengable because of a shortage of trained teachers, difficulties in providing better learning experiences to students on account of a shortage of playground in urban areas and over sized classrooms. Educators are gradually adopting technologies to overcome some of these challenges.
4. **Energy** The goal of *affordable and clean energy* (SDG7) is directly related with energy sector. This sector also drives industrial development and economic growth. The demand for energy is increasing exponentially because of increasing population and wide-spread use of electro-mechanical devices to carry out

routine works. Conventional energy generation methods that use natural resources such as coal and fossil fuels fails to meet this increasing energy demand. Hence use of non-conventional and renewable energy sources need to be increased on a large scale for sustainable development. In this context, it is required to provide technological solutions that would reduce energy demand, techniques for efficient energy production and replacement of conventional energy sources. [12]

5. **E-Governance** E-government is the use of Information and Communication Technologies (ICT) into day-to-day government processes. It is aimed to bring effectiveness in administration, transparency in the services provided by the government, and increasing participation of citizens in implementing government policies. The sector of E-governance is directly linked to Goal 16 and Goal 17. This sector plays a critical role in building accountable institutes necessary for enforcing peace and justice in societies (Goal 16). It also lays the technological infrastructure necessary to strengthen partnership at the global level required to implement various SDGs (Goal 17). [13, 14]
6. **Environment Science and Engineering** The policy makers formulating the developmental goals have realized the drawbacks of uncontrolled development that took place in the last century. The economic growth that pollutes air and water, that reduces the portion of forest and agricultural land, never satisfy the needs of the future generation. Hence the SDGs such as the provision of clean water and sanitation (SDG6) actions for regulating climate change (SDG13) and protecting life below water and on land (SDG14 & SDG15) are directly linked to environmental science and engineering. Newer clean and green technologies need to develop and adopted especially in the areas of civil engineering, construction, water management, urban development, and for maintaining biodiversity [15].
7. **Health** To provide good health and well being are the sustainable goals which are directly linked to the health sector. Besides the lack of primary health care mechanisms, there exist many factors which affect the health and wellness of individuals. Some of these are the byproducts of uncontrolled development. For example, industrialization and modern urban centred life are causing stress and respiratory system related diseases. Technologies such as information and communication, genetic engineering have been found useful in preventing, monitoring and diagnosis of diseases. [16]

1.3 Technological Perspective of Humanitarian Engineering

The sustainable development goals listed in the previous section are ambitious in terms of number, scope, and indicators used to measure the attainment of these goals. One of the effective ways to achieve the set targets is through innovative use of existing and emerging technologies. Some of the emerging technologies that will have a positive impact on sustainable development are listed in Table 1.3

Sr. No.	Emerging Technologies	Benefits of the technology
1.	Bioplastic, Biodegradable plastic and Sustainable plastic	To Protect from climate change and prevent degradation of natural resources (SDG13)
2	Renewable Energy Sources (e.g., Wind, Solar, and biofuels)	prevents degradation of natural resources, clean and green energy (SDG7)
3.	Electric Vehicle	Effective fuel consumption and pollution free automobiles (SDG7 and SDG13)
4.	Artificial Intelligence and Machine Learning	Personalized Medicine, outcomes based public health and diagnosis of cancer, pneumonia and other diseases (SDG3)
5.	Communication Technologies (e.g. Mobile communication, Wireless communication, Smartphone, Internet)	Dissemination of knowledge between doctors, patients and caretakers (SDG3)
6.	3D Printing	Lowers cost of personalized medicine and organ transplant (SDG3)
7.	Genetic Technology	Facilitates precision medicine (SDG3)
8.	Digital Financial Technologies (e.g., Cryptocurrencies and Blockchain)	Supports micro-payments, creates trustworthy environment for business transactions) (SDG8 & SDG17)

Table 1.3: **Emerging technologies for Sustainable Development**

These technologies can help to combat climate change, degradation of natural resources, achieve good health and well being, to speed up economic growth and promote all-inclusive and equitable social development.

Data is one of the common threads across all the technologies listed in Table 1.3. It has been envisaged that in the coming decade, data will drive sustainable development. At the same time, data-driven development is continuously raising many issues such as security of information, privacy, and ethical concerns.

In the following sections, we discuss and evaluate one the emerging technology called Blockchain technology in this context.

1.4 Blockchain Primer

The power and promise of emerging Blockchain technology can be understood by comparing the potential and pitfalls of the Internet as a platform for business and information exchange.

The Internet has introduced an information-centric model of business and revolutionized how people transact online. For example, the emergence of e-commerce sites (e.g., Amazon) is attributed to the growth and widespread presence Internet.

The Internet has bridged the information gap that exists between a service provider and service consumer by creating a third-party for information exchange called intermediaries or agents or service providers. These agents which are e-commerce sites hold the information about who sells what i.e. seller's information and who wants what i.e. buyers profile and their needs. Thus bringing together consumers of services or goods with that of producers.

