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BLOCKCHAIN DRIVEN SUSTAINABLE DEVELOPMENT

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Alla mia famiglia e ai miei Amici

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Abstract

The study carried out with this thesis aims to analyze the intersections of blockchain technology and sustainable development, specifically how the technology can be used to achieve the 17 Sustainable Development Goals (SDGs) announced by the United Nations in the Agenda 2030 (2015). The research focuses on the fundamental aspects of blockchain, including its evolution, characteristics, and application for fostering a sustainable future through traceability and transparency. This approach aims to promote a new vision of the world that preserves the value of our resources and ensures the future of our society.

We live in a world characterized by deep interconnections and dynamism, where we are increasingly focusing on the impacts our actions have on the environment and communities: in a context of exponential population growth and scarcity of available resources, we have understood how urgent it is to implement behaviors aimed at preserving the ecosystem and limiting waste and consequent losses of value. From International Organizations or multinational companies to small enterprises and individuals, the main objective is to '*meet the needs of the present without compromising the ability of future generations to meet their own needs'*. To achieve this goal, innovative technologies, such as the blockchain, are gaining ground and beginning to be understood and used to support the three fundamental pillars of sustainability: environmental growth, social inclusion, and economic balance.

The first chapter focuses entirely on blockchain technology and describes its history, functionality, and mechanism processes, highlighting the recent need to shift toward a more sustainable approach from the 'underlying technology of Bitcoin'.
The second chapter describes the world of sustainability. A comparison between the actions of the Club of Rome and those of the United Nations until the agreement of the Agenda 2030, with a focus on the SDGs and how technologies will help accomplish greater environmental collaboration.
The third chapter explores the power of blockchain to accelerate the process towards the achievement of the SDGs, focusing on specific Goals and providing examples of real-life projects and partnerships implementing the technology to support sustainable development.

CHAPTER 1

THE BLOCKCHAIN TECHNOLOGY

1.1 Start and Evolution of Blockchain Technology

Although the blockchain is one of the most innovative technologies of the latest century, the idea behind the blockchain was described as early as 1991 by researchers Stuart Haber and Scott Stornetta. Their main objective was to create a time stamping for digital documents that could assure authenticity. In the publication "How to Time-Stamp a Digital Document" Stornetta described a digital hierarchy system called "chains of blocks", a mechanism created specifically to represent a convenient solution to prevent the manipulation and modification of documents. At all times, for a client possessing a file that needed to be marked with the exact time and date, it was his responsibility to transmit it to a Time-Stamping Service (TSS) that recorded the information and retained a copy. At this point, whenever the integrity of the client's form was called into question, it could be compared with the archived copy at the TSS.

The employed methodology faced various critics, primarily regarding the domains of privacy preservation and the fatigue faced while archiving voluminous documents, as the time required was directly proportional to the size of the paper itself. In light of these impediments, the two scientists formulated a different solution implementing a cryptography hashing algorithm in their system, which created a unique identifier associated with the personal document, overcoming the difficulties faced.

Improving the efficiency and reliability of the system developed by Haber and Stornetta, in 1992 David Bayer, basing his studies on the existing model, introduced the Merkle trees[1], with the aim to gather as much documents as possible inside the various blocks. The tree is a data structure divided between several levels, which purpose is to relate information with a unique connected root. As roots anchored to a tree ensure its stability and absorb water and minerals needed to survive, the roots of the Merkle tree

[1] The concept of the Hash Tree, also known as Merkle Tree, takes the name from Ralph Merkle, an American cryptographer who patented it in 1979.

verify the integrity of the entire dataset, without which the security of the information can be compromised.

The tree structures and organizes large quantities of data to simplify their analysis and reduce resource waste. The Merkle tree operates when downloading files from open-source software; it divides the weight of a document into millions of different parts, each one labeled with a digest[2] resulting from the process of Hash, serving as an identifier for each part of the file, known as Merkle leaves. The values generated are paired through a second hashing process, generating the Merkle nodes and retrying providing the Merkle root (or root hash) [see *Figure 1*]. The user, at this point, will ensure that the hash obtained is the same as the one on the original downloaded document, ensuring the authenticity of the desired information. If this is not the case, the document is likely to be compromised. This type of structure allows users to verify the information contained in the blocks without the need to download the whole blockchain. The system was developed to improve research efficiency, data security, transparency, and traceability in a database.

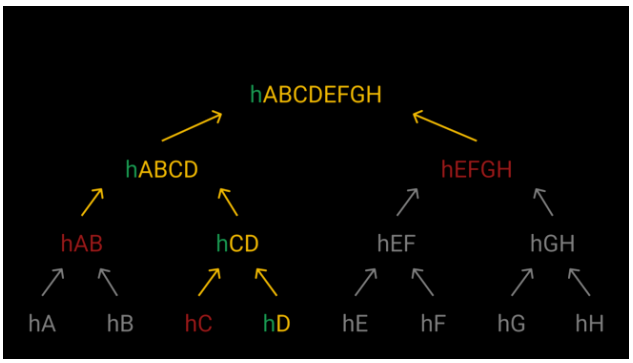

Figure 1: Binance Academy "Merkle Trees and Merkle Roots Explained"
Source: Binance Academy, 6 July 2020, academy.binance.com/en/articles/merkle-trees-and-merkle-roots-explained. Accessed 4 Apr. 2024.

Despite the revolutionary developments over the years, the technology remains unused, and its patent expired in 2004, until its latest application in 2009. The blockchain technology gained popularity thanks to the famous Bitcoin cryptocurrency. The newest

[2] A hash algorithm produces a message digest, a fixed length data string (output), developed from an input of variable length data set.

model, to date not yet updated, was recognized to be devised by Satoshi Nakamoto[3], who developed it with the aim of registering Bitcoin transactions (digital monetary transactions) from all over the world.

Facing the financial crisis of 2008, he decided to decentralize the transaction system with the purpose of having less control by banks. Nakamoto had to provide a series of rules to guarantee and maintain the integrity and security of data during transactions, ensuring privacy for users. The blockchain's main objective was to eliminate the intermediaries creating a secure system and overcoming the double-spending phenomenon. The latter could occur when an individual had the opportunity to spend several times the same value of the same currency, despite not having that value, as it had been previously spent. The problem has been defeated by introducing a system that allows users to create a network, from which anyone can control the transactions.

Over the years, the Blockchain was modified to make it more efficient and faster in its use, thanks to the application of new logic and algorithms. Blockchain 1.0 was born especially for financial applications to manage the cryptocurrency's transactions, particularly the crypto Bitcoin. Blockchain 2.0 became user-friendly, because of its simplified program language, and Turing Complete, a system that, with sufficient time, memory, and instructions, has the capability to solve whichever computational problem. It is applied to program languages that theoretically can run any algorithm, providing the resources and instructions needed. This newest version of the technology can be applied in various sectors by creating and developing smart contracts[4]. Furthermore, under the umbrella of blockchain 2.0, we have decentralized applications (DApps). DApps are applications similar to traditional apps, with the only difference being that they exploit blockchain platforms and the distributed network instead of a centralized server. They can be launched by anyone without needing approval from a central

[3] "a pseudonym used by the person or persons who developed Bitcoin and the first blockchain database" (*Wikipedia*, Wikimedia Foundation, 25 Mar. 2019, en.wikipedia.org/wiki/Satoshi_Nakamoto). The Japanese words 'satoshi' and 'naka-moto' have, respectively, the translation of 'clever' and 'center of origin' alluding to the fact that Satoshi Nakamoto is the inventor of this revolutionary technology.

[4] A smart contract can be defined as a digital code that ensures the warranty and conditions agreed by the parties. These 'contracts' are software based on the blockchain system and implemented to automate the execution of an agreement so that the parties can be immediately sure about the outcome without the need for third parties or intermediaries.

authority, gaining independence from the main marketplaces of apps, such as Apple Store and Google Play. Nowadays, the concept of blockchain 3.0 is being introduced, with the objective of relating the different blockchains and putting them in contact, allowing interoperability between them, a connection defined as Cross Chain. Another application of model 3.0 is the so-called Side Chain, which allows the creation of a network of blockchains with the perspective of letting it appear as a single blockchain through separate networks that have their own validators connected bilaterally to the main network. Those concepts are becoming increasingly important, and the technology allows for major improvements in the various sectors where it can be implemented.

In recent years, it has been demonstrated that Blockchain technology is an efficient means of exchanging value, but it has also become much more interesting with its application throughout numerous industries fields. For instance, within the industrial sector, the article "A Review of Blockchain Solutions in Supply Chain Traceability" by Xiaofeng Zhang, and Li Ling (*Tsinghua Science and Technology*, vol. 28, no. 3, 3 June 2023, pp. 500-510, https://doi.org/10.26599/TST.2022.9010030) examines the use of blockchain for tracking and verifying the supply chain of manufactured goods, from production to delivery. In the medical sector, publications such as "Blockchain Technology for Improving Clinical Research Quality" by Mehdi Benchoufi, and Philippe Ravaud (*Trials*, vol. 18, no. 1, 19 July 2017, https://doi.org/10.1186/s13063-017-2035-z) and research conducted by the Journal of the American Medical Association (JAMA)[5] explain how this technology can significantly improve privacy, security and interoperability for health records by enabling a decentralized and protected system. In the energy sector, studies conducted by the University of Waterloo[6] and the Massachusetts Institute of Technology (MIT)[7] show how the use of blockchain can lead to improvements in the use of renewable energy sources, ensuring the integrity and transparency of transactions in energy markets.

