Blockchain and DLT Application to Sustainable Development: New Architectures and Use Cases for Circular Economy, Climate Action and Biodiversity Conservation

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Abstract *– This article explores the blockchain and distributed ledger technology (DLT) application to sustainable development. Recent innovations in blockchain and DLT architectures have significantly improved scalability, reduced the environmental footprint, and maintained the sovereignty of their communities of developers, challenging the arguments that these technologies are inherently unsustainable. New architectures are now mature and viable for a widespread blockchain and DLT application in particular to sustainable development. Their inherent characteristics such as decentralisation, transparency, traceability, trust creation and contract automation, are particularly well-suited to support the United Nations Sustainable Development Goals (UN SDGs). This article provides a comprehensive overview of blockchain and DLT, examines early and new architectures, analyses their use cases to support sustainable development goals, and details implementations in standards and regulations, particularly within the European context.*

Keywords *– Biodiversity Conservation, Blockchain, Circular Economy, Climate Action, Digital Product Passport, Distributed Ledger Technology, Sustainable Development, Sustainable Development Goal*

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I. INTRODUCTION

This article explores the application of blockchain and distributed ledger technologies (DLT) for sustainable development.

New architectures in blockchain and distributed ledged systems have significantly improved their scalability (e.g. number of transactions per second), their sustainability as they have drastically reduced their environmental footprint (e.g. electric consumption, carbon footprint) and maintained a good level of sovereignty of their community of developers (e.g. number and openness of the community). They challenge the arguments that these technologies are inherently unsustainable.

New architectures are now mature and viable for a widespread blockchain and DLT application in particular to sustainable development. Indeed, the inherent characteristics of blockchain and DLT, including decentralisation, distribution, disintermediation, transparency (including measurement, reporting and verification (MRV)), traceability (including accountability, monitoring and tracking), trust creation (including security), certification (including labelling, timestamping), and contract automation, can support the United Nations Sustainable Development Goals (UN SDGs).

This article introduces blockchain and DLT through some definitions, explanations and cryptographic innovations (cf. **section II**), then details the characteristics of some early distributed ledger systems such as Bitcoin, Ethereum (1.0) and IOTA (1.0) including early scalability, sustainability and sovereignty characteristics (cf. **section III**), presents some new architectures such as Ethereum 2.0 and IOTA 2.0 and associated new scalability, sustainability and sovereignty characteristics (cf. **section IV**), details blockchain and DLT use cases for sustainable development in particular for circular economy, climate action and biodiversity conservation as well as associated impacts on UN SDGs (cf. **section V**), and finally shares some implementation in the standards proposed by ISO, CEN-CENELEC or ETSI, and in the European regulation (cf. **section VI**).

II. INTRODUCTION TO BLOCKCHAIN AND DLT

II.1. Definitions

A common vocabulary is essential for the wide adoption of new digital technologies such as blockchain or artificial intelligence.

The Oxford Dictionary proposed in 2015 a first definition of the blockchain for the general public as “a system in which a record of transactions made in bitcoin or another cryptocurrency are maintained across several computers that are linked in a peer-to-peer network” **[1a]**. The concepts of **blockchain system**, **transaction**, **cryptocurrency** and **peer-to-peer network** were thus gathered.

The European Commission enriched the previous definition in 2018 for the Digital Single Market (DSM) as follows: “blockchain is the best-known distributed ledger technology. A ledger is a database which keeps a final and definitive record of transactions. Records, once stored, cannot be tampered without leaving behind a clear track. Blockchain enables a ledger to be held in a network across a series of nodes, which avoids one centralised location and the need for intermediaries’ services. This is particularly helpful for providing trust, traceability and security in systems that exchange data or assets. There is a lot of potential for blockchain to be used in many different areas such as financial services, supply chains or healthcare.” **[1b]**. The blockchain joined a subclass of a **distributed ledger technology** (DLT) and was characterised with **decentralisation**, **disintermediation**, **trust creation**, **traceability** and **security**.

The Gartner IT Glossary refined the definition in 2018 where “a blockchain is an expanding list of cryptographically signed, irrevocable transactional records shared by all participants in a network. Each record contains a time stamp and reference links to previous transactions. With this information, anyone with access rights can trace back a transactional event, at any point in its history, belonging to any participant. A blockchain is one architectural design of the broader concept of distributed ledgers” **[1c]**. Concepts of cryptographic signature, timestamping and resulting characteristic of **traceability** were introduced.

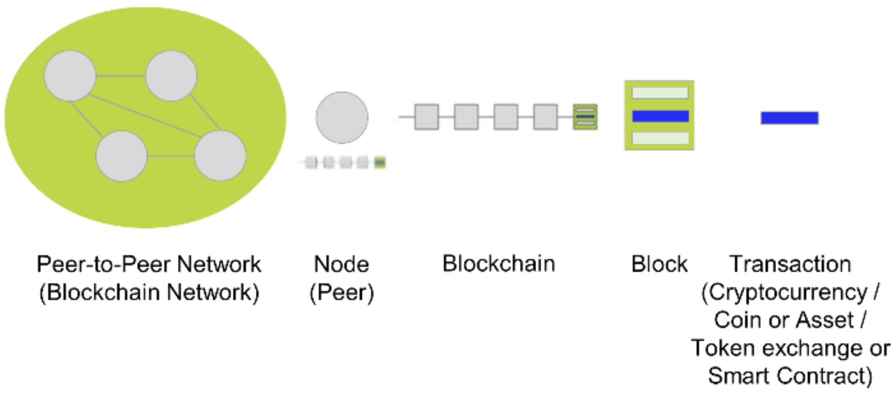
The ISO 22739:2020 standardised the definition of blockchain as a “distributed ledger with confirmed blocks organized in an append-only, sequential chain using cryptographic links; blockchains are designed to be tamper resistant and to create final, definitive and immutable ledger records” **[1d]**. The concept of an add-only and sequential chain as well as the characteristic of **immutability** were developed.

These four definitions provide a first level of understanding of blockchain and distributed ledger technology. Following explanations provide some technical and business background.

II.2. Technical Explanation

A blockchain, the technology behind Bitcoin, is a distributed ledger which is replicated among several nodes within a peer-to-peer (P2P) network (**Figure 1**).

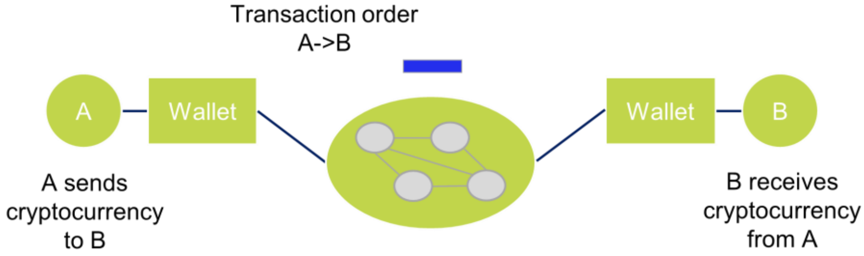
FIGURE 1. FROM BLOCKCHAIN NETWORK TO TRANSACTION



A blockchain gathers transactions into blocks that are validated by nodes, without central authority, thanks to a **consensus mechanism**. A transaction refers to **cryptocurrency / coin** or **asset / token exchange** or **smart contract**. Blocks are linked together through cryptographic functions and are given a timestamp, guaranteeing both immutability and traceability.

A transaction is ordered by the sender to the recipient thanks to an **electronic wallet service** (to be compared to an online banking service) and **account address** (to be compared to IBAN) (**Figure 2**).

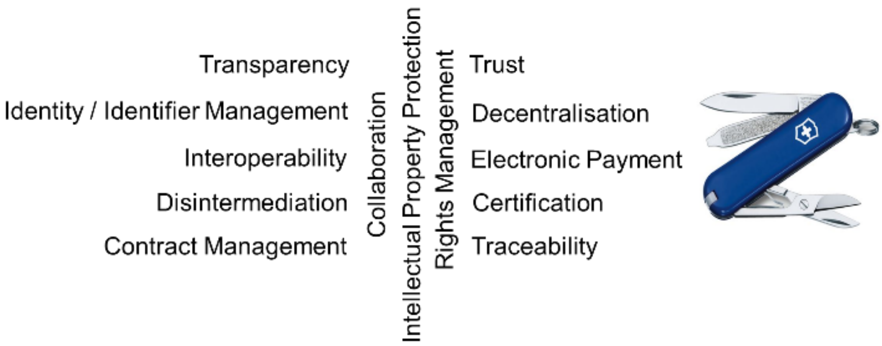
FIGURE 2. TRANSACTION ORDER FROM SENDER A TO RECIPIENT B



II.3. Business Explanation

A **smart contract** is a self-executing computing programme allowing new applications domains beyond electronic payment i.e. cryptocurrency exchange (**Figure 3**) **[2a]**.

FIGURE 3. NEW APPLICATION DOMAINS BEYOND CRYPTOCURRENCY EXCHANGE



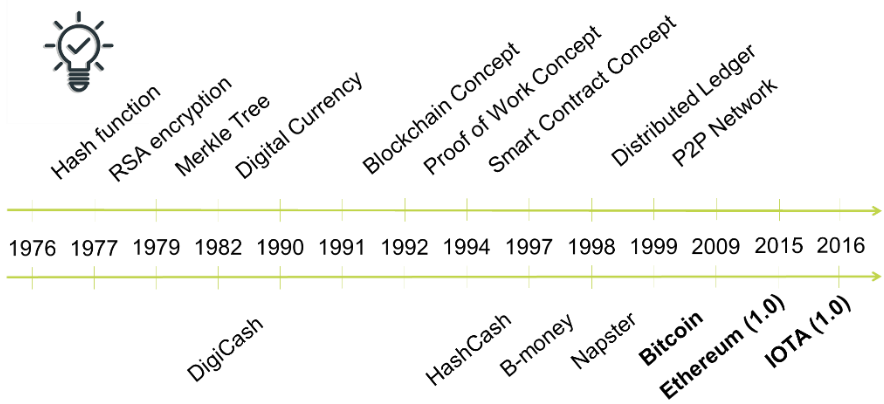
New **application domains** allow designing new business models and challenge current business processes, e.g. in the culture and entertainment business **[2b] [2c] [2d]**.

A blockchain creates distributed trust in ecosystems where actors do not trust each other *a priori*.

II.4. Cryptographic Innovations

Blockchain and DLT result in a long series of cryptographic innovations (**Figure 4**) from cryptographists, cryptologists, mathematicians, computer engineers and scientists. Some of them are detailed hereafter.

FIGURE 4. CRYPTOGRAPHIC INNOVATIONS BEHIND DISTRIBUTED LEDGER SYSTEMS



In 1976, cryptologists Whitfield Diffie and Martin E. Hellman published an article on "New directions in cryptography" in which they identified the need for a one-way **hash function** for **electronic signatures [3a]**.

In 1977, cryptographers Ronald L. Rivest, Adi Shamir and Leonard Adleman published a description of the **RSA encryption algorithm**, which uses a public key to encrypt data and a private key to decrypt it **[3b]**.

In 1979, the cryptographer Ralph C. Merkle published a description of a method for certifying digital signatures and introduced a tree signature known as the **Merkle tree [3c] [3d]**.

In 1982, mathematician David Chaum introduced the idea of **electronic money** by describing "blind" signatures used for untraceable electronic payments (by the issuing bank), which were implemented in 1990 in the DigiCash electronic payment system **[3e]**.

In 1991, cryptographers Stuart Haber and Wakefield Scott Stornetta set out the **principles of blockchain** by describing the **time-stamping** of electronic documents **[3f]**.

In 1992, computer scientists Cynthia Dwork and Moni Naor introduced the **concept of proof of work** as part of the fight against junk mail, which was later used in the Hashcash system **[3g]**.

In 1994, computer scientist and cryptographer Nick Szabo defined the **smart contract** as "a computerized transaction protocol that executes the terms of a contract. The general objectives of smart contract design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries. Related economic goals include lowering fraud loss, arbitration and enforcement costs, and other transaction costs" **[3h]**.

In 1997, cryptographer Adam Back presented the Hashcash **proof of work system** as part of the fight against spam **[3i]**.

In 1998, computer scientist Wei Dai published a description of the B-money distributed and anonymous electronic money system, which proposes to use the **proof of work function** to create money and to distribute monetary **transactions** to all participants, who record all transactions in a **distributed ledger** (or distributed registry) **[3j]**.

In 1999, cryptographers Henri Massias, Xavier Serret-Avila and Jean-Jacques Quisquater published their design for a secure time-stamping service **without a trusted third party [3k]**.

In 1999, computer scientist Shawn Fanning launched the Napster **peer-to-peer network**, which includes a central server that acts as a centralised ledger (or centralised registry) of all files shared by peers. In 2000, computer scientists Justin Frankel and Tom Pepper launched the Gnutella peer-to-peer network, some of whose peers operate as a distributed ledger of all files shared by their peers **[3l]**.

Previous innovations contributed to strengthen the characteristics of blockchain and DLT, including decentralisation, distribution, disintermediation, transparency (including measurement, reporting and verification (MRV)), traceability (including accountability, monitoring and tracking), trust creation (including security), certification (including labelling, timestamping) and contract automation.

III. CHARACTERISTICS OF SOME EARLY DISTRIBUTED LEDGER SYSTEMS

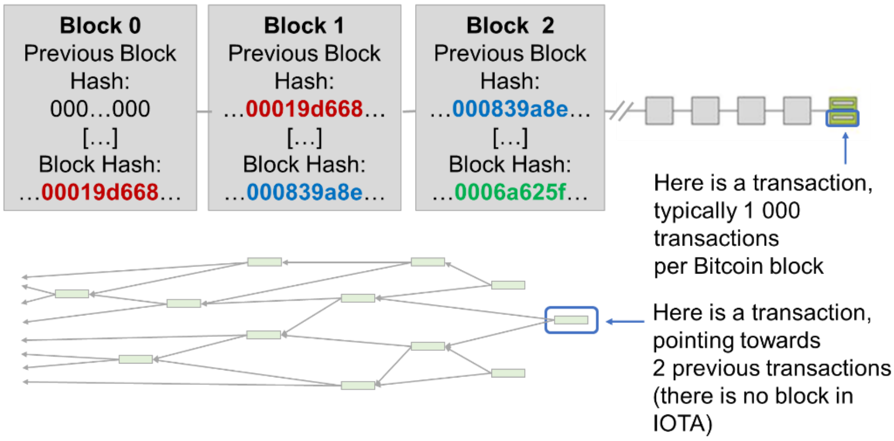
III.1. Bitcoin

III.1.a. Introduction to Bitcoin

The Bitcoin blockchain system was described in Satoshi Nakamoto's white paper, published on October 30th 2008 **[4a]**. The first block (or **genesis block**) of the Bitcoin blockchain was formed on January 3rd 2009. Blocks are created every 10 minutes.

The Bitcoin system introduces both the **bitcoin cryptocurrency** (BTC or XBT) and the **Bitcoin network**. Bitcoin blockchain is a **public and permissionless blockchain**. Each peer of this peer-to-peer network stores a **blockchain** data structure and runs the **proof of work (PoW) consensus mechanism**. Each transaction is integrated into a block, each block is validated within the P2P network and then added to the blockchain. Each block points to the previous block hash (obtained using the SHA-2 hash function) (**Figure 5**).

FIGURE 5. BITCOIN AND IOTA DATA STRUCTURES



The **transactional performance** of the Bitcoin system is on average 3 **transactions per second** (tx/s or tps) and at maximum 7 tx/s. **Transaction fees** are paid by the sender through the transaction order.

III.1.b. Scalability of Bitcoin

The average (or mean) / maximum number of transactions per second $R_{mean/max}$ is computed as the ratio between the average / maximum number of transactions per block $Q_{mean/max}$ and the average / minimum time for block validation $T_{mean/min}$.

A blockchain explorer such as *Blockchain.com* provides some charts that allow observing the average / minimum time for block validation $T_{mean/min}$ and providing a first assessment that T_{mean} ~10 minutes i.e. 600 seconds and T_{min} ~5 minutes i.e. 300 seconds **[4b]**.