The advantages of doing online business are that it simplifies the process of business transactions, reducing the time required for businesses, and as a result, brought prosperity in the society.

In the context of SDGs, the Internet as a platform for business has created various opportunities for decent work and economic growth. The Internet as a platform for communicating information has reduced the impact of natural disasters such as cyclones and spread of epidemics by timely disseminating useful information. The Internet as a learning platform has increased the accessibility of education fostering the goal of education to all.

Despite the various benefits of the Internet, it has always remained an unreliable platform to share valuable personal information because of its mediator-centric model for information exchange. The personal information shared to the mediators which can be a payment gateway, or an e-commerce site is always susceptible to breach of security and privacy attacks.

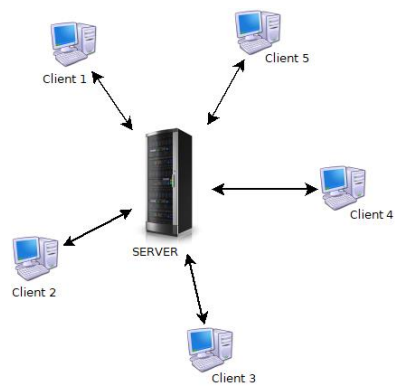

Figure 1.2 Client Server System

The emerging Blockchain technology removes these pitfalls by laying a trust layer on top of the existing Internet technology. It replaces the mediator-centric model of information exchange with the peer-to-peer model or decentralized model of information exchange. It transforms the Internet into a trustworthy platform for doing business when transacting parties do not trust each other. It eliminates the role of mediator responsible for authenticating the identities of transacting parties.

	Client/Server Architecture	Decentralized Architecture
Mode of Communication	Client Server communicate through each other via communication link	Peer-to-Peer
Components	Nodes, Server, Communication Link	Nodes, Communication Link
Architecture Style	Layered	Object-based
Availability	Need to achieve high availability	No need to achieve high availability
Servers	Only single server is present to serve client	Servers are distributed in system
Privacy	It is easy to determine who is handling the content	Difficult to determine who is handling the content
Failure	Bottleneck as the sever fails down	No bottleneck as services can be provided through other nodes
Cost	Implementation cost is high	Implementation cost is negligible

Table 1.4: Difference Between Client/Server and Decentralized Architecture

Initially emerged as a platform to exchange digital currency over the Internet, now the Blockchain technology gradually emerging as a general purpose platform for doing business over the Internet. Due to potential applications of Blockchain technology in various Fields, UN has included it as one of the frontier technologies to realize SDGs [17].

This section provides an overview of basic elements of Blockchain and how it achieves the various quality attributes that make it as one of the promising technology. The Blockchain technology can be understood at conceptual level and at specific instance level. The Bitcoin, Ethereum, and Hyperledger are few common examples of specific Blockchain. This section, reviews the Blockchain technology at conceptual level. The four basic concepts common across the Blockchain implementation are: [18]

1. Distributed Ledger
2. Cryptography
3. Consensus Protocols
4. Smart Contracts

1.4.1 Distributed Ledger

In a conventional sense, ledgers are the registers or log books employed for account or bookkeeping operations. Similarly, in the context of a Blockchain based information system, ledgers are the databases storing up-to-date information about business transactions. These are distributed among all the nodes participating in the network. In a Blockchain environment, ledgers are not stored at a central place. They are distributed among all the nodes so multiple copies of a ledger exist in a business network or a community. Hence these are referred to as distributed ledgers. Whenever a node in a network updates the ledger, all the copies of the ledger in the network are synchronized and they contain the same information.

These ledgers are used to store information about valuable assets. In the Bitcoin implementation, the first Blockchain based system, ledgers are used to store digital currencies. It may be used to store information about other valuable assets such as land records, diamonds, student's academic credentials and others.

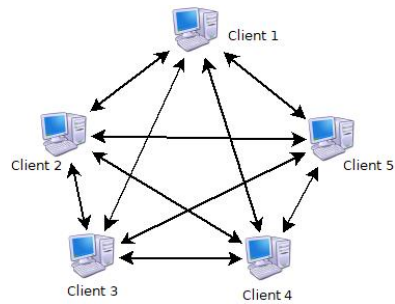

Figure 1.3 Decentralized System

In a Blockchain-based information system, records in a distributed ledgers are arranged in a chain-format as shown in Figure **??** for storage purpose. Here, multiple transactions related to an asset are grouped in a block. The $n+1$th block in the chain links to the nth block and the n block links to the $n-1$th block and so on. The first block in a chain is called a genesis block or the root block. Due to this peculiar storage arrangement the distributed ledgers are also known as Blockchain. Here it is worth to note that all Blockchain-based systems contain distributed ledgers but not all distributed ledgers employ Blockchain based storage mechanism. The Blockchain data structure permits only append of new records. Updating and deletion of records are not permissible.

