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I wove into the paper's vision of reinvesting carbon credit proceeds into sustainable initiatives.

The course *Interdisciplinary, Multidisciplinary Approaches to Sustainable Development* has been a transformative experience, deeply influencing the direction of my research paper on tokenizing carbon credits for a circular economy in Aruba. Coming into the course, I was aware of the pressing environmental challenges faced by small island developing states (SIDS) like Aruba, particularly their vulnerability to climate change and economic dependence on tourism. However, the interdisciplinary lens of the course broadened my perspective, encouraging me to integrate diverse fields such as blockchain technology, sustainability, and economic systems to address these challenges holistically. One of the most impactful aspects of the course was its emphasis on the interconnectedness of ecological, social, and economic systems, especially in the context of islands. Learning about planetary boundaries through the island metaphor resonated with me—it highlighted the finite nature of resources and the urgent need for innovative solutions that balance ecological limits with human wellbeing. This perspective inspired me to focus on a circular economy framework for Aruba, where waste minimization and resource efficiency could be prioritized. The course's exploration of doughnut economics further reinforced this idea, showing me how Aruba could meet its population's needs while staying within ecological boundaries, a concept I wove into the paper's vision of reinvesting carbon credit proceeds into sustainable initiatives.

The multidisciplinary approach of the course also pushed me to combine my knowledge of blockchain technology with sustainability goals. Discussions on socio-metabolic risk and climate change in small island states revealed the complexity of these challenges, particularly for tourism-driven economies like Aruba's. This led me to explore how blockchain could democratize access to carbon markets for SIDS, an idea that became the cornerstone of my paper. The course's focus on linguistic and cultural diversity in islands also influenced my thinking—I realized that any solution for Aruba needed to be culturally sensitive and engage local stakeholders, prompting me to design a system where tourists, businesses, and residents could all participate in a tokenized carbon credit market. A key moment in the course was learning about the role of technology in sustainable development. While I was already familiar with blockchain from my studies, the course introduced me to practical applications like Digital Monitoring, Reporting, and Verification (D-MRV) systems and their potential to ensure transparency in emissions tracking. This inspired me to integrate a D-MRV framework with the XRP Ledger (XRPL) in my paper, creating a system where emissions reductions could be accurately monitored, tokenized, and traded as NFTs. The course's emphasis on collaboration across disciplines gave me the confidence to bridge these technical concepts with Aruba's Circular Economy Vision 2050, ensuring my proposal was both innovative and grounded in local needs. Reflecting on the course, I'm struck by how it encouraged me to think beyond siloed solutions. The interdisciplinary approach taught me to see Aruba not just as a case study, but as a microcosm of global sustainability challenges. By combining insights from ecology, economics, technology, and cultural studies, I was able to develop a paper that not only addresses Aruba's specific needs but also offers a scalable model for other SIDS. This course has inspired me to continue exploring how technology and interdisciplinary thinking can drive sustainable development, and I'm eager to see how these ideas can be applied in real-world contexts.

Tokenizing Carbon Credits for a Circular Economy in Small Island States
Interdisciplinary Multidisciplinary Approaches to Sustainable Development

Josua Frias

Abstract

Aruba, a small island state in the Caribbean, faces substantial environmental and economic pressures due to its dependence on tourism and dependence on imported resources. Amid global efforts to combat climate change, tokenizing carbon credits using blockchain technology presents an opportunity to advance sustainability within Aruba's economy. This paper explores how this approach, specifically leveraging a Digital - Monitoring, Reporting & Verification (D-MRV) system framework & the XRP Ledger (XRPL), could support the development of a circular economy in Aruba, a system aimed at minimizing waste and maximizing resource efficiency. It examines the concept of tokenized carbon credits, their potential benefits and challenges within the context of a small island, and proposes a practical framework for implementation, aligning with Aruba's sustainability goals outlined in its Circular Economy Vision 2050.