As well, such charts allow observing the average / maximum number of transactions per block $Q_{mean/max}$ and providing a first assessment that Q_{mean} ~2 000 transactions per block and Q_{max} ~2 750 transactions per block **[4c]**.

The resulting average / maximum number of transactions per second is derived as $R_{max/mean} = Q_{mean} / T_{min/mean}$. It is worth noting that Q_{mean} is used rather than Q_{max} for computing R_{max}, as Q_{max} value appears more as an artefact than as a sustained maximum value. This computation leads to R_{mean} = 2 000 / 600 i.e. ~3 tx/s and R_{max} = 2000 / 300 i.e. ~7 tx/s.

III.1.c. Sustainability of Bitcoin

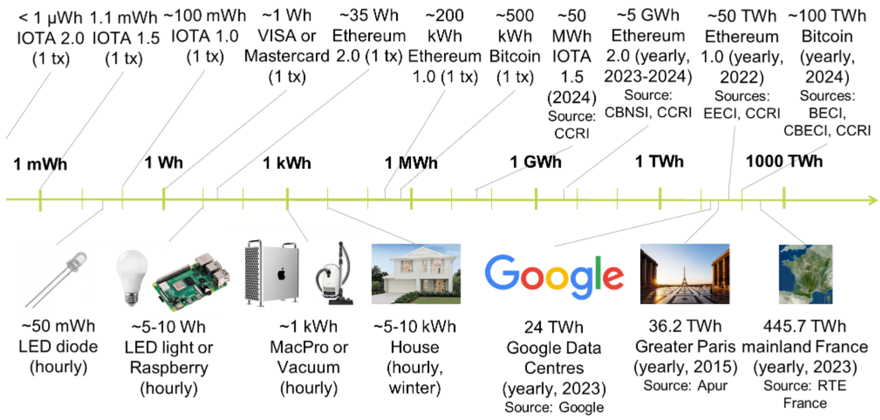
The sustainability of Bitcoin system is constrained by the proof of work (PoW) consensus mechanism, which leads to an **electric consumption** of 98.27 TWh (TeraWatt-hours), a **carbon footprint** of 54.81 MtCO2e (million tonnes of carbon dioxide equivalent (CO2e) emission in terms of greenhouse gas (GHG)), an **electronic waste** of 10.52 kt (kilotonnes) and a **water footprint** (i.e. freshwater consumption) of 1 049 GL (Gigalitres), which corresponds for a single transaction to 483.73 kWh, 269.81 kgCO2, 51.8 grammes and 7 624 litres respectively (yearly as of Aug. 21st 2024) according to BECI **[4d]**.

Alternative assessment leads to estimated electric consumption of 147.18 TWh and 147.17 TWh according to CBECI and CCRI respectively (yearly as of Aug. 19th 2024) **[4e] [4f]**.

Based on BECI, CBECI and CCRI assessments, the typical electric assumption of the Bitcoin system is ~100 TWh (yearly, 2024).

The electric consumption of the Bitcoin system and a single Bitcoin transaction, i.e. ~100 TWh and ~500 kWh respectively, are equivalent to the electric consumption of about three times of the Greater Paris, i.e. 36,2 TWh (2015) **[4g]** and less than a quarter of the mainland France, i.e. 445.7 TWh (2023) **[4h]**, and to about 500 *MacPro* or vacuums operating simultaneously at the maximum of their power (e.g. 1 kW) during 1 hour respectively (**Figure 6**).

FIGURE 6. COMPARED ELECTRIC CONSUMPTION



The carbon footprint of the Bitcoin system, i.e. 54.81 MtCO2e, is equivalent to the electric consumption of 4 times Google activities, i.e. 14,3 MtCO2e (2023) **[4i]**.

End of 2023, the environmental footprint of Bitcoin system, including **mining pools** and **mining farms**, was globally assessed, concluding to an electric consumption of 173.42 TWh, a carbon footprint of 85.89 MtCO2e, a water footprint of 1647.57 MCM (millions of cubic meters) i.e. 1.65 km^3 (cubic kilometres) i.e. 1 650 GL (GigaLitres), and a **land footprint** (i.e. land artificialisation) of 1869.69 km^2 (square kilometres) (yearly over 2020-2021) **[4j]**.

It is worth mentioning that the water and the land footprints of Bitcoin system, i.e. 1.65 km^3 and 1869.69 km^2 respectively, are the equivalent of the volume of 660 000 Olympic swimming pools and the surface of 1.4 times Los Angeles in California respectively.

III.1.d. Sovereignty of Bitcoin

The Bitcoin Foundation is a non-profit organisation originally established in Washington D.C. in the USA **[4k]**.

The Bitcoin community is open and counts 960 developers gathered through GitHub Bitcoin Core project. Top contributors, counting thousands of commits, are Wladimir J. van der Laan alias *laanwj* (Netherlands), Michael Ford alias *fanquake* (USA), Pieter Wuille alias *sipa* (USA), Hennadii Stepanov alias *hebasto* (Ukraine), Andrew then Chow alias *achow101* (USA) and Gavin Andresen alias *gavinandresen* (USA) etc. (as of August 24th 2024) **[4l]**.

The Bitcoin network is composed of 19 326 nodes, spread all over the world, including 63.40 % unknown locations, 10.20 % in the USA, 7.77 % in Germany, 2.26 % in France, 2.14 % in Finland, 1.67 % in the Netherlands etc. (as of August 21st 2024) **[4m]**.

The **mining capacity** of the Bitcoin network, which may be expressed as the **hashrate distribution** of the **mining hardware** over one year, is brought by legal entities spread all over the world, including 21.057 % unknown entity, 20.135 % for AntPool (China), 17,093 % for Foundry USA (USA), 13.776 % for F2Pool (China), 10.433 % for ViaBTC (China) etc. (as of August 21st 2024) **[4n]**.

III.2. Ethereum (1.0)

III.2.a. Introduction to Ethereum (1.0)

The Ethereum blockchain system was generally described in Vitalik Buterin's white paper, published on January 23rd 2014 and technically described in Gavin Wood's yellow paper, published in 2014 **[5a] [5b]**. The first block of the Ethereum blockchain was formed on 30 July 2015. Blocks are created every ~14 seconds.

The Ethereum system introduces the **ether cryptocurrency** (ETH), the **Ethereum network** (i.e. Ethereum 1.0 blockchain also known as the main chain) but also the **smart contract** and **asset / token**. The asset / token service is based on the Ethereum network, which allow creating a variety of tokens (fungible, non-fungible etc.) on the flow. The Ethereum blockchain is a **public and permissionless blockchain**. Each peer of this peer-to-peer network stores a **blockchain** data structure and runs to the **proof of work (PoW) consensus mechanism**.

The transactional performance of the Ethereum system is on average 8 transactions per second (tx/s or tps) and at maximum 20 tx/s. **Transaction fees** are paid by the sender through the transaction order.

III.2.b. Scalability of Ethereum 1.0

A blockchain explorer such as *Etherscan.io* provides some charts that allow observing the average / minimum time for block validation $T_{mean/min}$ and providing a first assessment that T_{mean} ~14 seconds and T_{min} ~13.5 seconds **[5c]**.

As well, such charts allow observing the average / maximum number of transactions per day $D_{mean/max}$ and providing a first assessment that D_{mean} ~700 000 transactions per day i.e. ~8 tx/s and D_{max} ~1 750 000 transactions per day i.e. ~20 tx/s **[5d]**.

III.2.c. Sustainability of Ethereum (1.0)

The sustainability of Ethereum (1.0) system is constrained by the proof of work (PoW) consensus mechanism, which leads an electric consumption of 82.78 TWh and a carbon footprint of 46.17 MtCO2e, which corresponds for a single transaction to 212.82 kWh and 118.7 kgCO2 respectively, just before *The Merge* (cf. Ethereum Evolution in **section IV.2**) according to EECI (yearly as of Sept. 13th 2022). Sooner, it led to an electric consumption of 102.47 TWh and a carbon footprint of 48.67 MtCO2e, which corresponds for a single transaction to 229.43 kWh and 108.98 kgCO2 respectively (yearly as of Dec. 28th 2021) **[5e]**.

End of 2023, the environmental footprint of Ethereum system was assessed, concluding to an electric consumption of 21 TWh and a carbon footprint of 11 MtCO2e, before *The Merge*, according to CCRI (yearly, Sept. 2022) **[5f]**.

Based on EECI and CCRI assessments, the typical electric assumption of the Ethereum system is ~50 TWh (yearly, 2022).

III.2.d. Sovereignty of Ethereum

The Ethereum Foundation is a non-profit organisation which is established in the Kanton of Zug in Switzerland (jurisdiction) **[5g]**.

The Ethereum community is open and counts thousands of developers who contribute to various GitHub repositories such as Ethereum Foundation Website **[5h]**, Ethereum Improvement Proposals (EIP) **[5i]** and Ethereum Research for the Ethereum Core project, and **Ethereum implementations** such as Go Ethereum (Geth), Nethermind **[5j]**, Erigon and Hyperledger Besu **[5k]** whose shares are 42.96 %, 40.22 %, 7.07 % and 6.54 % respectively (as of August 24th 2024) **[5l]**. It is worth noting that, in comparison, there is only one implementation of Bitcoin Core

The GitHub Ethereum Research counts 23 developers whose main contributor is Vitalik Buterin alias *vbuterin* (Russia) (as of August 24th 2024) **[5m]**.

The GitHub Geth implementation counts 1 090 developers whose top contributors are Jeffrey Wilcke alias *obscuren* (Netherlands), Péter Szilágyi alias *karalabe* (Romania), Felix Lange alias *fjl* (Germany), Martin Holst Swende alias *holiman* (Sweden) (as of August 24th 2024) **[5n]**.

The GitHub Erigon implementation counts 809 developers whose top contributors are Alex Sharov alias *AskAlexSharov* (Vietnam), Jeffrey Wilcke alias *obscuren* (Netherlands), Péter Szilágyi alias *karalabe* (Romania), Felix Lange alias *fjl* (Germany), Alexey Akhunov alias *AlexeyAkhunov* (UK) (as of August 24th 2024) **[5o]**.

The Ethereum (1.0) network is composed of 4 958 mainnet nodes, spread all over the world, including 46.47 % in the USA, 13.49 % in Germany, 3.79 % in South Korea, 3.31 % in Canada, 3.5 % in the UK, 2.79 % in France, 2.19 % in the Netherlands etc. (as of August 21st 2024) **[5p]**.

Alternatively, the Ethereum (1.0) network is composed of 6 421 *mainnet* nodes, part of the **main chain** (cf. Ethereum Evolution in **section IV.2**), spread all over the world, including 35.24 % in the USA, 13.74 % in Germany, 4.20 % in Finland, 4.05 % in France, 3.91 % in the UK, 3.36 % in Canada etc. (as of August 24th 2024) **[5q]**.

Additionally, the Ethereum 2.0 network is composed of 10 260 *beacon* nodes, part of the **beacon chain** (cf. Ethereum Evolution), spread all over the world, including 34.98 % in the USA, 16.05 % in Germany, 6.37 % in Finland, 4.48 % in the UK, 4.46 % in France, 3.24 % in Canada, 3.02 % in the Netherlands, 2.14 % in Australia, 1.92 % in South Korea etc. (as of August 24th 2024) **[5r]**.

The **mining capacity** of the Ethereum (1.0) network, before *The Merge*, is provided by legal entities spread all over the world, including 28.9953 % for Ethermine (Austria), 14.2953 for F2Pool (China), 10.2837 % for Hiveon Pool (Cyprus), 7.0117 % for 2Miners: PPLNS (Cyprus), 4.7753 % for Flexpool.io (Canada) etc. (as of September 1st 2022) **[5s]**.

III.3. IOTA (1.0)

III.3.a. Introduction to IOTA (1.0)

The IOTA distributed ledger was described in Serguei Popov's white paper, published on 28 December 2015 **[6a]**. No information may be found about the first transaction, however some alpha and beta release testing took place in H1 2016 (with some transaction screenshots), before the launch on July 11th 2016. Transactions are confirmed every 80 seconds.

The IOTA system introduces the **iota cryptocurrency** (IOTA or MIOTA = 10^6 IOTA), the **IOTA network**, the **smart contract** and the **oracle** (with Qubic). Each peer of the IOTA network stores a **graph of transactions** (referred to as **The Tangle**) of the Directed Acyclic Graph (DAG) type. A central node (called the **Coordinator node**) plays a key role in the **consensus mechanism** and the security of the IOTA system, in particular for selecting the confirmed transactions to be added to The Tangle. The Coordinator node is controlled by the IOTA Foundation. A transaction which is not yet confirmed is referred to as a **tip**. The Tangle is a **public and permissionless distributed ledger**.

The transactional performance of the IOTA system is on average ~10 transactions per second (tx/s or tps) and at maximum 40 tx/s. There is **no transaction fee**.

III.3.b. Scalability of IOTA (1.0)

The claimed transactional performance of the IOTA system is on average ~10 tx/s and at maximum ~1 000 tx/s (ranging from ~100 and ~10 000 tx/s) (January 2019) **[6b]**.

The confirmed transactional performance is on average 5-20 tx/s and at maximum 40 tx/s (August 2020) before *Chrysalis Phase 1* update (cf. IOTA Evolution in **section IV.3**) **[6c]**.

III.3.c. Sustainability of IOTA (1.0)

The sustainability of an IOTA (1.0) transaction was measured for the *Trinity* electronic wallet, which leads to an electric consumption of 0.00011 kWh (kilowatt-hours) (August 2019) and was compared to VISA and Mastercard transactions, respectively 0,000918 kWh (2018) and 0,00070 kWh (2017) **[6d]**.

The IOTA (1.0) transaction measurement was then refined, constrained by the rate control mechanism of IOTA (1.0) i.e. the proof of work, and led to an electric consumption of 0.00016 kWh (kilowatt-hours) i.e. 160 mWh (milliwatt-hours) (April 2020) **[6e]**.

The electric consumption of a single IOTA transaction is equivalent to twice the consumption of a light-emitting diode (LED) running during one hour.

III.3.d. Sovereignty of IOTA

The IOTA Foundation is a non-profit organisation established in Berlin in Germany (jurisdiction) whose team is spread over 25 countries **[6f]**.

The IOTA community is open and counts a hundred of developers who contribute to various GitHub repositories such as IOTA Hornet and IOTA Bee for the IOTA 1.5 update, IOTA Core project and GoShimmer for IOTA 2.0 update (cf. IOTA Evolution).

The IOTA Hornet counts 52 developers whose top contributors, counting hundreds of commits, are Max Hase alias *muXxer* (Germany), Alexander Sporn alias *alexsporn* (Germany), Luca Moser alais *luca-moser* (Switzerland) and Sebastian Fuchs alias *IoTMOD* (Germany) (as of August 25th 2024) **[6g]**.

The IOTA Bee counts 20 developers whose main contributor is Thibault Martinez alias *thibault-martinez* (Germany) (as of August 25th 2024) **[6h]**.

The IOTA Core project counts 16 developers whose top contributors are Hans Moog aka *hmoog* (Sweden), Ching-Hua (Vivian), Lin aka *jkrvivian* (Taiwan), Andrea Villa aka *karimodm* (Netherlands), Piotr Macek aka *piotrm50* (Poland), Jonas Theis aka *jonastheis* (Germany), Max Hase alias *muXxer* (Germany), Alexander Sporn alias *alexsporn* (Germany), Andrew Cullen aka *cyberphysic4l* (UK), Daria Dziubałtowska aka *daria305* (Poland) and Philipp Gackstatter aka *PhilippGackstatter* (Austria) (as of August 25th 2024) **[6i]**.

The IOTA GoShimmer counts 52 developers whose top contributors are Angelo Capossele aka *capossele* (Portugal), Jonas Theis aka *jonastheis* (Germany), Alexander Sporn alias *alexsporn* (Germany), Andrea Villa aka *karimodm* (Netherlands), Wolfgang Welz alias *Wollac* (Germany), Luca Moser alais *luca-moser* (Switzerland), Ching-Hua (Vivian), Lin aka *jkrvivian* (Taiwan), Hans Moog aka *hmoog* (Sweden), Piotr Macek aka *piotrm50* (Poland) and Levente Pap alias *lzpap* (Germany) (as of August 25th 2024) **[6j]**.

