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Opinion

Web 3.0 and Sustainability: Challenges and Research Opportunities

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Abstract: Web 3.0 is the next generation of the web and is still in its early stages. Web 3.0 uses many technical components to create an innovative Internet ecosystem. It is characterized by features such as decentralization, interoperability, data ownership, and smart contracts. Web 3.0 aims to enhance user experiences, privacy, and data control while fostering an equitable digital future. Web 3.0 holds significant potential for accelerating progress towards SDGs. As Web 3.0 technologies gain attraction, concerns arise about their potential impact on sustainability, encompassing energy consumption, hardware waste, and carbon footprint. By examining the current state of research about Web 3.0 and sustainability, this opinion paper discusses key Web 3.0 sustainability projects, sustainability challenges, and future directions to build a more sustainable digital era.

Keywords: Web 3.0; sustainability; sustainability research; blockchain; sustainable development

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1. Introduction

Web 3.0 is the next generation of the web that uses many technologies such as semantic web technologies, Web 2.0 principles, and artificial intelligence [1]. It is also referred to as the "decentralized web" or the "semantic web" [2]. It aims to enhance user experiences, privacy, and data ownership by integrating various technologies and principles. The term "Semantic Web" refers to the World Wide Web Consortium's (W3C) conceptualization of a linked data network on the Internet. It includes technologies that empower individuals to create data repositories on the web, build vocabularies, and set guidelines for data management [3,4]. The semantic web is a comprehensive data network that strives to integrate and link all available information within the virtual digital world [5]. Web 3.0 is characterized by several key features such as decentralization, interoperability, data ownership, smart contracts, semantic web integration, and openness [5–9]. Web 3.0 aims to create a more user-focused, privacy-preserving Internet ecosystem that empowers individuals and promotes a more equitable digital future by combining these key features. The widespread adoption of Web 3.0 technologies remains uncertain, yet their implications for various sectors such as e-commerce, digital media, social networking, supply chain management, and finance are already generating exciting and concerning prospects [10].

The emergence of Web 3.0 has raised sustainability concerns related to its use, particularly in terms of energy consumption, hardware/e-waste, and carbon footprint [9,11,12]. Therefore, it is important to consider the sustainability implications of Web 3.0 and to develop strategies to mitigate its negative impact on the environment and Sustainable Development Goals (SDGs). As companies focus more on blockchain technologies, they need to address associated issues such as energy consumption [12,13]. Web 3.0 also presents opportunities for achieving SDGs because it has the potential to significantly impact the financial system [14], economy [14], governance [15], medicine [16], and other innovation

systems through openness and decentralization [17]. Web 3.0 can contribute to sustainability by enabling effective, sustainable marketing strategies [18], sustainable business models [19], sustainable supply chain management [20,21], and utilizing decentralized systems such as blockchains [22].

To understand sustainability challenges in the digital age, it is crucial to critically examine the relationship between Web 3.0 and sustainability [9,17]. The emergence of Web 3.0 has sparked considerable interest in its potential implications for sustainability. However, there is limited research that provides a comprehensive description of sustainability issues related to Web 3.0. There is a need to understand sustainability issues and challenges related to Web 3.0 [17,23]. Web 3.0 presents great potential, as well as challenges regarding sustainability. Therefore, it provides unprecedented opportunities for research. Building on these considerations, this research paper aims to understand the current state of sustainability challenges and opportunities related to Web 3.0 and provides guidelines for future research. It delves into the potential sustainability benefits and challenges posed by Web 3.0, shedding light on the path toward a greener digital future.

The remainder of this paper is organized as follows: Section 2 discusses Web 3.0 components and its features, and Section 3 discusses Web 3.0 and sustainability literature. Section 4 discusses Web 3.0 and blockchain projects for sustainability, and in Section 5, areas of future research are discussed.

2. Web 3.0 Components and Features

Web 3.0 aims to revolutionize the existing static, read-only Web 1.0 and the dynamic, read-and-write-only Web 2.0 by establishing a decentralized web ecosystem [24]. An estimated 1-billion users are projected to use Web 3.0 by 2027, with current applications encompassing decentralized finance (DeFi), Non-Fungible Tokens (NFTs), play-to-earn games (P2E), and decentralized autonomous organizations (DAOs) [25]. Web 3.0 presents a new model (read-write-own) of the Internet, which is decentralized (ownership distributed), permissionless (equal access), and trustless (open-source, consensus-driven code), where cryptographically defined digital assets drive interactions and economic activities [5,10,26]. There is a need for a precise definition of Web 3.0 because of the lack of extensive research and inconsistent definitions associated with it [7]. While there is no universally accepted single definition of Web 3.0 [27,28], a study proposed a definition that states, "Web 3.0 is the new innovative and revolutionary technological tool that analyses, integrates, and links data, which will help individuals, as well as organizations, to systematize the chaos of unorganized, interconnected, unfiltered, unarchived, unconnected, and unclassified information using some different intelligent technological tools to provide meaningful information." [29] (p. 6224).