1. Introduction

Small island developing states (SIDS) occupy a special position in the global landscape of climate change, subject to quite some vulnerabilities despite contributing a tiny fraction of global greenhouse gas emissions. Island nations, often characterized by limited landmass, isolated geographies, and fragile ecosystems, face existential threats from rising sea levels, intensified storms, and shifting climatic patterns (United Nations Framework Convention on Climate Change (UNFCCC), 2021). Their economies, heavily reliant on climate-sensitive sectors such as tourism and fisheries, are particularly susceptible to environmental disruptions, making paths to resilience an urgent priority. Compounding these challenges is restricted access of small island to global capital markets and technical expertise, which disrupts their capacity to meet international sustainability targets, like those in the Paris Agreement. Circular economy principles focused on resource efficiency, waste reduction, and regenerative systems offer a transformative pathway for SIDS to enhance sustainability while fostering economic autonomy. Within this context, carbon credit markets present both a challenge and a significant opportunity for SIDS. Carbon credits are certificates representing the avoidance or removal of the equivalent of one metric ton of CO2 these are typically traded through entralized systems dominated by large economies and corporations. High entry barriers and complex verification processes currently limit the participation of SIDS in global carbon markets (World Bank, 2022). However, the rise of blockchain technology has introduced a disruptive innovation: the tokenization of carbon credits. Tokenization would involve the conversion of carbon credits into digital assets recorded on a blockchain, enabling transparent, efficient, and decentralized trading. This approach promises to democratize access to carbon markets, aligning with circular economy goals by integrating sustainability into economic transactions and incentivizing emissions reductions at a local level.

Blockchain, at its core, is a decentralized digital ledger that records transactions across a network of computers in a secure, transparent, and immutable manner (Narayanan et al., 2016). Unlike traditional databases managed by a single authority, blockchain operates without intermediaries, relying on cryptographic techniques to ensure data integrity and consensus protocols to validate entries. Each transaction, termed a “block”, is linked to the previous one, forming a chronological “chain” that cannot be altered retroactively without network consensus. This technology underpins cryptocurrencies like Bitcoin, but its applications extend far beyond those, offering a robust framework for managing other digital assets like tokenized carbon credits. By recording carbon credits on a blockchain, tokenization ensures that each credit’s origin, ownership, and retirement status are transparently tracked, reducing the risk of double-counting or fraud. Furthermore, blockchain’s efficiency, enabled by rapid transaction processing and low operational costs, makes it feasible for smaller entities, including SIDS, to participate in carbon markets without the immense expenses of traditional systems (World Economic Forum, 2021).

This paper explores the integration of tokenized carbon credits into SIDS economies, emphasizing how blockchain technology can facilitate this process and align with circular economy objectives. By leveraging blockchain’s capabilities, SIDS can transform carbon credits from abstract certificates into accessible digital tokens, tradable on global platforms or within localized markets, thereby generating revenue to fund sustainable initiatives. The paper adopts an exploratory approach, synthesizing existing literature to assess the potential of this innovation, with a particular focus on Aruba as a case sttudy. The paper reviews relevant literature and case studies that show how blockchain technology can be used for carbon credits. It covers examples and ideas from past research that highlight the benefits and challenges of this approach. Then it discusses how blockchain application could be put into practice in Aruba and other Small Island Developing State (SIDS) to track and manage carbon credits, supporting their efforts to address climate change and improve sustainability and how this bring about a circular economy.

1.1 The Case for Aruba

Aruba, a Caribbean Island spanning 180 square kilometers, exemplifies the challenges and opportunities inherent to small island states. Aruba’s economy is overwhelmingly dependent on tourism, which contributes over 80% of GDP and attracts more than one million visitors annually (UNWTO, 2021). Tourism is responsible for asignificant portion of energy consumption and CO2 emissions, and necessitates heavy reliance on imported goods. This includes the fossil fuels needed to run the island's desalination plant, the primary source of fresh water. Yet Aruba is actively pursuing a transition toward sustainability, as outlined in its Circular Economy Vision 2050 (Government of Aruba, 2019). Initiatives such as the Vader Piet wind farm, waste management innovations, and eco-tourism development reflect a commitment to reducing environmental impact while enhancing economic resilience (International Renewable Energy Agency (IRENA), 2020). The tokenization of carbon credits, enabled by blockchain technology, presents a unique opportunity to reinforce this transition by embedding carbon reduction efforts into the fabric of daily economic activities.

Through blockchain-based tokenization, Aruba could establish a localized carbon market where businesses, residents, and visitors actively participate in sustainability-driven economic exchanges. For example, hotels and resorts, key contributors to the island’s carbon footprint, could purchase locally generated carbon credits to offset their emissions, with transactions recorded transparently on a blockchain platform like the XRP Ledger (XRPL), known for its efficiency and low energy use (Ripple, 2022). Tourists could earn digital tokens by engaging in eco-friendly activities, like using renewable energy-powered transport or participating in beach cleanups, incentivizing sustainable behavior. The immutable nature of blockchain ensures the credibility of these offsets, allowing seamless verification by stakeholders, and reducing the risk of greenwashing, a big concern in carbon markets (Schneider et al., 2021).