In 2021, the IOTA network was composed of 300 public nodes, spread all over the world, including 214 (71.33 %) in Germany, 13 (4.33 %) in Finland, 10 (3.33%) in Austria, 10 (3.33%) in Taiwan, 9 (3 %) in Switzerland, 9 (3 %) in the Netherlands, 9 (3 %) in the USA, 6 (2%) in Canada, 4 in France (1.33%), 3 in Japan (1%), 3 in Malaysia (1%) etc. (as of May 15th 2021) **[6k]**.

Along with previous figures, in 2021 the **computing capacity** of the IOTA network was provided by legal entities spread all over the world, including 65 (21.66 %) for Contabo (Germany), 65 (21.66%) for Hetzner Online (Germany), 33 (11% %) for Netcup (Germany), 18 (6 %) for Deutsche Telekom (Germany), 8 (2.66 %) for Vodafone (Germany, Ireland, Netherlands), 8 (2.66 %) for Amazon (Germany, Japan, UK) etc. (as of May 15th 2021).

III.4. Compared Characteristics of some Early Distributed Ledger Systems

III.4.a. Compared Early Scalability

The **scalability** of distributed ledger systems may be assessed based on the transactional performance, i.e. the ability to run tens of thousands of transactions per second.

The transactional performance of Bitcoin, Ethereum (1.0) and IOTA (1.0) systems is not scalable with at maximum 7, 20 and 40 tx/s respectively.

Indeed, in comparison with previous systems, the transactional performance (in billion transactions per year or Btx/y) of **international payment networks and systems** such as VISA **[7a] [7b] [7c] [7d] [7e] [7f] [7g] [7h]**, Mastercard **[8]** or PayPal **[9a] [9b] [9c]** reaches several hundreds, thousands or tens of thousands of transactions per second with respectively at maximum 65 000, >5 000 and >1 000 tx/s (**Table I**).

TABLE I. EARLY SCALABILITY OF INTERNATIONAL PAYMENT NETWORKS AND DISTRIBUTED LEDGER SYSTEMS

Network / System	Average Number of Transactions per Second	Maximum Number of Transactions per Second
Bitcoin	**~3 tx/s** (2018-2019)	**~7 tx/s** (2018-2019)
Ethereum (1.0)	**~8 tx/s** (2021-2022)	**~20 tx/s** (2021-2022)
IOTA (1.0)	**~10 tx/s** (claimed, 2019) 5-20 tx/s (confirmed, 2020)	~1 000 tx/s (claimed, 2019) **40 tx/s** (confirmed, 2020)
VISA	**6 754 tx/s** (213 Btx/y, June 2023)	**65 000 tx/s** (August 2017)
Mastercard	**4 540 tx/s** (143.2 Btx/y, 2023)	Assumed **>5 000 tx/s** (2024)
PayPal	**793 tx/s** (25.0 Btx/y, 2023)	450 tx/s (2015) Assumed **>1 000 tx/s** (2024)

III.4.b. Compared Early Sustainability

The **sustainability** (i.e. the **environmental footprint**) of distributed ledger systems and transactions may be assessed based on the electric consumption, the carbon footprint (i.e. **CO2e emission**), the water footprint (i.e. **freshwater consumption**), the electronic waste and the land footprint (i.e. **land artificialisation**) (**Table II** for systems and **Table III** for transactions).

TABLE II. EARLY SUSTAINABILITY OF INTERNATIONAL PAYMENT NETWORKS AND DISTRIBUTED LEDGER SYSTEMS

Network / System	Electric Consumption	Carbon Footprint	Water Footprint	Electronic Waste	Land Footprint
Bitcoin	**~100 TWh** 173.42 TWh (2020-2021) 147.18 TWh (yearly, Aug. 19th 2024, CBECI) 98.27 TWh (yearly, Aug. 21st 2024, BECI)	**~50 MtCO2e** 85.89 MtCO2e (2020-2021) 54.81 MtCO2e (yearly, Aug. 21st 2024, BECI)	**~1 000 GL** 1 647.57 MCM i.e. 1.65 km^3 i.e. 1 650 GL (2020-2021) 1 049 GL (yearly, Aug. 21st 2024, BECI)	**~10 kt** 10.52 kt (yearly, Aug. 21st 2024, BECI)	**~1 000 km^2** 1869.69 km^2 (2020-2021)
Ethereum (1.0)	**~50 TWh** 102.47 TWh (yearly, Dec. 28th 2021, EECI) 82.78 TWh (yearly, Sept. 13th 2022, EECI) 21 TWh (yearly, Sept. 2022, CCRI)	**~25 MtCO2e** 48.67 MtCO2e (yearly Dec. 28th 2021, EECI) 46.17 MtCO2e (yearly, Sept. 13th 2022, EECI) 11 MtCO2e (yearly, Sept. 2022, CCRI)	Not assessed	Not assessed	Not assessed
IOTA (1.0)	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
VISA	**~0.2 TWh** 841 000 GJ (GigaJoules) of energy from electricity (687 000 GJ i.e. 191 GWh), natural gas and other fuels (2023)	**~0.4 MtCO2e** 10.6 ktCO2e (scopes 1 & 2, 2023) + 409.5 ktCO2e (scope 3, 2023)	**~400 ML** 365.0 ML (million litres) (2023)	**~4 kt** 3 900 t (2023)	Not assessed
Mastercard	**~0.1 TWh** 102.778 GWh (2023)	**~0.6 MtCO2e** 557.545 ktCO2e (2023, scopes 1, 2 & 3)	**~150 ML** 131 250 m^3 (cubic meters) i.e. 131 ML (2023)	**~0.75 kt** 1 637 393 lbs (pounds) i.e. 742.7 t (2023)	Not assessed
PayPal	**~0.2 TWh** 243.1 GWh (2023)	**~0.5 MtCO2e** 515.1 ktCO2e (2023, scopes 1, 2 & 3)	**~200 ML** 56.8 Mgal i.e. 212.0 ML (2023)	**~0.4 kt** 375 t (2023)	Not assessed

TABLE III. EARLY SUSTAINABILITY OF INTERNATIONAL PAYMENT AND DISTRIBUTED LEDGER TRANSACTIONS

Transaction	Electric Consumption	Carbon Footprint	Water Footprint	Electronic Waste	Land Footprint
Bitcoin	**~500 kWh** 483.73 kWh (Aug. 21st 2024, BECI)	**~250 kgCO2** 269.81 kgCO2 (Aug. 21st 2024, BECI)	**~7 500 litres** 7 624 litres (Aug. 21st 2024, BECI)	**~50 grammes** 51.8 grammes (Aug. 21st 2024, BECI)	Not assessed
Ethereum (1.0)	**~200 kWh** 229.43 kWh (Dec. 28th 2021, EECI) 212.82 kWh (Sept. 13th 2022, EECI)	**~100 kgCO2** 108.98 kgCO2 (Dec. 28th 2021, EECI) 118.7 kgCO2 (Sept. 13th 2022, EECI)	Not assessed	Not assessed	Not assessed
IOTA (1.0)	**~100 mWh** 0.00011 kWh (Aug. 2019) 0.00016 kWh (April 2020)	Not assessed	Not assessed	Not assessed	Not assessed
VISA	**~1 Wh** 0,000918 kWh (2018)	Not assessed	Not assessed	Not assessed	Not assessed
Mastercard	**~1 Wh** 0,00070 kWh (2017)	Not assessed	Not assessed	Not assessed	Not assessed
PayPal	Not assessed	**~0,5 gCO2** 0.5 gCO2e (grammes CO2e) (2023)	Not assessed	Not assessed	Not assessed

III.4.c. Compared Sovereignty

The **sovereignty** of distributed ledger systems may be assessed based on the **location of the legal entity** (e.g. foundation) **maintaining the system**, the **size and openness of the community of developers maintaining the system**, the **distribution of nodes** and the **distribution of the legal entities providing mining capacity** (**Table IV**).

TABLE IV. SOVEREIGNTY OF DISTRIBUTED LEDGER SYSTEMS

<table>
<tr><th>Network / System</th><th>Location of the Legal Entity maintaining the System</th><th>Size and Openness of the Community of Developers maintaining the System</th><th>Distribution of Nodes</th><th>Distribution of the Legal Entities providing Mining Capacity</th></tr>
<tr><td>Bitcoin</td><td>USA</td><td>~1 000
USA, Netherlands, Ukraine etc.</td><td>~19 000
USA, Germany, France, Finland, Netherlands etc.</td><td>China, USA etc.</td></tr>
<tr><td>Ethereum (1.0)</td><td rowspan="2">Switzerland</td><td rowspan="2">Thousands (depending on GitHub repositories)
Russia, Netherlands, Romania, Germany, Sweden, Vietnam, UK, etc.</td><td>~5 000 – 6 500
USA, Germany, South Korea, Canada, UK, France, Netherlands, Finland etc.</td><td>Austria, China, Cyprus, Canada etc.</td></tr>
<tr><td>Ethereum 2.0</td><td>~10 000 beacon nodes
USA, Germany, Finland, UK, France, Canada, Netherlands, Australia, South Korea etc.</td><td>Not applicable (no mining)</td></tr>
<tr><td>IOTA (1.0)</td><td rowspan="3">Germany</td><td rowspan="3">Hundreds
(depending on GitHub repositories)
Germany, Switzerland, Sweden, Taiwan, Poland, UK, Austria,</td><td>~300 (2021)
Germany, Finland, Austria, Taiwan, Switzerland, Netherlands, USA, Canada, France, Japan, Malaysia etc.</td><td>Germany, Netherlands, Ireland, Japan, UK etc.</td></tr>
<tr><td>IOTA 1.5</td><td colspan="2">Not assessed</td></tr>
<tr><td>IOTA 2.0</td><td colspan="2">Under development</td></tr>
</table>

IV. NEW ARCHITECTURES FOR DISTRIBUTED LEDGER SYSTEMS

IV.1. Bitcoin Evolution

Currently, the Bitcoin Foundation does not provide any path to Bitcoin 2.0, similarly to Ethereum 2.0 and IOTA 2.0, that would bring scalability (beyond 7 tx/s) and sustainability (no more proof of work consensus mechanism), in addition to current sovereignty **[10a]**. However, the Bitcoin system remains the most important blockchain system in the world in terms of **market capitalisation** i.e. the usefulness prevails over scalability and sustainability. Indeed, Bitcoin market capitalisation was 1.05 T€ (trillions of euros) whereas the Ethereum one was 288.35 B€ (billions of euros) (as of August 19th 2024) **[10b]**.

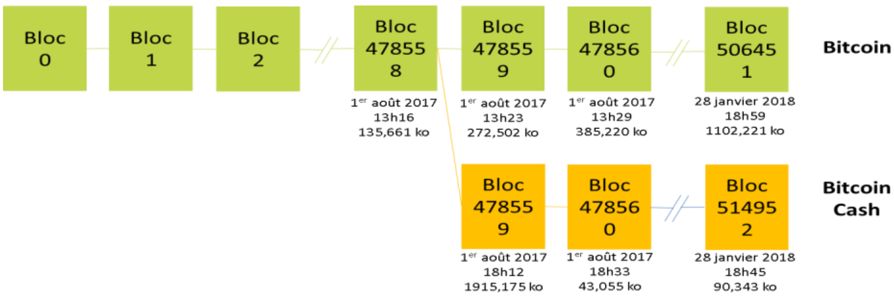
IV.1.a. Scalability of Bitcoin Layer 1 Solutions (Litecoin, Bitcoin Cash)

Some **layer 1 solutions** were derived from the Bitcoin system in order to increase the number of transactions per second.

For this, a part of the community of developers proposes an improvement in Bitcoin Core project such as the **decrease of the average or minimum time for block validation** (e.g. Litecoin) or the **increase of the maximum block size** (e.g. Bitcoin Cash). In case this improvement is not accepted by the other part of the community of developers, a new blockchain system is created from a given split block and a **hard fork** takes place between the Bitcoin blockchain and the new blockchain. Both blockchains have in common all blocks before and including the split block.

A first example is **Litecoin**, which decreases the average time for block validation to 2.5 minutes (instead of 10 minutes in Bitcoin) and increases the number of transactions per second up to $R_{max} = (10 / 2.5) * 2000 / 300 \sim 27$ tx/s **[11]**. The Litecoin hard fork took place on October 8th 2011. A second example is **Bitcoin Cash**, which increases the maximum block size to 8 MB and then 32 MB (instead of 1 MB in Bitcoin) and increases the number of transactions per second up to $R_{max} = (8 / 1) * 2000 / 300 \sim 53$ tx/s (8 MB) or $R_{max} = (32 / 1) * 2000 / 300 \sim 213$ tx/s (32 MB) **[12]**. The Bitcoin Cash hard fork took place on August 1st 2017 at the split block number 478 558 (**Figure 7**).

FIGURE 7. INTRODUCTION OF BITCOIN CASH BLOCKCHAIN AFTER A HARD FORK OF THE BITCOIN BLOCKCHAIN



IV.1.b. Scalability of Bitcoin Layer 2 Solutions (Blockstream, Lightning Network)

Compared to layer 1 solutions, i.e. Bitcoin, Litecoin and Bitcoin Cash blockchains, the **layer 2 solutions** increase the number of transactions per second, while reducing the transaction fees. For this, a layer 2 solution bundles many layer 2 transactions into one layer 1 transaction.

Several types of layer 2 bundle technologies coexist on top of the Bitcoin blockchain: a **buffer file** (layer 2 transactions are aggregated into a buffer file, whose file hash is stored into one layer 1 transaction), a **sidechain** (layer 2 transactions are processed on a sidechain and aggregated into one layer 1 transaction), some **off-chain state channels** (layer 2 transactions are processed off-chain) etc. **[13]**.

A first example is **Blockstream**, which implements a sidechain and increases the number of transactions per second up to ~10 tx/s (ranging from 7 to 10 tx/s) **[14]**. A second example is the **Lightning Network**, which implements some off-chain state channels and increases the number of transactions per second up to 1 000 000 tx/s (ranging from 1 000 000 tx/s to 1 000 000 000 tx/s) **[15a] [15b]**.

IV.2. Ethereum Evolution

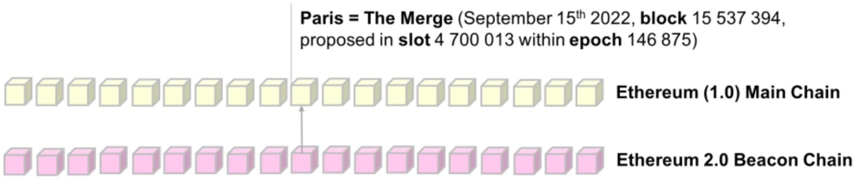
The Ethereum Foundation has shared a clear path to Ethereum 2.0, bringing scalability, sustainability and sovereignty.

IV.2.a. Introduction to Ethereum 2.0

The June 2020 initial roadmap of Ethereum 2.0 was based on four phases: Serenity Phase 0, Serenity Phase 1, Serenity Phase 1.5 and Serenity Phase 2 **[16a]**.

The Serenity Phase 0 introduces the Ethereum 2.0 **beacon chain** in addition to the Ethereum (1.0) **main chain** (**Figure 8**). Nodes running the beacon chain implement the **proof of stake (PoS) consensus mechanism** and the underlying **staking concept**, in which a minimum of 32 ethers is needed to become a validator among the 16 000 and more validators. The linking of the main chain to the beacon chain is referred to as *The Merge* sub-phase, which was completed as of Sept. 15th 2022, thus closing the Serenity Phase 0 **[16b]**.

FIGURE 8. INTRODUCTION OF ETHEREUM BEACON CHAIN IN ADDITION TO THE ETHEREUM MAIN CHAIN



It is worth noting that whereas the main chain refers to **block numbers**, the beacon chain refers to **slot and epoch numbers**. For *The Merge*, block 15 537 394 of the main chain was proposed in slot 4 700 013 within epoch 146 875 of the beacon chain. An epoch gathers 32 slots (potentially 32 blocks) and is built every 6.4 minutes.

