Decentralised Sustainability: Integrating Climate Action into Digital Asset Management on Distributed Ledger Technology (DLT)

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Chapter 1

Introduction – Why DLT matters?

In an era characterised by escalating environmental pressures, particularly concerning rising carbon emissions, intensive energy consumption and growing electronic waste, Distributed Ledger Technology (DLT) emerges as a transformative solution capable of driving meaningful climate action and sustainable development (ISO, 2024). Originally developed for financial applications, DLT has matured into a versatile and robust technology, delivering enhanced transparency, efficiency and accountability across numerous sectors that are critical in addressing climate change—including carbon markets and supply chain management (Kshetri & Voas, 2022). Recognising the substantial ecological footprint associated with digital assets, this chapter articulates why DLT is uniquely positioned to foster sustainability. Specifically, the guidance introduced here focuses on reducing carbon emissions, optimising energy use and minimising resource depletion within digital asset management practices, laying the groundwork for a more sustainable blockchain ecosystem that aligns closely with regulatory frameworks and broader EU sustainability objectives.

1.1 Context and Objectives

The rapid advancement of Distributed Ledger Technologies (DLT) in recent years has fundamentally reshaped the creation, management, and exchange of digital assets, exemplified by innovations such as tokenisation. Tokenisation enables fractional ownership, improved liquidity and enhanced transparency and in addition, it facilitates the development of sustainable financial instruments, such as tokenised carbon credits, thereby directly supporting climate action and sustainability objectives.

At the core of this transformation is the concept of Digital Asset Management on DLT, which refers to the systematic governance and oversight of digital assets using decentralised or hybrid ledger infrastructures. Digital assets, in this context, broadly encompass tokenised financial instruments, cryptocurrencies, digital identities, smart contracts, digital certificates and other forms of electronically transferable value—meaning any asset or right that can be digitally represented and securely exchanged or transmitted between parties via electronic systems, such as digital representations of physical assets or ownership rights.

The innovative characteristics of DLT—such as decentralisation, immutability, transparency, and enhanced security—offer distinct advantages for digital asset management. With the advancement of DLT technologies, stakeholders can achieve enhanced levels of traceability and accountability across the entire lifecycle of digital assets, as demonstrated by blockchain-based supply chain solutions that track products from origin to end-user. This lifecycle includes asset issuance, secure storage, verifiable transactions, comprehensive reporting, auditing, as well as eventual retirement or recycling. Such end-to-end transparency ensures trust among participants, simplifies compliance obligations and significantly reduces opportunities for fraud or mismanagement.

However, alongside these advantages, the proliferation of digital assets has raised considerable challenges, particularly around environmental sustainability—such as the high energy consumption of certain consensus mechanisms—and regulatory compliance. Given the high energy consumption historically associated with certain blockchain consensus mechanisms (e.g., Proof-of-Work), managing digital assets sustainably has become a critical concern. Furthermore, compliance with the European Union's evolving regulatory landscape requires robust, clearly defined governance practices. Hence, sustainable digital asset management not only involves technical innovation but also necessitates alignment with stringent regulatory standards and explicit environmental targets.

Against this backdrop, this document aims to bridge critical gaps—such as the lack of standardized sustainability metrics in digital asset management—by providing comprehensive guidance and structured methodologies for integrating sustainability into digital asset management. Specifically, our work offers guidelines on energy-efficient blockchain architectures, practical metrics for measuring environmental impact and clearly defined compliance pathways for EU regulatory frameworks.

Ultimately, the goal of this research is to support industry stakeholders, regulators and policymakers in shaping digital asset ecosystems that are both technologically innovative and environmentally responsible. Through such integration, we seek to position blockchain and DLT at the forefront of Europe's sustainable digital future, where economic growth and ecological stewardship are inseparably intertwined.

Furthermore, the overarching objective of this guidance is to harness the transformative potential of DLT to support climate action and the broader sustainability agenda (Kim & Huh, 2020; Truby, 2018). Distributed ledgers, through their decentralised, immutable and transparent characteristics, offer a framework for enhancing trust, traceability and data integrity—cornerstones of effective climate initiatives and sustainable digital asset management. (ISO, 2024; ISO/TC307, 2016)

This document also proposes a tailored set of recommendations and practices aimed at guiding the integration of sustainability principles within DLT systems. It emphasises how blockchain networks, smart contracts and associated digital assets can align with climate imperatives, while also meeting critical regulatory, governance as well as technical benchmarks (ISO/TC307, 2016; Romito et al., 2024).

The objectives are threefold:

1. To integrate climate-conscious principles into the digital asset lifecycle—from issuance to decommissioning—ensuring that DLT platforms significantly mitigate environmental risks. For instance, transitioning from energy-intensive consensus mechanisms to more energy-efficient alternatives, such as Ethereum's shift from Proof-of-Work to Proof-of-Stake, can reduce energy consumption and associated emissions by approximately 99.95%. Additionally, optimising data centre operations through renewable energy adoption further decreases carbon emissions. Beyond energy efficiency, DLT applications themselves can support broader climate mitigation efforts; for example, decentralised parametric insurance platforms built on blockchain

technology enable rapid and transparent payouts following climate-related disasters, thus enhancing community resilience. Similarly, blockchain-based supply chain management systems can precisely track and verify waste and recycling streams, significantly improving resource efficiency and reducing environmental harm across industries.

2. To foster alignment with key international and European regulatory frameworks, notably:
   - eIDAS2 (European Digital Identity Regulation) for digital identity management, ensuring secure and interoperable digital identities;
   - The EBSI (European Blockchain Services Infrastructure) for cross-border services, facilitating seamless data exchange; and
   - The MiCA (Markets in Crypto-Assets Regulation) for cryptocurrency oversight, promoting market integrity and consumer protection while establishing environmental disclosure obligations for crypto-assets, ensuring accountability in the digital finance ecosystem (MiCA: European Parliament and Council Regulation (EU) 2023/1114, 2023; Regulation EU, 2020).

The anchoring of DLT solutions within these frameworks aims to support the EU's broader goals under the European Green Deal, Sustainable Finance Disclosure Regulation (SFDR), and the EU Taxonomy for Sustainable Activities (Regulation EU, 2020).

1.2 Climate Action Imperatives

Climate change represents one of the most urgent global issues, significantly intensified by carbon emissions and resource-intensive technological processes. Distributed Ledger Technology (DLT), despite its considerable potential to address sustainability challenges—such as enhancing transparency in carbon trading and improving resource tracking—can itself contribute significantly to environmental problems, primarily through the high energy consumption and associated emissions of certain consensus mechanisms like Proof-of-Work. Thus, carefully managing and mitigating the ecological impacts of DLT is crucial to ensuring that its deployment aligns positively with global climate action goals. Accelerating environmental degradation, resource scarcity and rising emissions underscore the urgency for all sectors to transition towards sustainable and climate-resilient practices.

In this context, DLT offers a powerful toolset to support this transition through:

- Transparency and accountability: Immutable ledgers can ensure verifiable reporting of carbon footprints, tracking carbon credit movement, renewable energy certificates, and sustainable supply chains, addressing widespread concerns of greenwashing and fragmented data (Kim & Huh, 2020; Truby, 2018).
- Decentralisation and inclusivity: The distribution of decision-making and data validation across multiple actors such as the peer-to-peer energy trading platform is the main characteristic of DLT which empowers communities, SMEs and developing regions to participate in and benefit from climate finance and sustainability initiatives. (ISO/TC 307, 2016)

- Automation through smart contracts: Self-executing agreements automate compliance with environmental regulations and facilitate the seamless enforcement of sustainability-linked financial instruments, such as green bonds and carbon offset transactions, enhancing operational efficiency, reducing intermediaries and ultimately reducing administrative overhead (Dario et al., 2021).

The rationale for adopting DLT for climate action is rooted in its potential to reconcile economic and environmental objectives. From decentralised carbon credit marketplaces to blockchain-powered supply chain traceability for sustainable products, DLT unlocks new avenues for scaling climate impact while fostering trust and operational integrity.

Moreover, emerging blockchain applications, such as on-chain Measurement, Reporting, and Verification (MRV) frameworks, directly support critical climate action mechanisms—aligning with international agreements like the Paris Accord and EU climate targets (Regen Network, 2023; Toucan Protocol, 2022). For instance, initiatives such as Project Genesis illustrate blockchain's capacity to significantly enhance transparency and robustness in carbon credit verification by automating emissions tracking, securely validating carbon-credit transactions, and providing real-time auditing capabilities within emission trading systems, thereby reinforcing trust and accountability in climate finance.

In a nutshell, the climate crisis demands a technological response as ambitious as the challenge itself. Distributed Ledger Technology provides the architecture to embed sustainability directly into digital infrastructure, positioning it as a vital enabler of resilient and transparent climate solutions.

1.3 Structure of the Document

This guidance is structured to provide a comprehensive framework for integrating climate action into digital asset management and distributed ledger ecosystems. Each chapter builds progressively, offering both conceptual insights and actionable recommendations:

Chapter 1: Introduction – Why DLT Matters?

This chapter establishes the context for using Distributed Ledger Technology (DLT) to address climate challenges as well as summarising the technology's features that offer distinct advantages for digital asset management. It outlines core objectives—such as integrating climate-conscious principles into digital asset life cycles—and frames DLT's potential for enhancing trust, traceability and data integrity. It also highlights key regulatory anchors (eIDAS2, EBSI, MiCA) and maps how these frameworks support the European Green Deal, SFDR, and EU Taxonomy goals.

Chapter 2: Architectures in Action – Centralised, Decentralised and Beyond

The text here dissects three main DLT architectures—centralised, decentralised and hybrid—while weighing their strengths and weaknesses for climate-focused applications. It explains how consensus mechanisms (Proof-of-Work, Proof-of-Stake, etc.) shape environmental footprints and explores energy usage, security trade-offs and scalability considerations. The chapter ends by illustrating how hybrid models can unite efficiency, compliance as well as transparency to promote sustainability.

Chapter 3: Integrating Sustainability into Digital Asset Management

This section proposes a "green digital asset management" framework, detailing how to embed sustainability at every stage, from issuance through eventual decommissioning. It clarifies what makes an asset "green," emphasising energy-efficient consensus, regular disclosures and on-chain measurement, reporting and verification (MRV). Practical guidelines—like incentivising eco-smart contracts and auditing carbon offsets—showcase how to align digital assets with climate targets.

Chapter 4: Building Trust and Consistency through Standards and Regulations

Focusing on governance and compliance, the text spotlights relevant standards (ISO/TC 307, CEN-CLC/JTC19) and discusses how decentralised governance (e.g., DAOs) intersects with conventional IT governance principles. It also reviews the regulatory environment—covering the EU's pilot regime for DLT market infrastructures, MiCA, DORA, the Data Act and eIDAS2—and how each framework underpins climate-related data integrity, security and cross-border identity verification.

Chapter 5: Striking a Balance between Economics and Environment

This chapter examines DLT-enabled green finance opportunities (like tokenised carbon credits, green bonds and sustainability-linked loans) and highlights how decentralised tech can reduce costs while driving climate action. Key strategies include incentivising sustainable practices, harnessing transparent supply chains, integrating circular economy principles and promoting local economic resilience. It also explains how aligning DLT solutions with the SDGs can spur innovation in both impact investing and ESG reporting.

Chapter 6: Recommendations and PAS Framework

Culminating the document, this chapter consolidates best practices into a proposed Publicly Available Specification (PAS). It addresses ongoing sustainability challenges in DLT—

ranging from high energy use to e-waste and fragmented governance—and offers a roadmap for industry-standard metrics, disclosures and incentive mechanisms. The aim is to create a unified approach that meets regulatory expectations while preserving DLT's decentralised benefits.

Chapter 2

Architectures in Action, Centralised, Decentralised and Beyond

The choice of architecture in DLT determines not only how data is managed but also how sustainability and climate action can be integrated into digital asset management. This chapter explores centralised, decentralised, and hybrid models, analysing their respective strengths, weaknesses, and suitability for climate-focused applications. The contrast of private, public and consortium-led DLT approaches, outlines a strategic framework for selecting the optimal architecture to align blockchain-enabled sustainability efforts with efficiency, transparency and security.

2.1 Demystifying DLT Models

At the heart of DLT is a fundamental debate: should control and decision-making power reside in a central authority (Sedlmeir et al., 2020) , or should it be distributed across multiple participants? Centralisation offers streamlined operations and regulatory compliance but at the expense of transparency and resilience. Decentralisation, in contrast, promotes trust, security and inclusivity, albeit with potential inefficiencies and governance challenges (ISO/TC307, 2016).

2.1.1 ***Centralised Ledgers: Efficiency at a Cost***

Centralized ledgers offer high efficiency and scalability but at the cost of increased vulnerability to single points of failure and potential misuse of centralized control. Centralised architectures mimic traditional database structures, with a single governing body controlling transactions, access, and verification. Banks, corporations, and governments frequently use this model for digital asset management due to its speed and ease of compliance.