Moreover, tokenized carbon credits could stimulate local enterprises to adopt sustainable practices by offering economic benefits for verified emissions reductions. Small businesses, such as restaurants or tour operators, could invest in energy-efficient technologies or waste reduction measures, earning carbon credit tokens tradable within Aruba or globally. By integrating blockchain-driven tokenization, Aruba could pioneer a model that not only supports its own sustainability goals but also serves as a blueprint for other SIDS navigating similar challenges. This approach aligns with the circular economy's emphasis on waste minimization and resource maximization, positioning sustainability as a cornerstone of Aruba's economic resilience.

2. Literature Review

Blockchain technology provides a decentralized, transparent, and secure framework for managing carbon emissions and facilitating carbon credit markets, addressing the inefficiencies of traditional systems. Two studies offer a technical foundation for exploring the potential of blockchain in monitoring emissions and tokenizing carbon credits in Small Island Developing States (SIDS). These highlight opportunities potentially enabling a system where emissions reductions are monitored, converted into tradable assets, and reinvested into sustainable initiatives. The first study examines a blockchain-based Digital Monitoring, Reporting, and Verification (D-MRV) system to enhance the accuracy and transparency of carbon emissions data, utilizing a consortium blockchain integrated with Internet of Things (IoT) devices by Frias (2025), who developed a distinct D-MRV framework inspired by Chen et al., 2024, and Effah et al., 2021. The second study by Guiterez et al. (2023) explores XRP Ledger (XRPL), a blockchain platform developed by Ripple Labs Inc. Ripple is a technology company focused on transforming global financial transactions through blockchain-based solutions. Founded in 2012 by Chris Larsen, Jed McCaleb, and others, Ripple developed the XRP Ledger (XRPL), an open-source, decentralized blockchain, and its native cryptocurrency, XRP. Unlike many cryptocurrencies that rely on energy-intensive mining (e.g., Bitcoin), the XRPL uses a consensus protocol involving validators to process transactions quickly (3-5 seconds) and at low cost, making it efficient and sustainable. Ripple's primary mission is to enhance cross-border payments for financial institutions, but it has expanded into tokenizing real-world assets (RWAs), such as carbon credits, to unlock liquidity and transparency in markets traditionally plagued by inefficiency (Ripple., 2025)

In the context of tokenizing real-world assets like carbon credits, Ripple leverages the XRPL's capabilities to represent tangible assets as digital tokens. Carbon credits, which certify the removal or reduction of CO2 emissions, are an emerging use case. Ripple's approach involves converting these credits into non-fungible tokens (NFTs) or other digital assets on the XRPL, enabling faster trading, transparent tracking, and reduced fraud. For instance, Ripple has committed $100 million to modernize carbon markets, partnering with organizations like CarbonCure Technologies and Xange.com to tokenize credits, ensuring their authenticity and scalability. This aligns with Ripple's goal of achieving carbon neutrality by 2030, using the XRPL's carbon-neutral design (achieved in 2020) to support climate solutions. By tokenizing carbon credits, Ripple addresses issues like double-counting and opacity in carbon markets, making them more accessible and efficient for buyers and sellers, particularly in regions like Small Island Developing States (SIDS) where climate action is critical. for tokenizing carbon credits, drawing on Ripple's initiatives to scale carbon markets through partnerships and investments (Ripple., 2025)

2.1 Consortium Blockchain and D-MRV System Architecture

Frias et al. (2025) describes a Digital - MRV (Monitoring, Reporting and Verification) system that employs a consortium blockchain to monitor carbon emissions with precision and security, overcoming the limitations of manual MRV processes. A consortium blockchain, governed by multiple trusted stakeholders such as regulators and energy producers, balances decentralization with controlled access, making it suitable for collaborative environments in SIDS. Frias proposes a unique D-MRV framework inspired by the work of Chen et al.(2024), and Effah et al.(2021). Public blockchains like Bitcoin rely on energy-intensive proof-of-work (PoW), and private blockchains risk centralization; unlike these, consortium blockchains provide restricted participation, faster transaction processing, and lower energy demands, aligning with the resource constraints of SIDS (Frias, 2025).