Web 3.0 developers aim to deploy applications on decentralized networks such as blockchain platforms rather than relying on a single server, allowing for increased decentralization and higher resilience [27]. In Web 3.0, the generation of new information is primarily driven by computers rather than humans, representing a fundamental shift in information creation [7]. Web 3.0 aims to create an interconnected online ecosystem that is secure and has greater equity in the digital space for all users [10]. It provides a new way of organizing and incentivizing the work of society where individuals own and control their assets [9]. It can intelligently utilize unstructured web information by interpreting the context in which it is presented [7]. This paradigm shift towards Web 3.0 signifies a transition towards decentralized, user-centric, and blockchain-powered applications, promising enhanced security, privacy, and control for Internet users [9,10]. It advocates for asserting individual rights related to personhood, privacy, and property within open and trustworthy data ecosystems [9]. Web 3.0 essentially leverages blockchains, cryptocurrencies, and NFTs to empower consumers by restoring ownership and authority over digital assets [26,30]. It introduces a novel framework for organizing and incentivizing societal work wherein individuals gain ownership and control over their digital assets [9].

Web 3.0 is a multidisciplinary and rapidly evolving technology encompassing various disciplines such as computer science, finance, economics, and governance design, making it challenging to attain a comprehensive understanding due to the constant emergence of new innovations and projects [17]. It can potentially revolutionize multiple sectors, including finance, governance, data privacy, and digital identity management by enabling greater decentralization, user empowerment, and innovation in the digital landscape [10].

2.1. Web 3.0 Components

Web 3.0 will encompass a diverse range of technologies, some of which are yet to be developed, while others already exist in the existing web infrastructure [7,31]. Web 3.0 includes Metaverse, Blockchain, Artificial Intelligence (AI), DAOs, and other digital applications [5,10,24,32]. It incorporates several web technologies such as Resource Description Framework Schema (RDFS), Intelligent Agents (IAs), Ontology Web Language (OWL), Structured Query Language (SQL), Simple Protocol, and RDF Query Language (SPARQL) [7]. Some of the key Web 3.0 components are summarized in Table 1. It aims to enhance user experiences by creating a real-life immersive experience by integrating various technologies [26,33]. Web 3.0 technologies play a vital role in establishing secure, transparent, and decentralized systems [10].

Table 1. Web 3.0 components.

Components	Description	References
Semantic Web technologies	The Semantic Web is a vision of the web where data are structured in a way that is machine-readable and can be easily processed by computers.	[7] [1] [31]
Web 2.0 principles	Web 2.0 is a term used to describe the current version (read, write) of the Internet which focuses on user collaboration and usability using various web technologies.	[1]
Artificial intelligence	Web 3.0 applications are intelligent, meaning they can learn and adapt to user behavior using artificial intelligence algorithms.	[7] [1]
Metaverse	It is a decentralized digital realm where individuals and organizations participate in social and business activities. Metaverse envisions a 3D virtual world facilitated by augmented reality (AR) and virtual reality (VR) to create a networked, immersive, and sociable digital space where users engage with virtual environments and interact with others.	[34] [17] [24] [32] [30]
Blockchain	Blockchain is a decentralized network where cryptographically hashed blocks (digital records) are chained to one another, and each node replicates its previous blockchain. In Web 3.0, blockchains can be used to store and verify identity.	[22] [24]
Tokenization and cryptocurrencies	Web 3.0 embraces tokenization and cryptocurrencies as mechanisms for incentivization, value exchange, and governance. Tokens represent digital assets that can have various functionalities within decentralized applications and ecosystems. Transactions of digital assets (called cryptocurrencies) are recorded by blockchains.	[24] [35] [10]
Non-Fungible Tokens (NFTs),	NFTs are blockchain-enabled cryptographic assets that represent proof of ownership for digital objects. NFTs are non-fungible, and they are unique and not interchangeable. NFTs use cases in digital arts, the music industry, gaming, virtual world ownership, tokenized physical assets, and managing memberships for Web 3.0 governance.	[36] [37] [17] [10]
Distributed autonomous organizations (DAOs)	DAOs are self-governed organizations operated by blockchain-powered smart contracts. They possess their own bylaws and procedural rules, representing one of the most transformative applications of Web 3.0 [25]. DAOs represent a novel organizational paradigm that facilitates the creation, engagement, governance, and implementation of Web 3.0 applications and systems [26].	[25] [26] [27]

Blockchain is the key building block of Web 3.0 and Metaverse [10,25,33]. Blockchain and Web 3.0 represent the future rather than mere hype [38]. Blockchain technology gained prominence following the 2008 financial crisis, primarily driven by the emergence of cryptocurrencies such as Bitcoin [21]. Blockchain is a peer-to-peer decentralized network that is capable of preventing data modification [39]. Blockchain networks, functioning as peer-to-peer (P2P) networks, establish trust among actors by offering a universally reliable dataset containing a list of who owns which tokens, and tokens represent diverse assets or access rights [23].

Blockchain networks revolutionize data storage and management practices by introducing a novel approach. These networks offer a distinct dataset known as a universal state layer, which is collectively administered and maintained [23]. Within the existing client–server architecture of the Internet, digital information is susceptible to copying and disseminating across multiple computers simultaneously, whereas in a blockchain network, all participating computers maintain an identical ledger of transactions. In addition, the alteration of data requires the majority consensus of network actors and the modification of all subsequent blocks [23]. Blockchain can offer benefits including transparency, accountability, integrity, scalability, cost-efficiency, data security, immutability, information immutability, resilience, and privacy [21,39,40]. Blockchain-based applications have been successfully used in supply-chain management, healthcare management, real estate, energy sector, and finance industry [21,39].