[5] "How Blockchain Technology Will Reshape Health Care" *American Medical Association*, 26 Dec. 2018, www.ama-assn.org/practice-management/digital/how-blockchain-technology-will-reshape-health-care.
[6] University of Waterloo "Blockchain for Green Energy | Mathematics" *Uwaterloo.ca*, uwaterloo.ca/math/blockchain-green-energy.
[7] "How Blockchain Technology Could Give Us a Smarter Energy Grid" *MIT Technology Review,* 16 Oct. 2017, www.technologyreview.com/2017/10/16/148584/how-blockchain-could-give-us-a-smarter-energy-grid/.

The influence of this technology in multiple business models has created new products and services thanks to its new operating logic. The system is defined as functional and cutting-edge due to the characteristic of being a shared register that makes it immutable.

1.2 An Insightful Dive into Distributed Ledger Technology

"A blockchain is a distributed ledger with growing lists of records (blocks) that are securely linked together via cryptographic hashes. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data (generally represented as a Merkle Tree, where data nodes are represented by leaves). Since each block contains information about the previous block, they effectively form a chain (compare linked list data structure), with each additional block linking to the ones before it. Consequently, blockchain transactions are irreversible in that, once they are recorded, the data in any given block cannot be altered retroactively without altering all subsequent blocks." (Wikipedia. "Blockchain." *Wikimedia Foundation*, 14 Mar. 2019, en.wikipedia.org/wiki/Blockchain. Accessed 8 Apr. 2024).

The blockchain is nothing more than a decentralized ledger that uses cryptography to enable secure transactions; the technology permits people to exchange not only transactions but also properties. A central authority has been eliminated, thus creating a network between people who do not know each other and have no reason to trust each other, allowing transactions that are safe without the need for a guarantor. The ledger is distributed between several individuals, and it is shared by all the users who operate inside a determined network of computers based on specific technologies. Now, the most common and functional is the blockchain based on peer-to-peer technology[8].

Blockchain is a particular technology that belongs to Distributed Ledger Technology (DLT) systems, a database that allows the storage of data across multiple sites, countries, or institutions. They are not the same thing, but blockchain is a type of DLT. The latter decentralized the system, ensuring there is no need for guarantees like there is

[8] P2P (peer-to-peer) is a network where a series of devices share and archive files altogether. Each user (node) operates individually (peer) and has the same functions and powers. A P2P platform enables buyers and sellers to trade directly without intermediaries.

for banks. This technology allows each node to have a copy of data and transactions, enabling duplication to be archived between different network nodes. The ledger is shared simultaneously by different parties to prevent theft, deletion, and falsification of documents, as well as to avoid human errors. A DLT is a transparent and immutable system given that all the nodes have equal rights on data, and all the decisions are taken collectively through consensus mechanisms[9]. Furthermore, compared to a centralized database, this broad network is more secure against cyber-attacks due to its decentralized nature; being that it has multiple points of control, it is extremely difficult for attackers to alter data without detection. It is a system highly resilient to data loss or corruption, and in fact, if one node fails, the data can be recovered from other nodes.

1.3 Key characteristics and functionality of Blockchain

The main features of a blockchain that allow its proper functioning are the following:

- Nodes: the nodes are all the users in the P2P network.
- Transactions: the individual pieces of data stored within the different blocks.
- Blocks: collection of verified and approved transactions by the participants of the network.
- Ledger: register in which the various details of the transactions are recorded and inserted sequentially to ensure transparency and immutability.
- Hash Code: the blocks are interlinked by the Hash code, an alphanumeric sequence, obtained from a particular algorithm.

As previously mentioned, the blockchain is a type of Distributed Ledger Technology that differs from other types in that it stores data in a single file, distributed across various blocks linked together in a chain. A DLT typically performs CRUD operations, which stand for Create, Retrieve, Update, and Delete:

- Create: allows the creation of certain information
- Retrieve: allows the possibility of retrieving a certain information

[9] The consensus mechanisms are explained in section 1.4. They determine how agreement is reached among nodes. Specifically, the two most known processes are the Proof of Work (PoW) and the Proof of Stake (PoS).

- Update: allows the updating of the information
- Delete: allows the elimination of the information

Only two of the four functions are present in the blockchain context: Create and Retrieve, ensuring data integrity and immutability. Due to this, blockchain is designed to always expand, as it is impossible to delete data from it. Moreover, the system operates on a decentralized peer-to-peer web where all participants have a copy of the data present in the rest of the network. This ensures the blockchain's security by requiring the simultaneous hacking of 50% of the shared nodes in the ledger.

Each block forming the chain of this system is composed of seven elements:

- Data: stored data present in the blocks related to what the blockchain allows to be exchanged.
- Hash: alphanumeric code unique for each block. The fundamental part is that by modifying whatever data is inside a block, the hash code will automatically change, generating an inconsistency with the other blocks of the chain.
- Prev. Hash: the hash code relevant to the previous block; used to ensure correspondence between the new block and the previous one.
- Merkle root: corresponds to the digest resulting after hashing all the transactions present in a block later combined together.
- Timestamp: the timestamp of the most recent transaction among those entered in the block.
- Bits: block creation and validation value, corresponding to the maximum threshold of acceptability of the block digest value.
- Nonce: value, generated through a trial-and-error method, that reduces the block digest below the value specified in the Bits field (a random number added to a block to satisfy a specific condition).

Figure 2 is a graphic representation of a chain of blocks, with each one linked to the subsequent one by a hash code. On the left of the first block, there is the Prev. Hash, while on the right, is present the Hash of the block itself.

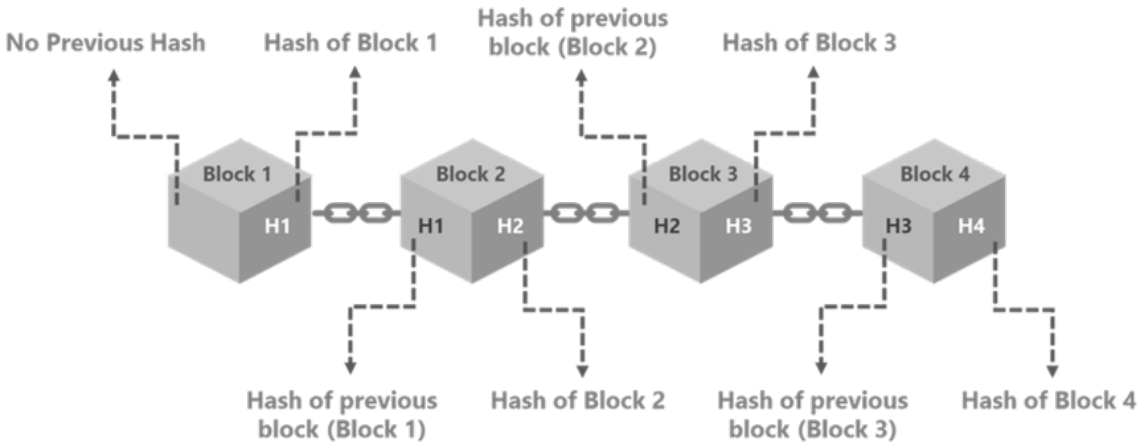

Figure 2: What is a block in a Block in a Blockchain?
Source: Brew, Techskill. "What is a Block in the Blockchain? (part 2-Blockchain Series)" *Medium.com*, 26 Dec. 2021, medium.com/techskill-brew/what-is-a-block-in-the-blockchain-part-2-blockchain-basics-53ad20c766cc. Accessed 10 Apr. 2024

This system works by ensuring the integrity of the previous block, which is then connected to the next block in sequence, all the way up to the very first block in the blockchain (also known as the genesis block). By using this method, it is possible to establish a chronological order for the blocks, which helps to solve the double-spending problem.

1.4 Proof-of-Work and Proof-of-Stake

The hash code serves the purpose of making the system immutable and difficult to attack. However, a weak point exists in the insertion of new blocks. The blockchain network requires almost unanimous approval from all users to add a block to their copy of the blockchain. Anyone could add a new block considering the previous one, for this reason, there is a need for a consensus protocol. Furthermore, it would be important to understand how to bypass definitely the double-spending phenomenon in a decentralized network.

Double-spending is a problem associated with the exchange of digital goods; the issue does not apply to physical goods. Across the internet, information can be traded multiple times. However, the problem arises when that information has a value that needs to be maintained and exchanged for something else. The key is to make the

information unique, and once it is no longer in the hands of the first owner, the new owner retains access. When the Timestamp was first introduced, it seemed a reliable solution since it allowed everyone to trace the history of the transactions. Unfortunately, knowing the time and date is not sufficient anymore. Nowadays, exploiting latency, computers, especially those with big computing power, publish millions of transactions, all with the same date. In this case, users who have the task of validating the block will be unable to perform the function. The only solution is to limit the possibility of each computer publishing information and inserting new transaction blocks into the chain.

There are two main consensus algorithms that blockchain uses to achieve majority approval. The consensus mechanisms permit a secure blockchain and verify the validity of a transaction by any user of the network. The two diverse types differ from one another since the Proof-of-Work (PoW) appears to be much safer against fraud or irregularities as it allows a large distribution of users. On the contrary, this algorithm requires a significant amount of electricity and incurs high energy costs. This is because the machines require extensive computing power, unlike Proof-of-Stake (PoS).

In 2008, Satoshi Nakamoto developed the Proof-of-Work algorithm. This function involves nodes (users), competing with each other, solving a mathematical problem to reach the top of the mining process. The latter is a validation procedure that consumes large amounts of electricity, leading to a prize consisting of Bitcoins, or other types of cryptocurrencies, and transaction fees. In order to guarantee the research and validation of operations, miners must maintain constant time intervals to enable the addition of new blocks to the analyzed blockchain. The first miner who finds a valid nonce, a random number that meets a certain difficulty target, gets to publish the new block and receive the prize.