The Serenity Phase 1 plans to introduce the **shard chains** in addition to the main chain and the beacon chain. The Ethereum (1.0) main chain goes on running and is linked to the beacon chain that may support up to 64 (initially 100) shard chains **[16c] [16d]**. The linking of the shard chains to the beacon chain is referred to as *The Surge* sub-phase, which will implement a rollup type layer 2 solution as well as data sharding **[16e].** Then, the Serenity Phase 1.5 plans to introduce an evolution of the Ethereum (1.0) blockchain that becomes a shard chain among others. Finally, the Serenity Phase 2 plans to introduce the state execution concept, Ethereum Web Assembly (eWASM) as well as several codes for programming smart contracts (including Solidity).

The November 2022 and December 2023 updated roadmaps now considers 6 sub-phases: *The Merge* (proof of stake consensus mechanism), *The Surge* (100 000 tx/s and rollup), *The Scourge*, *The Verge*, *The Purge*, *The Splurge* **[16f] [16g]**. It is worth noting that the Serenity Phases 1, 1.5 and 2 are not mentioned anymore within the roadmap provided by Vitalik Buterin.

IV.2.b. Scalability of Ethereum Layer 2 Solutions (Optimism, Arbitrum and Polygon)

Compared to layer 1 solutions, i.e. Ethereum blockchain, the **layer 2 solutions** increase the number of transactions per second, while reducing the transaction fees. For this, a layer 2 solution bundles many layer 2 transactions into one layer 1 transaction.

Several types of layer 2 bundle technologies coexist on top of the Ethereum blockchain: a **buffer file**, a **sidechain**, an **optimistic rollup** (a layer 2 transaction is assumed to be valid), a **zero-knowledge (ZK) rollup** (a layer 2 transaction uses validity proof) etc. **[17a] [17b] [17c] [17d]**.

A first example is **Optimism**, which implements an optimistic rollup, creates the OP token, and increases the number of transactions per second up to 2 000 tx/s **[18a] [18b] [18c]**. A second example of layer 2 solution is **Arbitrum**, which implements an optimistic rollup, creates the ARB token, and increases the number of transactions per second up to 40 000 tx/s **[19]**. A third example is **Polygon**, which implements a sidechain and a zero-knowledge rollup, creates the MATIC token, and increases the number of transactions per second up to 65 000 tx/s **[20]**.

IV.2.c. Scalability of Ethereum 2.0

The Ethereum 2.0 system introduces shard chains and the underlying sharding concept, to increase the number of transactions per second at maximum ~100 000 tx/s (ranging from 25 000 to 100 000 tx/s) **[21a] [21b]**. This evolution will be part of *The Surge* sub-phase.

IV.2.d. Sustainability of Ethereum 2.0

The Ethereum 2.0 system switches from the proof of work (PoW) to the proof of stake (PoS) consensus mechanism and thus reduces the electric consumption by ~99.95% compared to Ethereum (1.0), down to ~0.035 kiloWatt-hour (kWh) per transaction (May 2021) **[22a]**.

The Ethereum 2.0 system reached an electric consumption of 2.6 GWh and a carbon footprint of 870 tCO2e according to CCRI (yearly, October 2023) **[22b] [22c]**, increased to 5.57 GWh and 5.757 GWh / 1 855 tCO2e according to CBNSI and CCRI respectively (yearly, as of August 23rd 2024) **[22d] [22e]**.

IV.3. IOTA Evolution

The IOTA Foundation has shared a clear path to IOTA 2.0, bringing scalability, sustainability and sovereignty.

IV.3.a. Introduction to IOTA 1.5 and IOTA 2.0

The initial roadmap of IOTA evolution is based on three main updates: IOTA 1.5 Phase 1, IOTA 1.5 Phase 2 and IOTA 2.0.

The IOTA 1.5 update (also known as Chrysalis) brings a “simple transition to Coordicide” as well as some “substantial improvement in the scalability and reliability of the IOTA mainnet” **[23a]**. Chrysalis Phase 1 and Phase 2 were respectively launched on August 19th 2020 **[23b]** and April 28th 2021 **[23c]**.

The IOTA 2.0 update (also known as Coordicide) will remove the Coordinator node in order to provide **full decentralisation [23d]**. Furthermore, it will natively implement the oracle (no more Qubic) as well as smart contract features. In details, the IOTA 2.0 update will introduce three layers: network layer, communication layer (including The Tangle) and application layer (including the consensus mechanism). The consensus mechanism is based on two components: the **tip selection algorithm** and **the voting mechanism [23e] [23f] [23g]**.

The Shimmer network (also called GoShimmer network) was deployed on August 19th 2020 and consists in the stagging of IOTA 2.0 network, before the later goes into production **[23h]**.

IV.3.b. Scalability of IOTA 1.5 and IOTA 2.0

The *IOTA Tangle Explorer* provides some charts that allow observing the average / maximum number of confirmed transactions per day $D_{mean/max}$ and providing a first assessment that D_{mean} = 8 000 transactions per day <1 tx/s and D_{max} = 64 000 transactions per day <1 tx/s (as of July 11th 2024) **[23i]**.

The IOTA 1.5 update (Chrysalis Phase 1) increases the number of transactions per second up to average >1 000 tx/s and maximum 1 500 tx/s during testing. Transactions are now confirmed every 10 seconds instead of every 80 seconds in IOTA 1.0 **[23j] [23k]**.

The IOTA 2.0 update will remove the transactional performance limit, but is currently artificially limited to average 1000 tx/s (December 2021) **[23l]**.

IV.3.c. Scalability of IOTA Layer 2 Solutions (IOTA EVM, IOTA Chains Framework)

Compared to layer 1 solutions, i.e. The Tangle or Shimmer network, the **layer 2 solutions** bring new features that are not natively supported by the layer 1 e.g. the smart contract and associated fungible token and non-fungible token (NFT).

IOTA could have brought its own smart contract format such as the decentralised application (dApp) in Ethereum or the chaincode in Hyperledger Fabric system. On the contrary, IOTA proposes an Ethereum-compatible smart contract. Supporting Ethereum-compatible smart contract assumes that an Ethereum Virtual Machine (EVM) runs on the IOTA infrastructure.

For this, the **IOTA EVM** mainnet, a layer 2 solution, was launched on June 4th 2024. IOTA EVM natively supports smart contract writing (in Solidity, Go or Rust programming language) and deployment on top of IOTA infrastructure i.e. the Shimmer network. The bridge between the layer 2 solution and the layer 1 solution is provided by the **IOTA Chains Framework [24a] [24b] [24c]**.

The first block of the IOTA EVM mainnet was created on March 14th 2024. Even though it appears as an Ethereum blockchain from the *IOTA EVM Explorer*, all blocks only contain one transaction. Transactions are used for smart contract creation, contract call or token exchange **[24d]**.

IV.3.d. Sustainability of IOTA 1.5 and IOTA 2.0

The IOTA 1.5 system reduces electric consumption by 33-95% compared to IOTA (1.0), down to 1.1 millionth kWh i.e. 1.1 mWh per transaction (May 2021) **[25a]**.

The IOTA 1.5 system reached an electric consumption of 52.99 MWh and a carbon footprint of 17.07 tCO_2e according to CCRI (yearly, as of August 23rd 2024) **[25b]**.

The IOTA 2.0 system will reduce electric consumption to less than a billionth of kWh i.e. <1 µWh per transaction (December 2021) **[25c]**.

A simulation of the Chrysalis and Shimmer networks, including 450 nodes each, estimated the consumption to 28.9 MWh and 20.7 MWh respectively (yearly, October 2022) **[25d]**.

IV.4. Compared Characteristics of New Architectures for Distributed Ledger Systems

IV.4.a. Compared New Scalability

New architectures for distributed ledger systems improved the scalability in terms of number of transactions per second.

For the **Bitcoin system**, the transactional performance increased from at maximum 7 tx/s to 1 000 000 tx/s thanks to the Lightning Network layer 2 solution. However, the Bitcoin Foundation does not provide any evolution towards a more scalable Bitcoin 2.0. For the **Ethereum system**, the transactional performance increased from at maximum 20 tx/s to 65 000 tx/s thanks to the Polygon layer 2 solution with a target to reach ~100 000 tx/s with Ethereum 2.0. For the **IOTA system**, the transactional performance increased from at maximum 40 tx/s to 1 500 tx/s with IOTA 1.5 and to a target to remove the limit on the number of transactions with IOTA 2.0.

TABLE V. NEW SCALABILITY OF DISTRIBUTED LEDGER SYSTEMS

Network / System	Average Number of Transactions per Second	Maximum Number of Transactions per Second
Bitcoin Layer 1 Solutions	Not assessed	~27 tx/s (Litecoin) ~213 tx/s (Bitcoin Cash)
Bitcoin Layer 2 Solutions	Not assessed	~10 tx/s (Blockstream) 1 000 000 tx/s (Lightning Network)
Ethereum Layer 2 Solutions	Not assessed	2 000 tx/s (Optimism) 40 000 tx/s (Arbitrum) 65 000 tx/s (Polygon)
Ethereum 2.0	Not assessed	**~100 000 tx/s** (claimed, 2020)
IOTA 1.5	>**1 000 tx/s** (2020)	**1 500 tx/s** (2020)
IOTA 2.0	Under development	**Unlimited**, artificially limited to 1 000 tx/s (2021)

IV.4.b. Compared New Architectures Sustainability

New architectures for distributed ledger systems and transactions improved the sustainability in terms of electric consumption and carbon footprint (**Table VI** for systems and **Table VII** for transactions).

For the **Bitcoin system**, the sustainability remains unchanged. For the **Ethereum system**, the electric consumption and the carbon footprint decreased from ~50 TWh / ~25 MtCO2e to ~5 GWh / ~2 MtCO2e. For an Ethereum transaction, the electric consumption decreased from ~200 kWh to ~35 Wh per transaction with Ethereum 2.0. For an **IOTA transaction**, the electric consumption decreased from ~100 mWh to ~1.1 mWh with IOTA 1.5.

TABLE VI. NEW SUSTAINABILITY OF DISTRIBUTED LEDGER SYSTEMS

Network / System	Electric Consumption	Carbon Footprint	Water Footprint	Electronic Waste	Land Footprint
Ethereum 2.0	**~5 GWh** 2.6 GWh (yearly, Oct. 2023, CCRI) 5.57 GWh (yearly, Aug. 2024, CBNSI) 5.757 GWh (yearly, Aug. 2024, CCRI)	**~2 MtCO2e** 870 tCO2e (yearly, Oct. 2023, CCRI) 1 855 tCO2e (yearly, Aug. 2024, CCRI)	Not assessed	Not assessed	Not assessed
IOTA 1.5	**~50 MWh** 52.99 MWh (yearly, Aug. 2024, CCRI)	**~20 tCO2e** 17.07 tCO2e (yearly, Aug. 2024, CCRI)	Not assessed	Not assessed	Not assessed
IOTA 2.0	Under development				

TABLE VII. NEW SUSTAINABILITY OF DISTRIBUTED LEDGER TRANSACTIONS

Transaction	Electric Consumption	Carbon Footprint	Water Footprint	Electronic Waste	Land Footprint
Ethereum 2.0	~0.035 kWh i.e. **~35 Wh** (May 2021)	Not assessed	Not assessed	Not assessed	Not assessed
IOTA 1.5	1.1 millionth kWh i.e. **1.1 mWh** (May 2021)	Not assessed	Not assessed	Not assessed	Not assessed
IOTA 2.0	< billionth kWh i.e. **< 1 µWh** (Dec. 2021)	Under development			

IV.5. New Architectures are a Prerequisite to support Sustainable Development Efforts

Blockchain and distributed ledger technologies (DLT) are now **mature and viable** since new architectures have improved their scalability (e.g. ~100 000 transactions per second for Ethereum 2.0, unlimited for IOTA 2.0), sustainability (e.g. ~35 Wh for an Ethereum 2.0 transaction, 1.1 mWh for an IOTA 1.5 transaction) and sovereignty (no particular person, legal entity or country controls the system).

In particular, previous sections have deeply detailed the sustainability of these technologies, in terms of electricity consumption, carbon footprint, water footprint, electronic waste and land footprint. Understanding the relationship between causes and consequences of the production and consumption of digital services, as provided by blockchain and DLT, is a prerequisite before deploying these technologies to support sustainable development.

Blockchain and DLT use cases can now support the sustainable development efforts.

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V. BLOCKCHAIN AND DLT USE CASES FOR SUSTAINABLE DEVELOPMENT

V.1. United Nations Sustainable Development Goals and Coverage by ISO Standardisation

V.1.a. United Nations Sustainable Development Goals (UN SDGs) and Targets

The United Nations have defined **17 Sustainable Development Goals (SDGs)** and **169 targets** to be fulfilled by 2030 within the scope of the 2030 Agenda for Sustainable Development, which was adopted in 2015 i.e. the same year as the COP21 in Paris, France (**Table VIII**) **[26a] [26b]**.

This section will arbitrarily focus on UN SDG 9 (Industry, Innovation & Infrastructure) and UN SDG 12 (Responsible Consumption & Production) for **Circular Economy**, UN SDG 13 (Climate Action) for **Climate Action**, and UN SDG 14 (Life Below Water) and UN SDG 15 (Life On Land) for **Biodiversity Conservation** (marine and terrestrial biodiversity respectively).

TABLE VIII. UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS (SDGs) & TARGETS

Sustainable Development Goal	Number of Targets	Target
1 No Poverty	7	
2 Zero Hunger	8	
3 Good Health & Well-Being	13	
4 Quality Education	10	
5 Gender Equality	9	
6 Clean Water & Sanitation	8	
7 Affordable & Clean Energy	5	
8 Decent Work & Economic Growth	12	
9 Industry, Innovation & Infrastructure	8	9.1 Develop quality, reliable, **sustainable and resilient infrastructure** […] 9.2 Promote inclusive and sustainable industrialization […] 9.3 Increase the access of small-scale industrial and other enterprises […] 9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with **increased resource-use efficiency** and greater adoption of clean and environmentally sound technologies and industrial processes […] 9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries […] 9.a Facilitate sustainable and resilient infrastructure development in developing countries […] 9.b Support domestic technology development, research and innovation in developing countries […] 9.c Significantly increase access to information and communications technology […]
10 Reduced Inequalities	10	
11 Sustainable Cities & Communities	10	
12 Responsible Consumption & Production	11	12.1 Implement the 10-year framework of programmes on sustainable consumption and production |…] 12.2 By 2030, achieve the sustainable management and **efficient use of natural resources** 12.3 By 2030, halve per capita global food waste […] and reduce food losses along production and supply chains […] 12.4 By 2020, achieve the environmentally sound management of **chemicals and all wastes throughout their life cycle** […] and significantly **reduce their release to air, water and soil** in order to minimize their adverse impacts on human health and the environment 12.5 By 2030, substantially **reduce waste generation through prevention, reduction, recycling and reuse** 12.6 Encourage **companies** […] to integrate sustainability information into their **reporting** cycle 12.7 Promote public procurement practices that are sustainable […] 12.8 By 2030, ensure that people everywhere have the relevant information and

		awareness for sustainable development and lifestyles in harmony with nature 12.a Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production 12.b Develop and implement tools to monitor sustainable development impacts for sustainable tourism […] 12.c Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions […]
13 Climate Action	5	13.1 **Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters** in all countries 13.2 Integrate climate change measures into national policies, strategies and planning 13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning 13.a Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change […] to address the needs of developing countries […] and fully operationalize the Green Climate Fund […] 13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States […]
14 Life Below Water	10	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds […] 14.2 By 2020, sustainably manage and protect marine and coastal ecosystems […] 14.3 Minimize and address the impacts of **ocean acidification** […] 14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans […] 14.5 By 2020, conserve at least 10 per cent of coastal and marine areas […] 14.6 By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies […] 14.7 By 2030, increase the economic benefits to Small Island developing States and least developed countries from the sustainable use of marine resources […] 14.a Increase scientific knowledge, develop research capacity and transfer marine technology […] 14.b Provide access for small-scale artisanal fishers to marine resources and markets 14.c Enhance the conservation and sustainable use of oceans and their resources […]
15 Life On Land	12	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland **freshwater ecosystems** and their services […] 15.2 By 2020, promote the implementation of sustainable management of all types of **forests**, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally 15.3 By 2030, combat desertification, restore degraded **land and soil** […] and strive to **achieve a land degradation-neutral world** 15.4 By 2030, ensure the conservation of **mountain ecosystems** […] 15.5 Take urgent and significant action to reduce the degradation of **natural habitats**, halt the loss of **biodiversity** and, by 2020, protect and prevent the extinction of **threatened species** 15.6 Promote fair and equitable sharing of the benefits arising from the utilization of **genetic resources** and promote appropriate access to such resources […] 15.7 Take urgent action to end poaching and trafficking of protected species of flora and fauna and address both demand and supply of illegal wildlife products 15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species 15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts 15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems 15.b Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation 15.c Enhance global support for efforts to combat poaching and trafficking of protected species […]
16 Peace, Justice & Strong Institutions	12	
17 Partnerships For The Goals	19	
	169	

In first approach, the **scalability** and **sustainability** characteristics of blockchain and DLT (cf. **sections III and IV**) will help developing reliable, sustainable and resilient infrastructure (cf. UN SDG 9, target 9.1) and strengthening resilience and adaptive capacity against climate-related hazards and natural disasters (cf. UN SDG 13, target 13.1).