The Metaverse is another key component of Web 3.0. There will be more than 5-billion Metaverse users, and its economy will reach $8 trillion by 2030 [25,41]. The Web 3.0 metaverse represents a decentralized digital realm where individuals and organizations participate in social and business activities, freely exchanging digital assets without central authority [30]. The emergence of the Metaverse forces organizations to reconsider user-engagement protocols, including tax collection, data governance, and regulatory compliance [42]. The emergence of Metaverse as a virtual economy will create new employment opportunities in sectors such as manufacturing, tourism, healthcare, transportation, and finance [30]. The relationship between Metaverse and Web 3.0 primarily concerns its application in basic business and economic contexts, encompassing elements such as non-fungible tokens (NFTs) [10]. The autonomous integration and structuring capabilities of Web 3.0 technologies will enhance the precision and availability of searching data repositories [7]. Overall, Web 3.0 is focused on creating intelligent web applications that can learn and adapt to user behavior, provide machine-readable metadata, and are user-driven.

2.2. Web 3.0 Features

Web 3.0 is characterized by key features that make it promising for the new digital era. First, decentralization is one of the fundamental features of Web 3.0 [33]. Decentralized applications provide enhanced transparency, security, and trustworthiness compared to centralized alternatives [10]. Web 3.0 uses decentralized technologies (e.g., blockchains) to distribute data across multiple networks instead of centralized servers. Decentralization in Web 3.0 facilitates the development of robust and autonomous digital identity solutions, empowering users with sovereignty over their personal data and online engagements [10]. Second, interoperability is another key feature of Web 3.0. Web 3.0 emphasizes interoperability, enabling seamless communication between different platforms and blockchain networks [10]. In Web 3.0 applications, blockchains enable the transfer of assets and record transactions through interoperation among multiple blockchain networks [26]. It promotes open standards, allowing data to be easily shared across decentralized networks. The success of Web 3.0 is contingent upon the interoperability of blockchain networks, allowing seamless communication and interaction between different chains, eliminating the reliance on intermediaries such as centralized exchanges [23]. The interoperability feature encourages collaboration and innovation [10].

Third, data ownership and privacy are another key feature of Web 3.0. Web 3.0 addresses data ownership and privacy concerns in the current digital ecosystem and em-

phasizes user control over personal data, promoting self-sovereign identity and secure data management [10]. It prioritizes user privacy and security by implementing measures that require explicit user consent before accessing personal data to protect users' privacy [30]. Web 3.0 incorporates robust security measures, including consensus algorithms, cryptographic hashing, and smart contract audits to guarantee the integrity and reliability of decentralized platforms, applications, and digital assets [10]. Blockchain-based digital identity platforms (e.g., uPort and Civic) empower users to establish and control their digital identities, selectively disclosing necessary information solely to authorized service providers and relevant stakeholders [43]. Web 3.0 uses various privacy-enhancing technologies, including zero-knowledge proofs, homomorphic encryption, and multi-party computation to ensure secure and confidential storage, sharing, and computation of data [10]. In Web1/Web2, software companies initially prioritize data protection but eventually resort to monetizing or manipulating user data, leading to a privacy–convenience dilemma. In contrast, individuals in Web 3.0 have a greater control over their personal data [27]. Web 3.0 empowers users to take charge of their data to foster a digital ecosystem characterized by enhanced security, transparency, and personalized experiences [10].

Fourth, smart contracts are another key feature of Web 3.0. These are self-executing agreements on blockchains that automatically enforce predetermined rules and penalties, enabling transactions between entities without the need for human intervention [33,44,45]. These contracts are executed immediately as they are digital and automated [44]. A smart contract, administered by a peer-to-peer network of computers, is an autonomous software application that effectively facilitates rights management, coordination, and the enforcement of agreements among network participants bypassing the necessity for conventional legal contracts [23]. Smart contracts can be used in Web 3.0 to facilitate secure and transparent transactions, enforce digital rights, and enable decentralized applications with built-in governance mechanisms [44]. Smart contracts facilitate the real-time tracking of agreement performance, resulting in cost savings through on-the-fly compliance and control while also enhancing transparency and accountability and reducing bureaucratic processes [23].

Fifth, semantic technologies and artificial intelligence (AI) are other key features of Web 3.0. Web 3.0 incorporates semantic technologies and AI to enhance the organization and understanding of data [1,7]. It focuses on developing structured data using semantic markup and ontologies, enabling machines to interpret and process information in a more meaningful way [7]. AI technologies are used to extract insights, provide personalized experiences, and enhance decision-making within the decentralized ecosystem [1].

Last, open-source development and community-driven governance models are another key feature of Web 3.0. Web 3.0 promotes open-source development and community-driven governance models. Web 3.0 systems are distributed, meaning they use open-source code and are not controlled by a single entity [10]. Decisions regarding protocol upgrades, consensus mechanisms, and ecosystem developments are often made collectively by the community through consensus mechanisms such as on-chain voting [10]. Such a participatory approach fosters transparency, inclusivity, and democratic decision-making. For example, DeFi networks and protocols are built using open-source technology, providing an inclusive environment where any individual can participate [10].

3. Web 3.0 and Sustainability Research

Sustainability encompasses diverse objectives that foster innovation for generating value for individuals, economies, and the environment [46,47]. It entails safeguarding the natural environment, human health, and ecosystem balance while promoting innovation [39]. Achieving sustainable development necessitates transformative technological, organizational, and social changes, exerting significant influence over individuals, economies, and the environment [46,47]. Central to sustainable development is adopting circular economy principles, promoting regenerative exchanges of products and services to minimize waste and optimize the utilization of finite natural resources [39]. This devel-

opment paradigm prioritizes meeting present needs without compromising the needs of future generations [9]. United Nations Development Programme (UNDP) established 17 Sustainable Development Goals (SDGs), which aim to eradicate poverty, protect the environment, and improve the well-being and opportunities for people globally [48]. Table 2 shows the UN SDGs.