On the other hand, Proof-of-Stake is an alternative consensus mechanism. It was developed to drastically simplify the mining process and improve the scalability of the Proof-of-Work. This algorithm aims to decrease the energy consumption derived from it by replacing the traditional mechanism with a system in which users validate transactions using already existing cryptocurrencies that they own (an amount of stake

or ownership they have in the network). This eliminates the need for a dedicated mining process and reduces energy waste.

This process may seem risky for the nodes as they are mandated to deposit a certain amount of their cryptocurrencies into the network, which can put their coins at risk of possible cyber-attacks, thereby jeopardizing their security. The reward for this operation increases as the number of deposited coins increases. For this reason, miners, with majority or supermajority consent, take the risk with the hope of obtaining more cryptos. Just like in the economy, the more risk involved, the higher the potential gain.

1.5 Sustainable Blockchain with PoS Algorithm

Comparing the two different consensus mechanisms, it can be seen how Proof-of-Stake is an alternative solution created to meet the new demands for waste reduction and environmental sustainability. It not only lowers the cost associated with the decrease in used electricity but also saves consumption derived from all the users in the network who try to earn the coins, which, in the end, only one user will successfully manage to obtain.

The PoS algorithm offers a significant advantage in reducing electronic waste. The enormous quantity of devices used by miners to extract data eventually becomes garbage after being consumed or rendered unsuitable. Electronic devices are complex and difficult to recycle, making their disposal more complicated and harmful to the environment.

Several studies have shown that the Proof-of-Work algorithm, used by major blockchains such as Bitcoin and Ethereum (representing 60% of the total cryptocurrency market), consumes excessive energy. For instance, the White House published: “ As August of 2022, published estimates of the total global electricity usage for crypto-assets are between 120 and 240 billion kilowatt-hours per year, a range that exceeds the total annual electricity usage of many individual countries, such as Argentina or Australia. This is equivalent to 0.4% to 0.9% of annual global electricity

usage, and it is comparable to the annual electricity usage of all conventional data centers in the world." ("Climate and Energy Implications of Crypto-Assets in the United States". *The White House*, 8 Sept. 2022, www.whitehouse.gov/ostp/news-updates/2022/09/08/fact-sheet-climate-and-energy-implications-of-crypto-assets-in-the-united-states/ . Accessed 19 Apr 2024.)

The significant energy consumption leads to extensive emissions from non-renewable sources. This is because most mining activity occurs in regions with low-priced electricity, often generated from fossil fuels like coal or natural gas. This contributes to greenhouse gas emissions and climate change, making PoW unsustainable from an environmental perspective. However, switching to the Proof-of-Stake consensus mechanism "could drastically reduce overall power usage to less than 1% of today's level" (*The White House*). A graphical representation has been provided for the purpose of supporting this thesis. *Figure 3* displays the energy consumption and CO_2 emissions of the two major cryptocurrencies using the PoW and the drastic reduction of Ethereum before and after it transitioned in October of 2022 from the PoW to a greener solution, the PoS.

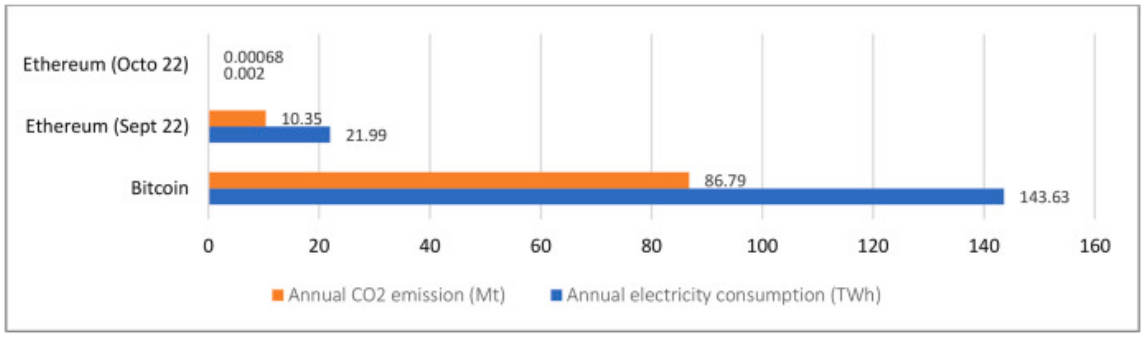

Figure 3*:* Annual electricity and CO_2 emission for Ethereum and Bitcoin (based on (CCRI, 2023))
Source*:* Mishra Alok and Yehia Ibrahim Alzoubi. "Green Blockchain – a Move towards Sustainability." *Journal of Cleaner Production*, vol. 430, no. 139541, 10 Dec. 2023, pp. 2–3. Science Direct, https://doi.org/10.1016/j.jclepro.2023.139541. Accessed 19 Apr 2024.

CHAPTER 2

DRIVING SUSTAINABLE DEVELOPMENT: THE ROLE OF THE SDGs

2.1 The genesis of Sustainable Development

In 1987 the World Commission on Environment and Development (WCED), also known as the United Nations Brundtland Commission, defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" ("Report of the World Commission on Environment and Development: Our Common Future". *UN*, 4 Aug. 1987, Accessed 26 Apr. 2024). A definition that marked a turning point in the global understanding of the relationships between economic development, environmental preservation, and social equality, laying the groundwork for a new model of worldwide progress.

The concept of sustainable development has deep roots that can be traced even before the late 1980s. In fact, it was already recognized ten years earlier when Aurelio Peccei, an Italian entrepreneur and manager of the Fiat, and Alexander King, a scientist, founded the Club of Rome in 1968. This organization was one of the first to explore the implications of unlimited growth within a planet of limited resources, whose members share the same concerns regarding the future of humanity and attempt to make a difference.

In September 1969, Peccei traveled to Alpbach, Austria, to participate in a conference. The participants, after a long discussion, found themselves in "agreement that the most promising way of pursuing our goals was to present and analyze the global problem through the systematic use of global models" (translated from Aurelio Peccei, "La qualità umana", *The human quality*, 1976, p. 90). In 1971, an American computer engineer, Jay Forrester, commissioned by the Club of Rome, developed the

problématique[10] model and called it World 1, which conclusions made it clear that in a world of limited resources, the continuous growth of the dynamics of the *problématique*, such as population growth and pollution, would eventually lead to the collapse of the system. After that, it was decided that it was necessary to delve deeper into the data needed to describe the key elements of the global issue. However, the description of the world would continue to be based on the five variables used by Forrester in his World 1 and World 2 models: population, availability of food, industrial production, non-renewable resources, and pollution.

The main concern for Peccei was that this project would not serve the purpose of its function, fade away in time, or become just an academic study. For this reason, the Club published a report developed in 1972 by the System Dynamics of MIT in Boston, entitled "Limits to Growth", a public version of the project conclusions. Even not using the term 'sustainable development', they anticipated numerous key concepts that were later formalized in the Brundtland Report. The three main conclusions of the report are:

1. The world cannot support the steadily increasing population, industrialization, and pollution. If this remains unchanged, the limits to growth on the planet will be reached in the next one hundred years, resulting in an uncontrollable decline in both population and industrial capacity.
2. Altering these growth trends can establish a condition of ecological and economic stability that is sustainable far into the future.
3. If the people of the world choose to pursue the second outcome instead of the first, they should start working towards it as soon as possible to improve their chances of success.

(based on "Limits to Growth – Abstract by Eduard Pestel". A report to the Club of Rome, 1972, by Donella H. Meadows, Dennis L. Meadows, Jorgen Randers, William W. Behrens III, Accessed 29 Apr. 2024).

The report used computerized models to predict the effects of population growth and resource exploitation. Concluding that unlimited economic expansion was

[10] "a cluster of intertwined global problems, be they economic, environmental, political or social" (Club of Rome, "History", https://clubofrome.org).

unsustainable, the Club of Rome called for a radical review of global development practices. At the same time, the United Nations (UN), an international organization established in 1945 to promote peace and global security, consisting of 52 member countries at the time (today 193), convened the first conference on the environment in Stockholm in 1972. This event marked the beginning of a coordinated international effort toward sustainability and the implementation of environmental and development policies, emphasizing the interdependence between humans and the environment.

Subsequent to the Brundtland report, in 1992, held in Rio de Janeiro, Brazil, the UN Conference on Environment and Development (UNCED), better known as "Earth Summit," was the most inclusive meeting until that point, with 172 governments. It brought to life the Agenda 21, with the '21' referring to the initial target of achieving sustainable development by the XXI century. The Rio Summit has also led to the formulation of three important environmental conventions: the United Nations Framework Convention on Climate Change (UNFCCC), to combat global warming and its effects, the Convention on Biological Diversity (CBD), focused on the preservation of the ecosystem, and the Convention to Combat Desertification, created to counteract desertification and mitigate the effects of drought.

Alongside the efforts of the UN, the Club of Rome continued its publication encompassing global sustainability issues and politics necessary to mitigate the potential risk of an ecological collapse, broadening the discussion on the matter. In 1991, A. King and Bertrand Schneider released "The First Global Revolution", in which the founders discussed how interconnected global crises require a coordinated response that involves a revolution in thought and in action; only a holistic approach can solve them efficiently. Exactly 20 years after the first publication of the Club, in 1992, it was released the sequel, "Beyond the Limits". The authors, Donella and Dennis Meadows, and Jorgen Randers, support the thesis that humans have overcome many times the sustainable limits of economic development and there was a need to take immediate and significant actions to avoid serious global consequences. Only four years later, in 1996 another founder of the Club of Rome, Eduard Pestel, in the book "Beyond Growth" examines the matters regarding the steady economic growth and its unsustainability.