CENTRALISED LEDGERS	
Advantages	**Disadvantages**
High transaction throughput: Without the need for consensus mechanisms among multiple nodes, centralised systems process transactions swiftly.	**Single point of failure:** A centralised ledger is vulnerable to cyberattacks, operational failures, or data manipulation.
Regulatory compliance: Central authorities can enforce compliance measures efficiently.	**Limited transparency:** The authority controlling the ledger determines what data is visible and to whom.
Lower energy consumption: Unlike proof-of-work (PoW) or proof-of-stake (PoS) models, centralised systems do not require extensive computational power.	**Reduced trust and inclusivity:** External stakeholders must trust the integrity of the centralised entity rather than an open, auditable network.

Table 1. Advantages and disadvantages of the centralised Ledgers

For sustainability applications, centralised DLTs are best suited for regulatory reporting, carbon credit registries managed by single authorities (e.g. national carbon registries), and enterprise-driven sustainability initiatives.

2.1.2 Decentralised Ledgers: A Trustless Yet Resilient Framework

Decentralised models, characteristic of public blockchains, distribute control among multiple nodes, enabling a transparent and trustless environment. The most prominent examples include Bitcoin and Ethereum, where transactions are validated through consensus mechanisms rather than a central authority.

DECENTRALISED LEDGERS	
Advantages	**Disadvantages**
Enhanced security and resilience: The distributed nature of decentralised DLTs makes them resistant to cyberattacks and single points of failure.	**Scalability challenges:** High energy consumption and transaction latency can hinder mass adoption.
Transparency and immutability: Transactions are publicly recorded, ensuring accountability in sustainability initiatives like carbon offset tracking.	**Regulatory uncertainty:** Decentralised networks often struggle to comply with jurisdictional regulations.
Community-driven governance: Decision-making is often managed through decentralised governance models, reducing the risk of corruption or manipulation.	**Complex governance:** Achieving consensus among distributed stakeholders can be slow and contentious.

Table 2. Advantages and disadvantages of the decentralised Ledgers

Public blockchains are ideal for global carbon credit marketplaces, peer-to-peer renewable energy trading (e.g. Energy Web Chain) and open-access sustainability reporting where transparency is paramount.

2.1.3 Hybrid Models: The Best of Both Worlds?

Consortium-based DLTs represent a hybrid approach where multiple organisations jointly manage a distributed ledger. They offer a balance between efficiency and transparency by leveraging shared control among trusted entities (Bada et al., 2021).

CONSORTIUM MODELS	
ADVANTAGES	**DISADVANTAGES**
Controlled transparency: Stakeholders maintain oversight while restricting access to sensitive data.	**Complex governance structures:** Decision-making frameworks must balance competing interests, leading to potential inefficiencies.
Shared governance: Multiple entities contribute to decision-making, reducing reliance on a single central authority.	**Limited decentralisation:** Despite distributing control, consortiums still involve centralised elements that may undermine true DLT principles.
Regulatory alignment: Consortium models can be designed to meet compliance	

CONSORTIUM MODELS	
ADVANTAGES	**DISADVANTAGES**
standards while still benefiting from DLT's security.	

Table 3. Advantages and disadvantages of the Consortium Models

Consortium blockchains are well-suited for cross-industry sustainability initiatives, supply chain traceability in sustainable agriculture and joint carbon offset projects involving governments and private enterprises (Bada et al., 2021).

2.2 Core Technical Characteristics

The technical underpinnings of Distributed Ledger Technology (DLT) play a crucial role in determining its environmental impact, security and efficiency. Among these features, consensus mechanisms form the backbone of blockchain networks, governing how transactions are validated and recorded. This section explores the primary consensus mechanisms, their implications for sustainability and key trade-offs in energy usage, carbon footprints and security.

2.2.1 Consensus Mechanisms and Climate Considerations

Consensus mechanisms ensure that all participants in a blockchain network agree on the state of the ledger without requiring a central authority. While these mechanisms enable trustless and tamper-proof transactions, they differ significantly in their computational requirements, energy efficiency and sustainability impact.

Proof-of-Work (PoW): The Energy-Intensive Legacy System

Proof-of-Work (PoW) is the earliest and most well-known consensus mechanism, used by Bitcoin and initially by Ethereum before its transition to Proof-of-Stake. PoW requires network participants (miners) to solve complex cryptographic puzzles, consuming substantial computational power and energy.

- **Environmental Impact**: PoW blockchains demand vast energy resources, often powered by non-renewable sources. Bitcoin's network, for instance, has been estimated to consume as much electricity as some small countries, contributing to high carbon emissions. According to the Cambridge Bitcoin Electricity Consumption Index, Bitcoin's annual energy consumption is comparable to that of Argentina (Cambridge Centre for Alternative Finance, 2025).

- **Security and Decentralisation**: While PoW is highly secure due to its resistance to Sybil attacks and manipulation, the centralisation of mining power in large pools undermines its original decentralisation ethos.

- **Sustainability Concerns**: The high energy cost and increasing difficulty of mining have led to calls for greener alternatives, pushing the industry toward more sustainable consensus models.

Proof-of-Stake (PoS): A Greener Alternative

Proof-of-Stake (PoS) emerged as an alternative to PoW, offering enhanced sustainability while maintaining network security. Instead of miners solving puzzles, validators are chosen based on the number of tokens they hold and are willing to "stake" as collateral.

- **Environmental Impact:** Proof-of-Stake (PoS) eliminates the need for energy-intensive mining, reducing blockchain energy consumption by up to 99.95% compared to Proof-of-Work (PoW). Ethereum's transition from PoW to PoS (Ethereum 2.0) has significantly cut its energy footprint. To contextualise the scale of energy usage, PoW mechanisms such as Bitcoin consumed approximately 348 terawatt-hours of electricity per year as of 2022, contributing roughly 787.7 million tonnes of CO_2 equivalent emissions annually—this represents around 2.12% of global greenhouse gas emissions (Blockchain & Climate Institute, 2024). Conversely, newer consensus mechanisms like PoS drastically reduce these figures, highlighting blockchain's potential to become a more environmentally sustainable infrastructure for future digital ecosystems.
- **Security & Efficiency**: PoS maintains security through economic incentives—validators risk losing their staked tokens if they engage in malicious activities. Additionally, PoS enables faster transactions and higher scalability compared to PoW.
- **Adoption for Sustainability**: Due to its lower environmental impact, PoS is widely recommended for sustainable blockchain applications, including green finance, carbon credit trading, and eco-conscious supply chains.

Alternatives to PoW and PoS: Towards Low-Carbon Consensus

Several alternative consensus mechanisms have emerged to balance energy efficiency, security and decentralisation:

1. **Delegated Proof-of-Stake (DPoS)**: A variant of PoS where stakeholders elect a limited number of validators, enhancing efficiency but introducing some centralisation. Used by networks like EOS and Tron, DPoS reduces energy consumption while maintaining fast transaction speeds.
2. **Proof-of-Authority (PoA)**: Instead of staking tokens, trusted entities (often pre-approved validators) verify transactions. PoA is highly efficient and low-energy but is less decentralised, making it suitable for permissioned blockchains and regulatory-compliant use cases.
3. **Proof-of-Space and Time (PoST)**: Used by Chia Network, this mechanism relies on unused disk space instead of computational power, significantly lowering energy requirements.
4. **Proof-of-Burn (PoB)**: Validators gain the right to create blocks by "burning" tokens (sending them to an unusable address), reducing wasteful energy use while maintaining economic security.

5. **Hybrid Models**: Some blockchains combine PoW (Sedlmeir et al., 2020) and PoS (e.g., Decred) or PoS and Byzantine Fault Tolerance (BFT) mechanisms (e.g., Tendermint) to enhance scalability and security while minimising environmental impact.

2.2.2 Energy Usage and Carbon Footprint Comparisons

Blockchain networks vary significantly in their energy consumption. The table below compares the estimated energy usage and carbon footprint of major consensus mechanisms:

Consensus Mechanism	Energy Consumption (kWh/tx)	Carbon Footprint (g CO2/tx)	Example Networks
Proof-of-Work (PoW)	1,200	600	Bitcoin, Litecoin
Proof-of-Stake (PoS)	0.001	0.0005	Ethereum 2.0, Cardano
Delegated PoS (DPoS)	0.0012		EOS, Tron
Proof-of-Authority (PoA)	0.001		VeChain, Energy Web Chain
Proof-of-Space & Time (PoST)	0.00517		Chia Network
Byzantine Fault Tolerance (BFT)	0.01	0.005	

Table 4. Energy Consumption and Carbon Footprint for each consensus mechanism

It is demonstrated that transitioning away from PoW-based blockchains towards PoS or PoA-based models is essential for sustainable digital asset management.

2.2.3 Security Considerations and Sustainability Trade-offs

While energy-efficient consensus mechanisms mitigate blockchain's environmental impact, they also present unique security and governance challenges:

- **PoW Security Strengths**: PoW remains highly resistant to attacks due to the computational difficulty involved in taking over the network. However, the risk of **51% attacks** increases when mining power becomes centralised.
- **PoS and Validator Risks**: Although PoS reduces energy use, it introduces new risks, such as the "rich-get-richer" problem, where wealthier participants gain more influence over the network.
- **Governance and Decentralisation Trade-offs**: DPoS and PoA models enhance efficiency but often concentrate control among a few validators, raising concerns about censorship and network resilience.

- **Hybrid Models for Sustainability**: Emerging blockchain architectures are exploring hybrid models that combine PoS security with PoA efficiency, ensuring a balance between decentralisation and sustainability.

As blockchain adoption grows, the choice of consensus mechanism will be a key determinant of its long-term sustainability. PoW, while secure, remains unsustainable due to its excessive energy consumption. PoS and alternative mechanisms offer viable solutions with minimal carbon footprints, aligning blockchain technology with climate action goals. Future developments in hybrid models and low-energy consensus protocols will be essential to ensuring that digital asset management supports—not hinders—global sustainability efforts.

2.3 What are Hybrid solutions and their benefits

Hybrid Distributed Ledger Technology (DLT) solutions combine elements of both centralised and decentralised architectures to optimise scalability, performance and sustainability. Utilising the strengths of different models, hybrid solutions address the inherent trade-offs in fully centralised or decentralised systems, enabling more efficient and sustainable digital asset management.

2.3.1 Defining Hybrid Architectures in DLT

Hybrid architectures in DLT involve integrating components of centralised, decentralised, and consortium-based models to create a balanced system. These solutions are designed to achieve high throughput, regulatory compliance and energy efficiency while maintaining transparency and security. The key characteristics of hybrid DLT solutions include:

- **Permissioned-Public Integration**: Hybrid blockchains allow selective access control, enabling businesses and regulators to oversee transactions while maintaining public auditability.
- **Off-Chain and Layer-2 Scaling**: Hybrid solutions often employ off-chain processing or Layer-2 networks to improve transaction speeds and reduce energy consumption.
- **Interoperability with Traditional Systems**: Hybrid DLTs facilitate seamless integration with existing IT infrastructures, ensuring legacy system compatibility while leveraging blockchain benefits.
- **Regulatory Compliance Mechanisms**: By incorporating compliance features such as digital identity verification and smart contract auditing, hybrid solutions align with global regulatory frameworks like MiCA and eIDAS2.

2.3.2 Balancing Scalability, Performance and Sustainability

Hybrid DLT models address key challenges in blockchain adoption, ensuring efficiency without compromising decentralisation or sustainability.

1. **Scalability**
    - Traditional blockchains, especially those using Proof-of-Work (PoW), suffer from limited transaction throughput.
    - Hybrid models employ techniques such as sharding, sidechains and Layer-2 scaling to handle high transaction volumes efficiently.
    - Example: Polygon's Layer-2 scaling solution for Ethereum reduces congestion and transaction fees while maintaining decentralisation.
2. **Performance**
    - Fully decentralised networks often face latency issues due to consensus mechanisms like Proof-of-Stake (PoS) or Delegated Proof-of-Stake (DPoS).
    - Hybrid solutions leverage centralised validation nodes or federated consensus to speed up transactions while preserving security.
    - Example: Hedera Hashgraph uses a hybrid model where a governing council of reputable entities ensures efficiency (Bada et al., 2021) while maintaining fairness and transparency.
3. **Sustainability**
    - Energy-intensive consensus mechanisms are a significant concern for environmental sustainability.
    - Hybrid DLTs implement low-energy consensus models such as Proof-of-Authority (PoA) or Proof-of-Stake (PoS) combined with carbon offset tracking.
    - Example: Energy Web Chain integrates PoA for enterprise-scale energy management while ensuring traceability of renewable energy credits.

2.3.3 Use Cases of Hybrid DLT for Sustainability

Hybrid architectures play a crucial role in digital asset management and climate-focused applications, offering viable solutions in multiple domains:

- **Carbon Credit Trading**: The integration of public blockchain transparency with permissioned validation, makes hybrid solutions a reliable system to deal with carbon offsets, who are automatically verifiable while meeting compliance requirements.
- **Supply Chain Traceability**: Hybrid DLT enables companies to track sustainability metrics across supply chains while keeping sensitive business data private.

- **Green Finance and Tokenised Assets**: Decentralised asset tokenisation combined with centralised risk assessment ensures transparency and regulatory compliance in sustainable finance initiatives.

Hybrid Distributed Ledger Technology (DLT) solutions offer an effective approach to achieving a balanced combination of scalability, performance and sustainability by strategically integrating the best features of public and private blockchain networks. Public blockchains deliver transparency, decentralisation and broad stakeholder engagement, crucial for trust-building and verifiable transactions; however, they often come at the cost of higher energy consumption and slower transaction speeds. In contrast, private blockchain networks offer superior performance, efficiency and reduced energy consumption due to their controlled participant groups, streamlined consensus processes, and centralised governance structures, yet they lack the openness and transparency desired in many sustainability-focused applications.