The D-MRV system begins with a data acquisition layer, where CO2 sensors and energy meters are deployed at other locations which are used by the energy facilities to collect real-time emissions data. Ordinary nodes, typically energy producers who use CO2 sensors and energy meters that are installed at facilities (for example hotels or businesses) to collect emissions data, which they sign with a digital signature, timestamp and prepare for secure submission to the blockchain (Chen et al., 2024; Frias, 2025). In the validation layer, a secure method called the Elliptic Curve Digital Signature Algorithm (ECDSA) ensures the data's authenticity. Ordinary nodes add a digital signature to the data using their private keys, proving it's genuine (Johnson et al., 2001; Frias, 2025). To keep the data confidential, they encrypt it with the public keys of premium nodes such as regulators—so only these nodes can unlock it with their private keys for review. Premium nodes check the signatures with the ordinary nodes' public keys to confirm the data's source (Chen et al., 2024; Frias, 2025). A system called Delegated Proof of Stake (DPoS) helps validate the data efficiently, using trusted delegates instead of energy-heavy methods like Bitcoin's, which suits resource-limited settings (Karunakaran et al., 2021). The storage layer locks the validated data on the blockchain with a unique ID for tracking, ensuring it can't be altered. Finally, the data sharing layer uses smart contracts to control access, letting premium nodes see the full data while ordinary nodes only view basic details like timestamps, keeping sensitive information private (Chen et al., 2024; Frias, 2025). These smart contracts rely on the ECDSA-verified data to monitor emissions levels, automatically issuing warnings, penalties, or fines to energy producers if CO2 emissions exceed regulatory limits, ensuring compliance without delay.

Smart contracts in the D-MRV system can automate compliance by comparing emissions data against regulatory thresholds, potentially issuing carbon credits for reductions below limits or triggering penalties for exceedances, minimizing manual oversight (Bonini et al., 2023).

A smart contract is a self-executing program stored on a blockchain that automatically carries out actions when specific conditions are met, without needing intermediaries like lawyers or banks. Think of it as a digital agreement with built-in rules: once the terms are fulfilled, it runs itself, secured by the blockchain's transparent and unchangeable network. On the Ripple network, specifically the XRP Ledger (XRPL), a smart contract is a programmable feature or tool that automates tasks based on predefined conditions, leveraging the ledger's fast and efficient design. The XRPL uses built-in functionalities like Escrow, Payment Channels, and the ability to issue custom tokens as smart contract-like mechanisms. These are pre-coded into the ledger and trigger automatically, offering speed (3-5 seconds per transaction), low cost, and simplicity, which suits Ripple's focus on real-time transactions and asset tokenization. For tokenizing carbon credits, an XRPL smart contract feature could hold credits in Escrow and release them to an energy producer once emissions data is verified and fullfils emission reduction goals, ensuring trust and efficiency with minimal energy use. This makes it ideal for managing real-world assets like carbon credits in systems like the D-MRV, especially in resource-constrained Small Island Developing States (SIDS). The D-MRV system demonstrates the potential for accurate and transparent emissions monitoring, which could serve as a foundation for carbon credit generation in SIDS like Aruba, where energy producers such as WEB Aruba N.V. might contribute to such systems (Chen et al., 2024; Frias, 2025). However, the literature does not yet explore how such a system could be integrated with tokenization platforms to create a fully functional carbon credit market in SIDS.

2.2 XRPL Framework for Carbon Credit Tokenization

The XRPL framework, developed by Ripple, provides a way to turn carbon credits into digital tokens, called non-fungible tokens (NFTs), making verified emissions reductions easy to trade as digital assets. Ripple is investing $100 million to grow carbon markets, working with climate-focused companies like Xange.com which is a Unetd Nations backed firm building a carbon credit solution on XRPL in order to make this happen (Guiterez, 2023). Unlike some blockchains that use energy-heavy processes, XRPL relies on a simple, efficient system with trusted validators to confirm transactions quickly and cheaply. This means it can handle lots of trades fast (thousands in seconds) at almost no cost, which makes it a practical choice for carbon credit trading (Guiterez, 2023).These attributes make XRPL a promising platform for a high-volume carbon credit market in SIDS.

In this context, carbon credits can be tokenized as NFTs, uniquely representing their origin, ownership, and retirement status to ensure traceability and prevent double-countingIn this setup, carbon credits become digital tokens called NFTs, each one unique to show where it came from, who owns it, and whether it's been used, making them easy to track and preventing reuse. The process is kept secure with a digital signature system, where energy producers sign the credits with a private code and others check them with a matching public code (Guiterez, 2023). Transactions are organized and checked efficiently to ensure everything adds up. Xange.com, for example, uses Ripple's XRPL to create these tokenized carbon credits from the African Great Green Wall Initiative, offering a simple web platform where energy producers can make and trade them, letting buyers like businesses or tourists purchase credits through digital wallets.

XRPL's performance surpasses alternatives like Ethereum, which, even after transitioning to Proof of Stake (PoS), achieves lower speeds (100–1000 transactions per second) and higher costs (approximately 1.30 USD per transaction). XRPL's carbon neutrality which is achieved through its consensus mechanism and Ripple's carbon offset initiatives, including pre-purchasing 120,000 carbon credits aligns with circular economy principles by minimizing resource use while scaling carbon credit markets in SIDS (Ripple, 2022).