Table 2. UN Sustainable Development Goals (SDGs).

Sustainable Development Goals (SDGs)	
1 No Poverty	10 Reduced Inequalities
2 No Hunger	11 Sustainable Cities
3 Good Health Awareness	12 Responsible Consumption
4 Quality Education Improvement	13 Climate Action Awareness
5 Gender Equality	14 Life below Water Awareness
6 Clean Water and Sanitation	15 Life on Land
7 Renewable Energy Awareness	16 Peace and Justice
8 Good Jobs and Economic Growth	17 Partnerships
9 Innovation and Infrastructure	

Web 3.0 holds significant potential for accelerating progress towards SDGs if organizations such as UNDP can play a proactive role in the evolution of Web 3.0. Such organizations can help by fostering innovation ecosystems, developing necessary skill sets, facilitating collaboration between organizations, conducting research and advocacy, establishing regulations, and assisting governments in leveraging Web 3.0 opportunities [17]. Web 3.0 is related to sustainability as the principles of sustainability can be applied to environmental, economic, technological, and social impacts of its technologies [9,17]. Web 3.0 can contribute to sustainability by enabling effective, sustainable marketing strategies [18], sustainable business models [19], and sustainable supply chain management [20,21], as well as utilizing decentralized systems such as blockchains [9,22,23].

As Web 3.0 is in its early stages, its future remains uncertain. However, by analyzing its technological and sustainability challenges, we can make informed decisions about its potential opportunities and risks [17]. There is not enough research that is specifically related to Web 3.0 and sustainability. A few industry reports and research papers in the literature have discussed sustainability issues related to Web 3.0. Table 3 shows research papers discussing sustainability issues related to Web 3.0 and its key components.

Table 3. Sustainability and Web 3.0 research table.

	Sustainability Topics	**References**
1	This research paper discusses the potential of Web 3.0 and blockchain technology, as well as the perceived sustainability challenges facing Web 3.0 technologies.	[9]
2	This research paper discusses the current state and key research topics related to the sustainability of the Metaverse.	[49]
3	This research paper analyzes the sustainability of Metaverse technology from three perspectives: environmental, social, and governance (ESG).	[50]
4	This research discusses factors that will help in the development, successful adoption, and sustainable use of the Web 3.0/Metaverse and its applications.	[33]
5	This research paper proposes an incentive mechanism that utilizes contract–theoretic methods to economically motivate users to support the sustainability and growth of the blockchain network in Web 3.0.	[22]
6	This research paper discusses two major sustainability issues of Blockchain: power consumption and scalability.	[51]

Table 3. *Cont.*

	Sustainability Topics	References
7	Risks and challenges that Web 3.0 possesses and how Web 3.0 can support achieving SDGs.	[17]
8	This research paper discusses why businesses should invest in Web 3.0 as a sustainable development platform.	[52]
9	This research paper examines the dynamics driving platform user adoption and sustainability during two growth phases (i.e., development and expansion).	[35]
10	This research paper analyzes the opportunities and best practices of blockchain applications for achieving SDGs.	[23]
11	This research paper discusses sustainable development, e-learning, and how Web 3.0 can contribute toward sustainable e-learning.	[46]

4. Web 3.0 and Blockchain Projects for Sustainability

Web 3.0 and Blockchain-based applications can potentially create economic, social, and environmental sustainability impacts. Many industry reports and web articles show that Web 3.0 and blockchain applications are helpful for sustainability and can help achieve SDGs. Numerous Web 3.0-based projects dedicated to sustainability efforts actively implement measures to combat climate change, such as EarthFund, Plastiks, etc. [53]. Some of these noteworthy Web 3.0 and blockchain applications that help achieve sustainability goals are mentioned in the Table 4 below.

Table 4. Sustainability and Web 3.0 projects.

Web 3.0 Projects	SDGs	References
World Food Programme (WFP), a humanitarian organization providing food assistance, leverages decentralized financial (DeFi) applications to enhance distribution efficiency and facilitate secure money transfers, empowering refugees.	1, 2, 10	[42]
Chinese blockchain-based carbon asset markets enable enterprises to efficiently generate carbon assets in alignment with China's Carbon Emissions Reduction goals for the Paris Agreement.	7, 12, 13	[54]
Blockchain-based peer-to-peer energy systems offer the potential to minimize energy wastage by eliminating the need for long-distance transmission and energy storage, while various blockchain-powered platforms such as Echchain, ElectricChain, and Suncontract aim to optimize supply chain efficiency in the energy sector.	12, 13	[54]
Open Earth Foundation is leveraging these Web 3.0 technologies to build an advanced carbon pricing mechanism.	12, 13	[55]
The Social Plastic project utilizes collection centers in developing nations to convert plastic waste into currency, services, or goods with the goal of addressing plastic pollution and poverty and is currently developing a blockchain-powered app for exchanging plastic for cryptographic tokens.	1, 11, 13	[56] [57]
Green World Campaign uses cryptocurrencies and a hybrid smart contract application. This project aims to start a global campaign to restore degraded land, raising living standards and increasing healthcare and living standards in rural areas, replenishing soil, and mitigating climate change	1, 2, 3, 13	[58] [59]
GridExchange is a blockchain-driven platform that facilitates the exchange of energy resources and mitigates the emission of greenhouse gases.	7, 12	[60]
Treejer acts as a connection between individuals who provide funds for planting trees and those responsible for planting them. It keeps a record of who owns the credits and facilitates safe transactions between various parties using smart contracts.	1, 2, 6, 13	[61] [53]