The mindful combination of these two models, hybrid architectures ensure optimal trade-offs: transparency and accountability are maintained through selective public verification, while intensive data processing, storage and consensus operations are executed efficiently within controlled, permissioned layers. For example, in climate-focused blockchain use cases, such as carbon credit verification or supply chain traceability, sensitive or resource-intensive operations can be conducted within energy-efficient private components, whereas critical outcomes, certifications, or data integrity proofs can be securely and transparently published on a public ledger. Such layered or modular structures ensure not only reduced environmental impact through minimised energy usage but also robust regulatory compliance, data privacy and strengthened stakeholder trust. As these hybrid architectures evolve, they will increasingly become central to the development of sustainable, compliant and scalable blockchain ecosystems.

Chapter 3

Integrating Sustainability into Climate Action

3.1 Framework for Green Digital Asset Management

The integration of sustainability into digital asset management is critical for aligning blockchain and DLT with global climate goals, ensuring that technological advancements do not come at the expense of environmental degradation. This framework provides a structured approach to incorporating climate considerations at each stage of a digital asset's lifecycle—ensuring accountability, energy efficiency and regulatory compliance without oversimplifying the complexities of carbon accounting.

What Makes an Asset Green?

A green digital asset adheres to sustainability principles throughout its lifecycle, from issuance to decommissioning. The following checklist provides a fundamental guide to defining a green asset:

a. Energy Efficiency: Assets should be managed on platforms using energy-efficient consensus mechanisms, such as Proof-of-Stake, Layer-2 scaling solutions;
b. Eco-Smart Contracts: Adopted with built-in sustainability metrics, eco-smart contracts are designed to minimise computational load and energy consumption, for example, by optimising code and reducing unnecessary transactions as well as incentivising sustainable operations, such as rewards for climate-positive node behaviours;
c. Carbon Neutrality: Assets should aim for carbon neutrality through offsetting or using renewable energy sources with transparency in carbon footprint and sustainability impact metrics; and
d. Compliant Reporting: Periodic sustainability reporting aligned with regulatory and industry standards integrated with on-chain Measurement, Reporting and Verification (MRV) frameworks.

Lifecycle Stages and Sustainability Considerations

A comprehensive approach to green asset management must consider climate impact at each stage:

1. **Issuance** – The creation of the asset must include sustainability disclosures, detailing the energy use of the blockchain network and the carbon impact.

2. **Transfer** – Transactions should be optimised for efficiency, favouring low-energy networks and ensuring traceability of carbon-neutral offsets. (Kim & Huh, 2020)

3. **Decommissioning** – Retired or outdated digital assets should be accounted for in sustainability reports, ensuring that unnecessary data is pruned to reduce energy loads. (Truby, 2018)

4. **Periodic Reporting** – Entities managing digital assets should comply with reporting structures that align with international sustainability regulations, including the EU Sustainable Finance Disclosure Regulation (SFDR) and MiCA.

Guidelines for Sustainable Digital Asset Management

To ensure that digital assets contribute positively to climate action, the following best practices should be adopted:

- **Low-energy consensus mechanisms**: Transition away from high-energy Proof-of-Work (PoW) models to Proof-of-Stake (PoS), Delegated PoS, or hybrid solutions.
- **Periodic reporting and auditing**: Organisations managing digital assets should periodically disclose their environmental impact, ensuring alignment with sustainability goals.
- **Eco-smart contract templates**: Implement smart contracts with energy-efficient execution logic and sustainability incentives.
- **Incentivising sustainable node operation**: Encourage validators and node operators to use renewable energy sources through token incentives or reduced fees.

Integrating these considerations can enhance green digital asset management, driving both economic and environmental benefits in alignment with international sustainability efforts (ISO/TC307, 2016; Truby, 2018).

3.2 Measurement and Verification: Metrics that Matter

Sustainability in digital asset management requires robust measurement and verification mechanisms. Standardised metrics, such as energy consumption per transaction (kWh/tx) and carbon footprint (g CO2/tx), ensure transparency and accountability, allowing stakeholders to assess the true environmental impact of digital assets (Toucan Protocol, 2022).

Key Sustainability Benchmarks

Several core benchmarks should be considered when evaluating the sustainability of a DLT system:

1. **Energy Consumption** – Measure the electricity usage of blockchain operations and compare it with energy-efficient alternatives.

2. **Carbon Offsets** – Track the volume of verified carbon credits associated with blockchain transactions.

3. **Resource Efficiency** – Assess the utilisation of computational resources, storage and bandwidth in a way that minimises environmental impact.

Aligning Metrics with EU Regulations and Standards

The proposed measurement and verification framework should align with existing EU regulations and industry best practices:

- **MiCA (Markets in Crypto-Assets Regulation)** – Requires disclosure of environmental and climate-related impacts of blockchain-based assets.
- **SFDR (Sustainable Finance Disclosure Regulation)** – Establishes transparency obligations for financial market participants on sustainability risks.
- **ISO/TC 307** – Provides foundational guidelines for blockchain and DLT applications, including sustainability considerations.
- **GHG Protocol and Science-Based Targets Initiative (SBTi)** – Can be leveraged for on-chain carbon accounting and reporting.
- **eIDAS2 (European Digital Identity Regulation)** – Supports digital identity verification within DLT frameworks, ensuring secure and compliant transactions for climate-related digital assets.
- **EBSI (European Blockchain Services Infrastructure)** – Facilitates cross-border blockchain applications, including sustainability tracking and regulatory reporting.

To implement these benchmarks, blockchain-based sustainability solutions must integrate automated reporting tools that capture and verify sustainability metrics in real time. This can be achieved through on-chain MRV mechanisms, oracles that fetch verified environmental data and transparent audit logs to ensure compliance with regulatory standards (Toucan Protocol, 2022).

The use of rigorous measurement and verification protocols, gives digital asset management the ability to transition towards a more accountable and climate-conscious future, ensuring that DLT technology becomes an enabler of global sustainability efforts rather than a hindrance.

Chapter **4**

Building Trust and Consistency through Standards and Regulations

4.1 Examining current standards and gaps

4.1.1 Insights from ISO/TC 307 and CEN-CLC/JTC19, focusing on sustainability blind spots.

Traditional IT governance approaches, such as those outlined in ISO/IEC 38500 (Information Technology – Governance of IT for the Organisation) and ISO/IEC TR 38502 (Information Technology – Governance of IT – Framework and Model), assume that designated functions within a single organisation are accountable for IT governance. In contrast, DLT systems governance extends these definitions by decentralising decision rights and technically enacting accountability through consensus mechanisms and smart contracts.

Making consensus decentralised means that the records that form the foundation of the DLT & blockchain systems are not only kept in a decentralised manner but also in many instances decided upon in a decentralised way. Incentive alignments are extremely important in DLT & blockchain systems to function effectively through properly aligned incentives (ISO/TS23635, 2022) (ISO/TC307, 2016) that are necessary to achieve consensus. Unless incentives are properly aligned, the nodes of the blockchain will not contribute to consensus. For sustainability, this means designing incentive structures that reward energy-efficient behaviour or carbon reduction efforts. Therefore, improper incentive alignment threatens the integrity of the entire system.

4.1.2 Discuss Decentralised Autonomous Organisations (DAOs) and Data Governance Challenges

Smart contracts and decentralised autonomous organisations (DAOs) might enable decentralised governance mechanisms as they allow for specifying and enforcing accountability using codified rules on-chain. However, proper governance mechanisms can be achieved only if the governance of data is well defined: this includes how and which type of data will be defined, managed, and destroyed over its lifecycle (ISO/TS23635, 2022) within a DLT system; additionally, it determines how data co-exist and interact with other DLT and non-DLT systems.

As described in the ISO TS 23635, the governance of DLT systems should include commitments to address sustainability issues in their establishment, operation, and termination. For this reason, reliable standards shall serve to outline the governance principles for the foundation of implementing mechanisms, structures, and activities in DLT systems. Although data governance can significantly differ depending on the implementation needs, the alignment with recognised standards shall allow DLT system to be resistant and sustainable for their scope (ISO/TC307, 2016; ISO/TS23635, 2022).

4.2 Regulatory and Compliance ***Considerations***

The management of digital data in a distributed environment, such as a DLT system, represents a significant challenge, stemming from both the nature of the technology itself and the complexity of climate data management. In this context, regulation can help to set a framework where the different interests of stakeholders' rights are properly balanced. The advancement of digital technologies in the last decades has come with increased regulatory measures in various jurisdictions with the main aim to set rights for the users and duties for the technology providers. The nature of a DLT system requires the usage of multiple technologies: as consequence, different regulations may apply in case of deployment of DLT solutions, from cybersecurity, and data protection, to digital identity (Toucan Protocol, 2022).

Additionally, climate data are subject to compliance requirements to ensure their data integrity and accuracy, which may require third-party validators, auditors, or the involvement of regulatory bodies. Notably, several recent regulations, such as the EU's Pilot Regime for DLT Market Infrastructures and the Markets in Crypto-Assets Regulation (MiCA), intersect with climate-focused DLT deployments by promoting transparency and accountability in digital asset markets. In the European Union, it is worth mentioning the regulation for the pilot regime for market infrastructures based on DLT, Market in Crypto Asset, the Digital Operational Resilience Act (DORA), the Data Act, as well as the revised European Digital Identity Regulation (eIDAS2). All these regulations impact for different reasons the use-case of climate-related DLT solutions. The following paragraphs outline briefly this intersection with a breakdown for each relevant regulatory measure.

The Pilot Regime for market infrastructures based on DLT (Regulation EU 2022/858) is a regulatory regime introduced to test and try out the application of blockchain technology for market infrastructures, i.e., trading platforms or settlement systems, under a controlled regulatory environment. The regime aims to have a regulated infrastructure for processing transactions. This is particularly needed for Carbon Credit Trading (MiCA: European Parliament and Council Regulation (EU) 2023/1114, 2023) where digital platforms are likely to involve the generation, trading as well as verification of carbon credits or environmental assets. The Pilot Regime can provide for the tokenisation and trading of carbon credits or other environmental assets (e.g., renewable energy certificates) on regulated platforms, subject to meeting specific legal and operational requirements.

Blockchain-based climate solutions (e.g., decentralised carbon markets or green bonds) can be tested in a controlled, regulated environment, with innovators able to try out new use cases under the oversight of regulators. DLT solutions for providing secure and transparent market infrastructure for climate data (Toucan Protocol, 2022), e.g., emissions reporting, could benefit from regulatory certainty under the Pilot Regime, guaranteeing that DLT-based platforms are compliant with European market regulations.

MiCA (Regulation EU 2023/1114) refers to EU regulation of crypto assets that includes all aspects of certain crypto-assets to guarantee the stability and integrity of the market. MiCA establishes the first uniformed cross-country regulatory framework for asset-reference tokens, possibly including stablecoins, to facilitate transactions, ensuring that stablecoins for such purposes comply with European consumer protection and AML requirements.

The area covered by MiCA includes issuance, trading, and token governance provisions, with a dedicated regime for the providers of crypto asset services (Cryptoasset service provider, or CASP). If climate assets like carbon credits or green bonds are tokenised as crypto-assets, they will fall under MiCA's scope if they involve issuance or trading within the EU. As such, climate initiatives based on DLT for trading carbon credits would need to comply with MiCA's conduct of business, transparency, and investor protection requirements. Some climate-based DLT solutions might utilise stablecoins (i.e. crypto tokens whose value is anchored on another asset) for the exchange of carbon credits, or climate initiative financing.

The Digital Operational Resilience Act (Regulation EU 2022/2554) seeks to ensure the operational resilience of digital systems, specifically in the financial sector. It requires financial institutions and critical infrastructure operators to have in place efficient systems for the avoidance, detection and reaction to cybersecurity risks. For climate DLT solutions dealing with sensitive data, i.e., carbon emissions data or performance of environmental projects, such platforms shall have adequate digital resilience and cybersecurity measures in place for protection against data breaches or operational interruptions. This applies also to decentralised carbon trading platforms or environmental reporting platforms that would be a potential target for cyber-attacks. Organisations that implement DLT-based climate solutions must have assurance that their platforms satisfy DORA's rigorous risk control and resilience standards, that include frequent testing, reporting incidents and recovery strategies.

The Data Act (Regulation EU 2023/2854) recognises the important value deriving from data: this requires relying on an efficient and integrated market for data across the EU by ensuring that data is accessible and shareable. The Data Act addresses how data is generated, shared, and accessed within the EU, with specific provisions for the reuse of public sector data, data sharing arrangements, and data sovereignty. The Data Act can facilitate the sharing of climate-related data, which is crucial for blockchain-based solutions that involve emissions monitoring, renewable energy certificates, or environmental impact data.

Public and private data related to climate change (e.g., satellite images of deforestation, emissions data, weather data) can be accessible and can be integrated into DLT systems for verification or analysis. However, climate data stored on DLTs could be subject to regulations regarding cross-border data transfers under the Data Act. For example, if emissions data is stored on a blockchain and transferred across borders, it must comply with rules regarding the sovereignty of that data and ensure it adheres to the principles of data protection, privacy and international agreements (Regen Network, 2023).