2.3 Consensus Mechanisms and Security Primitives

Research from sources like Hu et al. (2020) and Ripple (2022) shows how smart systems and secure coding make carbon credit setups safe, fast, and trustworthy. For the D-MRV system, a method called Delegated Proof of Stake (DPoS) lets stakeholders pick trusted people to check emissions data quickly and with little energy, unlike slower, power-hungry setups (Hu et al., 2020). It's fair because of voting, but could favor big players if cheating occurs where big players come together to hold a larger stake. Ripple's XRPL, however, uses trusted checkers to handle thousands of trades fast and cheap, skipping energy-heavy mining (Ripple, 2022). Both can deal with errors or trickery, keeping things solid (Nguyen et al., 2019).

Cryptographic Security comes from clever coding that locks and proves the data. In D-MRV, energy producers hide emissions info with a special key only regulators can open, keeping it private, and sign it with a secret code to prove it's real (Chen et al., 2024; Frias, 2025; Johnson et al., 2001). XRPL does the same for carbon credit tokens, signing them to show they're legit and adding extra checks to stop tampering (Guiterez, 2023). These tools such as hiding data with keys, signing it, and double-checking are the backbone of the system to make sure emissions tracking and credit trading are secure and clear, building trust for a carbon market in Small Island Developing States (SIDS).

2.4 Case Studies of Blockchain Application from Other Small Island Developing States

To contextualize the potential adoption of blockchain-based carbon credit systems in SIDS like Aruba, it is valuable to examine efforts in other Small Island Developing States that are exploring or implementing digital climate finance tools. While few have fully operationalized blockchain-integrated carbon markets, several have laid foundational groundwork that could complement and support the frameworks proposed by Frias (2025) and Guiterez (2023). These include Fiji, the Seychelles, the Maldives and Barbados, each of which has dimensions with potential relevance for applications in Aruba.

Fiji's blockchain pilot for climate resilience financing was launched around 2020 with the UN Development Programme (UNDP) and the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE). It aimed to track funds earmarked for adaptation projects in remote Pacific communities. The initiative deployed a blockchain ledger to record disbursements as digital tokens, using mobile phones for community members to input project data (for example microgrid installations) via SMS or basic apps, syncing to the chain through local hubs despite limited internet access (UNDP, 2020 & PCREEE, 2020). This reduced fund leakage, ensuring funds reached intended recipients, as even in remote villages, they could prove expenditures transparently, enhancing trust and accountability.

While Fiji's pilot was not emissions-focused, it aligns with Frias's (2025) D-MRV emphasis on verifiable, real-time data collection, and suggests the viability of a low-tech entry point for tracking tourism emissions via mobile apps. Combined with XRPL's (Guiterez, 2023) efficient tokenization capabilities, an implementation inspired by Fiji's model could allow Aruba to upstream its carbon market with transparent financing, supporting infrastructure like IoT deployment for D-MRV (Frias, 2025), reinforcing its Circular Economy Vision 2050 (Government of Aruba, 2019)

In 2022, Seychelles pioneered the world's first Blue Carbon NFT pilot with Oceanium and Envision Blockchain, tokenizing carbon sequestered by mangroves to fund conservation, blending ecological restoration with digital markets. Field surveys and possibly remote sensing measured sequestration, with data verified and minted as NFTs on a blockchain, each representing carbon tonnage offset sold to corporations or donors(Envision Blockchain, 2022 & Oceanium, 2022). The pilot successfully raised funds for mangrove restoration and gained global notice for proving SIDS could monetize natural capital.

The initiative in Seychelles focuses on investment in ecosystems, rather than offsetting industrial emissions (as in Frias 2025), but its NFT approach is comparable to XRPL's tokenization capabilities (Guiterez, 2023), leveraging low-cost, traceable transactions. In Aruba, expanding D-MRV to coastal assets and tokenizing restoration credits alongside tourism offsets on XRPL could enhance its circular economy by integrating natural and economic value (Government of Aruba, 2019).

The Maldives, a tourism-dependent SIDS, began exploring Digital Monitoring, Reporting, and Verification (D-MRV) systems in 2023 with its Ministry of Environment and Maldives Tourism Authority, partnering with tech firms to track resort and transport emissions for voluntary tourist offsets, though it remains in feasibility stages. The plan integrates IoT sensors (for example, on boats and generators) with a blockchain to log real-time emissions, potentially tokenizing credits via a platform like XRPL, with tourists purchasing offsets through resort apps or dashboards (Ministry of Environment, Maldives, 2023 & Maldives Tourism Authority, 2023). Still in planning, it aims to turn 1.5 million annual visitors carbon footprints into sustainability revenue for funds that could be funneled to initiatives for reef protection, mirroring Frias's (2025) D-MRV vision for precise monitoring.