Table 4. *Cont.*

Web 3.0 Projects	SDGs	References
EarthFund helps to create decentralized and autonomous communities with the aim of addressing humanity's most significant challenges such as reducing plastic pollution. The platform empowers token holders to participate in voting for various projects.	6, 7, 11, 12, 13	[62] [53]
Fishcoin is a decentralized peer-to-peer blockchain network that utilizes incentivization to encourage seafood supply chain stakeholders to exchange data, resulting in increased revenue for fishers and promoting sustainability by protecting biodiversity and reducing food waste while also providing secure and trusted data through a shared protocol for connecting seafood supply chain.	6, 12, 14, 15	[42]
Arbol project aims to disrupt the traditional insurance landscape by utilizing a Web 3.0 solution that combines smart contracts and climate data from the Chainlink Network, enabling the provision of insurance coverage to subsistence farmers against crop damages caused by extreme weather events.	1, 10, 15	[55]
Plastiks project aims to link individuals and enterprises globally in the battle against plastic pollution by backing plastic recovery initiatives through the utilization of technology and NFTs.	6, 11, 12, 15	[63] [53]

5. Future Research in Web 3.0 and Sustainability

The emergence of technological advancements such as Web 3.0 and Blockchain has prompted a reassessment of sustainability objectives and practices [21]. Web 3.0 enables organizations to align their business objectives with sustainability objectives [42]. Web 3.0 has a potential to contribute to sustainability through the utilization of blockchain technology [22]. Web 3.0 technologies such as blockchain technology are increasingly seen as a promising tool for fostering sustainability innovations to combat climate change, particularly in areas such as pollution monitoring and product sustainability tracking [64]. Blockchain-based applications contribute to sustainable business models by minimizing the presence of intermediaries, reducing payment delays and transaction times and mitigating greenhouse gas and carbon emissions [54,65].

It is crucial to critically examine the relationship between Web 3.0 and sustainability to understand sustainability challenges in the new digital age. Web 3.0 aims to build a digital ecosystem that is decentralized, user-centric, and blockchain-powered, which offers enhanced security, privacy, and control for the users. Web 3.0 offers promising technologies that have the potential to significantly contribute to achieving SDGs. Using advanced technologies such as blockchain, decentralized applications, and artificial intelligence, Web 3.0 offers innovative solutions to address environmental, social, and economic sustainability challenges.

There are four broad categories by which Web 3.0 applications can foster sustainability efforts.

5.1. Enhanced Efficiency, Resource, and Energy Optimization

Web 3.0 technologies offer significant potential for improving efficiency and optimizing digital systems' resource and energy consumption. Many Web 3.0 projects are contributing to sustainability efforts by enhancing efficiency in the business process, energy, and resource optimization [17,44,53,55]. Web 3.0 is recognized by many organizations for its potential to foster transparent and efficient climate markets, empower emerging economies, and unlock sustainability initiatives through decentralization, automation, and advancements in many fields such as energy infrastructure, carbon markets and crop insurance [55]. Web 3.0 applications can automate and streamline business processes, reducing the need for intermediaries, optimizing resource consumption, and minimizing administrative costs by using smart contracts [23,44].

Blockchain technology contributes to environmental supply chain sustainability through various applications, including the accurate tracking of substandard products and identifying subsequent transactions, leading to reduced rework, recalls, resource consumption,

and greenhouse gas emissions [54]. Due to the focus on sustainability, blockchain-powered Web 3.0 applications are increasingly utilized by companies and governments to ensure efficiency, waste reduction, and the prevention of surplus production in many sectors such as sustainable supply chain management [12]. Blockchain-based applications offer a more efficient means of measuring and monitoring environmental sustainability concerns such as carbon emissions, water usage, energy consumption, waste generation, and recycling [54]. The adoption of blockchain technology has the potential to foster sustainability by improving process efficiency, replacing paper-based information exchange, and reducing fossil fuel usage and production loss [12]. Blockchain-enabled renewable energy projects have the potential to mitigate measurement, optimizing verification challenges through smart meters, enhancing transparency via smart contracts, mitigating double-counting issues through unique transaction identifiers, and providing co-benefits such as bill savings or cost savings [66].

Decentralized energy systems (DeE) represent a new paradigm in energy production, distribution, and consumption and offer enhanced control to users for effectively managing their energy consumption [10,67]. DeE platforms use smart contracts and peer-to-peer energy trading to enhance efficiency and resilience in energy systems [10]. Using smart contracts, energy transactions, and grid management can be decentralized, and incentivizing the adoption of renewable energy is possible [10,66]. Chainlink is a Web 3.0 services platform that has the potential to establish a climate ecosystem that is interoperable, transparent, and scalable, contributing to the progress towards achieving net zero emissions by the integration of digital climate assets from various Web 3.0 environments [68].

From smart buildings to intelligent transportation systems, Web 3.0 applications promote energy efficiency, waste reduction, and sustainable resource management [12,39,54,66]. The emergence of Web 3.0 and Metaverse contributes to sustainability by minimizing global warming by reducing traffic, accidents, and pollution as it reduces the necessity for human travel and minimizes pollution by virtually conducting many work activities such as military training [42]. Blockchain-powered Web 3.0 applications can enhance business transaction efficiency, eliminate redundant business processes, improve data management, increase energy efficiency, and reduce waste to build a more sustainable digital ecosystem.