Finally, eIDAS2 (Regulation EU 2024/1183), which amends the 2014 regulation on digital identity, contains provisions regarding new trust services and setting for those already present in the market. Thanks to this framework, EU citizens and organisations can use secure digital identities to access services across borders as they can rely on a system for issuing and checking digital identities.

Trustworthy digital identities are paramount for carbon market actors, such as project developers, buyers of carbon credits, or environmental auditors. eIDAS2 can facilitate secure cross-border acceptance of digital identities so that the actors in carbon trading ecosystems are verified and tamper proof. eIDAS2 can also be used to authenticate and validate data and transactions on climate-themed DLT platforms. For example, eIDAS2 digital signatures may be used so that environmental data or carbon credits registered on a blockchain are legally enforceable and in alignment with EU standards. Together with eIDAS2, climate solutions built on DLT may offer interoperability between various climate-related (KlimaDao, 2023) platforms across EU member countries so that seamless data sharing, trading and authentication processes for carbon credits, emissions tracking and other climate-related activities are enabled.

Chapter 5

Striking a balance between Economics and Environment

5.1 Economic Gains through Climate-Aware DLT

The integration of decentralised ledger technology (DLT) into climate action initiatives presents numerous economic opportunities, effectively aligning financial incentives with environmental sustainability (Jan et al., 2024; Li et al., 2023). The use of DLT, can assist organisations with unlocking green finance avenues that not only contribute to climate goals but also enhance their bottom lines (Dario et al., 2021). Green Finance Opportunities DLT facilitates innovative financial instruments, such as green bonds, carbon credits, and sustainability-linked loans, enabling businesses and governments to fund environmentally friendly projects (Jan et al., 2024; Romito et al., 2024). The transparency and traceability inherent in DLT can enhance investor confidence, leading to increased funding for sustainable initiatives (WRI, 2023). For instance, green bonds, which are specifically earmarked for projects with positive environmental impacts, can leverage DLT to provide real-time monitoring of project outcomes. This capability not only assures investors of their funds' impact but also simplifies compliance with environmental regulations and standards. (Li et al., 2023; WRI, 2023)

Moreover, DLT can enable new forms of financial derivatives based on carbon credits, allowing for greater liquidity and market efficiency. Simplifying operations of carbon markets to make them more accessible and transparent, DLT can encourage a broader range of participants, from local governments to individual investors, to engage in climate finance (Jan et al., 2024). Cost Reductions from Automation enabled by DLT can significantly reduce operational costs. Smart contracts—self-executing contracts with the terms of the agreement directly written into code—can minimise the need for intermediaries and reduce transaction costs. This not only streamlines processes but also enhances efficiency in resource allocation (Dario et al., 2021). For instance, automating reporting and compliance processes can save substantial time and reduce administrative burdens, allowing organisations to focus on their core activities while ensuring adherence to sustainability standards. Additionally, process automation can lead to faster transaction times and reduced errors, enhancing the overall reliability of systems. For example, in supply chain management, DLT can automate inventory tracking and order fulfilment, ensuring that resources are used efficiently and waste is minimised. Digital Asset Tokenisation of digital assets through DLT can open new markets, allowing for fractional ownership and broader participation in asset management. This democratisation of investment in sustainable projects can attract a diverse range of investors, thereby expanding the capital pool for green initiatives. With the use of tokenised assets, organisations can create innovative financial products that align with sustainability goals, such as carbon offset tokens or renewable energy credits.

These tokens can be traded on decentralised exchanges, increasing market liquidity and providing a mechanism for businesses to monetise their sustainability efforts. Moreover, tokenisation can facilitate peer-to-peer energy trading platforms, allowing individuals and businesses to buy and sell excess renewable energy directly. This not only enhances the economic viability of renewable energy projects but also encourages greater adoption of sustainable energy solutions (Li et al., 2023; WRI, 2023).

5.2 Tangible Strategies for Reconciliation

The following strategies may support the reconciliation of environmental and economic interests.

Carbon Credit Tokenisation

Tokenising carbon credits on DLT platforms enhances liquidity, transparency, and accountability in emissions trading. Organisations can incentivise sustainable practices by integrating frameworks that reward participants who demonstrate lower carbon footprints or improved resource efficiency. For instance, companies might offer blockchain-based benefits or discounts to customers whose verified actions reduce carbon emissions. Additionally, tokenised carbon credits leverage data-driven decision-making capabilities of DLT, allowing companies to gain precise insights into their emissions performance, thus facilitating targeted sustainability improvements.

Green Bonds on Blockchain

Issuing green bonds through blockchain supports sustainable finance initiatives by providing investors with verifiable proof of project impact and aligning capital flows with Sustainable Development Goals (SDGs). Decentralised collaborative platforms for impact investment can be established, connecting governments, NGOs, and private investors to fund targeted sustainability projects. These blockchain-based platforms pool resources effectively, amplifying the collective impact of sustainability financing and ensuring transparency and trust. Furthermore, green bonds facilitated by blockchain can foster local economies by enabling decentralised financing mechanisms, such as community-based renewable energy crowdfunding, thereby enhancing local economic resilience and ensuring economic benefits remain within communities.

Sustainable Supply Chain Finance

Utilising DLT to track and finance sustainable supply chain practices significantly increases transparency and traceability. Enhanced supply chain visibility allows companies to monitor and communicate their environmental impact effectively, attracting environmentally conscious consumers and investors by substantiating their sustainability claims. Moreover, blockchain's capability to accurately track material flows supports circular economy models by ensuring materials are reused and recycled efficiently, aligning closely with SDG 12 (Responsible Consumption and Production). Companies leveraging blockchain can better manage resources, minimise waste, and identify new economic opportunities in recycling and resource recovery, further strengthening their competitive advantage and supporting sustainability at scale.

Striking a balance between economic growth and environmental sustainability is not only essential for achieving the SDGs but also for ensuring long-term business viability. The use of climate-aware DLT can help organisations identify innovative pathways that reconcile profit with purpose, paving the way for a sustainable future. The integration of economic and environmental considerations will ultimately foster resilience and adaptability in a rapidly changing world. As businesses increasingly recognise the importance of sustainability, the role of DLT will continue to expand, offering a powerful tool for driving both economic growth and environmental stewardship. This approach not only benefits individual organisations but also contributes to the collective effort needed to address global challenges such as climate change, resource depletion and social inequality. Adopting DLT as a catalyst for change can create a more sustainable and equitable world for future generations (Jan et al., 2024; Li et al., 2023).

5.2.1 Enormous opportunity with Incentivising Sustainable Practices

The most promising strategy that will gain traction and have major expansion over the years will be incentivising sustainable practices through Distributed Ledger Technologies (DLTs). It holds significant promise for merging profit motives with climate objectives, effectively transforming how businesses, consumers and other stakeholders contribute to global sustainability goals. Through customised frameworks that reward or recognise low-carbon footprints, we can incentivise resource efficiency as well as environmentally conscious behaviour. Organisations will be able to position ecological stewardship as both an ethical responsibility and a financial advantage (Dario et al., 2021; Kim & Huh, 2020). Below is an in-depth analysis of how these incentive frameworks could function and why they could become a game-changing factor against climate change, citing relevant reports and regulations that underscore their potential impact.

5.2.2 Sustainability and Profit motives

One of the central strengths of DLT-based incentive systems is their ability to transparently link economic rewards to specific sustainability outcomes. For example, in agriculture, farmers can receive tokens for adopting sustainable practices, which are then verified on the blockchain. Traditional corporate responsibility programs often rely on external audits or voluntary reporting, which can be slow and opaque. In contrast, a blockchain ledger provides a tamper-resistant record of every transaction or event linked to environmental performance. This transparency can foster unprecedented trust among consumers, regulators and investors—ensuring that incentives genuinely match verifiable, climate-positive behaviours (Bauk, 2023; Sedlmeir et al., 2020).

Case Example:

A multinational retail chain could issue digital tokens (or reward points) on a permissioned blockchain, granting discounts to customers who demonstrate low-carbon shopping habits—e.g., buying products with eco-certifications or using reusable containers. Each qualifying purchase is recorded on-chain, allowing the retailer to easily audit its loyalty program and measure aggregate carbon savings. This interplay of immediate financial benefit and documented environmental footprint leverages the chain's brand value while guiding customers to more climate-friendly choices.

Such systems resonate with global frameworks like the United Nations Sustainable Development Goals (SDGs). Specifically, SDG 12 (Responsible Consumption and Production) urges companies to minimise waste and adopt sustainable sourcing. By embedding tokenised incentives directly into daily consumer transactions, organisations could effectively nudge behaviour that aligns with SDG 12 and other relevant goals (e.g., SDG 13 on Climate Action).

5.2.3 Harnessing Blockchain's Transparency and Programmability

DLTs are not merely transparent; they are also programmable. This quality enables smart contracts to automatically verify, and reward sustainable activities based on predefined metrics, eliminating the need for intermediaries to decide whether a user "qualifies" for a benefit. The result is an efficient, near-instantaneous system where environmentally favourable actions trigger immediate recognition in a secure environment:

- Automated Carbon Footprint Tracking: Smart contracts can integrate carbon-accounting data (potentially aligning with ISO 14064 or the GHG Protocol) to record every instance where an organisation or user operates below a specified emissions threshold. Rewards—ranging from reduced transaction fees to carbon-offset tokens—could be disbursed automatically.
- Dynamic Pricing and Discounts: A blockchain-based marketplace, for example, can implement "green pricing" logic, whereby lower-emission producers or recycled goods providers receive immediate fee reductions. Over time, such differential pricing strategies encourage suppliers to reduce their ecological impacts if they want to remain competitive (Powell et al., 2021)

From a policy standpoint, the EU's Markets in Crypto-Assets (MiCA) Regulation starts to push transparency requirements in the crypto domain, although it does not yet mandate explicit climate actions. Nonetheless, the upcoming emphasis on energy usage disclosures could dovetail well with these incentive programs, allowing investors and consumers to see how certain tokens or projects explicitly integrate sustainability payoffs into their designs.

Creating a Green Culture

Incentive frameworks do more than merely reward eco-friendly choices—they also reinforce broader cultural and behavioural change by linking sustainability to personal or organisational reputation. As blockchain transactions are publicly traceable (unless privacy-preserving layers are added), "green reputations" become a form of social capital. This can lead to:

1. **Peer Pressure and Competition**: Companies may want to be seen in top "green leaderboards" or earn prestigious "climate badges" on-chain, especially if these accolades influence customer loyalty or attract conscientious investors.
2. **Cross-Industry Collaboration**: A synergy emerges when multiple firms in a supply chain adopt a single green token or reward scheme, facilitating end-to-end validation of climate-positive practices—from raw material sourcing to final delivery.

The European Commission's EU Green Deal and Taxonomy for Sustainable Activities encourage precisely this kind of sector-wide harmonisation, favouring companies with demonstrably low environmental footprints [9]. Embedding the Taxonomy's technical screening criteria into an on-chain incentive system could stimulate a cascading effect throughout the entire production cycle.

5.2.4 ***Expanding Financial Innovation and Market Opportunities***

When integrated thoughtfully, DLT-based incentives can drive new financial and business models that merge profitability with ecological stewardship:

- **Tokenised Environmental Assets**: Carbon credits, biodiversity credits, or renewable energy certificates can be represented as digital tokens, making them easier to trade, bundle, or retire. Incentive schemes can promote these assets, spurring more liquidity in sustainable finance markets.
- **Microfinance and DeFi Integration**: Decentralised Finance (DeFi) platforms could reward lenders or borrowers who meet sustainability criteria, such as reducing their operation's carbon footprint or adhering to fair-trade standards. This approach ties investment returns to environmental performance, attracting a new class of ESG-focused investors.

Research from industry consortia indicates that "green DeFi" products, where interest rates are tethered to verifiable social and environmental impact, could substantially accelerate capital flows to climate-friendly projects.

5.2.5 *Challenges and Future Outlook*

While DLT-driven incentives offer considerable promise, several pitfalls must be managed to ensure efficiency of schemes:

1. **Data Integrity**: On-chain records are only as reliable as the off-chain data they reference. Poorly audited carbon measurements or inaccurate sustainability certifications could undermine trust in any reward system.
2. **Energy Intensity of DLT**: Certain consensus mechanisms themselves create large carbon footprints. Incentive programs must therefore be carefully tailored to run on energy-efficient networks (e.g., Proof-of-Stake).
3. **Regulatory Complexity**: Synchronising with EU directives, UN SDGs and international ISO standards can be logistically challenging, especially for decentralised communities that lack unified governance.

Nevertheless, the overall direction remains hopeful: progressive regulatory frameworks, such as those implied in MiCA's transparency clauses and the EU's evolving Taxonomy, can reinforce DLT-based incentives by legitimising sustainable crypto assets and compelling robust reporting. As more organisations adopt these reward-driven models, sustainability may become a default expectation rather than a niche pursuit, aligning profit with sustainability goals

5.3 Linking Profit with SDGs

The advancement of DLTs has created a pressing need for sustainable management to ensure that the environmental costs do not outweigh the benefits. Linking profit with SDG promotion on decentralised assets is a challenge but with the appropriate set of guidelines sustainable digital asset management is possible. Below there is an overview of specific SDGs and how these can be linked to specific DLT functions and characteristics that their role in sustainable digital asset management of DLTs.