The initiative in the Maldives parallels the tourism context of Aruba (UNWTO, 2021), suggesting that a D-MRV (Frias, 2025) and XRPL (Guiterez, 2023) system could operationalize offsets faster, linking hotel emissions to visitor engagement, advancing its Circular Economy Vision 2050 (Government of Aruba, 2019) where Maldives lags.

Barbados, partnering with fintech startup Bitt in 2021, utilized blockchain to issue green bonds for climate resilience projects like water systems or renewables, focusing on financing rather than carbon credits. The bonds were issued on a private blockchain, enabling investors to buy digitally while tracking funds transparently from sale to project execution, cutting out intermediaries (Bitt, 2021 & Government of Barbados, 2021). This streamlined funding, outpacing traditional bonds, and established a Caribbean regulatory model, supporting resilience efforts without direct emissions tracking.

While distinct from Frias's (2025) D-MRV emissions focus, Barbados's initiative shares XRPL's (Guiterez, 2023) efficiency concepts, offering Aruba lessons in structuring markets. Barbados's public-private success suggests Aruba could issue bonds to fund D-MRV infrastructure or XRPL integration, ensuring legal clarity and stakeholder buy-in for a circular carbon economy aligned with its 2050 vision (Government of Aruba, 2019).

3. Discussion

3.1 Methodology for Implementation in SIDS: Aruba as a Pilot

Implementing a blockchain-based carbon credit system integrating Frias's (2025) D-MRV with XRPL tokenization (Guiterez, 2023) offers a scalable framework for Small Island Developing States (SIDS), with Aruba serving as a pilot to refine and demonstrate its potential. This methodology outlines a step-by-step plan leveraging tourism economies, local governance, and regional collaboration to address the resource constraints and climate vulnerabilities common across SIDS (UNFCCC, 2021). Anchored in Aruba's Circular Economy Vision 2050 (Government of Aruba, 2019), it provides a short flexible exploratory blueprint adaptable to other SIDS contexts.

The first step involves deploying IoT devices like CO2 sensors and energy meters at major emission sources, such as Aruba's WEB Aruba N.V. and hotels who are key contributors to tourism-related emissions (UNWTO, 2021). These devices, managed by local businesses acting as nodes, capture emissions data in real-time, with solar-powered sensors addressing power disruptions which is common in SIDS (IRENA, 2020). Training programs, supported by regional bodies like IRENA or PCREEE (PCREEE, 2020), equip local technicians, enhancing the technical capacity of SIDS like it did for Fiji & Barbados.

The second step establishes a collaborative consortium blockchain, involving government bodies, private sector players, and regional SIDS partners, following the framework of Frias (2025). The use of Delegated Proof of Stake (DPoS) consensus, with elected delegates like regulators, ensures efficient data validation while minimizing energy use, crucial for SIDS limited grids (Karunakaran et al., 2021). Smart contracts automate credit issuance based on emissions benchmarks (Bonini et al., 2023), allowing seamless tokenization and the potential to create a Caribbean coalition, sharing expertise across SIDS.

The third step integrates validated carbon credits into XRPL, tokenizing them as NFTs such as “AruCarbon” for Aruba. A web-based platform, developed locally or with partners like Xange.com, enables minting and trading which leverages XRPL’s low-cost, high-speed transactions, providing wallet access for tourists, businesses, and potential regional buyers. This positions Aruba to engage with global carbon markets, with Aruba testing scalability.

The final step involves initiating a pilot phase in Aruba, starting with select participants such as hotels and WEB Aruba N.V., before expanding island-wide and regionally. Incentives, including tax reductions and accessible IoT kits could encourage small business participation, while workshops and awareness campaigns funded by tourism levies drive stakeholder buy-in. Proceeds from token sales would be reinvested into renewable energy projects or waste management, further amplifying sustainability efforts. Regional collaboration with other SIDS like Seychelles (Envision Blockchain, 2022) would help standardize the approach, strengthening climate finance and resilience across vulnerable island nations.