The efforts of the Club of Rome to stimulate critical thinking and global debate around sustainable development and resource management were cutting-edge. Their ideas often anticipated and influenced discussions and policies at a global level. During the 1990s, while the Club focused on rigorously examining the economic models required for a shift towards acknowledging the planet's limited boundaries, the United Nations attempted to translate the principles of sustainability into actionable measures through global assemblies.

In 1997 the UNFCCC adopted the Kyoto Protocol, "the first international agreement that contains the commitments of industrialized countries[11] to reduce the emissions of some greenhouse gases, responsible for global warming" ("The Kyoto Protocol" – *ISPRA*, *Istituto Superiore per la Protezione e la Ricerca Ambientale*, www.isprambiente.gov.it/en/ispra-services/forms-and-services/Emission-Trading-registry/context/the-kyoto-protocol. Accessed 1 May 2024).

The Member States in the year 2000 launched the Millennium Development Goals (MDGs) [refer to *Figure 4*] during the occasion of the UN Development Programme (UNDP) Summit, with the participation of 192 countries and 23 global organizations. The Millennium Declaration was approved, aiming to achieve the goals within fifteen years.

Figure 4: The eight Millennium Goals
Source: UN, https://www.un.org/millenniumgoals/. Accessed 2 May 2024

[11] Listed in Annex I of the UNFCCC.

The global effort towards Agenda 21 was revitalized in 2002 with the World Summit on Sustainable Development held in Johannesburg, South Africa, where clear priorities and implementation strategies were identified. It "resulted, after several days of deliberations, decisions that related water, energy, agriculture, biological diversity and other areas of concern." ("World Summit on Sustainable Development, Johannesburg 2002", *UN*, 2002, https://www.un.org/en/conferences/environment/johannesburg2002. Accessed 2 May 2024).

At a later date, marking the 20th anniversary of the Rio Conference, the assembly Rio+20 (2012) reaffirmed the commitment to achieve a sustainable future. For the first time in history it was coined the acronym SDGs; the Member States, building the project around the MDGs, launched the Sustainable Development Goals (SDGs). Those were later formalized in 2015 with the adoption of the Agenda 2030, including these 17 Goals intended to guide global politics until 2030. In the same year, the UN reunited in France, signed the Paris Agreement, which represented a crucial moment for the 192 states committed to the fight against climate change, devoted to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" (Official Journal of the European Union, "International Agreements", council decision (EU) 2016/1841, 5 Oct. 2016, p. 1, Accessed 4 May 2024).

On the other hand, from 2015 until today, the Club of Rome has remained influential in promoting sustainable development strategies through debates and publications addressing environmental challenges. Some of its most important publications can be traced to the years 2016, with "Reinventing Prosperity", a book suggesting thirty-three proposals on numerous matters, such as reducing economic inequality, addressing climate change, and implementing radical changes in politics, and 2018, with an action document proposing immediate measures to address the climate change emergency, entitled "The Climate Change Plan". Additionally, in 2019, the organization launched the "Planetary Emergency Plan", a plan of action drawing attention to the interconnected crises of biodiversity, climate, and pollution, while in 2021, a program targeted to catalyze transformative changes in society, promoting a circular economy approach. Their latest publication based on "Limits to Growth", proposing an updated

analysis, was published in 2022, with the title "Earth for All: A Survival Guide for Humanity".

2.2 Understanding the SDGs

The year 2015 was of fundamental importance for sustainable development, as outlined in section 2.1. This significance can be attributed to the publication "Transforming our world: the 2030 Agenda for Sustainable Development" which was released and approved in September of the same year, during the Earth Summit in New York. It was the result of two years of work started at the end of the United Nations Conference on Sustainable Development (UNCSD), also known as the Summit Rio+20, where from the conclusion report of the assembly "The Future we want" emerged the need to further integrate the economic, social, and environmental aspects of sustainability, while paying attention to the interconnection between them.

The Member States, through "The Millennium Development Goals Report 2015", finally recognized how the goals achieved were uneven and not sufficiently satisfactory in different thematic areas of global interest and stressed the need to pursue the path of sustainability with a new set of goals.

It started a process of replacement and update of the MDGs to what will result in the origin of the SDGs, thanks to the Open Working Group (OWG) institution[12]. Those should be inspired by global actions and universally applicable to all signatory countries, keeping in mind each of the different national realities and priorities, as well as the capacity and levels of development. Moreover, the Goals should be coordinated and limited in numbers, easily communicable, and a source of inspiration for the subjects who have to receive them (based on "The Future we want").

The scope of the OWG was reached in July 2014 with the publication "Report of the Open Working Group of the General Assembly on Sustainable Development Goals", in

[12] The OWG is an intergovernmental association, formed in 2013 after the release of "The Future we want" (2012). Its aim was to elaborate the Goals to present to the UN General Assembly.

which there were explained the 17 SDGs, then presented to the seventy-eighth UN General Assembly, that, little to say, approved unanimously together with the Agenda. The Goals, as the former Minister of Labor and Social Policy of the Government Letta and today spokesman for the Italian Alliance for Sustainable Development (ASviS), Giovannini, declared in 2019 in his book "L'Utopia Sostenibile" ('*The Sustainable Utopy*'), regard all the dimensions of human life and Planet[13]. Each one of the Objectives is associated with some Targets, counting for a total of 169, which represent not only an operative guide to orient the initiatives of the international organizations and political decisions of the national governments but also a tool to explain the content of the SDGs clearly (Giovannini stated). Moreover, the Targets are characterized by being interconnected and indivisible to the different Goals to which they are associated.

Figure 5 shows the set of SDGs presented in the publication "Transforming our world: the 2030 Agenda for Sustainable Development" (2015):

Figure 5: Sustainable Development Goals
Source: UN, https://www.un.org/sustainabledevelopment/news/communications-material/. Accessed 6 May 2024.

Elaborating on the Sustainable Development Goals, the United Nations focalized their attention on five macro intervention areas of crucial importance, defined by ASviS as

[13] Translated from "riguardano tutte le dimensioni della vita umana e del Pianeta", p. 39, L'Utopia Sostenibile (2019) by Enrico Giovannini.

the five "P" of sustainable development. They can be summarized as People, Planet, Prosperity, Peace, and Partnership with the following definitions[14]:

- People: determination to end poverty and hunger in all forms to ensure that humans, in a healthy environment, can fulfill their potential in dignity and equality. Combined in this category are Goals 1, 2, 3, 4, and 5.
- Planet: implementing sustainable consumption and production, the management of natural resources, and limiting climate change to protect the planet from degradation. Combined in this category are Goals 6, 12, 13, 14, and 15.
- Prosperity: taking that economic, social, and technological progress occurs in harmony with nature, the determination to ensure that all humans can enjoy prosperous and fulfilling lives. Combined in this category are Goals 7, 8, 9, 10, 11.
- Peace: the determination to foster peaceful, just, and inclusive societies that are free from fear and violence. Represented by Goal 16.
- Partnership: requiring global cohesive work, such as solidarity and participation from all stakeholders and all people, for Sustainable Development. Represented by Goal 17.

The Agenda, which requires full implementation by 2030, is particularly relevant in that all the 193 countries belonging to the UN have subscribed to the document and have pledged to respect the commitment arising. The declaration of the United Nation Organization in fact, states: "never before have world leaders pledged common action and endeavor across such a broad and universal policy agenda" ("Transforming our World: the 2030 Agenda for Sustainable Development", 2015, p.18). For this reason, it has become of major importance for the Member States, and this is also confirmed by Giovannini. The author of "L'Utopia Sostenibile" in his interpretation of the Agenda outlines three essential aspects identified as "innovative characteristics": the universality, the necessary participation of all to the change, and the integrated vision of the problems and actions to be implemented to achieve sustainable development (translated from p. 41).

[14] Definitions based on the report of the UN "The 5Ps of the Sustainable Development" (https://www.unescwa.org/sites/default/files/inline-files/the_5ps_of_the_sustainable_development_goals.pdf).

This third characteristic recognized by Giovannini permits the deepening of the distinctive features of the SDGs. The interconnection between them, as the Agenda states in paragraph 17: "there are deep interconnections and many cross-cutting elements across the new Goals and Targets", is a distinguishing feature of the Objectives. This aspect is also present in the document published by the Eurostat, in May 2020, entitled "Sustainable Development in the European Union: Monitoring report on progress towards the SDGs in an EU context". It underlines how it is fundamental to understand the connection between them to fully acknowledge their potential and to prevent them from being pursued and achieved in one area at the expense of another.

The integrated approach that designates the Agenda has to be considered not only as an element that generated the SDGs and Targets but also, as ASviS stated, an element that promotes the connection between the sustainable development dimension and the one of the Goals. The Italian Alliance proceeded to emphasize, starting from the three pillars of sustainability (environmental, social, and economic), how these Goals are closely related and need to be analyzed with a systematic approach that considers the interrelation between the three.

In line with what has just been stated, the "2020 SDGs Report" published by the Italian National Institute of Statistics (Istat) proposed the division of the 17 Goals by areas of belonging [shown in *Figure 6*].