5.2. Enhancing Transparency and Trust

Web 3.0 applications built using blockchain technology offer the potential to enhance transparency and trust in conducting business transactions. Blockchain technology has the capacity to deliver unparalleled transparency through a distributed and encrypted database where immutable copies of information are stored on multiple network nodes [23]. These applications enable verifiable and traceable transactions by leveraging a decentralized and transparent ledger system, ensuring data integrity and transparency [10]. Blockchain-based applications are emerging as promising solutions to address global supply-chain-management challenges by improving transparency, traceability, and security [54,69]. These applications have significant implications across various industries such as supply chain management and renewable energy. Blockchain technology facilitates data collection, storage, and management, enhancing supply chain information with openness, reliability, and security features for all stakeholders involved [54].

Supply chains are susceptible to disruptions and uncertainties, necessitating the adoption of blockchain applications for risk monitoring and control. Blockchain-based Web 3.0 applications play a pivotal role in enhancing food safety and quality by providing transparent information about the origin of food within supply chains [54]. Notably, collaborations between industry leaders such as IBM and Walmart leverage blockchain infrastructure to trace product origins, empowering supply chain participants to track the flow of materials, goods, and information through a robust blockchain system [54,70]. The traceability enabled by blockchain technology promotes sustainability by ensuring an improved assurance of human rights, fair and safe work practices, and ethical sourcing of goods through a transparent record of product history [54]. The lack of transparency in global supply

chains poses significant concerns such as fraud, pollution, and human rights violations [23]. Addressing these issues aligns with the United Nations Sustainable Development Goals (SDGs), emphasizing the need for sustainable and responsible practices throughout supply chains [23]. By embracing Web 3.0 applications and blockchain technology, companies and stakeholders can work towards achieving SDGs while improving transparency, traceability, and sustainability in global supply chains [23,54]. In the marketing field, Web 3.0's transparency mandates a transformative shift in marketing strategies, necessitating collaborative engagement between companies, customers, and partners to develop shared marketing values [71,72].

The Metaverse, another Web 3.0 technology, holds promise for enhancing transparency through improved data sharing, real-time collaboration, immersive experiences, and visual representation, fostering trust and improving transparency in business transactions [42,73,74]. Transparency, a key characteristic of blockchain-based systems, fosters trust among stakeholders, empowering consumers to make informed choices regarding sustainable products, and enabling companies to demonstrate their commitment to responsible practices [54]. Transparency in business practices fosters trust in stakeholders and encourages them to participate in and promote corporate sustainability initiatives such as renewable energy adoption, reduced carbon emissions programs, and electronic waste recycling [75].

5.3. Promote Innovation and Collaboration

Web 3.0 has immense potential to generate social and economic impact and promotes innovation and collaboration across multiple industries [10]. It is anticipated to cultivate open and collaborative environments through decentralized technologies, including blockchain-based decentralized finance (DeFi), cryptocurrencies, and non-fungible tokens (NFTs) [25]. Web 3.0 technologies hold immense potential that is continuously expanding, presenting exciting opportunities for innovation and collaboration [10]. The utilization of blockchain technology within Web 3.0 enables trust-based systems, facilitating collaboration among diverse individuals and organizations and starting a new era of cooperative businesses [39]. Decentralized applications (dApps) built on blockchain technology within Web 3.0 enhance collaboration by providing secure work environments and transparent compensation processes [10,26,27]. Leveraging smart contracts, Web 3.0 automates collaboration processes, ensuring fair compensation and profit distribution and, in turn, enabling seamless collaboration on new projects [23,44].

Web 3.0 applications and blockchain-based platforms hold the potential to create a new economic and entrepreneurial framework that fosters collaborative and sustainable innovation, ensuring equitable access to benefits for all participants contributing to its advancement [23]. The interoperability and composability of blockchain technology offer vast opportunities for innovation in Web 3.0 products where each open-source product acts as a modular building block that can be utilized and redeveloped [30]. Web 3.0 offers enhanced interoperability, which promotes seamless communication and interaction among diverse blockchain networks, enabling an open and collaborative digital ecosystem that facilitates user access to services and assets across networks, eliminating the need for intermediaries [10]. In Web 3.0, the decentralized model and collaboration between developers and users drive rapid innovation, facilitating the creation of innovative business models and enhanced user experiences that are not possible on traditional centralized platforms [30].

With decentralized networks, individuals and organizations can collaborate directly, share resources, and innovate sustainable solutions collectively. This collaborative aspect of Web 3.0 can facilitate the emergence of decentralized applications focused on environmental sustainability, such as carbon footprint tracking, sustainable finance, and decentralized marketplaces for green products and services [9,10,17,30]. From an entrepreneurial standpoint, the motivation to adopt blockchain arises from recognizing that value creation extends beyond a single point on the platform, instead occurring at the ecosystem level, resulting

in reduced capital requirements for developing and offering specific products and services while benefiting from the ongoing collective advancement of the platform [23].

Collaborative innovation facilitates the achievement of SDGs by enhancing performance through ecological, economic, and social considerations, thereby enabling more consistent operationalization of local sustainability across all SDGs [76,77]. Innovation and collaboration play a crucial role in advancing sustainability efforts by contributing to the achievement of SDGs, generating organizational value, overcoming innovation barriers, and promoting climate-sensitive technology [76,77]. The environment fostered by Web 3.0 is conducive to innovation and collaboration, thereby playing a critical role in achieving SDGs and promoting sustainable development through the collective efforts of diverse stakeholders.