Additionally, the inherent **electric consumption**, **water footprint** and **land footprint** of the new architectures in blockchain and DLT as well as their **usage** will contribute to increase the resource-use efficiency of industries (cf. UN SDG 9, target 9.4) and more generally to use more efficiently the natural resources (cf. UN SDG 12, target 12.2) but also chemicals and wastes through their life-cycle to reduce their release in air, water and soil (cf. UN SDG 12, target 12.4) thus minimising ocean acidification (cf. UN SDG 14, target 14.3), protecting freshwater ecosystems, forests, land and soil, mountain ecosystems, natural habitats, biodiversity, threatened species and genetic resources (cf. UN SDG 15, targets 15.1 to 15.6).

Furthermore, blockchain and DLT can help accelerating the **deployment of some regulation** such as the Circular Economy Action Plan (CEAP) including the digital product passport (DPP) or the Corporate Sustainability Reporting Directive (CSRD) as part of the European Green Deal (cf. **section VI**) with the reduction of waste generation through prevention, reduction, recycling and reuse (cf. UN SDG 12, target 12.5) and companies reporting (cf. UN SDG 12, target 12.6), but also the achievement of a land degradation-neutral world (cf. UN SDG 15, target 15.3) e.g. Net Zero Artificialisation in France.

V.1.b. United Nations Sustainable Development Goals Report 2024

Previous focus on UN SDGs 9, 12, 13, 14 and 15 shows, in first approach, how blockchain and DLT can help accelerating the deployment of the UN SDGs. The acceleration against stagnation, the reduction against increase and the protection against degradation, when relevant, are at the essence of the alarming conclusions of the United Nations SDG Report 2024 **[26d]**.

Indeed, about UN SDG 9, this report states that "[…] while there has been progress in **reducing CO2 intensity** in manufacturing, it falls short of 2030 target values. To expedite progress towards SDG 9, efforts should prioritize **accelerating the green transition**, strategically prioritizing sectors, and addressing inequalities in digital and innovation sectors."

About UN SDG 12, it adds that "the crisis of unsustainable consumption and production patterns worldwide is fuelling the ongoing triple planetary crisis of climate change, nature loss and pollution. Domestic **material consumption and material footprint continue to rise**, […] stockpiles of **e-waste steadily grow**. […] Each stage of production or manufacturing presents an opportunity to **reduce resource and fossil fuel use**, foster innovation, conserve energy, cut emissions, and advocate for a circular economy approach."

About UN SDG 13, it also states that "climate records were shattered in 2023, with the world watching the climate crisis unfold in real time. Communities around the world are suffering the effects of extreme weather, which is **destroying lives and livelihoods** on a daily basis. The roadmap to **limit the rise in global temperature** to 1.5°C and avoid the worst of climate chaos […] demands immediate action for drastic **reductions in global greenhouse gas emissions** in this decade and the achievement of net zero by 2050."

About UN SDG 14, the report states that "oceans cover over 70% of the Earth's surface and play a crucial role in providing food and livelihoods for more than 3 billion people as well as combating the effects of climate change. Yet, alarming trends from **declining fish stocks, marine pollution, ocean acidification and habitat destruction** threaten marine ecosystems and the livelihoods of coastal communities worldwide. Urgent action is needed to address these challenges and ensure the long-term health and sustainability of the ocean through sustainable fishing practices, **marine conservation efforts**, **pollution reduction** and global cooperation to safeguard marine life and ecosystems for future generations."

About UN SDG 15, it states that "SDG 15 underscores the critical importance of biodiversity as humanity's life-support system. Yet, the relentless **depletion of forests,** coupled with an alarming rate of **species extinction** and **stagnation in safeguarding key biodiversity areas**, jeopardizes the delicate balance of our ecosystems. To address the pressing global environmental challenges and crises, including climate change, **biodiversity loss**, and pollution, as well as desertification, **land and soil degradation**, drought and **deforestation**, it is imperative to intensify efforts in fulfilling our global environmental and biodiversity commitments"

V.1.c. Sustainable Development Goals Coverage by ISO Standardisation

All ISO Technical Committees (TCs) have adopted the UN SDGs as a reference tool to meet the goals. In particular, the **TC207** (Environmental Management including Climate Change), **TC307** (Blockchain and DLT), **TC323** (Circular Economy) and **TC331** (Biodiversity) who mentioned their coverage of the UN SDGs in terms of **global coverage** by the technical committee (**Table IX**) and **specific coverage** by a given standard published by the technical committee **[27a] [27b] [27c] [27d]**.

TABLE IX. UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS GLOBAL COVERAGE BY ISO TECHNICAL COMMITTEES

Sustainable Development Goal	ISO TC207 (Environmental Management incl. Climate Change)	ISO TC307 (Blockchain and DLT)	ISO TC323 (Circular Economy)	ISO TC331 (Biodiversity)
1 No Poverty		X	X	X
2 Zero Hunger			X	X
3 Good Health & Well-Being			X	X
4 Quality Education		X	X	
5 Gender Equality			X	X
6 Clean Water & Sanitation		X	X	X
7 Affordable & Clean Energy		X	X	X
8 Decent Work & Economic Growth		X	X	X
9 Industry, Innovation & Infrastructure		X	X	X
10 Reduced Inequalities		X	X	X
11 Sustainable Cities & Communities		X	X	X
12 Responsible Consumption & Production		X	X	X
13 Climate Action	X	X	X	X
14 Life Below Water			X	X
15 Life On Land			X	X
16 Peace, Justice & Strong Institutions		X	X	
17 Partnerships For The Goals				

Currently, the ISO/TC307 (Blockchain and DLT) standards do not yet address the UN SDGs 2, 3, 5, 14, 15 and 17. However blockchain and DLT use cases are already addressing all the UN SDGs (cf. **section V.2**) and some working groups, within ISO/TC307 are developing some standards addressing all the UN SDGs (cf. **section VI.1**).

V.2. Blockchain and DLT Use Cases for Sustainable Development

V.2.a. Sustainable Development Goals Coverage by Blockchain and DLT Use Cases

The characteristics of blockchain and DLT, including decentralisation, distribution, disintermediation, transparency (including measurement, reporting and verification (MRV)), traceability (including accountability, monitoring and tracking), trust creation (including security), certification (including labelling, timestamping) and contract automation, as well as the cross-sector applicability can help reaching the UN SDGs globally (**Table X**) **[28a] [28b] [28c] [28d] [28e] [28f] [28g] [28h] [28i] [28j] [28k] [28l] [28m] [28n] [28o] [28p] [28q] [28r] [28s] [28t] [28u]**.

TABLE X. UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS COVERAGE BY BLOCKCHAIN AND DLT USE CASES

Sustainable Development Goal	Blockchain and DLT Use Cases and Solutions Disclaimer: this list is not exhaustive and some solutions may be defunct
1 No Poverty	**Use cases**: **Person identity management** (including national identity issuance, identification) Note: cf. UN SDG 16 for decentralised identifier / identity management **Solutions**: Digital ID Framework in Thailand - ID2020 by Digital Impact Alliance
	Use cases: **Humanitarian funding infrastructure and platform** (including micro-credit, micro-finance, micro-lending, micro-transaction) Note: cf. UN SDG 8 for business funding infrastructure and platform including crowdfunding and crowdlending **Solutions**: BanQu,- Blockchain Bond by World Bank - Blockchain Border Bank by MIT – Smart Infrabonds by Global Infrastructure Hub
	Use cases: **Crowdsourcing platform** **Solutions:** Vevue (Bitcoin, Qtum, Ethereum)
	Use cases: **Humanitarian management** (including aid and assistance, coordination, financial traceability, cash entitlement delivery, food voucher delivery and transfer, humanitarian supply chain, crowdsourcing) **Solutions**: AidCoin by Disberse - Blockchain by UNICEF - Building Blocks by World Food Programme - Cash transfer in Jordan by UN-Women and World Food Programme - Datarella for FCDO – UnifyAid for women and children by StatWig
2 Zero Hunger	**Use cases**: **Food supply management** (including access to food, food voucher, food waste) Note: cf. UN SDG 1 for humanitarian aid / assistance management, including food voucher Note: cf. UN SDG 12 for waste management, including food waste **Solutions**: Foodchain (Polygon)
3 Good Health & Well-Being	**Use cases**: **Healthcare data** (including patient data security, ownership and sovereignty), **Public health data** (including disease, pandemics), **Public health data management** (including issuance, exchange and monitoring) **Solutions**: Healthcare Data Gateway in China – Medicalchain - SOFTEL in Cuba
	Use cases: **Air quality management** (including monitoring, reporting) Note: air quality covers atmospheric pollution Note: quality management covers quality control **Solutions**: PlanetWatch (Algorand)
4 Quality Education	**Use cases**: **Education data management** (including skill assessment, exam evaluation, transcript authentication), **Education certificate and record management** (including issuance, validation, verification, certification), **Education funding platform** (including credit, fee) Note: record covers e.g. curriculum vitae (CV), diploma Note: CV provides information on experience, education / training and abilities / competencies / skills **Solutions**: BadgeChain - BCdiploma - Blockcerts by MIT Media Lab and Learning Machine, now Hyland (Bitcoin) - CVTrust - dAppER - Diploma.report by Paymium for ESILV / ESSEC (Bitcoin) - EduCTX - Hyland Credentials for higher education by Hyland – Nespor - Sony Global Education Blockchain (Hyperledger Fabric) - UZH CAS in Blockchain by UZH Blockchain Center in Switzerland
	Use cases: **Learning management** (including collaborative environment, learning system), **Library and school management** (including library and school environment, learning books copyright) **Solutions**: CHiLO (Hyperledger Fabric) - School Information Hub in Kenya with IBM (Hyperledger Fabric) - Ubiquitous Learning
5 Gender Equality	**Use cases**: **Empowerment and independence** (for women through access to credit, money transfer and markets), **Literacy** (including digital literacy through digital technologies) Note: cf. UN SDG 1 for humanitarian funding infrastructure and platform **Solutions**: VipiCash
	Use cases: **Woman equality** (through leadership and opportunities in governance structures) **Solutions**: She Counts by UN Women
6 Clean Water & Sanitation	**Use cases**: **Water supply management** (including availability, consumption, cybersecurity, rights management, transparency, traceability, accountability), **Water trading and marketplace** **Solutions:** AQUAOSO – Arup with IBM in Australia (Hyperledger Fabric) - Botanical Water Exchange (BWX) by Fujitsu & Botanical Water Technologies (Hyperledger Fabric) - Water Ledger by Civic Ledger in Australia (Hedera Hashgraph) - WaterChain by OriginClear
	Use cases: **Water quality management** (including monitoring, reporting) Note: covers freshwater and drinking / potable water **Solutions**: Smart Water Quality Management and Distribution (Hyperledger Fabric)
	Use cases: **Wastewater management** Note: cf. UN SDG12 for waste management **Solutions**: Newater Technology with NW Blockchain in China
7 Affordable & Clean Energy	**Use cases**: **Energy supply management** (including local and peer-to-peer production, transparency, traceability, accountability, tracking),

	Energy certificate management (including issuance e.g. renewable energy certificate, validation, verification), **Energy tokenisation and trading marketplace** (e.g. cryptocurrency, token) Note: token covers fungible token and non-fungible token (NFT) **Solutions**: Bitlumens - DIVE with DENA, Energy Web & al. - Electron (Ethereum) - Energy Accounting Using Blockchain Technology by Rosseti with Waves Enterprise & Alfa-Bank in Russia (Waves blockchain) - Energy Community Token (Cosmos) - Energy Data-X - Energy Web Chain & Energy Web Origin by Energy Web Foundation - Grid Singularity – Jasmine Energy (Polygon) - NRGcoin - Power Ledger (Ethereum, Power Ledger Blockchain) - Power of the Many by 2Tokens - PriWatt (Bitcoin) – Pyse – React Network (Polygon) - Reneum by Reneum Labs (Polygon) – Skylight by Via Science (Polygon) - SolarCoin - Solstroem, now Carbon Clear in Denmark - Sun Exchange - TransActive Grid in New York City – Unergy Protocol by Unergy - WePower
8 Decent Work & Economic Growth	**Use cases**: **Business funding infrastructure and platform** (including loan issuance, crowdfunding, crowdlending traceability, tracking), **Initial coin offering (ICO) platform** Note: cf. UN SDG 16 for continent, country and institution funding infrastructure and platform **Solutions**: Kickstarter (Celo) - MasterChain in Russia (Ethereum)
	Use cases: **Business organisation** (including governance, self-governing organisation), **Decentralised autonomous organisation (DAO) platform** (including creation) **Solutions**: Aragon (Ethereum)
	Use cases: **Work management** **Solutions:** WorkChain
9 Industry, Innovation & Infrastructure (Circular Economy)	**Use cases**: **Distributed infrastructure** (including cloud infrastructure, network infrastructure, storage infrastructure) **Solutions**: ADEPT System by IBM and Samsung (Ethereum) - Alibaba Cloud Blockchain as a Service (Ant Blockchain, Hyperledger Fabric, Quorum) - Filecoin Green (Filecoin) – Storj by Storj Labs
	Use cases: **Forecasting and prevision platform** (including oracle) **Solutions**: Augur (Ethereum)
	Use cases: **Supply chain management** (including sourcing, production, transparency, traceability, monitoring, reliability, life cycle assessment & management) Note: covers **circular economy** **Solutions:** Catena-X with BMW & al. – Blockchain Food Safety Alliance by JD.com, Walmart, IBM & al. in China - CONA by Coca Cola (Ethereum) – Seafood Traceability by Fishcoin - FoodLedger by StatWig - GAIA-X iECO with IOTA Foundation (IOTA) - IBM Food Trust for Nestlé, Unilever, Walmart & al. (Hyperledger Fabric) - JD Chain by JD.com with IBM (Hyperledger Fabric) - Manufacturing-X with Bosch, Deutsche Telekom & al. - Mining and Metals Blockchain Initiative (MMBI) by WEF for De Beers & al. - Mobility Open Blockchain Initiative (MOBI) by BMW, Ford, General Motors, Honda, Renault & al. – Nexity Network (Polygon) - PartChain by BMW – Real Items (Polygon) - Responsible Sourcing Blockchain Network (RSBN) by RCS Global for Ford, Volkswagen, Volvo & al. with IBM - VaccineLedger by StaTwig - Visible.digital for Carrefour in France (Ethereum) - Walmart PoC with IBM (Hyperledger Fabric) - Walmart China with VeChain
	Use cases: **Contract management** (including disintermediation in value chain, process automation, translation of legacy contract terms into smart contract), Note: disintermediation refers to the removal of unnecessary intermediary parties **Solutions**: Accord Project by Linux Foundation - DocuSign (Ethereum)
	Use cases: **Open Innovation** (including blockchain innovation, sustainable innovation) **Solutions**: Alastria in Spain - Alliance Blockchain France - Austrian Blockchain Center - Bitcoin Embassy Helsinki - Blockchain Research Laboratory in Turkey - Blockchain Association of Kenya - Blockchain Group by UNIN - Blockchain Innovation Center by Fujitsu in Belgium - Blockchain Laboratory in Saudi Arabia - Blockchain Association of Ukraine – Blockchain Bundesverband in Germany - Industrial Blockchain Task Force by INATBA - Latvian Blockchain Association - Modex Blockchain Labs in Romania
10 Reduced Inequalities	**Use cases**: **Connectivity supply management** (including digital inclusion) **Solutions**: Project Connect Giga by UNICEF
	Use cases: **Income equality,** **Financial inclusion,** **Sharing economy** (including digital sharing economy through digital technologies), **Social inclusion** Note: cf. UN SDG 1 for humanitarian funding infrastructure and platform including micro-credit / micro-lending **Solutions**: BLAST - Human DAO - Soramitsu by National Bank of Cambodia (Hyperledger Ihora) - Xcapit (Polygon)
11 Sustainable Cities & Communities	**Use cases**: **City infrastructure** (including network infrastructure) **Solutions**: DistArch-SCNet
	Use cases: **City management** (including governance, decision-making in public spending and public market allocation, election, voting, transparency, traceability) **Solutions**: Civic Ledger
	Use cases: **User identity management** (including road user) **Solutions**: GAIA-X moveID with Airbus, BigChain DB, Bosch, DeltaDAO & al.
	Use cases: **Mobility and transportation infrastructure and platform**, **Traffic management** Note: mobility and transportation cover cycle, train, ship, flight, vehicle e.g. shared vehicle **Solutions**: Blockchain in Transport Alliance (BITA) - FlightChain by SITA in France - La'zooz in France – LinkedCar