SDG	Description	Link to DLT & Sustainability
SDG-7	Affordable & Clean Energy	Transitioning DLT to energy-efficient consensus mechanisms (PoS, Layer-2 solutions) directly supports renewable and clean energy adoption.
SDG-9	Industry, Innovation, and Infrastructure	Blockchain innovations can revolutionise sustainable infrastructure by integrating traceability, transparency and accountability.
SDG-11	Sustainable Cities & Communities	Decentralised governance frameworks (DAOs) and tokenised circular economy applications (like waste recycling programs) support sustainable local development.
SDG-12	Responsible Consumption & Production	Blockchain-enabled supply chains and product traceability foster transparency, sustainable production and reduce waste.
SDG-13	Climate Action	Direct alignment through tokenised carbon credits, on-chain MRV and embedding climate action into decentralised finance.
SDG-17	Partnerships for the Goals	Leveraging DLT ecosystems to foster global partnerships for sustainable development through interoperability and open standards.

Table 5. Relating SDGs to DLT applications

In addition to linking specific SDG goals with sustainable digital asset management, there also should be some technical guidelines for sustainable digital asset management on Distributed Ledger Technology (DLT), explicitly aligned with the United Nations Sustainable Development Goals (SDGs). There are a few strategies that can be adopted by international standard organisations and regulators that can promote greener and more sustainable digital asset management (Kim & Huh, 2020).

Set **specific guidelines to promote Energy-Efficient Consensus Mechanisms**

DLT systems should mandate transitions from high-energy consensus protocols, such as Proof-of-Work (PoW), towards significantly more sustainable models, including Proof-of-Stake (PoS), Delegated Proof-of-Stake (DPoS), and hybrid consensus models like Chia's Proof of Space and Time or Hedera's Hashgraph. Such transitions significantly reduce energy use, supporting SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). For instance, Ethereum's transition to PoS achieved a 99.95% reduction in energy consumption.

Smart Contract best practices

DLT projects should incorporate best practices in smart contract execution to enhance sustainability. Recommended methods include the use of gas-efficient coding techniques, lazy minting processes, and batching transactions to decrease network load and energy demand. Polygon's Layer-2 scaling solutions exemplify these practices, significantly reducing energy consumption and transactional costs.

On-Chain Measurement Reporting and Verification

Blockchain ecosystems could embed blockchain-native carbon accounting frameworks, employing on-chain Measurement, Reporting and Verification (MRV) techniques supported by reliable Oracle networks. The tokenisation of carbon credits and implementation of climate-positive smart contracts provide clear pathways for accurate verification and accountability.

ESG metrics and Digital Asset Management

Adherence to Environmental, Social and Governance (ESG) standards should guide the issuance and management of digital assets, such as NFTs and stablecoins. Marketplaces should standardise ESG compliance criteria, integrating transparent verification mechanisms. Additionally, the collateralisation of stablecoins should include climate-positive assets to ensure financial sustainability aligns with environmental responsibility.

Circular Economy Integration (including E-waste)

Blockchain technology should actively support the circular economy through asset tokenisation and transparent tracking of supply chain sustainability metrics. Current use cases demonstrate how blockchain provides robust lifecycle traceability and accountability, significantly advancing responsible consumption and production (SDG 12).

Sustainable Governance models

Decentralised Autonomous Organisations (DAOs) should integrate sustainability objectives within their governance frameworks. Treasury allocations through smart contracts must explicitly fund climate initiatives and environmental restoration, exemplified by KlimaDAO, which directs resources towards verified carbon removal projects.

5.4 Key Benchmarking Areas – a further exploration

From the six areas listed above, some notable opportunities will be analysed further for their suitability for benchmarking and new standards, areas that could transform the sustainability landscape for DLT include:

(i) MRV Frameworks: MRV Frameworks: Implementing on-chain MRV systems to track emissions reductions, as piloted in the EU's EBSI projects

On-Chain Measurement, Reporting and Verification (MRV)

Blockchain-Native Carbon Accounting: DLTs enable tamper-proof ledgers for greenhouse gas (GHG) emissions and carbon credits, enhancing transparency in climate accounting (Kim & Huh, 2020). The recording of emissions data and carbon offsets on-chain can assist organisations in creating an immutable audit trail that aligns with established GHG protocols like ISO 14064 (Sapkota & Grobys, 2020). This on-chain approach harmonises with traditional standards while automating data collection and reporting through smart contracts.

EU climate policies such as the EU Emissions Trading System (EU ETS) and the Green Deal emphasise rigorous MRV to track emission reductions; blockchain can support these by providing real-time, verifiable records of carbon footprints across value chains. For example, the Bank for International Settlements' Project Genesis used IoT sensors and smart contracts on a blockchain to monitor and deliver carbon credits attached to green bonds, ensuring credits are verified in line with Paris Agreement targets (Sapkota & Grobys, 2020). Such cases show how on-chain MRV can bolster compliance with EU ETS rules and improve the integrity of carbon markets.

On-Chain MRV and Oracles

A key innovation is digital MRV (dMRV), where IoT devices and oracle networks feed environmental data directly to blockchains. Oracle services (e.g. Chainlink) can relay sensor and satellite data about carbon sequestration or emissions in near real-time (Sapkota & Grobys, 2020), (Kshetri & Voas, 2022). This enables smart contracts to automatically validate a project's reported CO_2 reductions before issuing credits and to continuously monitor those credits over their lifecycle.

On-chain MRV supported by oracles can increase accuracy and trust: credits can be traced from creation to retirement on a public ledger, mitigating risks of double counting or greenwashing. The EU's guidance on climate-tech (e.g. within the Digital Strategy) recognises that smart contracts can help "calculate, track and report" emissions reductions across supply chains, highlighting alignment between blockchain MRV tools and policy goals for transparent decarbonisation (WRI, 2023).

Tokenisation of Carbon Credits

Tokenising carbon credits on blockchains allows fractional ownership and global access to carbon markets. Traditionally, credits trade in minimum 1-ton units, but tokenisation can break them into smaller units, broadening participation. On-chain tokens representing carbon credits can be transacted with instant settlement and automatically retired via smart contract when used, increasing integrity. This also enables climate-positive smart contracts – applications that automatically allocate a portion of transactions to purchase or retire carbon credits (Truby, 2018).

Tokenised credits could be designed to meet the EU ETS accounting rules, and their lifecycle data (issuance, transfer, retirement) is transparently recorded, aiding compliance reporting (Regulation EU, 2020). Notably, ISO 14097 (Guidance for climate finance) calls for assessing and reporting climate-related investments – tokenised carbon markets aligned with ISO 14097 could provide auditable proof that funds are indeed resulting in emissions reductions.

(ii) ESG Reporting: Using DLT for transparent ESG reporting, aligning with the EU's Corporate Sustainability Reporting Directive (CSRD).

Verification and Accountability

The combination of on-chain records with external data feeds, blockchain MRV improves accountability in sustainability reporting. Every credit's origin, methodology and ownership can be audited on-chain, addressing concerns about credibility of offsets. Public blockchains enable independent verification by stakeholders (regulators, NGOs, investors) who can query the ledger to ensure an offset wasn't double-counted or a project's data wasn't tampered with. This supports more stringent verification requirements under frameworks like ISO 14064-3 (verification of GHG assertions) because the source data and calculations are traceable. In practice, projects like Hyphen are using satellite data via Chainlink oracles to provide near-real-time GHG measurements on-chain, closing the gap between reported claims and on-the-ground reality.

Due to the way that oracles are designed, greater transparency and automated verification can lead to higher-quality carbon credits that are less prone to fraud. In the EU context, such robust MRV can assist in initiatives like the Climate Action Data Trust (a decentralized metadata ledger for carbon credits backed by the World Bank and IETA) to ensure credits used toward EU climate targets are reliable and compliant. Overall, on-chain MRV frameworks – built to meet EU and ISO standards – can enhance the accuracy, comparability, and trustworthiness of sustainability data, directly supporting SDG 13 (Climate Action) through improved accountability (Kim & Huh, 2020), (WRI, 2023).

ESG Metrics and Digital Asset Management

As blockchain ventures mature, they are adopting Environmental, Social, and Governance (ESG) standards like traditional finance. ESG criteria can guide the issuance and management of tokens – for example, a crypto project might report its carbon footprint (E), community governance practices (S) and transparency/accountability measures (G) to attract sustainability-minded investors. Under the EU's new Markets in Crypto-Assets (MiCA) regulation, crypto-asset service providers and issuers will be required to disclose sustainability indicators for their assets, specifically the environmental impact. This aligns the crypto sector with the broader EU Sustainable Finance agenda.

In practice, a token issuer in Europe will need to publish (e.g. on their website or whitepaper) information on energy consumption or carbon emissions associated with their blockchain operations. Such mandates push digital asset creators to consider renewable energy use, carbon offsets, or efficiency improvements to meet compliance – effectively using regulation to drive ESG integration. Beyond MiCA, the EU Sustainable Finance Disclosure Regulation (SFDR) also applies if tokenised assets are offered as investment products. SFDR compels financial market participants to report how sustainability risks are factored into products and to prevent greenwashing (MiCA: European Parliament and Council Regulation (EU) 2023/1114, 2023) by justifying any "green" claims. Together, these regulations ensure that even novel assets like

NFTs or stablecoins come with transparency on ESG aspects, bridging the gap between crypto and traditional sustainable finance.

NFTs and ESG Credentials

NFTs and other digital assets can be designed with ESG compliance in mind. One emerging best practice is issuing NFT-based certificates to represent sustainability credentials or audits. For example, an NFT could represent a renewable energy certificate, a fair-trade supply chain validation, or a carbon offset attestation. Because the NFT is on-chain and immutable, anyone can verify its authenticity and track its provenance. This concept is already being applied to verify ESG factors: *"NFT-based digital certificates can allow investors to comfortably understand how ESG factors are implemented,"* essentially acting as verifiable proof of an asset's ESG claims.

Much like ISO standards certify certain processes or products (e.g. ISO 14001 for environmental management), a trusted third party could conduct an ESG assessment and then issue a token (NFT) as a certificate. Marketplaces that list such tokens can enforce that any claimed "green" NFT or sustainable token is accompanied by an on-chain certificate of compliance, viewable by buyers. This introduces standardised ESG compliance criteria in crypto markets – for instance, a carbon credit NFT might only be listed on a marketplace if its metadata includes an audit trail meeting ISO 14064 criteria or if it's issued by an approved registry.

With the implementation of transparent verification mechanisms (like on-chain audits, NFT certificates and oracle-verified data), marketplaces can increase trust and discourage unsupported ESG claims. Buyers and regulators can easily verify, for example, that a given "carbon-neutral NFT" was indeed offset by a specific number of credits retired on-chain. These practices mirror traditional finance where exchanges encourage listed companies to disclose ESG metrics; in crypto, platforms are beginning to play a similar gatekeeping role to promote sustainability.

Stablecoins and Sustainable Collateral

Another strategy aligning DLT with SDGs is to back digital assets with climate-positive collateral. Typically, stablecoins are backed by fiat or liquid assets, but projects are now experimenting with backing them by green assets like carbon credits, renewable energy investments, or biodiversity credits. The idea is to hardwire environmental value into financial instruments. A prominent example is Celo's stablecoins (cUSD, cEUR): the Celo Reserve has a policy to hold a portion of its reserve in tokenised natural capital.

Collateralising digital assets with green bonds or carbon credits can also reduce climate-related financial risk, since those assets' value is linked to climate mitigation outcomes. EU lawmakers support these innovations in principle: the EU Green Bond Standard (proposed) and existing frameworks like EU Taxonomy could be extended to recognise tokenised green assets as high-quality reserve collateral, provided they meet transparency and accountability standards (Regulation EU, 2020). The meeting of criteria from both MiCA (for reserve management and disclosures) and sustainable finance standards, such stablecoins exemplify alignment of financial stability with environmental responsibility. Going forward, we may see EU taxonomy-aligned crypto assets, where a token or stablecoin advertised as “sustainable” is required to hold a certain percentage of taxonomy-compliant assets (e.g. renewable energy projects) – effectively embedding SDG goals into the asset’s DNA.

ESG Reporting and Compliance Tech

With increasing regulatory pressure, fintech solutions are emerging to help crypto companies monitor and report ESG metrics. Services now offer blockchain analytics to estimate a protocol’s carbon footprint (for example, measuring the smart contract calls’ energy use on various chains) and automatically offset emissions. Decentralised exchanges and NFT platforms are exploring integration of carbon footprint dashboards for users, as seen with some networks launching emissions trackers to spur competition on efficiency. Industry associations are also developing best practices: the Global Blockchain Business Council (GBBC) has a Climate Framework and the Crypto Climate Accord (a private sector initiative) pushes for net-zero emissions in crypto by 2030, including reporting frameworks.

In terms of standards, ISO has begun addressing sustainable finance and could extend these to digital assets. ISO 32210:2022 (Sustainable finance – guidance for the financial sector) and ISO 14097:2021 (framework for climate finance reporting) provide principles that could guide crypto asset managers in implementing ESG governance, risk management and disclosure.