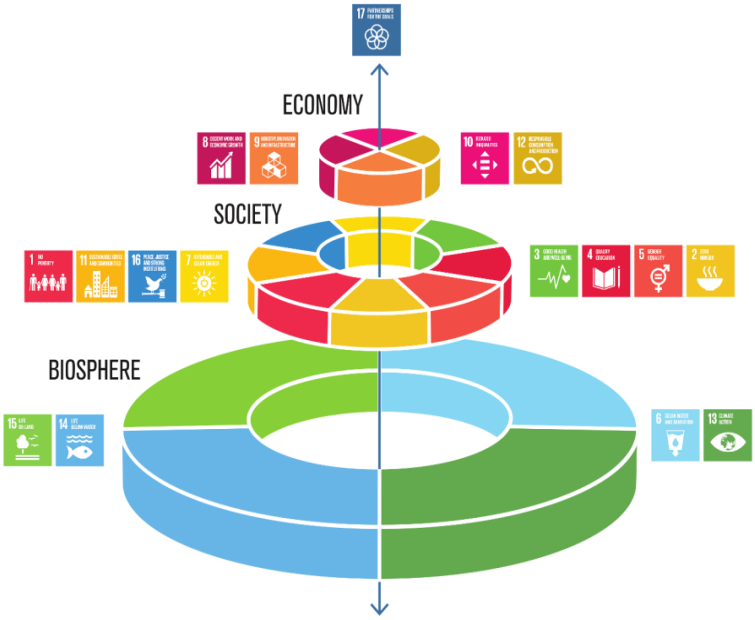

Figure 6: The SDGs wedding cake
Source: Stockholm Resilience Center, https://www.stockholmresilience.org/research/research-news/2016-06-14-the-sdgs-wedding-cake.html. Accessed 8 May 2024.

In conclusion, the Agenda is presented as a "plan of action for people, planet and prosperity" ("2030 Agenda"). From a global viewpoint, its presentation, with the interconnected Goals, represents a critical passage to embark on the decisive step towards implementing sustainable behaviors, as previously mentioned, not only from an environmental point of view but also from a social and economic point of view. Even the European Commission, with the document "A Sustainable Europe by 2030" (30 Jan. 2019), affirms how the Sustainable Development Goals provide a roadmap for achieving international cooperation aimed at improving sustainable development issues.

2.3 Challenges and Opportunities in SDG Implementation

The Agenda (2015) stated that the document must be implemented by all signatory countries, regardless of their level of development, at both the national and regional levels. It also recognizes how regional economic integration can favor the transition from political commitments to concrete actions in realizing the Goals. The achievement of the SDGs, in each country, without any distinction, has to be done through the preparation of appropriate national strategies, meaning that it does not in any way preclude the authority of individual countries within their territories, but recognizes,

instead, the primary role played by the respective Parliaments, for example through the implementation of laws or the adoption of budgets, in realizing the content of the Agenda.

The UN has detected in the "Addis Ababa Action Agenda," presented in July 2015 during the third edition of the International Conference for Financial Development, the critical implementation framework for financing the actions necessary to pursue the Objectives set out in the Agenda. Moreover, the "2030 Agenda" established, as an essential instrument, the High-Level Political Forum (HLPF)[15] in order to facilitate global monitoring and review. HLPF partners with the United Nations Economic and Social Council (ECOSOC), which plays the key role in overseeing tracking and assessment processes. This collaboration, as stated by the UN (2015), has the task of facilitating shared experiences and challenges learned during the pursuit of the SDGs. Furthermore, it provides political leaders recommendations from monitoring while also promoting the coherence and coordination of the various sustainable development policies implemented by the signatory countries. However, in 2019, the HLPF underlined with their disclosure "Global Sustainable Development Report" (GSDR) the considerable delay in pursuing some of the 17 Goals. For this reason, as stated by Istat (2020), to intervene in healing the gap in reaching those, the UN has launched the program "Decade of Action" to redirect and accelerate the pursuit. In addition, the Istat declared how, in the context presented by the report GSDR, the "Voluntary National Review" (VNR) played an essential role and are of considerable importance. They represent some of the mechanisms to monitor and revise the Agenda, and their scope is to favor the shared experiences matured over the 142 countries present at the moment of the Report. Other than the VNR, the ASviS dispensed another instrument, denominated "Voluntary Local Reviews" (VLR), having the aim for regional authorities to undertake the commitment and present to the HLPF the progress achieved in the SDGs fulfillment.

The question at this point regards the modalities with which the monitoring and verifying happen. The Agenda identified for this purpose a series of Indicators, stating: "this framework will be simple yet robust, address all Sustainable Development Goals

[15] The main UN platform for the follow-up and review of the "2030 Agenda" for the 17 SDGs.

and targets, including for means of implementation, and preserve the political balance, integration and ambition contained therein" (par. 75). In March 2016, during the forty-seventh session of the UN Statistic Commission, it was presented by the Inter Agency Expert Group on SDGs a list of 200 indicators divided in three sections: Tier I, II, and III[16]. However, due to the deadlines scheduled by the Italian National Statistics Institute for 2020 and 2025 for the purpose of ensuring constant updating, the last revision classified a total of 248 Indicators. Lastly, the United Nations (2015) encouraged Member States to identify a regional body allowing such monitoring and verification mechanisms, accentuating the fact that the HLPF "will be informed by an annual progress report on the Sustainable Development Goals to be prepared by the Secretary-General in cooperation with the United Nations systems, based on the global indicator framework and data produced by the national statistical systems and information collected at the regional levels" (par. 83).

In recent years, the European Commission has confirmed several times its willingness to commit to achieving the Objectives through many publications, such as "A Sustainable Europe by 2030" (2019). A particular importance has given to the President of the European Commission Ursula Von Der Leyen, which has made sustainability, and more precisely, the SDGs, the cornerstone on which are based the priorities of her presidency for the entire length of the mandate (2019-2024). In her programme for the presidency "A Union that Strives for More – My Agenda for Europe", made public in 2019, she presented the Political Guidelines that "focus on six headlines ambitions for Europe over the next five years and well beyond: a) A European Green Deal, b) An economy that works for people, c) A Europe fit for the digital age, d) Protecting our European way of life, e) A stronger Europe in the world, f) A new push for European democracy" (Ursula Von Der Leyen, "A Union That Strives for More – My Agenda for Europe", 2019. https://commission.europa.eu/system/files/2020-04/political-guidelines-next-commission_en_0.pdf. Accessed 12 May 2024). The EU Statistical Office (2020) points out that all the Goals can be found in at least one or more of the six priorities

[16] Tier I represents the indicators with an established methodology and regularly produced by the countries. Tier II are the indicators not regularly produced by countries, and Tier III includes the one without established methodologies or standards. Additionally, some indicators belong to more than one of the mentioned levels.

announced by the President of the Commission in such a way that the EU's programs and strategies will concretely promote the achievement of what is contained in the Agenda.

However, not long after Von Der Leyen became President, Covid-19 was spread, entirely affecting how humans live, work, and relate globally. The year 2020 has had a significant impact, not necessarily a negative one, in achieving the Sustainable Development Goals. To support this thesis *Figure 7* has been taken from the article "Progress towards the Sustainable Development Goals has been slowed by indirect effects of the COVID-19 pandemic" (by Yuan H., Wang, X., Gao L., *Commun. Earth Environ.* 4, 184 (2023). https://doi.org/10.1038/s43247-023-00846-x. Accessed 12 May 2024).

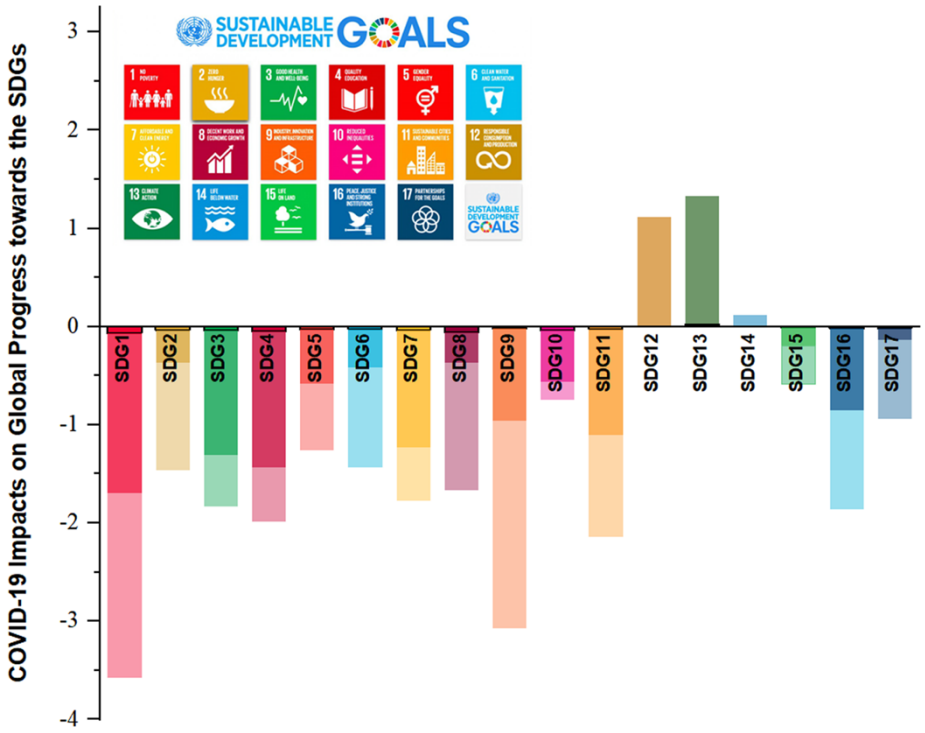

Figure 7: Covid-19 Impacts on Global Progress towards the SDGs
Source: https://www.nature.com/articles/s43247-023-00846-x/figures/4. Accessed 12 May 2024.