	in Belgium – Share&Charge by EDF, Volkswagen & al. in Germany (Ethereum) - Smart Refund System by Trenitalia with Trakti in Italy
12 Responsible Consumption & Production (Circular Economy)	**Use cases**: **Logistics chain management** (including distribution, invoicing / billing, shipping, freight, transport), **Product marketplace** (including direct sale from producer to consumer), **Product quality management** (including monitoring, reporting) Note: product covers e.g. food, electronic device **Solutions**: CargoLedger & ReCollect by StatWig – CargoX - Global Shipping Business Network (GSBN) with Oracle, Microsoft, AntChain & Alibaba Cloud (Hyperledger Fabric) - Lota Digital by Bitcliq –Trade Logistics Information Pipeline (TLIP) by TradeMark Africa with IOTA Foundation (IOTA) - State Railway of Thailand and Thailand Post - Sustainable Clothing by Tentree - TradeLens by IBM and Maersk (Hyperledger Fabric) – TradeWaltz with NTT Data (Hyperledger Fabric) - Walmart Canada with DLT Labs (Hyperledger Fabric)
	Use cases: **Product identifier management** (including vehicle identifier, identification) Note: cf. UN SDG 16 for decentralised identifier / identity management **Solutions**: Vehicle Identity (VID) by MOBI
	Use cases: **Product life cycle assessment and management** (including reusing, repairing, recycling), **Product certificate management** (including issuance, passport, anti-counterfeiting, certification, labelling, fair trade conditions), Note: covers **circular economy** and **digital product passport (DPP)** **Customer action** (including engagement, incentivisation, collaboration, anti-greenwashing, sustainability claim verification) **Solutions**: Arianee - Aura - Authena - Battery Birth Certificate (BBC) by MOBI - Billon - Circularise (Ethereum) - CircularChain by Suez - CIRPASS with Energy Web, GS1 & al. – Digital Battery Passport by Circulator (Hyperledger Fabric) - Everledger – Eviden Battery Passport, Product Passport & Media Passport by IOTA Foundation (IOTA) - InfiniChains by Credibl – LoopID - MyLime – Batteries, Luxury Goods, Textile, Toys & al. Passports by Protokol - Provenance by Provenance Blockchain Foundation - TRICK (Hyperledger Fabric, Quadrans Foundation blockchain)
	Use cases: **Waste management** Note: covers food waste, plastics waste e.g. packaging Note: cf. UN SDG 6 for wastewater management **Solutions**: Bee2WasteCrypto with Compta – Circular Plastic Supply Chain by ABC Research - Dell with VMare (VMware blockchain) – Mitsubishi Chemicals, Philips, Porsche & al. with Circularise (Ethereum) - Plastic Bank – Plastics in automotive industry for Porsche & al. with Circularise (Ethereum) - Plastiks - REBO Smart Water Bottle by RE-Company (Polygon) - Sanergy Collaborative by Sanergy – TraceChain by Snapper Future Tech - Waste2Wear - Zero Waste Foundation
13 Climate Action	**Use cases**: **Climate action certificate and credit management** (including issuance, measurement, reporting and verification (MRV), transparency, traceability, accountability, tracking), **Climate action certificate and credit tokenisation and trading marketplace** (e.g. cryptocurrency, token) Note: cf. UN SDG 15 forest conservation and restoration including carbon sink and tree planting Note: carbon covers carbon sink and carbon-based greenhouse gas (GHG) e.g. carbon dioxide (CO2), methane (CH4) **Solutions**: Allinfra Climate by Allinfra - Astral Protocol by Astral – Atem (Polygon) - Bitmo by Blockchain for Climate (Ethereum) - Blockchain Triangle - Cambridge Centre for Carbon Credits (4C) - Cabon Bridge by Toucan – Carbon Credit by Carbonland Trust - Carbon Credit by Open Forest protocol (OFP) - Carbon Credit by Regen Network Development – Carbon Credit by ReSeed (Polygon) - Carbon Credit by Solid World (Alchemy) – Carbon Token by 2Tokens - Carbon Offsets To Alleviate Poverty (COTAP) – Carbonbase - CarbonClear – CarbonPath - Climate Accounting Infrastructure (CAI) by KPMG - Climate Action Data (CAD) Trust with Climate Change Coallition, Climate Check, Open Earth Foundation & al - Climate Ledger Initiative (CLI) – ClimateCoin - DAO IPCI by Russian Carbon Foundation – dClimate – DigitalMRV by IOTA Foundation with ClimateCHECK (IOTA) – Earthchain - ECO2 Ledger by ECO2 Foundation - ECOTA with Earthchain & al. - ELV Carbon Credits by Meta Materials Circular Markets (MMCM) – Evercity,- Ethereum Climate Platform (ECP) by Ethereum Climate Alliance (Ethereum) - First Carbon Corp. by DeepMarkit – Flowcarbon (Celo) – Goodcarbon (Polygon) – Hiphen by Hyphen Global - Hyperledger Climate Action & Accounting SIG (CA2SIG) by Linux Foundation – Klima Infinity by KlimaDAO (Polygon) - Kolektivo - Moss - Nested Climate Accounting by Open Earth Foundation - Nori (Polygon) - Project Genesis 2.0 – Rebalance Earth –SavePlanetEarth (SPE) (Phantasma) - Senken (Polygon) – Spirals Protocol by Spirals (Celo) – Sushi Carbon Offset by Sushi with KlimaDAO (Polygon) – Thallo - Universal Protocol by Universal Protocol Alliance
	Use cases: **Climate action** (including engagement, incentivisation, collaboration, collaboration, cooperation, accountability, **Climate funding platform** (including digital arts e.g. apes, gamification e.g. play-to-earn, metaverse) **Solutions**: Atlantis World by Gomry – Blockchain & Climate Institute (BCI) by Sierra Industry - Blockchain for Climate Foundation - Climate Chain Coalition (CCC) - Climate Collective gathering Celo, Flowcarbon, Open Earth Foundation, Senken, Spirals, Thallo & Toucan - DigitalArt4Climate (Unique Network) – Earth Fund by 1Earth-Ecosapiens – Emerge by Emerge Technology Lab – GoodDollar governed by GoodDAO – Green Manifesto by Polygon Labs (Polygon) - greenApes - Impact Arcade by Dollar Donation Club - Kultur-Token in Austria - Mercy Corps Ventures - Ripple Sustainability Fund by Ripple Labs (Ripple)
	Use cases: **Climate action decentralised autonomous organisation (DAO)** Note: cf. UN SDG 16 for DAO platform **Solutions**: All for Climate (A4C) DAO – Climate DAO (Ethereum) – Eco Rise - Gitcoin DAO - GoodDAO – KlimaDAO (Polygon) – Kuma DAO - ReFi DAO – SparkEko
	Use cases: **Life below water credit management** (including issuance, transparency, measurement, reporting and verification (MRV), traceability, accountability, monitoring, tracking),

14 Life Below Water (Biodiversity)	**Life below water credit tokenisation and trading marketplace** (e.g. cryptocurrency, token) Note: life below water covers ocean, coral reef, marine species, mangrove etc. **Solutions**: Biodiversity Credit by Regen Network Development - Biodiversity Offset Scheme for marine resources by BioDiversity Solutions Australia (BDS)
	Use cases: **Life below water action** (including engagement, incentivisation, collaboration, cooperation, accountability, conservation, restoration), **Life below water funding platform** **Solutions:** CryptoCorals by Possible Future – Nature restoration by Solid World (Alchemy) – Ocean Depollution by Diatom DAO – Plastic Bank by IBM (Hyperledger Fabric)
15 Life On Land (Biodiversity)	**Use cases**: **Life on land credit management** (including issuance, measurement, reporting and verification (MRV), transparency, traceability, accountability, monitoring, tracking), **Life on land credit tokenisation and trading marketplace** (e.g. cryptocurrency, token) Note: life on land covers grassland, wetland, cropland, peatland, forests, wildlife, endangered species, seed etc. **Solutions**: Biodiversity Credit by BIOTA - Biodiversity Credit by Regen Network Development – Biodiversity MRV by Natural Solutions - Biodiversity Offset Scheme for land resources by BioDiversity Solutions Australia (BDS) - CarbonCoin –EthicHub - Hedera Guardian by Hedera (Hedera Hashgraph) – Hiveonline in Africa - NARIA by Credit Nature - Preservaland – Carbon Tokens by TreeCoin – Nature-Based Solutions by Veritree - Wildchain by WildDAO - Wildlife Credits in Namibia
	Use cases: **Life on land action** (including carbon sink, tree planting, sustainable agriculture, conservation, restoration), **Life on land funding platform** Note: sustainable agriculture covers e.g. conservation agriculture, organic agriculture, regenerative agriculture **Solutions**: Afforestation and reforestation by Open Forest Protocol (OFP) - Avatree by Unifyre - Carbon sequestration with forests by Carbonland Trust - Cocoa tree plantation by UNDP with CocoaLife in Ghana – EcoTree - GainForest - GLI-TEA in Kenya – Kokonut Network by Kokonut Foundation, governed by Kokonut DAO - Nature restoration by Solid World (Alchemy) - Nature-Based Solutions (NbS) Hub - Reforestation by TreeCoin - Regenerative agriculture by ReSeed (Polygon) - Tree planting by Tentree – Tree planting by Veritree
	Use cases: **Life on land decentralised autonomous organisation (DAO)** **Solutions:** Basin DAO - Kokonut DAO – United Species DAO - WildDAO
	Use cases: **Agriculture data management** (including farm / farmer identification, farmer consent management) **Solutions**: AgDataHub in France
	Use cases: **Soil quality management** (including monitoring, reporting)
16 Peace, Justice & Strong Institutions	**Use cases**: **Continent, country and institution blockchain and DLT infrastructure** **Solutions**: Alastria in Spain - European Blockchain Service Infrastructure (EBSI)
	Use cases: **Continent, country and institution management** (including governance, decision-making, law, public funding, public spending and public market allocation, election, voting, anti-fraud, transparency, traceability, accountability, crisis and disaster risk management) **Solutions**: BitNation (Ethereum) - Delaware Blockchain Initiative - Follow My Vote - Procurement System by Government of Colombia
	Use cases: **Continent, country and institution action** (including engagement, collaboration, cooperation, institutional inclusion, accountability), **Continent, country and institution funding infrastructure and platform** (including charity, philanthropy, traceability, tracking) Note: cf. UN SDG 1 for humanitarian funding infrastructure and platform Note: cf. UN SDG 8 for business funding infrastructure and platform **Solutions**: BitGive Foundation (Bitcoin) – Blockchain Charity Foundation by Binance - CryptoFund by UNICEF (Bitcoin, Ethereum) – Glo Dollar (Arbitrum, Base, Cello, Ethereum, Optimisim, Polygon, Stellar)
	Use cases: **Continent and country currency** (including crypto-currency, central bank digital currency (CBDC) and commercial bank money token (CBMT), interbank settlement fees reduction) **Solutions**: Blockchain Community Initiative (BCI) in Thailand - El Salvador (Bitcoin) – Diem (formerly Libra) by Diem Association
	Use cases: **Continent and country registry** (including land registry) **Solutions**: Abu Dhabi Land Registry by Tech Mahindra (Hyperledger Fabric) – Land Register by Bitland in Ghana - Land Registries by Bitfury in Georgia (Exonum blockchain) - UN-Habitat (Unique Network)
	Use cases: **Decentralised identifier / identity management** (including issuance, verification) **Solutions**: Alastria ID in Spain - ChainAnchor by MIT – Dalion Project with Alastria &al. - Decentralized Identity Foundation (DIF) – E-Devlet & MODKA in Turkey – European Digital Identity Wallet (EUDIW) - European Self Sovereign Identity Framework (ESSIF) - Hyperledger Identity SIG by Linux Foundation (Hyperledger Aries, Hyperledger Indy) - IDunion in Germany – IDnow - IOTA Identity Framework (IOTA) –NGI ESSIF-Lab – Sovrin by Sovrin Foundation (Hyperledger Indy) - uPort by Consensys (Ethereum) – Veramo - W3C DID & W3C VC by W3C
17 Partnerships For The Goals	**Use cases**: **UN SDGs action** (including engagement, collaboration, cooperation, accountability) **Solutions**: Blockchain for Social Impact Coalition (BSIC) (Ethereum Climate Platform) - Sustainability Chain by Porino Foundation (Zero-Carbon Chain)

Source: DiCoDaMo.org

In practice, the **transparency**, **traceability**, **trust creation**, **certification** and **contract automation** characteristics of blockchain and DLT support use cases for which a **management function** is needed, in particular data management (e.g. public health, education and agriculture), quality management (e.g. air, water, product, soil), certificate, credit and record management (e.g. education, energy, product, climate action, life below water, life on land), identifier / identity management (e.g. person identity, user identity, product identifier), life cycle assessment and management (e.g. product), waste management (e.g. wastewater), value chain management (e.g. supply chain, logistics chain), supply management (e.g. food, water, energy, connectivity).

Additionally, the **decentralisation**, **distribution**, **disintermediation** and **trust creation** characteristics of blockchain and DLT support use cases for which some **infrastructure and platform** are needed, in particular funding infrastructure and platform (e.g. humanitarian, education, business, climate, life below water, life on land, continent, country and institution) and tokenisation and trading marketplace (e.g. water, energy, product, climate action, life below water, life on land).

Finally, the **transparency**, **traceability**, **trust creation** and **contract automation** characteristics of blockchain and DLT support user cases for which some **action** is needed in terms of engagement, collaboration and cooperation (e.g. customer, climate, life below water, life on land, continent, country and institution, UN SDGs).

Next sections will detail blockchain and DLT use cases for Circular Economy (UN SDGs 9 and 12), Climate Action (UN SDG 13) and Biodiversity Conservation (UN SDGs 14 and 15).

V.2.b. Blockchain and DLT Use Cases for Circular Economy

Circular economy is defined as an "economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (ISO 20400:2017) **[29a]**.