5.4. Promote Inclusivity and Empowerment

Web 3.0 applications can foster inclusivity and empower individuals and communities. Inclusivity and empowerment of the users facilitated by Web 3.0 applications directly impact SDGs. Web 3.0 applications use decentralized platforms, allowing individuals to have greater control over their digital assets and protect their privacy [9,10,30,43]. This self-sovereignty ensures privacy and security while enabling participation in the digital economy. In Web 3.0 applications, decentralized networks empower democratic and inclusive decision-making processes by allowing users to engage in governance through voting and consensus mechanisms [10]. Web 3.0 also facilitates financial inclusion through decentralized finance (DeFi) systems, providing access to financial services for underserved populations [10]. Web 3.0 empowers individuals and communities in this manner and contributes to sustainable development by reducing inequalities and enabling equitable participation in the digital age. DeFi, a rapidly expanding sector of Web 3.0, utilizes decentralized platforms and protocols to deliver financial services and products, offering advantages like enhanced accessibility, transparency, and efficiency through blockchain technology and decentralized governance models [10,78,79].

Blockchain technology can contribute to enhancing social sustainability by establishing an incentivization system such as Backfeed that motivates companies to actively participate in improving social values using blockchain infrastructure [54]. The Backfeed, a model built on blockchain technology, promotes collaboration among participants and provides incentives for their contributions. The incentive structure provided by Web 3.0 has the potential to be transformative by rewarding innovation, promoting the best peer support workers, encouraging positive behavior change, and reducing economic disparities through network effects that financially benefit peer supporters and users [80]. Such efforts can reduce economic disparities and help in achieving SDGs. Web 3.0 and healthcare are converging as blockchain technology, and cryptocurrencies are being explored to enhance HIV outcomes, support cancer research funding, encourage healthy behaviors through wearable device data tracking, and ensure secure digital medical records [80]. Web 3.0 can play a critical role in empowering individuals by providing better healthcare outcomes and improving the efficiency of healthcare services.

The emergence of Web 3.0 and its associated technologies brings forth a myriad of possibilities and challenges in the realm of sustainability research. Numerous Web 3.0 projects have already progressed with a strong emphasis on addressing SDGs [9,53,55–57,68]. Nevertheless, it is imperative to acknowledge the existence of several other research domains that need attention in the pursuit of SDG attainment. These research topics include sustainability practices within the Metaverse, hardware and e-waste generated by Web 3.0 technologies, sustainable energy solutions for Web 3.0 applications, interoperability, privacy and security of Web 3.0 sustainability applications, integrating artificial intelligence into Web 3.0 applications to enhance sustainability, legal, and regulatory issues of Web 3.0 technologies, etc. [9,10,23]. Altogether, these research areas collectively contribute to a holistic understanding of how Web 3.0 intersects with sustainability and the multi-faceted challenges and opportunities it presents. A compilation of these research areas, as highlighted

in the existing literature, is presented in Table 5. Future research studies should prioritize these research areas to foster a comprehensive comprehension of the sustainability issues at hand.

Table 5. Sustainability and Web 3.0 research topics table.

	Research Topics	References
1	Does the Metaverse exemplify sustainable technology practices?	[50]
2	How is the economic system organized in the Metaverse, and how are profits generated and shared within it?	[49]
3	How do we optimize technology and architecture for new environments and solve for sustainability?	[9]
4	Hardware/e-waste due to Web 3.0 and its impacts	[9]
4	What are the sustainable energy approaches for Web 3.0 applications?	[9]
5	Identify new security threats and privacy challenges in Web 3.0 and how they impact sustainability.	[10]
6	To develop standardized protocols to address the issue of interoperability between various Web 3.0 platforms and understand its sustainability implications.	[10]
7	To develop quantum computing resistant cryptographic algorithms to ensure the long-term security of Web 3.0 architectures and understand its sustainability implications.	[10]
8	How does integrating ML and AI in Web 3.0 trust models enhance decision-making and sustainability?	[10]
9	What risks and challenges do Web 3.0 face, and how can it contribute to achieving SDGs?	[17]
10	How can Web 3.0 applications be used to achieve better healthcare outcomes and services?	[80]
11	How do blockchain networks act as enablers or barriers for achieving SDGs?	[23]
12	What are the key enablers for interdisciplinary collaborations to facilitate the successful implementation of blockchain technology for sustainability?	[23]
13	Compare the carbon footprints of blockchain-based cryptocurrency transactions (e.g., Bitcoin) with traditional financial transactions (e.g., credit card payments) and their impact on Web 3.0 sustainability.	[23]
14	What are the challenges associated with the utilization of blockchain technology in any field (e.g., supply chains), and what potential sustainability risks might emerge as a result?	[23]
15	To investigate potential threats, challenges, and pitfalls of blockchain implementation in carbon markets.	[66]
16	Examine blockchain's influence on sustainable supply chains at different levels, including organizational, operational, supply chain dynamics, industry networks, and the macroeconomic landscape.	[21]
17	What are the legal and regulatory issues related to Web 3.0 technologies that can impact sustainability?	[81] [10]

6. Web 3.0 Sustainability Challenges

While Web 3.0 applications and blockchain networks hold promise in promoting sustainability, it is important to recognize that the technology itself is merely a tool and not a universal solution, capable of facilitating informed decisions by various stakeholders [23]. Nevertheless, due to its current nascent state, there are numerous challenges pertaining to technology, legal frameworks, and network effects that lie ahead. Some of the key sustainability challenges associated with Web 3.0 are presented in the next section.