Figure 7 displays the total impact of Covid-19, combining direct (darkest color) and indirect (lighter color) shock loss and growth delay loss (lightest color). A positive value suggests a positive effect on the SDGs, while a negative value indicates a negative

effect. The impact on the SDGs is measured by the change in the SDG index (a score representing the progress toward achieving each SDG) by 2030 after Covid-19 (based on the description of the article "Progress towards the Sustainable Development Goals has been slowed by indirect effects of the COVID-19 pandemic").

In the last "Sustainable Development Report" of 2023, the Sustainable Development Solutions Network (SDSN) defined the SDGs as still reachable but achieving them requires double the effort.

2.4 Towards a sustainable future: Innovation and Technology

As the world struggles with escalating environmental challenges, technology has become vital to achieving a sustainable future; environmental, social, and economic sustainability cannot exist without digital technologies. After the Covid crisis, attention has centered on protecting the Planet and conserving natural resources, leveraging the green and the digital, as the Next Generation EU[17] states in its recovery plan.

According to Stefano Epifani, author of the book "Sostenibilità Digitale" ('*Digital Sustainability*') and President of the Digital Sustainability Foundation, digital sustainability defines the way in which new technologies will have to be developed to help contribute to the creation of a better world, with respect to its Nature and its instrumental role for the environment, economy, and society. Long before the recent acknowledgment of the matter, in 2001 the Global e-Sustainability Initiative (GESI) was formed; it claimed and still argues that digital transformation has the potential to contribute to the achievement of all the 17 SDGs. Furthermore, S. Sparviero and M. Regnedda in their publication "Towards digital sustainability: the long journey to the sustainable development goals 2030" pointed out how "digital technologies can provide an important contribution to the realization of a sustainable future through a variety of different paths, but only if they are applied by public and private actors for reaching the

[17] The Next Generation EU, also known as the European Union Recovery Instrument, was adopted by the European Council on 14th December 2020.

same cluster of universal, terminal values[18]" (Digital Policy, Regulation and Governance, 2021, pag. 217, Vol. 23 No. 3, https://doi.org/10.1108/dprg-01-2021-0015. Accessed 15 May 2024). However, to use technology efficiently, individuals need to have a high level of digital literacy. For the latter, in 2018, the UNESCO[19] published the document "A Global Framework of Reference on Digital Literacy Skills for Indicator 4.4.2" underlying how digital literacy is an essential component throughout the Sustainable Development Goals. As a matter of fact, Goal 4.4 aims to increase the number of individuals with specific skills, such as computer literacy, ICT (Information and Communication Technologies) literacy, and computer and media literacy, intended to help them secure employment in decent jobs and for enterprises.

When it comes to digital sustainability, it is crucial to use digital technologies in a way that optimizes universal values, enhances quality of life, and positively impacts society and the economy while safeguarding the ecosystem. In such cases, businesses play a central role in constantly adapting to the persistent evolution of technologies with the purpose of having success and reaching digital sustainability. It is important that the business organizational structures are flexible so that can easily adapt to environmental changes and modify positioning in the market, making new strategic decisions. One of the focal points of digital sustainability regards, in fact, the ability of companies to integrate digital technology into the business environment and adapt it to management processes. For this reason, managers and entrepreneurs need to be able to choose the most appropriate technologies with respect to the organization and support the value-added innovations to achieve digital sustainability. However, the contribution of the digital depends on the behaviors related to its use; as Stefano Tomasini, head of INAIL (Italian National Institute for Insurance against Accidents at Work) Information System, stated in one of his interviews that, to have the right approach in this field, one must not lack awareness. He proceeds to add how technology, combined with individuals and the right communication, are three fundamental factors that permit a business organization

[18] The term "terminal values" can be traced to Rokeach in his publication "The nature of human values" of 1973 presents values as beliefs about specific modes of conduct (instrumental values) or final state of existence (terminal values).
[19] UNESCO: United Nations Educational, Scientific, and Cultural Organization. Born on the 16th of November 1945.

to reach digital sustainability. Implementing digital sustainability can help enterprises achieve a unique value that is difficult to replicate for other businesses.

On the other hand, the digital can have negative impacts on the environment, but it can surely be contained and certainly is a crucial tool for environmental sustainability. For example, since the production of digital devices demands the extraction of rare minerals, it requires a significant consumption of fossil fuels and water. These devices, at the end of their life cycle, become electronic waste that can rarely be recycled and disposed of. Nevertheless, more efficient engineering and production processes can reduce dependence on raw materials. In addition, the creation of increasingly efficient technologies can extend the service life of devices by reducing the production of electronic waste and improving their recycling. Despite the risks, the correct use of digitalization allows for a significant reduction of CO_2 emissions by ensuring that the energy budget for an organization is positive. The study "SMARTer 2030", conducted by GESI in 2015, claims that ICT applications will be able to avoid up to 20% of annual greenhouse gas emissions by 2030, while the sector of ICT will cause only 1.97% of global greenhouse gas emissions (#SMATer2030 ICT Solutions for 21st Century Challenges, https://unfccc.int/sites/default/files/smarter2030_executive_summary.pdf Accessed 15 May 2024).

In order to measure the digital sustainability of people, organizations, and territories, the Digital Sustainability Foundation has elaborated the Digital Sustainability Index (DiSi). It provides information on the level of digitalization of the territory, awareness of sustainable issues and conscious use of technologies as sustainability tools with reference to the diffusion of digital and the relevance of the resulting sustainable behaviors. It is a useful tool to accompany enterprises in digitalization as it measures their adaptability and success in digital economies.

In the quest for digital sustainability, innovative technologies, such as artificial intelligence, the Internet of Things (IoT)[20], and blockchain technology play a pivotal role in enabling companies to reduce their environmental footprint while enhancing operational efficiencies.

Artificial intelligence (AI) is very useful in the field of circular economy since it can, for example, automatically design a product with suitable characteristics to promote it. AI is also fundamental regarding decarbonization because it can calculate the carbon footprint of specific activities and provide solutions to reduce it. It also makes the recycling and waste disposal processes efficient. As an example, the Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA) realized the Smart Bin, a container for electrical and electronic waste, to implement the correct recovery, reuse, and recycling of these waste in accordance with circular economy principles. Another application of AI, in the field of environmental sustainability was adopted by the Lidl distribution center opened in Finland in 2018. This center benefits from a specific Microgrid Advisor solution that ensures 100% renewable energy operation for a carbon-neutral environment, the Schneider Electric EcoStruxure. The network comprehends a vast system of solar panels that works on a cloud-based server that leverages analysis capabilities to control and optimize energy resources to achieve sustainable and economic plant performance.

The IoT can provide great help in terms of sustainability, and its application areas enclose intelligent infrastructures, healthcare, logistics, automotive, agriculture, and social applications. Integrating intelligent devices into physical infrastructure can improve the flexibility, reliability, and efficiency of their operations. These improvements reduce costs and labor requirements and increase safety. Smart grids use IoT to capture energy consumption data and make it available online. Typically, information is entered into reports to display usage trends and expenses. Thus, IoT technologies can be employed within industries, homes, offices, and other buildings. All

[20] "The Internet of Things (IoT) describes devices with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet and other communication, and computer science engineering" ("Internet of Things", Wikipedia, Wikimedia Foundation, 16 Mar. 2019, en.wikipedia.org/wiki/Internet_of_things. Accessed 16 May 2024).

these infrastructures can be equipped with sensors and devices that monitor and control energy consumption, lighting, air conditioning, and surveillance systems. On a larger scale, these technologies can be applied to increase the efficiency of cities to improve the life of citizens through upgrading traffic control, air quality measurements, monitoring of parking spaces, and so on.

Blockchain technology offers several benefits. The sustainable economic advantages derived from using this technology in supply chains include improved operational efficiency, cost advantages, and value creation. From a social point of view, it promotes trust between partners in the supply chain, improves food security, supports humanitarian logistics, and promotes social equity. Environmental collaboration in the supply chain is encouraged, enabling companies to deploy resources efficiently based on real-time data.

In the context of environmental sustainability, the use of blockchain technology offers the possibility of reducing the ecological impact in the logistics sector. Different environmental protection and monitoring measures can be implemented by leveraging the blockchain and smart contracts, including energy management, raw material production, and emission control. This system simplifies the participation of actors in low-emission carbon initiatives, promotes environmental protection projects, and increases the consumer's access to clean energy. The transparency that the blockchain offers guarantees that the apparent sustainable products are, in fact, eco-friendly. Moreover, it facilitates product carbon footprint tracking and the exchange of carbon allowances between organizations.

CHAPTER 3

EXPLORING THE POTENTIAL OF BLOCKCHAIN TO ACHIEVE THE SDGS

3.1 The role of Blockchain Technology in Advancing the SDG Targets

Most people associate the blockchain as a concept strictly related to cryptocurrencies, as it was launched by Satoshi Nakamoto in 2008. However, beyond the underlying technology of cryptocurrencies, blockchain is gaining recognition for its diverse applications across numerous fields. In the 21st century, it is essential for countries to stay updated on innovations in order to lay the basis for growth, and this technology is an opportunity for governments and businesses to improve traditional systems and reach greater financial inclusion and transparency.

The achievement of the Sustainable Development Goals, set in the "2030 Agenda" by the United Nations in 2015, turned out to be a challenge much more difficult to realize than what was thought about ten years ago. With only a little more than five years to face, a stronger connection between human effort and the implementation of technologies is required. Smart innovations, such as blockchain technology, can identify and minimize unsustainable practices, recognize alternative resources as natural resources are depleting, constantly check carbon footprint, and monitor greenhouse gas emissions, which are critical to ensure sustainable development. "The theme 'Application of Blockchain technology for Sustainable Development' has gained momentum in the past few years and is viewed as a next-generation information technology tool for sustainable development in the energy sector, FinTech, agriculture, food supply chain, healthcare, and transportation", as stated by authors of the article "Blockchain Technology for Sustainable Development: A Systematic Literature Review" (Joshi Parikshit et al., 9 Feb. 2023, "Journal of Global operations and Strategic Sourcing", https://doi.org/10.1016/j.jclepro.2023.139541. Accessed 19 May 2024).