Circular economy thus introduces products, components (including natural resource), material (including raw material) and cycles. In this context, a **product** is defined as "any goods or service", a **natural resource** as a "part of nature that provides benefits to humans or underpins human well-being", a **raw material** as a "primary or secondary material that is used to produce a product", a **life cycle** as the "consecutive and interlinked stages from raw material acquisition or generation from natural resources to final disposal" (ISO 14050:2020) **[29b]**.

Additionally, **life cycle assessment** (LCA) is defined as the "compilation and assessment of the inputs, outputs and the potential **environmental impacts** of a product system throughout its life cycle". Life cycle assessment thus introduces the environmental impacts and in particular the **footprint** (e.g. carbon footprint, water footprint, land footprint) defined as "metric(s) used to report life cycle assessment results addressing an area of concern", an **area of concern** being an "aspect of the natural environment, human health or resources of interest to society" (ISO 14050:2020). It is worth noting that **life cycle management** (LCM) is defined, e.g. for the concrete industry, as a "set of systematic and coordinated activities and practices through which a structure [product] is appropriately managed over its life cycle" (ISO 22040:2021) **[29c]**.

The area of concern introduces the interest of society. For this, the social, societal, legal but also ethical considerations about how products are assembled are covered by the **social responsibility**, which is defined as the "responsibility of an organization for the impacts of its decisions and activities on society and the environment, through transparent and ethical behaviour that contributes to sustainable development, including health and the welfare of society, takes into account the expectations of stakeholders, is in compliance with applicable law and consistent with international norms of behaviour and is integrated throughout the organization and practised in its relationships" and by **decent work** as the "work performed in conditions of freedom, equity, security and human dignity" (ISO 20400:2017).

Transparency, traceability and certification characteristics of blockchain and DLT contribute to bring some evidence or proof of social responsibility. These characteristics rely on some solutions for **supply chain management** (cf. UN SDG9 in **Table X**), for **logistics chain management**, for **product life cycle assessment and management**, and for **product certificate management** (cf. UN SDG 12). Solutions such as certificates are brought by **digital technologies** under the impetus of both **standardisation** (cf. **sections VI.1 and VI.2**) and **regulation** (cf. **section VI.3**).

As an illustration, some emerging companies propose a blockchain and DLT use case for **product certificate management** (e.g. batteries, electronic devices, luxury goods, textiles, toys) that is well suited to address the European regulation in terms of **digital product passport** (cf. **CEAP** in **section VI.3**). For **batteries**, MOBI proposes the battery birth certificate (BBC), Circulator the Digital Battery Passport, Protokol the DPPs in Batteries, IOTA Foundation the Eviden Battery Passport etc.

The same way, blockchain and DLT have been “tokenising” many physical and digital assets, these technologies are now “circularising” the same or new assets.

V.2.c. Blockchain and DLT Use Cases for Climate Action

Climate action is defined as a “human intervention to achieve climate change measures or goals based on mitigation or adaptation priorities under climate change policies” (ISO 14050:2020).

Climate action refers to climate, reacts to climate change, is given two means for this purpose with climate change adaptation and climate change mitigation, and is guided by climate change policies. In this context, **climate** is defined as a “statistical description of the weather in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years”, **climate change** as a “change in climate that persists for an extended period, typically decades or longer”, **climate change adaptation** as the “process of adjustment to actual or expected climate and its effects” and **climate change mitigation** as some “human intervention to reduce greenhouse gas emissions or enhance greenhouse gas removals” (ISO 14050:2020).

The climate change mitigation introduces the greenhouse gas and associated reduction or removal. **Greenhouse gas** (GHG) is defined as “gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surface, the atmosphere and clouds”, **greenhouse gas emission** (GHG emission) as the “release of a greenhouse gas into the atmosphere” and **greenhouse gas removal** (GHG removal) as the “withdrawal of a greenhouse gas from the atmosphere by a greenhouse gas sink” (ISO 14050:2020).

The **Kyoto Protocol**, adopted on December 11th 1997, focuses on the greenhouse gas emission of carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) **[30a]**. In order to compare the greenhouse gas emissions, the **carbon dioxide equivalent** (CO2e) was defined as a “unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide” (ISO 14050:2020).

The **carbon footprint of a product** (CFP) is derived and is defined as the “sum of greenhouse gas emissions and greenhouse gas removals in a product system, expressed as carbon dioxide equivalents and based on a life cycle assessment using the single impact category of climate change” (ISO 14050:2020).

Transparency, traceability, trust creation and certification characteristics of blockchain and DLT contribute in the collect and in the communication of the carbon footprint of a product or an organisation, thus reinforcing the social responsibility. These characteristics rely on some solutions for **climate action certificate and credit management** and for **climate action certificate and credit tokenisation and trading marketplace** (cf. UN SDG 13 in **Table X**). Again, solutions such as credits are brought by **digital technologies** under the impetus of both **standardisation** and **regulation**.

As an illustration, some emerging companies propose a blockchain and DLT use case for **climate action certificate and credit management** that is well suited to address the European regulation in terms of **Corporate Sustainability Reporting** (cf. **CSRD** in **section VI.3**). Indeed, **carbon credits** are proposed by many companies such as Carbonland Trust, Open Forest protocol (OFP), ReSeed, Solid World etc.

Furthermore, the greenhouse gas removal process introduces the **greenhouse gas sink** (GHG sink) which is defined as the “process that removes a greenhouse gas from the atmosphere” (ISO 14050:2020). The oceans, soils, peatlands and forests are examples of carbon sinks **[30b]**.

The next section will develop the relationship between carbon credit and biodiversity conservation.

V.2.d. Blockchain and DLT Use Cases for Biodiversity Conservation

Biodiversity conservation is defined as the “active management of the ecosystem to ensure the survival of the maximum diversity of species and the maintenance of genetic variability within them” (ISO 23405:2022) **[31a]**.

Biodiversity conservation directly refers to the **biodiversity**, literally the biological diversity, defined as the “variability among living organisms on the earth, including the variability within and between species, and within and between ecosystems” (ISO 14050:2020) and inherent components i.e. **ecosystem diversity**, **species diversity** and **genetic diversity**.

The United Nations Convention on Biological Diversity (UN CBD) distinguishes **in-situ conservation**, defined as “the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties”, and **ex-situ conservation**, defined as “the conservation of components of biological diversity outside their natural habitats” (UN CBD) **[31b]**.

The biodiversity conservation thus applies to ecosystems, habitats and species. An **ecosystem** is defined as a “dynamic complex of communities of plants, animals and microorganisms and their non-living environment, interacting as a functional entity” (UN CBD, ISO 14050:2020), a **habitat** as “the place or type of site where an organism or population naturally occurs” (UN CBD, ISO 14055-1:2027) **[31c]** and a **species** as “a group of organisms capable of interbreeding freely with each other but not with members of other species” (CBD Toolkit Glossaries) **[31d]**.

Biodiversity conservation reacts to **biodiversity loss**, described as “the reduction of any aspect of biological diversity (i.e. diversity at the genetic, species and ecosystem levels) [is] lost in a particular area through death (including extinction), destruction or manual removal; it can refer to many scales, from global extinctions to population extinctions, resulting in decreased total diversity at the same scale” (IPBES Glossary) **[31e]**.

According to the United Nations Environment Programme (UNEP), the five drivers of the nature crisis, i.e. the five **causes of biodiversity loss**, are **invasive alien species**, **changes in land and sea use, climate change**, **pollution** and **direct exploitation of natural resources** (i.e. overexploitation) **[31f]**.

Transparency, traceability, trust creation and certification characteristics of blockchain and DLT contribute in the collect and in the communication of the water footprint (impacting both life below water and life on land) and the land footprint (impacting life on land) of a product, an organisation, a venue or an event, thus reinforcing the social responsibility. These characteristics rely on some solutions for **life below water / life on land credit management**, for **life below water / life on land credit tokenisation and trading marketplace** and for **life below water / life on land action** (cf. UN SDGs 14 and 15 in **Table X**). Again, solutions such as credits and actions are brought by **digital technologies** under the impetus of both **standardisation** and **regulation**.

As an illustration, some emerging companies propose a blockchain and DLT use case for **life on land action** that is well suited to address the European regulation in terms of **corporate sustainability report** (cf. **CSRD**). For life on land actions, Carbonland Trust proposes **carbon sequestration** with forests, Open Forest protocol (OFP) some **afforestation** and **reforestation**, ReSeed some **regenerative agriculture**, Solid World some **nature restoration** etc.

Climate change is one of the causes of biodiversity loss. In return, climate action supports biodiversity conservation based on the expenditure of carbon credits in favour of life below water and life on land actions, like communicating vessels.

VI. IMPLEMENTATION IN STANDARDS AND REGULATION

A high number of blockchain and DLT use cases exist, locally or nationwide, to support the UN SDGs but only few use cases are standardised and deployed continentwide. Standardising blockchain use cases for sustainable development is key to ensure their global and massive adoption and deployment, thus helping reaching the UN SDGs.

Several standardisation works are under development especially at ISO, with the study of **blockchain and DLT use cases for sustainable development** at ISO/TC307/WG6, with the study of the **role of smart contracts in contributing to the UN SDGs** at ISO/TC307/WG3, with the study of the **representation of physical assets (including physical products) using non-fungible tokens (NFT)** at ISO/TC307/WG8 (cf. **section VI.1**), at CEN-CENELEC, with the study of the **environmental and sustainability classification methodology of consensus mechanisms** at CENCENELEC/JTC19/WG2, and at ETSI, with the study of **permissioned digital ledger (PDL) use cases for sustainable development** at ETSI/ISG PDL (cf. **section VI.2**).

These standardisation works will complement and feed the legacy works (i.e. apart blockchain and DLT) already taking place at ISO, with **Circular Economy** at ISO/TC323, **Environmental Management** (including Climate Action) at ISO/TC207 and **Biodiversity** (including Biodiversity Conservation) at ISO/TC331 and at CEN-CENELEC, with **Digital Product Passport (DPP)** at CEN-CENELEC/JTC24.

These standardisation works will also feed the European regulation, in particular the **Circular Economy Action Plan (CEAP) including the Digital Product Passport (DPP)** and the **Corporate Sustainability Reporting Directive (CSRD)** (cf. **section VI.3**).

It is worth mentioning that some liaisons already exist between ISO/TC307 and ISO/TC323, ISO/TC207, CEN-CENELEC/JTC19, European Commission, Blockchain & Climate Institute (CLI) and INATBA.

VI.1. Implementation in ISO Standards

VI.1.a. Blockchain and DLT Use Cases for Sustainable Development at ISO/TC307/WG6

A previous article proposed a **taxonomy of blockchain and DLT use cases** and highlighted the necessary distinction between application domains, use case purposes and economic activity sections **[32a]**.

Six **application domains** were detailed: “Productive and Creative Collaboration”, “Intellectual Property Protection / Certification”, “Disintermediation in Distribution / Actions Traceability”, “Rights and Identifier Management / Identification”, “Contract Management / Automation” and “Electronic Payment / Cryptocurrency and Asset Exchange”.

Then, for each application domain, some **use case purposes** were defined e.g. “Certifying” and “Labelling” purposes within the “Intellectual Property Protection / Certification” application domain or “Monitoring, Tracing and Tracking” purposes within the “Disintermediation in Distribution / Actions Traceability”.

Additionally, the **economic activity sections** were based on the 21 sections defined in the United Nations International Standard Industrial Classification of All Economic Activities Revision 4 (UN ISIC Rev. 4) **[32b]**.

Previous taxonomy of blockchain and DLT use cases was discussed at ISO/TC307/WG1, and then refined and integrated into section 5.4 of ISO/TS 23258:2021 Blockchain and distributed ledger technologies — Taxonomy and Ontology **[32c]**. The six application domains were refined as “Collaboration, Decision Making, Structuration”, “Intellectual Property Protection, Certification”, “Disintermediation in Distribution, Actions Traceability”, “Rights and Identifier Management, Identification”, “Contract Management, Automation” and Electronic Payment, Cryptocurrency and Token Exchange”.

In parallel, ISO/TC307/WG6 has developed ISO/TR 3242:2022 Blockchain and distributed ledger technologies – Use cases **[32d]** which distinguishes five types of **use case classification categories**: “Transversal categories”, “Horizontal categories”, “Vertical categories”, “Sustainable Development Goals categories” and “Status of Use Case categories”.

The **transversal categories** derived from the Rolling Plan for Information and Communications Technology (ICT) Standardisation established by the European Commission **[32e]**.

The **horizontal categories** were harmonised between ISO/TS 23258 and ISO/TR 3242 so that “Identity Management” category refers to “Rights and Identity Management, Identification” application domain, “Data Provenance” category to “Disintermediation in Production, Actions Traceability” application domain, “Governance” category to “Collaboration, Decision Making, Structuration” application domain, “Cryptocurrency and asset exchange” category to “Electronic Payment, Cryptocurrency and Token Exchange” application domain, “Process Optimisation” category to “Intellectual Property Protection, Certification” application domain and “Automation” category to “Contract Management, Automation” application domain.

The **vertical categories** correspond to the economic activity sections and were also based on the 21 sections defined in the United Nations International Standard Industrial Classification of All Economic Activities Revision 4 (UN ISIC Rev. 4).

Finally, the **sustainable development goals categories** were based on the 17 goals defined in the United Nations Sustainable Development Goals (UN SDGs).

The resulting ISO/TR 3242:2022 describes many use cases for Data Provenance, FinTech, Supply Chain and Smart Energy. The sustainable development goals categories allow browsing some use cases for a given UN SDG.

A recommendation about new blockchain and DLT use cases is under development at ISO/TC307/WG6 and will be published as ISO/AWI TR 24878 New and emerging DLT/Blockchain Use Cases **[32f]**.

VI.1.b. Role of the Smart Contracts in contributing to the UN SDGs at ISO/TC307/WG3

A guidebook on the role (initially the use) of smart contracts in contributing to the UN SDGs is under development at ISO/TC307/WG3 and will be published as ISO/AWI PAS 24874 Guidebook on the Use of Smart Contracts in Contributing to the Sustainable Development Goals **[33]**.

VI.1.c. Representation of Physical Assets (including Physical Products) using Non-Fungible Tokens (NFT) at ISO/TC307/WG8

A standard about the representation of physical assets (including physical products) using non-fungible tokens (NFT) is under development at ISO/TC307/WG8 and will be published as ISO/CD 20435 Representing Physical Assets using Non-Fungible Tokens **[34]**. This standard will support UN SDGs 8, 12 and 13.

By covering UN SDG 12, this standard becomes of interest as soon as physical assets refer to physical products that may be associated with the Digital Product Passport (DPP).

VI.2. Implementation in European Standards

VI.2.a. Environmental and Sustainability Classification Methodology of Consensus Mechanisms at CEN-CENELEC/JTC19/WG2

A recommendation about the environmental and sustainability classification methodology of consensus mechanisms is under development at CEN-CENELEC/JTC19/WG 2 and will be published as a TR (cf. “blockchain and DLT” section of the Rolling Plan for ICT Standardisation 2024) **[35]**.

VI.2.b. Permissioned Digital Ledger (PDL) Use Cases for Sustainable Development at ETSI/ISG PDL

ETSI/ISG PDL has developed ETSI GR PDL 001 Permissioned Distributed Ledger (PDL); Landscape of Standards and Technologies **[36]** which distinguishes two types of **use case classification domains**: “Horizontal domains” and “Vertical domains”.

The **horizontal domains** cover “Identity Management”, “Data Management”, “Logistics and Supply Chain”, “Security Management”, “Digital Evidence”, “Invoicing Management”, “Crypto-Structures and DAO”, “Contract Management”, “Commodity Management”, “Decision Management”, “Privacy Management” and “Infrastructure management”.

The **vertical domains** cover sectorial activities i.e. “eGoverment”, “Healthcare”, “Industries”, “Automotive and IoT”, “Commerce”, “Finance”, “Utilities”, “Media and Social Media”, “Agriculture”, “Education”, “ICT” etc.

The ETSI GR PDL 001 horizontal domains would gain being harmonised with ISO/TS 23258 application domains and ISO/TR 3242 horizontal categories.