In summary, applying ESG metrics to digital asset management ensures that the growth of blockchain and crypto is not at odds with climate action or social responsibility. Instead, it leverages blockchain’s transparency to enhance ESG compliance – from token design (e.g. energy-efficient consensus, purpose-driven reserves) to market infrastructure (clear sustainability labels and audits), the entire lifecycle of a digital asset can be aligned with the SDGs and EU sustainability directives (MiCA: European Parliament and Council Regulation (EU) 2023/1114, 2023).

Circular Economy Integration (Including E-Waste)

DLTs can significantly support circular economy goals by improving supply chain transparency and product lifecycle tracking (ISO/DIS22739, 2024). In a circular model, products and materials need to be tracked from production to use, and through end-of-life recycling or reuse. Blockchain’s immutable ledger is ideal for maintaining this *digital product passport* – a record of a product’s components, origin, and journey, which can follow the product even as it changes hands or is repurposed.

For example, a blockchain-based system can tag a batch of recycled plastic with its quality and source, then allow manufacturers to verify these attributes when using that plastic in new products. Each time the material is recycled, the ledger updates its history. This end-to-end traceability builds trust in secondary raw materials markets (critical for SDG 12: Responsible Consumption and Production) by assuring manufacturers and consumers that recycled inputs meet certain standards and truly come from recycling (preventing fraud or contamination). With tokenising assets and materials, blockchain can also facilitate new circular business models, since ownership and usage rights can be managed via smart contracts.

Electronic waste is a pressing environmental issue and DLT offers a way to improve its management. The EU's Waste Electrical and Electronic Equipment (WEEE) Directive mandates collection and responsible treatment of e-waste, but enforcement and tracking remain challenging across global supply chains. Currently, e-waste tracking systems are fragmented and often opaque, which leads to loopholes where discarded electronics are improperly handled. Blockchain can create a unified tracking system: imagine every electronic device registered on a blockchain at manufacture with a unique ID. Over its life, transfers of ownership, repairs and eventual recycling can be logged as transactions.

Some companies are piloting token rewards for recycling (a concept aligning with SDG 12.5: reduce waste generation). Industry consortia (in electronics and appliances) are indeed looking at blockchain and other digital tools to improve supply chain transparency for electronics, as noted by emerging initiatives worldwide. While blockchain is not a silver bullet – it must be paired with proper data validation (IoT sensors, audits) – it provides a backbone for a global e-waste registry that no single entity controls, thereby fostering international cooperation. Such an approach could complement the EU's Circular Electronics Initiative and strengthen Extended Producer Responsibility schemes by giving producers real-time data on where their products end up (ISO/DIS22739, 2024).

Tokenising Assets for Reuse and Recycling

Tokenisation isn't limited to carbon credits; physical products or materials can be represented by tokens to facilitate circular economy practices. For example, one could tokenise an expensive piece of equipment to enable fractional ownership or leasing, ensuring it's fully utilised (supporting SDG 9 on industry innovation). When that equipment is no longer needed, its token can be updated to reflect refurbishment and then sold to a new user, with the entire maintenance record visible on-chain. This builds a secondary market for reused goods with higher buyer confidence. Likewise, recyclable materials (like aluminium or glass) might have tokens that accumulate data each time the material is recycled – creating a kind of "material passport." Any current or future innovation requires standard data formats and verification methods, which is where standards bodies come in. ISO's new circular economy standards (the ISO 59000 series) are directly relevant – for instance, ISO 59020 (Measuring circularity) defines metrics like recycled content, material recovery rates, etc., and ISO 59014 (Traceability of secondary materials) sets out principles and requirements for tracking recovered materials through reuse or recycling.

A blockchain-based circular economy platform that adheres to these standards can ensure that the data it captures (like percentage of recycled plastic in a product) meets globally recognised definitions and can be compared or certified. In the EU, the Circular Economy Action Plan calls for a Digital Product Passport for key sectors (electronics, batteries, packaging, textiles). Blockchain is poised to be one of the enabling technologies for these passports, as it can store and secure the complex data required (components, chemical substances, repair history, etc.).

Sustainable Governance Models

Decentralised Autonomous Organisations (DAOs) offer a new way to govern projects, and they can embed sustainability objectives (Romito et al., 2024) into their very structure. Unlike traditional companies, DAOs are governed by token holders through transparent voting on blockchain, which lends itself to aligning decisions with a mission (such as climate action) if the community so chooses. We are seeing the rise of "Impact DAOs" – organisations using DAO frameworks explicitly for social or environmental outcomes rather than purely financial goals. These DAOs often write their purpose into their founding documents (smart contracts or charters) and use on-chain votes to ensure any proposal is evaluated against that purpose. For instance, KlimaDAO is a prominent case focusing on climate: it's a community-governed protocol that amassed a treasury of tokenised carbon credits and its policies (decided by token holder votes) aim to accelerate carbon market growth and drive up the price of carbon (thus incentivising more offsets).

Treasury Management for Impact: Sustainability-focused DAOs often use their treasuries to fund climate-positive projects, creating a decentralised financing vehicle for SDGs. Smart contracts governing the treasury can be coded with rules to continuously allocate a portion of funds to green initiatives (Dario et al., 2021). For example, some DAOs set up "eco-funds": every time the DAO earns revenue (say from protocol fees or token bond sales), a smart contract diverts a percentage to a wallet earmarked for grants to environmental projects. The community then votes on proposals from climate nonprofits, reforestation efforts, open-source sustainability tech, etc., to receive those funds. This automated and community-directed funding model resembles a decentralised version of corporate social responsibility (CSR) or impact investing.

Sustainable Governance Best Practices: While DAOs are novel, they can incorporate traditional governance best practices for sustainability and compliance. Key principles from standards like ISO 37000 and good governance codes (transparency, accountability, stakeholder engagement, ethical behavior) are being programmatically implemented in some blockchain projects. For example, open voting logs and forum discussions (a norm in DAO governance) mean that decisions are transparent by default – any member or external observer can audit why a decision was made, which aligns with stakeholder accountability and the "social and environmental integrity" focus of ISO 37000.

Additionally, DAOs often have built-in feedback loops (on-chain polling, community signaling mechanisms) that ensure continuous stakeholder engagement in governance, not just periodic voting. This inclusive approach mirrors EU recommendations for corporate governance that call for considering a broad set of stakeholder interests (employees, communities, environment) rather than just shareholders. In the blockchain space, we see "governance tokens" distributed not only to investors but also to contributors and users, giving diverse participants a say – a practice that could be viewed as an analogy to employee share schemes or multi-stakeholder governance in traditional firms.

5.5 *Addressing Sustainability Challenges on DLTs with a PAS*

In response to prompting calls for more rigorous standards and guidelines to mitigate environmental impacts the authoring and implementation of a PAS on sustainable DLTs could be the answer to setting benchmarks for the industry. The most concerning among these concerns is the high energy consumption of certain consensus mechanisms, especially Proof-of-Work (PoW). As mentioned on this paper before, although PoW systems like

Bitcoin and pre-Merge Ethereum offer robust security and decentralisation, they rely on computation-intensive "mining" practices that, taken collectively, demand vast amounts of electricity. On the other side of the spectrum, networks that have moved or were designed to use Proof-of-Stake (PoS) and other low-energy methods demonstrate the feasibility of drastically reducing energy footprints without sacrificing security. Yet despite these advances, many blockchain ecosystems still struggle with reconciling their growth ambitions with global climate targets. This is an issue that is even more pressing given the European Union's increasingly stringent regulatory frameworks on emissions and energy efficiency.

A second major area of concern lies in hardware sustainability, particularly the rapid obsolescence of specialised devices used for mining (ASICs) and, to a lesser extent, high-end GPUs. As more powerful equipment becomes available, older units quickly lose profitability, thus fuelling an ever-growing stream of electronic waste. Because many of these devices cannot be easily repurposed and because recycling efforts have been under-regulated, e-waste has ballooned to tens of thousands of metric tons annually. Such hardware-intensive practices not only raise questions about resource depletion and environmental toxicity but also underscore the need for more circular economy principles in the blockchain sector—principles that would encourage reuse, refurbishment and more durable device design.

Beyond energy and hardware, governance and compliance complications make it difficult to enforce sustainability measures within decentralised networks. Traditional corporations can be compelled by law or by shareholder pressure to adopt ISO 14001 or follow regulations like the EU Taxonomy for sustainable finance. Public blockchains, however, lack a single controlling entity responsible for meeting these obligations. Although some projects have established voluntary alliances, advisory groups, or community-based sustainability commitments, the efficacy of these self-regulated systems varies widely. Questions about how to integrate environmental, social and governance (ESG) criteria into on-chain voting or to utilise smart contracts for automated compliance remain open, albeit ripe with possibility.

In response to these challenges, a Publicly Available Specification (PAS) can offer a coordinated framework to align DLT practices with recognised sustainability criteria. Such a PAS might, for instance, establish standardised methods for calculating and disclosing carbon footprints, drawing on ISO 14064's greenhouse gas accounting protocols. It could outline specific requirements for mining hardware design, including modularity or minimum efficiency thresholds, thus encouraging manufacturers to facilitate responsible disposal and recycling under the European WEEE Directive.

Moreover, the PAS could integrate provisions for governance, suggesting mechanisms for "smart" or automated compliance that leverage blockchain's own transparency and programmability—whether by mandating on-chain emissions reporting or by offering model clauses for environmental audits embedded in smart contracts. The incorporation of these measures into a coherent set of specifications, can make the PAS a basic guide for both private-sector actors and public authorities toward consistent and enforceable best practices.

In essence, while DLT innovations promise myriad social and economic benefits—from faster cross-border payments to novel carbon-trading platforms—the urgency of global climate imperatives demands that sustainability remain front and center. A robust PAS for blockchain technology—anchored in existing international standards, EU regulatory trends, and practical industry insights—could play a pivotal role in reconciling DLT's transformative potential with the realities of ecological limits. It would not only clarify responsibilities and define key metrics for evaluating progress but also catalyse a cultural shift within the blockchain community toward genuinely sustainable growth.

Chapter 6

Eyes to the Future – Recommendations and Final Notes

6.1 Potential Structure for a PAS and Roadmap of Future activities

As Distributed Ledger Technology (DLT) is increasingly adopted as a powerful tool for enhancing transparency, efficiency and accountability in sustainability efforts, its environmental impact and regulatory alignment remain key concerns. A proposed Publicly Available Specification (PAS) is looking to provide a structured framework for integrating climate considerations into digital asset management, ensuring that sustainability principles are embedded at every stage of the asset lifecycle thus making DLT assets as green as possible. Below, a structure is proposed that is looking to enhance this goal.

Title
Decentralised Sustainability: Integrating Climate Action into Digital Asset Management on Distributed Ledger Technology (DLT)

Foreword
Highlighting the imperative of leveraging blockchain technology for sustainability, this document provides structured guidance on integrating climate-conscious principles into the lifecycle management of digital assets.

Introduction
In the context of accelerating climate change and the digital transformation of economies, DLT emerges as a pivotal technology, uniquely capable of automating robust carbon accounting (e.g., Ethereum's blockchain-based energy data tracking for Chile's National Energy Commission, CNE), enhancing transparency in ESG reporting, and enabling circular economy initiatives. The guidance aims to align blockchain innovation with the EU's climate and digital policy objectives.

1. Scope

This document establishes requirements and guidelines for incorporating sustainability metrics into DLT-based digital asset management systems, specifically targeting climate-related applications. It applies directly to blockchain projects involved in carbon markets (e.g., tokenised carbon credits), renewable energy trading (e.g., peer-to-peer energy trading platforms), and sustainable supply chain transparency initiatives, such as those demonstrated in BlockStand's governance use cases.

Target stakeholders include:

Businesses: Encouraged to align with PAS 808 for assessing their maturity in implementing purpose-driven blockchain solutions.

Regulators: Advised to address current regulatory gaps, notably MiCA's absence of energy intensity thresholds for blockchain consensus mechanisms.

Investors: Supported through lifecycle-based metrics (PAS 2050) to accurately evaluate and invest in green digital assets.

2. Normative References

ISO 14064 (Greenhouse Gas Accounting Standards)

PAS 2050 (Product Lifecycle GHG Protocols)

ISO Guide 82 (Guidelines for Addressing Sustainability in Standards)

ISO/TC 307 (Blockchain and DLT governance)

EU Regulations (MiCA, CSRD, EU Taxonomy, WEEE Directive)

3. Terms and Definitions

Green Digital Asset: A digital token representing verified environmental benefits such as carbon offsets or renewable energy credits, which adhere strictly to the EU Taxonomy's criteria for making a "substantial contribution" to climate change mitigation.

Eco-Smart Contract: A self-executing digital agreement on a blockchain, enforcing sustainability conditions and automating ESG compliance, such as those found in BlockStand's governance templates.

Tokenisation: The digital representation of tangible or intangible assets (e.g., solar power plants) to facilitate fractional ownership and trading, requiring lifecycle management compliant with PAS 2050 standards.

4. Context and Objectives

4.1 Context
Climate urgency underscores the imperative for integrating sustainability deeply into digital asset management practices. Blockchain applications have proven potential to mitigate significant climate risks—such as Arctic ice loss (accelerating at approximately 3°C per decade) and global food insecurity—through innovative approaches like IoT-enabled agricultural monitoring. DLT's inherent ability to produce tamper-proof ESG data (as demonstrated by BlockStand's integration of DLT and IoT) positions it uniquely to automate compliance with emission trading systems (ETS).