3.2 Technical Challenges and Research Opportunities

The literature identifies several technical challenges in applying these frameworks to SIDS carbon markets, which present opportunities for future research. The D-MRV system’s reliance on IoT devices and cryptographic overhead may strain infrastructure in resource-limited settings like Aruba, suggesting a need for lightweight algorithms or cost-effective deployment strategies (Chen et al., 2024; Frias, 2025). DPoS risks centralization if delegates collude, while XRPL’s validator network requires trust and coordination that should be developed through policy making in SIDS. These challenges highlight the need for future research to optimize cryptographic processes, test integrated pilots in SIDS like Aruba, and develop governance models to ensure equitable participation. Such studies could refine the potential of these frameworks, providing a clearer path for implementing carbon credit markets in SIDS that support circular economy principles.

3.3 Potential Integration of D-MRV and XRPL for Carbon Credit Tokenization Across SIDS

The literature reviewed suggests that combining a D-MRV system with XRPL tokenization could create a strong carbon credit market for Small Island Developing States (SIDS), with Aruba as a promising example. Frias et al. (2025) show that the D-MRV system can track emissions in real-time, ideal for Aruba’s goal of transparent monitoring under its Circular Economy Vision 2050 (Government of Aruba, 2019). For Aruba, this could mean placing IoT devices at facilities like WEB Aruba N.V. to gather emissions data, stored securely on a consortium blockchain. Smart contracts could then reward verified low emissions with carbon credits, tailored to Aruba’s energy sector (Chen et al., 2024; Frias, 2025). Ripple’s XRPL could turn these credits into tradable digital tokens (NFTs), using its fast, low-cost system to boost Aruba’s carbon market and attract buyers like tourists or businesses (Guiterez, 2023). For instance, a hotel in Aruba reducing emissions through energy-efficient practices might earn credits that are tokenized as "AruCarbon" NFTs, which could be traded to tourists or businesses via a web application integrated with XRPL wallets, with proceeds potentially funding sustainable projects like solar installations or waste-to-energy plants.

Combining the D-MRV system with Ripple's XRPL could blend their strengths for a better carbon credit system in Small Island Developing States (SIDS). The D-MRV's group-managed blockchain keeps emissions data honest and secure using trusted checkers and special coding, while XRPL's fast, low-energy setup turns credits into digital tokens (NFTs) for easy trading. Smart contracts which are automatic digital agreements could be able to connect the two systems, handing out credits in D-MRV and sending them as NFTs on XRPL, cutting out middlemen and speeding things up. In Aruba, this could support a circular economy by using money from NFT sales to fund green projects, like cleaner energy or less waste, fitting its sustainability goals. While this mix of D-MRV and XRPL looks promising, it hasn't been tried in SIDS yet, leaving questions for future studies to answer.

The D-MRV and XRPL frameworks could collectively offer a technical benchmark for carbon credit tokenization in Aruba, addressing key challenges in emissions monitoring and market creation. The D-MRV system's multi-layered architecture ensures that emissions data is accurate, tamper-proof, and verifiable, a prerequisite for credible carbon credits. XRPL's high throughput and low-cost transactions could enable a vibrant market, making carbon credits accessible to diverse stakeholders, from local businesses to international investors. The use of NFTs ensures traceability, preventing fraud and double-counting, while XRPL's carbon neutrality aligns with circular economy goals by minimizing the environmental footprint of blockchain operations (Ripple, 2022).

In Aruba, implementation of this benchmark could support a circular economy by creating a cycle where emissions reductions are monitored, tokenized, and traded, with proceeds reinvested into green initiatives, reducing waste and enhancing sustainability. The frameworks' reliance on ECDSA, smart contracts, and efficient consensus mechanisms suggests security and scalability, making them potentially adaptable to other SIDS with similar resource constraints and sustainability goals.

4. Conclusion

This paper illustrates how integrating Frias's (2025) D-MRV framework with XRPL tokenization (Guiterez, 2023) could redefine carbon management across Small Island Developing States (SIDS), using Aruba as a pioneering example to advance its Circular Economy Vision 2050 (Government of Aruba, 2019). By deploying IoT and blockchain for emissions monitoring (Frias, 2025, inspired by Chen et al., 2024, and Effah et al., 2021) and tokenizing carbon credits on XRPL, Aruba transforms its tourism-driven emissions into a resource, reducing waste and diversifying revenue streams amid import and visitor dependency (UNWTO, 2021). This not only strengthens local resilience but positions SIDS as active players in global climate solutions.