As well, the ETSI GR PDL 001 vertical domains would gain being completed with UN ISIC Rev. 4 economic activity sections and UN SDGs, for example “Healthcare” with UN SDG 3, “Education” with UN SDG 4, “Industries” with UN SDG 9, “Agriculture” with UN SDG 15, “eGovernment” with UN SDG 16 etc.

VI.3. Implementation in European Regulation

VI.3.a. European Green Deal

In order to derive the worldwide goals and targets defined by the UN SDGs, the European Commission presented in December 2019, the **European Green Deal**, including **10 action streams** as well as a **roadmap of European Regulation** (**Table XI**) so that Europe reduces greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels, and becomes the first climate-neutral continent by 2050 **[37a] [37b] [37c]**.

TABLE IX. UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS COVERAGE BY THE EUROPEAN GREEN DEAL

Sustainable Development Goal	European Green Deal Action Stream and European Regulation Disclaimer: this list is not exhaustive
1 No Poverty	
2 Zero Hunger	
3 Good Health & Well-Being	
4 Quality Education	
5 Gender Equality	
6 Clean Water & Sanitation	**European Regulation**: Stronger Rules for Cleaner Air and Water (2022) - **Environmental Action Programme (EAP) to 2030** (2022) – Agreement on more Thorough and more Cost-Effective Urban Wastewater Management (2024)
7 Affordable & Clean Energy	**European Green Deal action stream**: **#1** Clean, affordable and secure energy (2019) **European Regulation**: Adoption of the EU Strategies for Energy System Integration and Hydrogen (2020) - REPowerEU Plan (2022) – Rules for Renewable Hydrogen (2023) – Stronger Rules to boost Energy Efficiency (2023) – Proposal to reform of the EU Electricity Market Design (2023) - EU Law to deploy sufficient Alternative Fuels Infrastructure (2023) – Fit for 55 Package of Measures to reduce Net Greenhouse Gas Emissions by at least 55% by 2030 compared to 1990 levels (2023) - European Wind Power Action Plan (2023) – Rules to boost Energy Performance of Buildings across the EU (2023) – EU rules to decarbonise the Gas Market and create a Hydrogen Market (2023) – Agreement on the reform of the EU Electricity Market Design (2023) – Energy Performance of Buildings Directive (2024) – Regulation on Deployment of Alternative Fuels Infrastructure (2024) – Adoption of the Electricity and Gas Market Reforms and the New Framework to boost the Development of Hydrogen (2024) – Adoption of the Electricity Market Design Reform and the Decarbonised Gasses and Hydrogen Package (2024)
8 Decent Work & Economic Growth	
9 Industry, Innovation & Infrastructure	**European Green Deal action stream**: **#2 Industrial strategy for a clean and circular economy,** **#3** Towards a zero-pollution ambition for a toxic free environment (2019) **European Regulation**: Plastics Strategy (2018) - European Industrial Strategy (2020) - **Circular Economy Action Plan (CEAP)** (2020) - Chemical Strategy (2020) - Methane Strategy (2020) - Zero Pollution Action Plan (2021) – Strategy for Sustainable and Circular Textiles (2022) - Circular Economy Packaging and Packaging Waste Regulation (2022) - **Environmental Action Programme (EAP) to 2030** (2022) – CSRD / Pollution (ESRS E2) (2022) – **CSRD / Resource Use and Circular Economy (ESRS E5)** (2022) - Green Deal Industrial Plan (2023) – Net-Zero Industry Act (2023) – Critical Raw Materials Act (2023) – Initiative to enhance the Circularity of the Automotive Sector covering the Design, the Production and End-of-Life Treatment of Vehicles (2023) – Agreement on modernising Management of Industrial Emissions (2023) – Agreement on improving Classification Labelling and Packaging of Hazardous Chemicals (2023) – Agreement on the Net-Zero Industry Act (2024) – Agreement to ban all remaining intentional uses of Toxic Mercury in the EU (2024) – Principles on limiting Harmful Chemicals to Essential Uses (2024) – Adoption of the Net-Zero Industry Act and of the EU Regulation to reduce Methane Emissions in the Energy Sector (2024)
10 Reduced Inequalities	**European Regulation**: Adoption of New Regulation ensuring Better and Sustainable Connectivity in Europe (2024)
11 Sustainable Cities & Communities	**European Green Deal action stream**: **#4** Sustainable and smart mobility (2019) **European Regulation**: Provisional Agreement on Stricter CO2 Emission Performance Standards for New Cars and Vans (2022) – Rules on applying the EU Emissions Trading System in the Aviation Sector (2022) - 2030 Zero-Emissions Targets for New City Buses and Trucks (2023) – Agreement on cutting Maritime

	Transport Emissions by promoting Sustainable Fuels for Shipping (2023) – Agreement on the ReFuelEU Aviation (2023) – Measures to make Freight Transport more Efficient and Sustainable (2023) – Agreement on more Sustainable and Resilient Trans-European Transport Network (2023) - Strong EU Targets to reduce CO2 Emissions from New Trucks and Urban Buses (2024) – Rules on Emission Limits for Cars, Vans and Trucks (2024) – Regulation on CO2 Emission Standards for Heavy-Duty Vehicles (2024)
12 Responsible Consumption & Production	**European Regulation**: Proposals to make Sustainable Products the Norm in the EU, boost Circular Business Models and Empower Consumers for the Green Transition (2022) - Consumer Protection enabling Sustainable Choices and ending Greenwashing (2023) – Proposal to revise the existing Marketing Standards of Agri-Food Products (2023) - Right to Repair Proposal on Common Rules promoting the Repair of Goods (2023) - Revision of the Energy Labelling Regulation to help Consumers make Informed and Sustainable Choices (2023) – Agreement on Common Rules to promote the Repair of Goods for Customers (2024) - Directive on Empowering Consumers for the Green Transition (2024) – Adoption of Right to Repair Directive (2024) – Adoption of **Ecodesign for Sustainable Products Regulation (ESPR)** (2024)
13 Climate Action	**European Green Deal action stream**: **#5** Climate Ambition, **#6 Working together / a European Climate Pact** (2019) **European Regulation**: 2030 Climate Target Plan (2020) - **European Climate Pact** (2020) - New EU Strategy on Adaptation to Climate Change (2021) – **European Climate Law** (2021) - Proposal for a first EU-wide Voluntary Framework to reliably Certify High-Quality Carbon Removals (2022) - **Environmental Action Programme (EAP) to 2030** (2022) – **CSRD / Climate Change (ESRS E1)** (2022) - Recommendation for 2040 Emissions Reduction Target to set the path to Climate Neutrality in 2050 (2024) –Industrial Carbon Management Strategy setting out how to sustainably Capture, Store and Use CO2 (2024) – Agreement on New Air Quality Standards in the EU (2024) – Agreement on EU-wide Certification Scheme for Carbon Removals (2024) – Regulation on Fluorinated Greenhouse Gases (2024) – Key Steps for Managing Climate Risks to protect People and Prosperity (2024) - Revised Directive on Industrial Emissions (2024)
14 Life Below Water	**European Regulation**: EU Algae Initiative (2022) – **CSRD / Water and Marine Resources (ESRS E3)** (2022) - Package of Measures to improve the Sustainability and Resilience of the EU’s Fisheries and Aquaculture Sector (2023) - Agreement on tackling Ship-Source Pollution to help make European Seas cleaner (2024)
15 Life On Land	**European Green Deal action stream**: **#7** Greening the Common Agricultural Policy / “Farm to Fork” Strategy, **#8 Preserving and protecting biodiversity** (2019) **European Regulation**: Farm to Fork Strategy (2020) - **Biodiversity Strategy for 2030** (2020) - Organic Action Plan (2021) – **Forest Strategy for 2030** (2021) – **Soil Strategy for 2030** (2021) - Proposals to stop Deforestation, innovate Sustainable Waste Management and make Soils Healthy (2021) - **Environmental Action Programme (EAP) to 2030** (2022) – Nature Protection package (2022) – Biodiversity Stronger Measures against Wildlife Trafficking (2022) - EU Law to fight Global Deforestation and Forest Degradation (2022) - **CSRD / Biodiversity and Ecosystems (ESRS E4)** (2022) - New Deal for Pollinators to tackle the Alarming Decline in Wild Pollinating Insects in Europe (2023) – Package of Measures for a Sustainable Use of Key Natural Resources to help Soil Resilience, increase the Sustainability and Resilience of our Food Systems, improving Plant and Forest Reproductive Material and reducing Food and Textile Waste (2023) – New Forest Monitoring Law (2023) - Proposal of Targeted Review of Common Agricultural Policy to support EU Farmers (2024) – Adoption of **Nature Restoration Law** (2024)
16 Peace, Justice & Strong Institutions	**European Green Deal action stream**: **#9** The EU as a global leader (2019)
17 Partnerships For The Goals	**European Green Deal action stream**: **#10** Mainstreaming sustainability in all EU policies (2019)

Circular Economy is covered by e.g. the **Circular Economy Action Plan (CEAP)**, the **Environmental Action Programme (EAP) to 2030** and the **CSRD / Resource Use and Circular Economy (ESRS E5)** as part of the “Industrial strategy for a clean and circular economy” action stream of the European Green Deal (cf. UN SDG 9) and the **Ecodesign for Sustainable Products Regulation (ESPR)** (cf. UN SDG 12).

Climate Action is covered by e.g. the **European Climate Pack**, the **European Climate Law**, the **Environmental Action Programme (EAP) to 2030** and the **CSRD / Climate Change (ESRS E1)** as part of the “Working together / a European Climate Pact” action stream of the European Green Deal (cf. UN SDG 13).

Biodiversity Conservation is covered by e.g. the **CSRD / Water and Marine Resources (ESRS E3)** (cf. UN SDG14), the **Biodiversity Strategy for 2030**, the **Forest Strategy for 2030**, the **Soil Strategy for 2030**, the **Environmental Action Programme (EAP) to 2030**, the **CSRD / Biodiversity and Ecosystems (ESRS E4)** and the **Nature Restoration Law** as part of the “Preserving and protecting biodiversity” action stream of the European Green Deal (cf. UN SDG 15).

Next sections will detail CEAP and CSRD regulation.

VI.3.b. Circular Economy Action Plan (CEAP) including the Digital Product Passport (DPP)

The European Commission adopted the **Circular Economy Action Plan (CEAP)** in March 2020 as part of the European Green Deal in order to reduce pressure on natural resources. This plan is a prerequisite to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss. This plan covers the entire life cycle of products, including design, production, consumption and waste management so that the resources used are kept in the EU economy for as long as possible. One of the objectives of the plan is to focus on sectors that use most resources and where the potential for circularity is high such as electronics and ICT, **batteries** and vehicles, packaging, plastics, textiles, construction and buildings, food, waste and nutrients **[38]**.

The analysis of blockchain and DLT use cases shows that some solutions exist in order to implement the Digital Product Passport (DPP) and apply it to the life cycle of e.g. battery products (cf. **section V.2**).

Beyond solutions, some circular economy and DPP standards are under development at ISO/TC323 and CEN-CENELEC/JTC24 respectively and can benefit from blockchain and DLT standards under development at ISO/TC307/WG8 (cf. **section VI.1**).

VI.3.c. Corporate Sustainability Reporting Directive (CSRD)

The European Commission adopted the **Corporate Sustainability Reporting Directive (CSRD)** in December 2022 as part and beyond the European Green Deal, in order to require large companies and listed companies to publish regular reports on the social and environmental risks they face, and on how their activities impact people and the environment. The first companies will have to apply the new rules for the first time in the 2024 financial year, for reports published in 2025. Companies subject to the CSRD will have to report according to **European Sustainability Reporting Standards (ESRS) [39a]**.

The first set of 12 ESRS standards was published on December 22nd 2023 and covers in particular **Climate Change** (ESRS E1), **Pollution** (ESRS E2), **Water and Marine Resources** (ESRS E3), **Biodiversity and Ecosystems** (ESRS E4) and **Resource Use and Circular Economy** (ESRS E5) **[39b]**.

The blockchain and DLT use cases that applied to the DPP perfectly fit with the traceability and transparency requirements of the ESRS standards **[39c]**. Companies who proposed some blockchain-based solutions for the DPP e.g. Circularise **[39d]** as well as new companies e.g. Monadi **[39e]** are already addressing or investigating the CSRD reporting.

VII. CONCLUSION

This article introduced blockchain and distributed ledger technologies (DLT) through some definitions, technical explanations, business explanations and cryptographic innovations (cf. **section II**).

The characteristics of some early distributed ledger systems such as Bitcoin, Ethereum (1.0) and IOTA (1.0) were detailed including early scalability, sustainability and sovereignty (cf. **section III**). This section analysed that the transactional performance of Bitcoin, Ethereum (1.0) and IOTA (1.0) systems were not scalable with at maximum 7, 20 and 40 tx/s respectively.

New architectures such as Ethereum 2.0 and IOTA 2.0 and associated new scalability, sustainability and sovereignty characteristics were presented (cf. **section IV**). This section analysed that the Bitcoin Foundation did not provide any path to Bitcoin 2.0, similarly to Ethereum 2.0 and IOTA 2.0, that would have brought scalability (beyond 7 tx/s) and sustainability (no more proof of work consensus mechanism), however, the Bitcoin system remains the most important blockchain system in the world in terms of market capitalisation. Additionally, the section concluded that blockchain and DLT are now mature and viable since new architectures have improved their scalability (e.g. ~100 000 transactions per second for Ethereum 2.0, unlimited for IOTA 2.0), sustainability (e.g. ~35 Wh for an Ethereum 2.0 transaction, 1.1 mWh for an IOTA 1.5 transaction) and sovereignty (no particular person, legal entity or country controls the system).

Some blockchain and DLT use cases for sustainable development were detailed in particular for circular economy, climate action and biodiversity conservation as well as the associated impacts on UN SDGs (cf. **section V**). Some use cases were highlighted for product certificate management in terms of digital product passport (DPP) (e.g. batteries), for climate action certificate and credit management (e.g. carbon credits) and for life on land action in terms of corporate sustainability report (e.g. carbon sequestration, afforestation, reforestation, regenerative agriculture, nature restoration).

And finally, the article shared some implementation in the standards proposed by ISO, CEN-CENELEC or ETSI, and in the European regulation (cf. **section VI**). This section introduced how the standards under development at ISO/TC307, CEN-CENELEC/JTC19 and ETSI/ISG PDL address the UN SDGs and will feed or complement other standardisation committees at ISO and CEN-CENELEC. It also detailed how blockchain and DLT perfectly fit with the European Green Deal and associated European regulation, in particular the Circular Economy Action Plan (CEAP) including the DPP and the Corporate Sustainability Reporting Directive (CSRD).

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Entrepreneur, he founded Music won't stop in 2011, a live music production business that diversified in 2013 by developing a consulting activity focused on digital technology and strategy in media and entertainment activity sectors.

Specialist of the stakes related to the digital transformation, he published many articles and studies (INA, Annales des Mines, AFDEL / TECH IN France, Techniques de l'Ingénieur) related to culture funding, value sharing, metadata-based rights management and intellectual property protection.

Expert in data modelling, he is designing a Digital Content Data Model (DiCoDaMo), common to three ecosystems (culture, computing and consumer electronics, telecommunications), including nine media and entertainment activity sectors and natively integrating blockchain technology, as well as some Digital Content Data Management Tools (DiCoDaMaTo).

Specialist of blockchain technology, he devoted himself to blockchain standardisation since 2016, drives the "architecture and modelling" working group at the French Standardisation Body (AFNOR) and participates to several study groups and working groups (terminology, reference architecture, taxonomy, ontology, use cases, smart contracts, governance, interoperability and identity) within ISO/TC307 and CEN-CENELEC/JTC19.

Since 2018, he develops consulting and vocational training activities at Music won't stop, focused on blockchain-based and environment-friendly service development within media and entertainment activity sectors, teaches blockchain technology to master degree students at Telecom Paris, VUB and Cergy University, while managing the Orange Expertise Programme at Orange.