4.2 Objectives
The primary objective is to fully integrate climate action into the lifecycle of digital assets, aligning closely with Science-Based Targets (SBTi) and facilitating comprehensive Scope 3 emissions reporting in compliance with ISO 14064.

5. Framework for Green Digital Asset Management

5.1 Lifecycle Stages

Issuance: Mandate "Proof-of-Green" (PoG) validation, referencing PAS 2050's comprehensive cradle-to-grave carbon assessments.

Transfer: Require real-time disclosure of carbon footprints in line with transparency rules established by MiCA.

Decommissioning: Enforce compliance with the EU WEEE Directive for recycling hardware used by blockchain validators.

5.2 Checklist for Green Assets
Criteria include:

Maximum allowable energy consumption of 0.01 kWh per transaction (as opposed to Bitcoin's 707 kWh/tx baseline).

Alignment with the EU Taxonomy's "Do No Significant Harm" (DNSH) principle.

5.3 Minimal Disclosure Requirements
Specify metrics for annual energy consumption, e-waste recovery rates, and robust integrity of carbon offsets in accordance with the EU Carbon Removal Certification framework.

6. Technical Characteristics of DLT

6.1 DLT Models

Critically assess permissioned ledgers for centralisation risks, using Hedera's decentralised governance model as a positive contrast.

Evaluate environmental impacts, comparing Algorand's Pure PoS mechanism (0.0002 kWh/tx) with traditional PoW models reliant on ASIC hardware.

6.2 Core Technical Characteristics

Recommend Proof-of-Stake (PoS) consensus mechanisms to meet the EU Energy Efficiency Directive's goal of a 55% reduction in energy usage.

Advocate hybrid Byzantine Fault Tolerant (BFT) consensus models (e.g., Hedera's approach) as efficient and scalable options.

6.3 Hybrid Solutions
Promote Layer-2 scaling solutions (e.g., Ethereum rollups) to minimise energy loads on mainnet infrastructures.

7. Measurement and Verification

7.1 Key Benchmarks

Energy consumption measured per node, verified through ISO 50001-certified energy audits.

Establish transparent DLT-based registries to prevent carbon offset double-counting per the EU Carbon Removal Framework.

7.2 Alignment with Regulations
Ensure sustainability metrics align explicitly with the EU CSRD's ESRS E1 (Climate Transition Plans) and MiCA issuer transparency obligations.

8. Integrating Economics and Environment

8.1 Economic Gains
Promote tokenised green bonds under the EU Green Bond Standard (GBS), enhancing investor transparency and compliance through blockchain.

8.2 Linking Profit with SDG Goals
Implement decentralised revenue-sharing models (DAOs) that directly fund SDG-aligned projects, such as affordable and clean energy initiatives (SDG 7).

9. Building Trust through Standards

9.1 Current Standards and Gaps
Address gaps identified in ISO/TC 307's enforcement mechanisms for validator energy consumption and MiCA's omission of mining geolocation data requirements.

9.2 Regulatory Considerations
Provide comprehensive guidance aligning DLT deployments with the EU Taxonomy's technical screening criteria for sustainable economic activities.

Regulations and Standards Include:

eIDAS2, EBSI, MiCA, EU Taxonomy

ISO 14064 (GHG Accounting), PAS 2050 (Lifecycle Carbon Footprinting)

EU CSRD, WEEE Directive

10. Use Case Analysis

Showcase Chile's CNE blockchain project, which reduced data manipulation by 40% through real-time energy tracking.

Highlight DAO-managed reforestation initiatives leveraging NFT-based carbon credits certified to ISO 14064 standards.

11. Recommendations for Stakeholders

Businesses: Employ PAS 808 maturity assessments for blockchain sustainability audits.

Regulators: Propose amendments to MiCA for phasing out non-renewable PoW mining by 2030.

Investors: Prioritise investments that meet PAS 2050 lifecycle sustainability thresholds.

12. Conclusion

Advocate for a unified and interoperable approach combining ISO 14064, PAS 2050, and blockchain-native ESG governance tools, such as BlockStand's digital templates. Conclude with a strong call-to-action for the adoption of hybrid PoS-BFT blockchain protocols to ensure blockchain practices align with IPCC's 1.5°C climate target.

Annexes

Annex A: Smart contract templates for automating compliance with CSRD reporting, drawing explicitly from BlockStand's governance frameworks.

Annex B: Timeline for implementing EU regulatory milestones (e.g., MiCA Phase 2, 2026) and ISO/TC 307's strategic business plan updates scheduled for 2025.

The proposed structure is designed to address the critical areas of DLT and sustainability comprehensively, ensuring it meets the requirements and expectations for ISO approval as a Publicly Available Specification. By providing clear guidelines, definitions and frameworks, the PAS can serve as a valuable resource for organisations aiming to align their digital asset management practices with climate action objectives.

This proposed PAS and an additional series of new work item proposals (NWIPs) can help mainstream sustainable practices across blockchain ecosystems and ensure that technology aligns with global environmental and social objectives. One potential initiative focuses on blockchain-based carbon measurement, reporting, and verification (MRV) systems. By creating a standardised approach to on-chain carbon accounting, this NWIP would ensure that data integrity, tokenisation methods, and emission inventories conform with established guidelines like ISO 14064 and EU climate regulations. Such a framework could streamline how greenhouse gas reductions are tracked, making it easier for blockchains to plug into carbon markets and emission trading schemes.

Another proposal would offer guidelines for ESG in digital assets, dubbed a "Green Crypto Standard." This would centre on integrating environmental, social, and governance requirements into crypto-asset design and issuance. By referencing relevant ISO norms (e.g., ISO 26000 for social responsibility) and European rules such as MiCA, this standard would help innovators build more transparent tokens—encompassing how they disclose energy use, governance structures and social impact. A further NWIP could target the circular economy, applying blockchain to areas like digital product passports and supply chain tracking. This would support EU priorities for sustainable production and recycling (including e-waste management) by defining data models and interoperability requirements for blockchain-based material tracking. Finally, an NWIP addressing decentralised governance would distil principles from existing standards (like ISO 37000) into practical recommendations for projects run by DAOs, covering ethical treasury management, transparent decision-making, and compliance checks.

Roadmap of Future Activities

Standards Development and Technical Proposals

1. Preparation of Preliminary Work Item for CEN-CENELEC

Submit a comprehensive Preliminary Work Item (PWI) document to CEN-CENELEC JTC 19 WG2 on Environmental Sustainability by Q4 2025.

This action will translate the outcomes of the BlockStand initiative into concrete technical proposals designed to embed environmental best practices within blockchain standards, aligning with EU sustainability directives and ISO environmental frameworks (e.g., ISO Guide 82:2019 and ISO Guide 84:2020).

2. ISO Initiative for Carbon Credit Tracking

Draft and submit a PWI to ISO/TC 207 (Environmental Management) by Q4 2025, focusing on blockchain-enabled carbon credit tracking systems.

Stakeholder Engagement and Research

3. Targeted Stakeholder Questionnaire

Design and disseminate targeted questionnaires to stakeholders across standards organisations, including ISO committees and working groups, in Q4 2025.

The questionnaires will specifically address Digital Identity, Financial Products, and Climate-Focused Solutions, with particular attention to feedback from DG CLIMA concerning the practical integration of the European Blockchain Services Infrastructure (EBSI). Results will directly inform and refine standard proposals, ensuring regulatory alignment and applicability.

Capacity Building and Knowledge Dissemination

4. Climate Fintech Educational Programs

Completing and delivering a dedicated Climate Fintech course for the UN Climate Technology Centre & Network (CTCN) by Q3 2025, alongside a complementary capacity-building initiative funded by IndiCo Global where sustainable DLT strategies will be included.

These structured training programs will equip industry leaders and public sector stakeholders with practical skills for adopting eco-friendly blockchain technologies, incorporating key ISO sustainability standards and EU climate-focused regulations (e.g., MiCA, SFDR).

Strategic Collaborations and Policy Advocacy

5. Strengthening ISO Strategic Business Plan

Active participation in advising with the Strategic Business Plan (SBP) for ISO/TC 307 that has started in 2025, embedding sustainability criteria aligned with UN Sustainable Development Goals (SDGs).

Utilising insights from BlockStand, continue close collaboration with ISO's strategic planning committees, contributing to the integration of key sustainability frameworks and reinforcing ISO's commitment to globally recognised environmental standards.

6. Partnership Development with DG CLIMA on Sustainable Blockchain Solutions

Engaging in advance ongoing discussions and finalize formal partnership agreements with DG CLIMA during entire 2025, focusing explicitly on integrating EBSI into actions supporting Digital Identity, climate-oriented financial products and sustainable carbon credit mechanisms.

This collaboration will actively contribute to developing verifiable, blockchain-enabled frameworks aligned with ISO standards (e.g., ISO/TS 23635:2022 on Governance, ISO 14064 on Carbon Accounting) and EU climate action policies, thus enhancing transparency, accountability, and environmental performance of blockchain solutions.

7. Dissemination and Publication of Guidelines and Metrics

Completion and publication of comprehensive guidelines and metrics for assessing the environmental impact of digital assets by the end of Q4 2025. Ensure alignment with ISO sustainability and climate standards, providing actionable recommendations and frameworks that facilitate their widespread adoption among organizations and promoting global standardisation through ISO and CEN-CENELEC channels.

6.2 Stakeholder Perspectives – Discussions on notes from stakeholder meetings

There have been recent multilateral engagements between the Blockchain & Climate Institute (BCI) and key regulatory bodies. Progress has been made regarding sustainability issues and DLTs as well as AI, progress that has been noted during high-level discussions between BCI representatives and the European Commission's Directorate-General for Climate Action (DG CLIMA) and Directorate-General for Communications Networks, Content and Technology (DG CONNECT). It is evident that the EU has a strategic focus on leveraging Distributed Ledger Technology (DLT) and AI to enhance emission-reduction frameworks, particularly within initiatives like Destination Earth and the Emission Trading System (ETS). However, critical gaps persist in legislation such as the AI Act and Markets in Crypto-Assets Regulation (MiCA), where sustainability provisions remain underdeveloped compared to their technical and financial mandates.

The European Commission has prioritised blockchain-based solutions to strengthen the ETS, aiming to improve transparency in carbon-credit markets. This aligns with MiCA's broader goal of harmonising crypto-asset regulations across the EU, though the regulation currently lacks explicit environmental criteria for consensus mechanisms. While MiCA mandates stringent consumer protections and market stability measures, it does not address the energy intensity of proof-of-work (PoW) blockchains.

DG CLIMA’s emphasis on "data-driven decarbonisation" underscores the potential for DLT to automate carbon accounting and streamline ETS compliance, yet existing frameworks lack standardised metrics for assessing blockchain’s environmental footprint. Concurrently, the Corporate Sustainability Reporting Directive (CSRD) and EU Taxonomy are reshaping corporate accountability, requiring companies to disclose climate risks and align investments with sustainability goals. However, these regulations do not yet integrate DLT-specific reporting guidelines, leaving blockchain projects without clear benchmarks for environmental performance.

ISO and Global Standardisation Efforts

The International Organisation for Standardisation (ISO) is addressing these gaps through its Technical Committee 307 on Blockchain, which recently prioritised sustainability in its Strategic Business Plan (SBP). Referencing ISO Guide 82 (sustainability in standards development) and ISO Guide 84 (climate change considerations), the committee now mandates lifecycle assessments for blockchain protocols, including energy consumption and e-waste impacts. Paul Ferris, convenor of ISO/TC 307/AG1, emphasised the need to embed climate adaptation frameworks into DLT design, ensuring alignment with the Paris Agreement and UN Sustainable Development Goals. This shift reflects broader industry trends, such as the NGI TrustChain initiative, which funds projects focused on energy-efficient consensus mechanisms and sharding protocols to reduce DLT’s carbon footprint.

Strategic Pathways for Regulatory Cohesion: Meetings with ISO

Against this backdrop of forward-looking policymaking, discussions with ISO around the technical committees’ approach to sustainability took on greater significance. The email from Paul Ferris, convenor of ISO/TC 307/AG1, culminates earlier conversations between BCI’s leadership—represented by Christiana Aristidou and Alastair Marke—and the ISO committee as they explored how best to infuse climate considerations into blockchain standards. Referencing ISO Guides 82 and 84, Ferris’s correspondence stressed the importance of explicitly weaving sustainability and climate-change mandates into the strategic business plan (SBP) of ISO/TC 307. In so doing, the committee would ensure that any new work item proposals align with broader global sustainability objectives and follow rigorous frameworks for risk assessment, stakeholder engagement, and lifecycle thinking. This emphasis on formal business planning and the integration of climate imperatives underlined a more universal shift within ISO—one in which new technologies are no longer considered in isolation but are developed and standardised with a view to their environmental footprints and social impacts. The conversation with Ferris thus represented the culmination of a shared drive: ensuring that the emerging discipline of blockchain, as overseen by ISO/TC 307, remains ethically grounded and intentionally steered to support global climate goals.