Blockchain can offer various solutions for transparent and immutable records. For instance, converting transactions into impact tokens[21] using smart contracts creates new opportunities to enhance ESG ratings. This demonstrates that investments in projects have yielded positive results, and these tokens help tackle challenges in SDG implementation. Impact tokens, as described by D. Uzsoki and P. Guerdat in their publication "Impact Tokens. A blockchain-based solution for impact investing", "can increase trust between parties, promote financial and social inclusions, improve data collection and accelerate monitoring, reporting and verification processes" and, most importantly, "incentive behaviors that promote sustainability" (April 2019, https://www.iisd.org/system/files/publications/impact-tokens.pdf. Accessed 20 May 2024).

Digital tokens improve traceability in supply chain ecosystems, which should further develop the idea of the application of blockchain-based solutions to achieve the Goals. Moreover, given the interconnection between the SDGs, blockchain could address more than one Objective at a time, resulting in an acceleration process towards the accomplishment set by 2030. Furthermore, the decentralized system on which the technology is based will benefit sustainable development by facilitating collaboration and competition among organizations and private businesses, as it connects and integrates different databases, promoting fast information flows. However, it will lead to effectiveness once the network is adopted by constantly increasing participants.

3.2 Environmental Sustainability: Monitor and Incentivize Sustainable Practices [SDG 12,13]

The fact that the blockchain has the capability to monitor and incentivize sustainable practices by tracking data and ensuring transparency at the same time is evident, and it is recognized as a powerful tool to accelerate progress towards the Goals.

[21] Digital tokens (assets that allow information and value to be securely transferred, stored, and verified) are used by blockchain to unlock investments for projects, with a positive social and environmental impact in supporting the SDGs.

The role of this technology for SDG 12, stated by the UN as “Responsible Consumption and Production”, can be outlined in many publications such as “Blockchain-Empowered Sustainable Manufacturing and Product Lifecycle Management in Industry 4.0: A Survey” by J. Leng (2020), and “A Systematic Literature Review of Blockchain-Enabled Supply Chain Traceability Implementation” by T. Dasaklis. Leng explains sustainable manufacturing and product lifecycle management and highlights how responsible production practices can be achieved through this technology. On the other hand, Dasaklis examines the potential of blockchain for general implementation on supply chain traceability and how this can help verify practices and compliance with environmental standards along the chain. Nevertheless, both studies emphasize the enhancement of supply chain transparency and traceability using the blockchain, emphasizing how this is fundamental for stakeholders who need to verify the sustainability of products and practices, fostering greater accountability in production and distribution.

“Blockchain technology has been suggested as one possible critical solution to overcome the current barriers of implementing the circular economy concept” (A. Böckel et al., “Blockchain for the Circular Economy: Analysis of the Research-Practice Gap”, Sustainable Production and Consumption, vol. 25, pp.525, 25 Jan. 2021, https://doi.org/10.1016/j.spc.2020.12.006. Accessed 20 May 2024), referring to target 12.5, defined as the need to “substantially reduce waste generation through prevention, reduction, recycling and reuse”. Exploiting this technology can raise awareness and encourage both people and organizations to adopt sustainable behaviors (target 12.8) since the visibility of the information related to, for example, carbon footprints in the supply chain is detectable. Furthermore, it can increase the reputation of companies that adopt sustainable practices, facilitating the verification of eco-labeling and certifications. In addition, it can monitor energy use and the corresponding consumption, promote the use of green energy, and decrease the use of fossil fuels, contributing to the development of smart cities, encompassing altogether SDG 7 (affordable and clean energy) and 11 (sustainable cities and communities) and targets 12.6 (encourage companies, especially of large and transnational companies to adopt sustainable practices and to integrate sustainability information in their reporting cycle)

and 12.a (support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production).

Promoting SDG 12, simultaneously with SDGs 2 (zero hunger), 8 (decent work and economic growth), 9 (industry, innovation and infrastructure), and 14 (life below water), supported by the UN World Food Program is the initiative Fishcoin. It is a real-life project on the theme of supply chain on the "life below water" (referring to species that live underwater and SDG 14), a decentralized ecosystem that incentivizes data capture and shares the seafood supply chain at all its stages. The aim of this initiative is to enhance the livelihoods of fishers while promoting a more sustainable approach within the industry to safeguard biodiversity. It focuses on the fragmentation of the supply chain using the Blockchain, allowing buyers, governments, and consumers to know each step of the journey of the fish.

In sustainable supply chains enabled by blockchain with traceability, effective distribution of resources can decrease fuel and energy usage, diminish greenhouse gas emissions, and lessen pollution, thereby enhancing the condition of the environment. So, the application of this system can boost the capability of organizations to "combat climate change and its impacts", as SDG 13 is defined. Indeed, its contribution to pollution reduction includes improved carbon emission compliance and trading, as confirmed by the study conducted by C. Shen and F. Pena-Mora entitled "Blockchain for cities – A systematic literature review".

Among the targets of the 13th Objective, 13.2 (integrate climate change measures into national policies, strategies and planning) and 13.3 (improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning) can be directly addressed by this technology. From a policy perspective, transparency is fundamental and can bring attention to the need for regulations between countries, such as policies regarding sustainable development. Moreover, by exploiting transparency and monitoring, the level of pollutants can be tracked, thereby recognizing the need to improve air quality and reduce CO_2 emissions. The environmental tech start-up Verdium is an example of how Blockchain and its

decentralized system can be used as a tool to report the impact of carbon footprints of companies and individuals and neutralize the impact they have on the environment. They partner with IBM (International Business Machine Corporation), a company also known as 'Big Blue', that operates in the IT sectors providing services and products in the areas of cloud and quantum computing, hardware, blockchain and AI, data analytics, and consulting. Together, they transform carbon credits into digital tokens ("Verde"), which any entity can purchase and trade, working towards the goal of cutting down the total amount of pollution companies produce.

3.3 Economic Empowerment: Applications for Financial Inclusion and Poverty Reduction [SDG 1,8]

SDG 1 calls for an "end of poverty in all its forms everywhere" and SDG 8 "promotes sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" by 2030. Both Goals focus on the importance of financial inclusion and unbiased value distribution. By ensuring support for those in need and facilitating access to financial services, the Blockchain can help the poorest and assist in sustainable economic growth.

Leveraging the new generation of financial services can help mitigate the effects of poverty around the world. Over the last few years, many banks with a significant global presence have initiated projects utilizing blockchain. An example is the Asian Development Bank, in partnership with a Californian blockchain-based decentralized platform, Everes, that enables cross-border payments involving money transfers from Australia, New Zealand, and Samoa, exploiting the technology for verification and compliance. A similar project takes place in Indonesia to facilitate transactions along the Indonesia-European corridor in partnership with the Indonesian Bank Rakyat. Another example is M-PESA, a mobile money system operating in Kenya, that has "lifted 194,000 households, or 2% households, out of poverty" ("The Long-Run Poverty and Gender Impacts of Mobile Money" by T. Suri and W. Jack, vol. 354, no. 6317, 8 Dec. 2019, pp. 1288, https://doi.org/10.1126/science.aah5309. Accessed 22 May 2024) that, even not using the Blockchain, integrating it can potentially improve

interoperability, transparency, and security, allowing lower transaction cost and promoting financial inclusion. In summary, blockchain-based solutions, accessible via phones and the internet, although not everyone can own one, still can transform financial systems, making them more inclusive and efficient, contributing to poverty reduction and economic growth.

Member of the UN International Computing Center (UNICC) since 2019, the ID2020, an alliance working in collaboration to ensure that the future of digital identity is needed, states in the document "Digital Impact Alliance" that a "digital identity is the foundation that allows people to exercise their rights, access life-enhancing services, and ultimately join the formal economy" ("ID2020 and Digital Impact alliance Join Forces to Champion people-Centric Digital Transformation" 2 Aug. 2023, https://dial.global/id2020-and-digital-impact-alliance-join-forces-to-champion-people-centric-digital-transformation/. Accessed 22 May 2024). ID2020 works to provide digital identities to people who lack official documents and are in vulnerable populations; their focus is to promote privacy and security, work towards the achievement of the SDGs, in particular, SDG 1, 5 (gender equality), and 8, support humanitarian efforts, and facilitate access to services. The alliance, leveraging emerging technologies - and blockchain is a key component of their strategy -, allows individuals to have access to a range of services, such as government, financial, and healthcare services, leading to positive results on the economic livelihoods of the large segments of rural populations, which lack of banks.

The Blockchain has the potential to help solve humanitarian problems, including identity, migration, food, and alimony distribution. Organizations such as Save the Children UK explored the use of the technology to provide a humanitarian passport, to know exactly what people have gone through in case of emergency. The UN World Food Programme (WFP) implemented it with their initiative Building Blocks (BB), which is defined as "the world's largest humanitarian use of blockchain technology" and serves to "allow organizations to work together, coordinate efforts and stretch resources farther helping serve more people, more effectively than before" ("Building Blocks | World Food Programme", https://www.wfp.org/building-blocks. Accessed 23

May 2024). As a result, with 25 million transactions, it provided food to more than 1 million refugees in Jordan and Bangladesh. It assisted UNICEF[22] in the distribution of water, sanitation, and hygiene items in Bangladesh and has also helped coordinate assistance to those affected by the Russia-Ukraine conflict. Thanks to the use of BB, between May and August 2022, 18 organizations provided 1 million households. Furthermore, in Lebanon it served as a coordination platform for the 15 different organizations operating there before assisting people after the Beirut port explosion.