The most important design feature of Blockchain based information system is use of hash pointers instead of physical memory based pointers to link blocks in a chain. A hash pointer is a message digest calculated from the information content of a block. When never a node attempts to tamper the information content, a small change in the information leads to ripple effect of changes in hash-pointers. Making it impossible to change the information once it has been recorded in the Blockchain.

Facilitating mediator-less business transactions and supporting immutability of stored information are the two significant quality attributes associated to Blockchain

based information systems. These qualify attributes are derived from replicating ledgers on all the nodes in a network and linking blocks in a chain through hash pointers.

Typically block chains are of two kinds based on how block chains are accessed i.e. private and public block chains. In a public Blockchain, any node can join and leave the network and validate the business transactions. While in case of private Blockchain the network is small and required permission to join and leave the network. Hence private Blockchains are also known as permissioned Blockchain and public Blockchain are known as permission-less Blockchain. For example, Bitcoin is a public Blockchain and Hyperledger is an example of private Blockchain.

1.4.2 Cryptography

Blockchain technology makes heavy use of cryptographic functions to assure trust among user community transacting over a Blockchain-based business network. A typical business network includes many un-trustworthy elements. In a conventional banking domain, an agent issuing the check without having sufficient balance in the account, or an agent forging a signature are typical examples. In a digitized economy, these challenges are aggravated because of information transfer over an unreliable communication medium. Hence, cryptographic functions, a set of mathematical functions, are used to encode messages to assure the security of information in a network containing malicious or un-trustworthy agents. These cryptographic functions address various purposes. Some of them are:

1) Authenticating identity of agents involved in a business transaction: Blockchain-based systems use a kind of asymmetric key cryptography. These protocols use two different keys called public and private keys, which are very large numbers. The public keys are open and used as addresses for performing business transactions while private keys are secret and used for validating the transactions. SHA-256 (e.g., Bitcoin) and ECDSA (e.g.,Hyperledger) are some of the cryptographic protocols used for this purpose. The private Blockchain use another service called membership service, which authenticates the identity for business transactions.

2) Ensuring Privacy: Maintaining the privacy of transactions is a challenge, especially in public blockchains (e.g., Bitcoin). In such systems, transactions are possible to trace to real-life identities. Advanced cryptography based techniques such as cryptographic mixers (e.g., Zerocoin) and Zero-Knowledge proof (e.g., Zerocash) have been found effective to address this challenge.

Cryptographic functions such as digital signature are also used to authenticate a particular transaction.

1.4.3 Consensus Protocols

In decentralized systems, agreeing upon the global state of the transaction is a challenge. In a centralized system, this is not an issue because only one copy of transaction history is present at the central authority (e.g. Banks main Server machine). Blockchain being a decentralized system holds multiple replicas of transactions at several nodes. Agreeing upon the unique state of the transaction is an issue which

is solved by executing a consensus process involving all the nodes in the system. This process is typically carried out in three stages. In the first phase, a node is elected/selected as a leader node to decide upon a unique state. In the second stage, transactions are validated. In the third stage, transactions are committed. A variety of consensus algorithms exists in Blockchain based system. These are often compared based upon how scalable the algorithm is and a number of malicious nodes it tolerates. The Proof of Work (PoW) algorithm used in Bitcoin is one example of the consensus protocol. It selects the leader node responsible for deciding upon a global state by solving a cryptographic puzzle. It takes about 10 mins for solving the puzzle requiring large computational work and a lot of electric energy. It can work in the presence of 50% malicious nodes in the network. The Proof of Stake(PoS) is another consensus protocol in which a leader is selected with the highest stakes in the network. It has been found scalable as compared to PoW also works in the presence of 50% malicious nodes in the network.

The Practical Byzantine Fault Tolerant (PBFT) is the third example consensus protocol which has been found scalable and works in the presence of 66% (2/3) malicious nodes in the network.

1.4.4 Smart Contracts

Smart contract the most significant element in the Blockchain based system because it provides configuring the behavior of such systems. Blockchain programmers can customize the working of Blockchain systems by writing programs called *Smart Contract*. The smart contracts are scripts which are executed when a specific event occurs in a system. For example, in the context of Bitcoin, a coin may be released when more than one signatures are validated, or when miners solve a cryptographic puzzle.

These scripts can be written in a native language provided by Blockchain systems or general purpose programmable language. For example, Bitcoin provides a simple and less expressive native language to write a smart contract while Ethereum provides a Turing complete native language called Solidity to write smart contracts. In Hyperledger, Blockchain programmers can write a smart contract in general purpose language such as Java/Go.