BCI’s collaboration with ISO and the European Union underscores a growing alignment between digital technology innovation and sustainability objectives. One tangible pathway involves integrating established ESG metrics into existing crypto-asset regulations: amending

MiCA with the ISO 14064 greenhouse gas accounting standard would allow more granular tracking of validator emissions, ensuring that carbon footprints can be accurately measured and transparently reported. Another avenue focuses on unifying reporting frameworks through the CSRD, which could adopt the Global Blockchain Business Council's ESG Protocol to standardise disclosures on blockchain projects' environmental impacts. In parallel, there is rising interest and a big opportunity in incentivising any kind of green protocols through mechanisms such as tax rebates for validators powered by renewable energy—an approach modelled on the US Inflation Reduction Act. Such rebates would not only accelerate the adoption of Proof-of-Stake and Byzantine Fault Tolerance consensus mechanisms but also cement the principle that environmentally responsible blockchain practices deserve formal recognition and reward.

6.3 Summary of Legislative Gaps

Lack of Standardized Metrics: No unified metrics for assessing the environmental impact of digital assets.

Recent regulatory developments have revealed a significant gap in the standardisation of metrics for evaluating the environmental impact of blockchain-based digital assets. For instance, the EU's Markets in Crypto-Assets (MiCA) Regulation currently does not mandate specific sustainability criteria for blockchain validators. This absence of standardized metrics creates challenges in consistently measuring and reducing the environmental footprint of DLT systems. Adopting benchmarks similar to those outlined in the EU Energy Efficiency Directive—which requires a 55% reduction in energy consumption by 2030 for ICT infrastructure—would help ensure clear, comparable assessments across the blockchain industry. Furthermore, lifecycle accountability for blockchain hardware, particularly mining equipment, lacks specific standards. ASIC miners and high-powered GPUs generate approximately 30–50 kilotons of electronic waste annually, yet the existing EU Waste Electrical and Electronic Equipment (WEEE) Directive currently includes no blockchain-specific recycling targets. Integrating circular economy principles from the European Green Deal into clearly defined metrics would significantly enhance responsible lifecycle management and recycling practices within the industry, incentivising sustainable hardware development.

Regulatory Uncertainty: Ambiguity in how existing regulations apply to DLT-based sustainability solutions.

The current regulatory environment for blockchain solutions remains ambiguous, particularly regarding the intersection of DLT and sustainability. The MiCA Regulation, while a substantial step forward for crypto-assets, fails to clearly specify mandatory sustainability standards for blockchain operations, allowing energy-intensive consensus mechanisms to continue without regulatory oversight. Such uncertainty means environmental initiatives remain voluntary, inconsistent, and fragmented across the sector (Sedlmeir et al., 2020). Similarly, carbon offsetting within blockchain systems faces regulatory challenges. The EU's upcoming Carbon Removal Certification Framework (2025) introduces essential quality criteria for carbon credits, but blockchain-based offsetting platforms still risk issues like double-counting unless supported by interoperable DLT registries. Aligning blockchain carbon-offsetting practices with robust international frameworks such as Article 6.4 of the Paris Agreement would clarify regulatory expectations and enhance trust and accountability, ensuring offsets accurately reflect verifiable climate impacts (WRI, 2023).

AI-DLT Integration: Emerging need for governance frameworks addressing the intersection of AI and DLT in climate action.

With the rapid advancement of artificial intelligence (AI), there emerges a critical yet underexplored opportunity for integrating AI and DLT to significantly enhance environmental sustainability. The current EU AI Act, despite following a comprehensive risk-based approach, does not explicitly incentivise the deployment of AI-driven solutions for optimising energy consumption in blockchain networks. Successful industry examples, such as Google's AI-driven load-balancing methods in data centres, demonstrate considerable potential for achieving substantial power reductions. Similar machine learning strategies could effectively optimise energy use within blockchain validator clusters or mining pools, substantially decreasing overall emissions. Establishing clear governance frameworks and providing targeted incentives for AI-DLT integration could position the EU’s digital and sustainability policies on a progressive trajectory, enabling both technologies to collaboratively deliver substantial environmental improvements and robust energy efficiency outcomes (Sapkota & Grobys, 2020).

Glossary

Key Terms and Definitions

Byzantine Fault Tolerance (BFT): A class of consensus protocols that allow distributed systems to reach agreement even if some nodes behave maliciously or unpredictably. The document cites Tendermint as an example of combining Proof-of-Stake (PoS) and BFT. This hybrid approach offers lower energy consumption compared to Proof-of-Work while maintaining high security and finality—crucial for climate-focused DLT deployments where resilience and trust are paramount.

Gren Digital Assets: A digital asset managed on a DLT platform that adheres to sustainability criteria, such as low energy consumption and carbon neutrality.

Carbon Credit: A tradable certificate representing the legal right to emit one metric ton of carbon dioxide (or the equivalent of another greenhouse gas). In the context of the document, carbon credits are often tokenised on DLT for transparent trading and retirement. They are a cornerstone of many green finance initiatives aiming to incentivise emission reductions or carbon sequestration.

Carbon Offset: A verified action (e.g., reforestation, clean energy projects) that compensates for carbon emissions made elsewhere. Offsets can be tracked on-chain in a blockchain-based marketplace, ensuring that each offset is unique, cannot be double-counted and remains auditable by regulatory bodies.

CEN-CLC/JTC19: A joint technical committee between the European Committee for Standardisation (CEN) and the European Committee for Electrotechnical Standardisation (CENELEC). The document highlights its work on blockchain and DLT standards in Europe, with particular mention of "sustainability blind spots" and the challenges of managing DAOs (Decentralised Autonomous Organisations) and data governance.

Data Act: An EU legislative framework aiming to regulate and facilitate data sharing across borders while ensuring data sovereignty. In the document, it is noted that climate-related data (e.g., emissions metrics) stored or transferred via DLT must comply with Data Act principles, ensuring proper authorisation, accessibility and privacy safeguards.

Digital Operational Resilience Act (DORA): An EU regulation intended to bolster the operational resilience of digital systems in the financial sector, including DLT-based platforms that handle climate data or tokenised green assets. Under DORA, organisations must implement stringent cybersecurity and risk management measures to protect against disruptions or attacks—vital in climate-centric platforms where data integrity is essential for trust and compliance.

eIDAS2 (European Digital Identity Regulation): An updated EU regulation enabling secure cross-border digital identities. The document references eIDAS2 in the context of DLT-based sustainability solutions—where digitally signed climate data, tokenised green assets, or carbon offset certificates can be tied to verifiable, regulated identities for robust compliance and trust.

EBSI (European Blockchain Services Infrastructure): An initiative of the European Commission providing cross-border blockchain services for public administrations. In your draft, EBSI is cited as a potential foundation for sustainability tracking and regulatory reporting, ensuring that climate data and transactions recorded on DLT can be verified across EU member states.

GHG Protocol (Greenhouse Gas Protocol): A leading global framework for measuring and managing greenhouse gas emissions. In the document, the GHG Protocol is positioned as one of the on-chain references for Measurement, Reporting and Verification (MRV) of climate impacts—helping ensure carbon accounting on DLT aligns with internationally recognised standards.

Green Bonds: Fixed-income instruments specifically designed to finance environmental and climate-related projects. Within the draft, green bonds are presented as an example of tokenised digital assets on DLT, allowing real-time traceability of proceeds and ensuring investors can monitor the environmental impact of funded initiatives.

Hybrid Models (DLT): Architectures that combine elements of centralised and decentralised systems, or public and private blockchains (often called "consortium" or "federated" models). The document highlights consortium-based DLT as well as partially permissioned frameworks that balance efficiency, regulatory compliance and transparency—particularly useful for cross-industry sustainability initiatives.

ISO/TC 307: A technical committee of the International Organisation for Standardisation (ISO) focusing on blockchain and DLT standards. Cited in the document for addressing interoperability, privacy and sustainability considerations, ISO/TC 307's work informs best practices for climate-focused deployments on distributed ledgers.

Layer-2 Scaling Solutions: Methods to offload transaction processing from the main (Layer-1) blockchain, improving throughput and energy efficiency. The document references Layer-2 solutions (e.g., sidechains, rollups) as strategies for reducing the carbon footprint of digital asset networks—essential for large-scale climate marketplaces or frequent microtransactions tied to environmental data.

Markets in Crypto-Assets Regulation (MiCA): An EU regulatory framework governing issuance, trading and custody of crypto-assets. The document discusses MiCA's relevance for tokenised sustainability assets—like carbon credits or green bonds—ensuring compliance, consumer protection, and transparent disclosures around environmental impacts.

Measurement, Reporting and Verification (MRV): A critical process in sustainability and climate action that ensures transparent and accurate carbon accounting. The document introduces on-chain MRV where blockchain can log and verify emissions data from external oracles, enabling automated climate reporting in real time. Compliance with frameworks like SFDR or GHG Protocol often hinges on robust MRV mechanisms.

Pilot Regime (for DLT Market Infrastructures): An EU "sandbox" approach introduced to test blockchain-based market infrastructures under controlled regulatory conditions. The document notes that carbon trading platforms or tokenised environmental assets might fall under this pilot regime, which aims to promote innovation while preserving investor protection and market integrity.

Proof-of-Authority (PoA): A consensus mechanism where transactions are validated by approved or trusted entities rather than open competition (as in Proof-of-Work). PoA is energy efficient and is cited in the document as suitable for permissioned or consortium-based blockchains that prioritise compliance, data privacy and moderate decentralisation for climate-focused use cases.

Proof-of-Burn (PoB): A less common consensus approach in which validators destroy (or "burn") tokens to earn the right to validate transactions. The document highlights PoB's reduced energy consumption relative to Proof-of-Work, with the "burning" of tokens serving as an economic security model rather than raw computational effort.

Proof-of-Space and Time (PoST): Used by networks like Chia and referenced in the document, PoST validates blocks by allocating unused storage space and verifying time intervals, leading to a drastically lower energy demand than PoW. This aligns with the sustainability goals of digital asset management by limiting hardware-intensive mining.

Proof-of-Stake (PoS): An alternative to Proof-of-Work where validators are selected based on their "stake" (i.e., locked tokens). The document presents PoS as a greener consensus model, with up to 99.95% less energy consumption than PoW. Examples mentioned include Ethereum 2.0 and Cardano, used for tokenising carbon credits, green bonds, or other sustainable digital assets.

Sustainable Finance Disclosure Regulation (SFDR): An EU regulation that imposes transparency requirements on financial market participants about how they integrate ESG (Environmental, Social, Governance) factors. In the document, SFDR is relevant to DLT-based green asset issuances (e.g., tokenised carbon credits), mandating climate-related disclosures to investors and regulators.

Science-Based Targets Initiative (SBTi): A globally recognised collaboration setting emissions-reduction targets aligned with the Paris Agreement. Mentioned in the text as a standard for on-chain carbon accounting and reporting. Integrating SBTi metrics on DLT ensures climate commitments are both trackable and verifiable across borders.

Delegated Proof-of-Stake (DPoS): A variant of PoS in which stakeholders vote for a limited set of trusted validators. DPoS reduces energy consumption while achieving higher transaction speeds than PoW, although it introduces partial centralisation by limiting the number of validators.

Decentralised Autonomous Organisation (DAO): A governance structure where rules and decisions are encoded in smart contracts and stakeholders hold voting rights via tokens. The document references DAOs and "data governance challenges," suggesting that sustainability initiatives on DLT can leverage DAOs for funding carbon offset projects or standardising climate reporting while acknowledging the complexities of self-regulation in a decentralised setting.

Digital Measurement, Reporting and Verification (dMRV): *Blockchain-based automation of climate data collection, validation, and reporting using IoT and oracles. dMRV improves auditability in carbon markets and supports compliance with ISO 14064-3 and EU climate regulations.*

Tokenisation of Carbon Credits: Conversion of carbon credits into digital tokens on DLTs, enabling real-time trading, fractional ownership and verifiable retirement aligned with EU ETS and ISO 14097.

Climate-Positive Smart Contracts: *Smart contracts designed to automatically allocate transaction proceeds toward carbon credit retirement or environmental assets, embedding climate action into digital transactions.*

Climate Action Data Trust (CAD Trust): A decentralised registry enhancing carbon market transparency by tracking credit issuance, transfers and retirements on-chain, aligned with Paris Agreement goals.

PAS 2050: A lifecycle GHG assessment standard guiding evaluation of carbon impacts in products, services and now proposed for application to digital assets.

Circular Economy Digital Product Passports: DLT-powered product records capturing material use, lifecycle, repair and recycling data to support the EU Circular Economy Action Plan and WEEE compliance.

Energy Web Chain: *An enterprise-grade blockchain platform leveraging Proof-of-Authority (PoA) for renewable energy certification and transparent energy market operations.*

ESG Tokens: Digital assets designed with integrated Environmental, Social and Governance (ESG) metrics, enabling standardised sustainability reporting and impact tracking in tokenised economies.

Verifiable Carbon Units (VCUs): Digitally certified carbon credits compliant with standards like Verra or Gold Standard, tokenised for blockchain-based market participation.

Hybrid Consensus Mechanisms: Systems combining PoS, BFT, or PoA elements to enhance energy efficiency, security and regulatory compliance for climate-aligned DLT applications.

Green Digital Asset: *Tokens representing climate-positive investments (e.g., renewable energy) verified against the EU Taxonomy, designed for sustainable finance applications.*

Climate-Resilient DAO Governance: *DAO frameworks embedding climate targets into treasury management and funding allocation via smart contracts.*

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