Beyond Aruba, this model addresses systemic SIDS exclusion from carbon markets (World Bank, 2022), offering a blueprint rooted in blockchain's accessibility and efficiency. Its potential spans the Caribbean and Pacific like that of Seychelles could scale its Blue Carbon NFTs (Envision Blockchain, 2022), Maldives could operationalize tourism offsets (Ministry of Environment, Maldives, 2023), and Barbados could fund it via green bonds (Bitt, 2021). Collectively, this could amplify SIDS contribution to Paris Agreement goals (UNFCCC, 2021), turning vulnerability into a unified strength. Yet, success demands rigorous testing. Pilot programs must assess infrastructure limits, cultural adoption, and economic viability, while policies must balance equity between large and small stakeholders . Future research should prioritize multi-SIDS trials to further go about Aruba's IoT deployment and token uptake could inform a regional framework, refined through comparisons with Fiji's financing model (UNDP, 2020) or Seychelles' ecological approach. Such studies could solidify blockchain as a cornerstone of SIDS resilience, linking local action to global markets. By leading this charge, Aruba not only secures its sustainability but elevates SIDS as innovators, harnessing technology to shift from climate victims to climate leaders, with ripple effects for small economies worldwide

References

- Banking Innovation through Technology. (2021). Barbados explores blockchain for green bond issuance and digital payments. Bitt. Retrieved April 9, 2025, from https://www.bitt.com/
- Chen, M., & Hsiao, H. (2024). Blockchain for environmental monitoring in SIDS: A comprehensive framework. Journal of Sustainable Technology, 12(3), 112-130.
- Chen, Z., Liu, Y., Wang, E., You, H., Gao, Q. G., F. D., & Li, J. (2024). Advancing the deployment and information management of direct air capture: A solution enabled by integrating consortium blockchain system. Carbon Capture Science & Technology, 13, 100112. https://doi.org/10.1016/j.ccst.2024.100300
- Envision Blockchain. (2022). Seychelles launches blue carbon NFT pilot for climate change mitigation. Envision Blockchain. Retrieved April 9, 2025, from https://www.envisionblockchain.com/
- Ellen MacArthur Foundation. (2015). Towards the circular economy: Economic and business rationale for an accelerated transition. Retrieved April 9, 2025, from https://www.ellenmacarthurfoundation.org
- Frias, J. (2025). Blockchain-based carbon credit systems for Small Island Developing States: A case study of Aruba. Retrieved April 9, 2025, from https://docs.google.com/document/d/1rl6QgF_49pCFsFE_0IAiwV2wCAzaWJOdPIUiWs4v31U/edit?tab=t.0
- Government of Aruba. (2019). Circular economy vision 2050. Retrieved April 9, 2025, from https://www.government.aw
- Government of Barbados. (2021). Blockchain-based green bonds to finance climate resilience. Retrieved April 9, 2025, from https://www.gov.bb/
- Guiterez, M. (2023). Tokenizing college courses using the XRPL. Retrieved April 9, 2025, from https://content.manhattan.edu/reference/thesesOA/gutierrez2023.pdf
- Hu, Z., Du, Y., Rao, C., & Goh, M. (2020). Delegated

proof of reputation consensus mechanism for blockchain-enabled distributed carbon emission trading system. IEEE Access, 8, 214932–214944. https://doi.org/10.1109/access.2020.3041689

- International Renewable Energy Agency. (2020). Renewable energy roadmap for Aruba. Retrieved April 9, 2025, from https://www.irena.org
- Johnson, D., Menezes, A., & Vanstone, S. (2001). The elliptic curve digital signature algorithm (ECDSA). International Journal of Information Security, 1(1), 36–63. https://doi.org/10.1007/s102070100002
- Karunakaran, C., Ganesh, K., Ansar, S., & Subramani, R. (2021). A privacy-preserving framework for health records using blockchain. Pertanika Journal of Science and Technology, 29(4), 2725–2746. https://doi.org/10.47836/pjst.29.4.45
- KlimaDAO. (2023). Annual report: Decentralized carbon markets. Retrieved April 9, 2025, from https://www.klimadao.finance
- Ministry of Environment, Maldives. (2023). Exploring digital MRV systems for tourism emissions tracking and offsetting. Retrieved April 9, 2025, from http://www.environment.gov.mv/
- Maldives Tourism Authority. (2023). Feasibility study on integrating blockchain and IoT for emissions tracking. Retrieved April 9, 2025, from http://www.tourism.gov.mv/
- Narayanan, A., Bonneau, J., Felten, E., Miller, A., & Goldfeder, S. (2016). Bitcoin and cryptocurrency technologies. Princeton University Press.https://press.princeton.edu/books/hardcover/9780691171692/bitcoin-and-cryptocurrency-technologies?srsltid=AfmBOopIDJ-a1R_6iWyuJbI5rzTT86nfSdAZthaxTTodFkSksMboLWBl