1.5 Promises and potential of Blockchain Technology for Humanitarian Engineering

1.5.1 Applications of Blockchain in Agriculture:

Blockchain is one of the secure and efficient technology can be used as substitute to existing methods in agri-supply chains. One of the product is developed by AgriDigital who designed the digitized platform having interface with Blockchain for agriculture businesses. While designing such platform one of the challenge faced is *mapping of physical commodity to digital*. For this, Internet of Things (IoT) techniques and various sensors are used to overcome such challenges. Second challenge was designing standards that certify the Blockchain technology is immutable and

accurate. Also data fed to system is true. And last is poor Internet connection at the various places at the time of implementation of the system.

Such platforms help to sell and buy grains, cotton, and rice etc. from grower to buyer. This platform uses cloud, IoT and Blockchain based technologies. Using these technologies all operations such as contract between grower to buyer, delivery, and payment of parties come under single interface. All data is recorded in immutable ledger. It helps to reduce food fraud by tracing the products or commodities.

The AgriDigital uses Ethereum based platform for FIE. In this auto settlement of payment to grower as the grains delivered to buyer. In the case CHB group, Raft consensus mechanism used which helps to process four transactions per second. For the payment, it used Agricoin whose price is stabilize by by legislation or as per the market operation.

Another example is Proof-of-concepts in the case of RoboBank. It facilitates the contracts between grower, buyer and RoboBank. The ownership of the commodity first transfer from grower to Robobank and then its transfer to third party as buyer sell it [**?**]. The overall benefits of such technologies are provide business opportunities and payment security to growers (farmers). This help to achieve the SDG8 as given in Table 1.2 .

1.5.2 Applications of Blockchain in Banking and Finance:

The main purpose of use the Blockchain in the banking and finance is to reduce the inter-mediator between the two different parties. It helps to save the cost which is given to third parties. It helps to achieve the SDGs are SDG1, SDG9, & SDG8. The one of the example is “Building blocks ”used by World Food Programme (WFP) to securely transfer money to refugee from Syria country in Jordan for food assistance.

1.5.3 Applications of Blockchain in Education:

1.5.4 Applications of Blockchain in Energy:

1.5.5 Applications of Blockchain in E-Governance:

1.5.6 Applications of Blockchain in Environment Science and Engineering:

1.5.7 Applications of Blockchain in Health:

1.6 conclusion

References

[1] Arya A, Klenerman L. The jaipur foot. The Journal of bone and joint surgery British volume. 2008;90(11):1414–1421.

[2] McCall B. UNDP to re-engineer funding strategy. The Lancet. 2013;381(9867):613.

[3] Fao I. WFP. 2015. The state of food insecurity in the world. 2015;p. 1–62.

[4] Organization WH, et al. WHO traditional medicine strategy 2002-2005. Geneva: World Health Organization; 2002.

[5] Goddard J, Chatterton P. Regional Development Agencies and the knowledge economy: harnessing the potential of universities. Environment and planning C: Government and Policy. 1999;17(6):685–699.

[6] Assembly G. Sustainable development goals. SDGs), Transforming our world: the. 2015;2030.

[7] Nilsson M, Griggs D, Visbeck M. Policy: map the interactions between Sustainable Development Goals. Nature News. 2016;534(7607):320.

[8] Wu J, Guo S, Huang H, et al. Information and communications technologies for sustainable development goals: state-of-the-art, needs and perspectives. IEEE Communications Surveys & Tutorials. 2018;20(3):2389–2406.

[9] Culibrina FB, Dadios EP. Smart farm using wireless sensor network for data acquisition and power control distribution. In: 2015 International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM). IEEE; 2015. p. 1–6.

[10] Singh D, Pande A, Kulkarni S, et al. Innovation for crop quality certification using ICT. In: 2015 7th International Conference on Communication Systems and Networks (COMSNETS). IEEE; 2015. p. 1–6.

[11] Rioja F, Valev N. Finance and the sources of growth at various stages of economic development. Economic Inquiry. 2004;42(1):127–140.

[12] Lund H. Renewable energy strategies for sustainable development. Energy. 2007;32(6):912–919.

[13] Ndou V. E–Government for developing countries: opportunities and challenges. The electronic journal of information systems in developing countries. 2004;18(1):1–24.

[14] Lim Jh. E-Government for sustainable development in SIDS;.

[15] Clayton T, Radcliffe N. Sustainability: a systems approach. Routledge; 2018.

[16] Deen MJ. Information and communications technologies for elderly ubiquitous healthcare in a smart home. Personal and Ubiquitous Computing. 2015;19(3-4):573–599.

[17] United Nations DoE, Affairs S. Frontier technologies for sustainable development,World Economic and Social Survey 2018;.

[18] Dinh TTA, Liu R, Zhang M, et al. Untangling blockchain: A data processing view of blockchain systems. IEEE Transactions on Knowledge and Data Engineering. 2018;30(7):1366–1385.