This innovative technology promotes collaboration, can foster sustainable and inclusive economic development, has created new business models and jobs, for example, within the supply chain domains, and expanded revenue streams. Utilizing its transparent and decentralized system offers a secure structure for a social production framework, guaranteeing equitable distribution of value and rewards among contributors. With the absence of intermediaries, transaction costs are decreased, benefiting smallholders and small and medium-sized enterprises (SMEs), which generally have difficulties raising funds. Moreover, blockchain ensures human rights and fair working conditions; monitoring and tracking working conditions and practices can stop unethical and illegal activities, such as child labor and modern slavery, contributing to reducing inequalities and discrimination.

3.4 Social Impact: Blockchain for Transparent Governance and Inclusive Development [SDG 10,16]

The aim of SDG 10 is to "reduce inequalities within and among countries." Encompassing 10 targets and multiple indicators, it specifies how to promote social, economic, and political inclusion, eliminate any inappropriate 'labeling' about race, ethnicity, religion, etc., and promote fair laws, regulations, and policies to achieve greater equality by 2030.

[22] The United Nations Children's Emergency Funds (UNICEF) created by the UN General Assembly on the 11th of December 1946.

The role of blockchain, as stated in section 3.3, can contribute to poverty reduction, and help achieve significant financial inclusion. This will lead to economic growth and inclusivity in terms of resources and value distribution, reducing inequalities and discrimination. The point is that when the blockchain is implemented, it operates inevitably in a way in which it contributes to the achievement of multiple Goals at a time since they are all interconnected, and it could seem as if its role has already been defined for Goal 10, which is partially true.

The technology's network creates trust between users and facilitates fair trading. Since inequalities in wealth distribution in societies and economies arise from corruption and system manipulations, the blockchain, through decentralization, allows transparency, contributes to risk reduction, and can potentially integrate low-income groups into the market. Moreover, leveraging the collaborative scheme facilitates decision-making, such as e-voting, and promotes joint ruling in urban settings. Lastly, its application in banking and financial systems can bring changes in the structures of organizations, directly influencing targets 10.5 (improve the regulation and monitoring of global financial markets and institutions and strengthen the implementation of such regulations) and 10.6 (ensure enhanced representation and voice for developing countries in decision-making in global international economic and financial institutions in order to deliver more effective, credible, accountable and legitimate institutions).

Continuing with the themes of financial inclusion, poverty reduction, and addressing inequality, Moeda is a cooperative investment platform founded by Chinese entrepreneur Taynaah Reis. It blends financial technology with social responsibility, focusing on SDGs 1 and 10. It connects impact investors with small businesses that promote the Goals of the “2030 Agenda”. Leveraging blockchain ensures transparency for projects, allowing investors, using digital tokens, to track their impacts. It is a lending system that focuses on the community and seeks to address issues present in traditional banking systems, as well as gender bias against projects led by women. Additionally, it helps raise funds for small, underbanked businesses.

The blockchain is a relatively new technology, and as organizations, businesses, and individuals discover the various facets of it, they try to implement it to benefit from it. In the case of sustainability, the main scope is to use it to address government issues and unfair regulations, it points out the problem of transparency and traceability, fraud, or other unethical behaviors in all sectors within a community. These are the foundations to "promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and built effective, accountable, and inclusive institutions at all levels" (SDG 16).

Governments and Organizations can promote efficient and reliable systems by utilizing the technology to reduce corruption and ensure accountability across sectors. Applications to address SDG 16 took place all over the world; an example is the Ethereum-based blockchain used by the government in Colombia that aims at reducing corruption when choosing vendors for public programs and addressing initiatives such as the "Programa de Alimentaciòn Escolar", that over the years has been subject to many scandals. Projects such as e-Residency in Estonia, and the Quay Connect in the Netherlands have similar characteristics in terms of revolutionizing public services, making them more inclusive. The e-Residency uses blockchain to provide secure digital identities to non-residents, allowing access to online services and the possibility of interacting with the advanced Estonian digital system. It ensures a secure, trustworthy system for digital identity and transactions, reducing fraud risks. Similar situation with Quay Connect, which ensures a safe and transparent system using the blockchain to track the exchange of shipped goods from the UK, providing real-time visibility about the status of the cargo ship, allowing direct data exchange with authorities, and, in the end, facilitating international trade logistics and improve trust between parties.

3.5 UN Partnerships with Blockchain

The 73rd United Nations General Assembly of 2019 "was dominated by the Sustainable Development Goals (SDGs) and how blockchain and related technologies could help expedite the achievement of the goals" (Lawrence Wintermeyer, "Blockchain At The United Nations Leading Solution To The Global Crisis", 27 Sep. 2019,

https://www.forbes.com/sites/lawrencewintermeyer/2019/09/26/blockchain-at-the-united-nations-leading-solutions-to-the-global-crisis/. Accessed 25 May 2024).

It is important that everyone, including the United Nations, engages with innovative technologies to understand and learn from them. Around that year, the potential of blockchain was explored to show that there are options to better reorganize society.

Many events were hosted with the intent of raising awareness on the matter, for example, the "Blockchain for Social Good: Blockchain to Aid Economic Development", organized by the Women Political Leaders (WPL) in partnership with other organizations, or the "Cryptocurrencies & Blockchain – A New Boost for SDG-Financing?" by the Leading Group on Innovative Financing Development.

Important partnerships were formed between UN organizations and blockchain companies to address a wide range of issues related to the specific organization's objectives. As mentioned in section 3.3, with the aim of providing aid to 'affected' populations, the WFP created the BB using blockchain technology to reduce administrative overhead and prevent fraud in the job they are carrying on. The UNDP recently announced partnerships with the Algorand Foundation, a digital currency, and a blockchain platform, that serves as a 'blockchain academy' for its staff to provide them with knowledge and insights into the practical application for sustainable development, that will be available to the employees across the 170 countries and territories in which UNDP operates. A similar project is carried out by the UN Conference on Trade and Development (UNCTAD), outlined in the "Global Report on Blockchain and its Implication on Trade Facilitation Performance". They launched the e-platform "The Use of Blockchain in Trade Facilitation" to equip policymakers with the correct methodology to implement the technology, allowing faster, economical, and more secure trade. Based on their report the course aims to: "a) provide an overview of the evolution of blockchain technology and outline success stories of leveraging the blockchain for trade facilitation and supply chain efficiency, b) shed light on the necessary policy environment, regulatory frameworks, compliance, and governance preconditions to accelerate blockchain adoption, c) develop model guidance for

stakeholder coordination and process implementation, d) establish the basis for use causes such as certification, credentials, and distributed data management to facilitate international trade" (UNCTAD, "New UNCTAD Online Course to Ease Trade with Blockchain Technology" 5 Feb. 2024, https://unctad.org/news/new-unctad-online-course-ease-trade-blockchain-technology. Accessed 25 May 2024). The UNICEF Innovation Fund also started a project leveraging the technology, it created eight start-ups using blockchain-based solutions to achieve greater financial inclusion, namely Xcapit in Argentina, Grassroots Economics and KotaniPay in Kenya, Somish Blockchain Labs in India, BX Smart Labs in Mexico, Leaf Global FinTech in Rwanda, Rumsan Associates in Nepal, and Trejeer in Iran. "These investments are the second cohort of blockchain solutions and are UNICEF's larger exploration of blockchain technology, including using smart contracts to increase organizational efficiency and transparency, leveraging innovative financing models to distribute resources, and incentivizing and encouraging the creation of open-source public goods in the countries where UNICEF works" (UNICEF, "Levering Blockchain for Financial Inclusion, 8 Jun. 2021, https://www.unicef.org/innovation/InnovationFund/blockchain-financial-inclusion-cohort#:~:text=UNICEF's%20Innovation%20Fund%20announces%20first,in%20USD%20and%2For%20cryptocurrency. Accessed 25 May 2024).

In conclusion, blockchain technology has the potential to bring about significant change in achieving the Sustainable Development Goals (SDGs) by improving effectiveness, transparency, and inclusiveness in various fields. The ongoing investigation and use of blockchain within the UN framework emphasize its crucial contribution to promoting sustainable development worldwide.

Conclusion

From the research carried out, it is possible to say that we have achieved the objective of identifying the contribution blockchain technology makes to sustainability. It is clear how the characteristics that distinguish this technology are functional to the realization of solutions aimed at social, environmental, and economic sustainability.

From the examples made and the real-life projects presented, it is possible to point out how the blockchain is surely an advantageous tool that can encourage and support behavioral changes toward sustainable and responsible practices, thanks to its characteristics of transparency, safety, immutability, traceability, and decentralization. This thesis emphasizes the importance of continued exploration and adoption of blockchain solutions in the quest for a sustainable and equitable future.

From my point of view, innovative technologies are inevitably changing the way in which we live, work, and relate, and their use should be viewed as an opportunity for businesses and important organizations to have a role aimed at achieving sustainability. Nevertheless, new technologies such as the blockchain are ambiguous: on one hand, they offer new opportunities, but on the other hand, they also offer new challenges. For this reason, it is important to be aware of the risks and benefits of using them, considering how they can be leveraged to improve the daily lives of individuals and their activities to always be a starting point and not a destination towards sustainability. It is fundamental to promote cross-sector collaborations and the creation of supportive regulatory environments to maximize the benefits of blockchain.

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