First, the energy consumption associated with blockchain networks remains a concern for Web 3.0 applications [9,51,69]. Proof-of-Work (PoW) consensus algorithms, employed by popular blockchains like Bitcoin, are known for their energy-intensive mining processes [11,13]. For example, the high cost of using Ethereum is a significant sustainability challenge for the Web 3.0 ecosystem [30]. Transitioning to more energy-efficient consensus mechanisms such as Proof-of-Stake (PoS) and exploring layer-two scaling solutions can mitigate the environmental impact of Web 3.0 [13]. If corporate miners increase their utilization of stable and renewable energy sources such as those found in Canada, Iceland, and Sweden, they have the potential to mitigate the carbon footprint associated with Bitcoin mining [9]. The adoption of energy-efficient consensus mechanisms is necessary to address the environmental concerns related to the energy consumption of blockchain networks.

Second, electronic waste (e-waste) and hardware upgrades are another challenge related to Web 3.0 applications. The mining process in Web 3.0 and blockchain technology consumes significant resources, particularly hardware components such as electronics, CPUs, GPUs, etc., to enhance the computational power and maintain overall competitiveness [33,82]. The rapid evolution of Web 3.0 technologies has the potential to contribute to shorter hardware life cycles and increased e-waste because of the frequent hardware upgrades that come from the emergence of new protocols and applications [10]. Encouraging sustainable manufacturing practices, promoting recycling initiatives, and exploring alternative approaches such as cloud-based computing can address these challenges [10].

Last, there are legal and regulatory compliance challenges related to Web 3.0 technologies, including Blockchain and AI [9,10,25]. The growth of Web 3.0 decentralized technologies necessitates careful consideration of the legal and regulatory compliance implications that may arise, as their ongoing evolution and expansion require proactive attention to potential challenges affecting their development and adoption [10,23]. These sustainability challenges include decentralized finance, distributed energy networks, energy consumption, etc. [9,10,23]. For example, Japan contemplated legal modifications aimed at classifying bitcoin and other cryptocurrencies as currencies [81].

7. Discussion

Web 3.0 is still in an emerging phase. The emergence of Web 3.0 has raised concerns about its impact on sustainability. Technological advancements such as Web 3.0 require re-evaluations of sustainability practices. Sustainability issues must be addressed for sustainable use in developing Web 3.0 applications. Many Web 3.0 applications and technologies have been developed to promote sustainability. This research paper makes several contributions by discussing various concepts related to Web 3.0 and sustainability.

First, this research paper presents the current state of research about Web 3.0 and sustainability based on the existing literature, web articles, and industry reports. Understanding the present state of research is essential in identifying gaps and critical topics for future research. The extant literature review part highlights various examples where Web 3.0 has shown potential to contribute to sustainability objectives in many ways such as the utilization of blockchain technology by developing sustainable marketing strategies and business models, implementing sustainable supply chain management practices, using decentralized finance, etc. [10,18,20–22,83,84]. Some Web 3.0 projects focused on enhancing sustainability initiatives are already running [9,53,57,68]. However, it is noted that the existing research in the field of Web 3.0 and sustainability is still limited, indicating the need for further investigation.

Second, this research paper highlights the key research topics for Web 3.0 and sustainability. These topics serve as a guide for researchers to identify areas that warrant further investigation [9,10,23]. By considering the topics mentioned in Table 5, future research can delve into these specific areas and contribute to the existing body of knowledge related to Web 3.0 and sustainability.

Last, this research paper discusses challenges associated with Web 3.0 and sustainability. These challenges need to be addressed to realize the full potential of Web 3.0 for

sustainability. Some of the key sustainability challenges are energy consumption [9,51,69], e-waste [33,82], and legal and regulatory issues [9,10,25]. Future research can study these challenges and how these challenges impact Web 3.0 and sustainability.

Web 3.0 presents both opportunities and challenges for sustainability in various industries. Industry practitioners can proactively engage with Web 3.0 developments by staying informed, integrating sustainability into their strategies, supporting research initiatives, and actively addressing sustainability challenges. This approach not only aligns with responsible business practices but also positions organizations to thrive in a rapidly evolving technological landscape with a focus on sustainability.

It is important to interpret this paper while taking its limitations into account. One of these limitations is the absence of well-established research methods. This paper is written in the form of an opinion piece; thus, the arguments put forth within it are subjective in nature.

8. Conclusions

Web 3.0 is the next generation of the Internet. Web 3.0 has important technical components such as blockchain technology and the Metaverse. Its key features include decentralization, interoperability, data ownership and privacy, smart contracts, semantic technologies and AI, and open-source development and community-driven governance models. Web 3.0 presents a remarkable potential to advance sustainability objectives through various mechanisms, including enhancing transparency and energy optimization, promotion of trust, and innovation and facilitation of inclusivity. Challenges related to energy consumption, e-waste, and legal and regulatory issues need to be addressed to realize the full potential of Web 3.0 for sustainability. Some of the key research areas that can be addressed in future research include the Metaverse sustainability practices, hardware, and e-waste, sustainable energy solutions for Web 3.0 applications, interoperability, privacy, and security of Web 3.0 sustainability applications, using AI into Web 3.0 applications to enhance sustainability, legal, and regulatory issues of Web 3.0 technologies, etc.

This study discussed Web 3.0 sustainability projects, sustainability challenges, and key research topics for future research. More research on challenges and opportunities is needed to understand Web 3.0 and sustainability better.

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