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Blockchain-Based Carbon Registry and MRV System: A Review

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ABSTRACT: In recent times, the demand for reliable carbon accounting and transparent carbon credit tracking system has increased. One of the factors that plays crucial role in ensuring the credibility of carbon credits is Measurement, Reporting, and Verification (MRV), although the current MRV system mostly relies on manual verification, centralized registry, fragmented data sources, etc. This makes them vulnerable to fraud, double counting, data manipulation and greenwashing. Various new technologies such as blockchain, Artificial Intelligence (AI), Internet of Things (IoT), satellite remote sensing and smart contracts can be used to make MRV system more secure, transparent, and automated digital platform. In this review paper we are covering analysis of existing Blockchain-Based Carbon Registry and MRV System, their framework, the methodologies used, application, advantages and limitations. This review also identifies crucial research gaps such as lack of standardized MRV protocols, scalability challenges and insufficient integration of technologies emerging in recent times into a single platform. Based on the findings, the paper discusses various aspects of Blockchain based carbon registry and MRV system such as methodology and design principles. It also combines decentralized ledger technology with AI and satellite based image verification and automates smart contracts in order to improve transparency, traceability and operational efficiency. It also tracks the lifecycle of carbon credits in blockchain technology so that the transparency is maintained throughout the process.

The review is then concluded by highlighting future scope and research directions towards making scalable, interoperable and trustworthy digital carbon credit markets and support global climate reduction initiatives.

KEYWORDS: Carbon Credits, Blockchain, Measurement Reporting and Verification (MRV), Smart Contracts, Internet of Things, Artificial Intelligence, Carbon Registry, Satellite Data, Carbon Trading.

I. INTRODUCTION

One of the primary reasons for the global climate change is rapid increase in greenhouse gases (GHG). This creates significant environmental, economic and social challenges. To overcome these effects various organizations including government, industries and international organizations are using carbon credits to reduce the emission. A carbon credit can be defined as removal of one metric ton of carbon dioxide provided it has been verified properly. This allows organization to practise sustainable development. The issuance and credibility of these credits depend on Measurement, Reporting and Verification (MRV) process. MRV system ensures the claim of emission reduction is accurate and transparency is maintained throughout the lifecycle.

Although we have made significant progress, carbon registry system is still mostly centralized and verification processes are manually done. These limitations can lead to verification delays, high operational costs, inconsistent reporting standards and various other problems. Moreover, limited transparency can reduce investor's confidence and can oftentimes become a barrier for a business.

Various digital technologies that have been emerging in recent times can play a key role in solving these problems. Blockchain provides a decentralized platform and the records stored in blockchain is tamper proof. Smart contracts can be used to issue, cancel and verify the records without involving any intermediate parties. Various other technologies such as Artificial Intelligence (AI), Internet of Things (IoT), satellite remote sensing can also be used to improve the system.

Studies done in recent year have given various blockchain based MRV frameworks for applications such as electric car, microgrid carbon trading, lifecycle assessment and sustainable supply chain. Although these studies provide various improvements in transparency and efficiency, most of them still have various disadvantages. Many existing systems

also fail to integrate technologies such as blockchain, AI, IoT, satellite data which can help us to improve system performance.

This review analyses current blockchain based registry and MRV system. Various recent research paper, technical advancement and existing research gaps have been taken into consideration. This paper aims to provide an understanding about how technologies can improve transparency, automation, traceability and scalability in carbon system. The review serves as a foundation to develop advanced blockchain-based carbon registry system that supports sustainability goals.

Review of “A Hybrid Blockchain–AI–IoT Framework for Low-Cost Digital MRV in Sustainable Bioethanol Supply Chains”

Authors: Insaf Nori, Kaoutar Khallaki, Salah Touil (2026)

The main focus of paper is to address the need of an efficient and low-cost digital Monitoring, Reporting and Verification system for sustainable bioethanol supply chains. The certification that has been issued traditionally is based on manual documentation and fragmented database which results in high costs, delayed audits and limited transparency. To tackle this problem, the paper proposes a hybrid architecture integrating blockchain, Artificial Intelligence (AI), Internet of Things (IoT) to provide secure, transparent and real-time monitoring while also following protocols such as RED II, CORSIA and GDPR. The framework is designed for small and medium business by reducing cost.

It proposes a hybrid blockchain-AI-IoT framework that is cost effective and digitally traceable MRV for bioethanol fuel. It combines PoS-PBFT consensus mechanism because it is more energy efficient. The system has gone through various stages of evaluation such as stakeholder surveys, blockchain simulations, smart contracts, benchmarking and Monte Carlo financial analysis. The results display a throughput of approximately 1960 TPS, reduced gas consumption and a 20% ROI this all indicates that the framework is feasible, economically feasible and sustainable for fuel certificate.

Methodology used by the authors consists of four major stages and has a mixed method research approach. The four major stages are:

- Stage one consists of international survey conducted by the authors involving 200 stakeholders to analyse digital readiness, adoption barrier and infrastructure limitations.
- Stage 2 involves a controlled blockchain simulations to evaluate Proof of Stake (PoS) and Practical Byzantine Fault Tolerance (PBFT).
- Stage 3 is based on smart contracts to measure gas consumption and execution efficiency.
- It also applies Monte Carlo simulation for economic analysis using Net Present Value (NPV), Return on Investment (ROI) and payback period.
- Stage 3 also includes integration of IoT sensors for real time data collection and AI based random forest model for anomaly detection before the credits are transferred into blockchain.
- Stage 4 mostly focuses on storage using off-chain IPFS storage with on-chain hash verification to reduce storage cost.

The proposed framework can be used in:

- Digital Monitoring, Reporting and Verification (MRV) system for sustainable production of bioethanol fuels.
- Carbon emission tracking and renewable fuel certificate.
- Regulatory compliance with protocols such as RED II, CORSIA AND GDPR.
- IoT based smart agriculture and renewable energy monitoring.
- Carbon credits verification and sustainable fuel certification for SMEs.

The proposed framework is better than existing framework as it integrates blockchain, AI, IoT into a single platform making MRV easier. It also uses energy efficient consensus mechanisms such as Pos and PBFT that uses much less energy than Proof of Work. It also achieves approximately 1960 transactions per second with sub second finality. The storage used in this framework reduces the cost by more than 99.99%. It also shows positive economic feasibility with 20% ROI.

Although the framework has many advantages the authors have also admitted some limitations. All the experiments and framework were conducted in controlled environment and real industrial deployment. It has not been deployed in real

world so the performance may vary in real world network condition. The study also does not include cybersecurity testing.

The authors have suggested various future work direction, this includes:

- Deploying the framework in real world conditions with geographically distributed blockchain nodes.
- Carbon credit registries and tokenization MRV platform integration with existing framework.
- Privacy enhancement using Decentralized Identity (DID) and Zero Knowledge Proofs (ZKPs).
- Deploy the model in real world and observe production traffic and large-scale industrial deployment.

This integrates blockchain-AI-Iot framework, this improves transparency, security and efficient in bioethanol supply chain monitoring. It also aims to reduce implementation costs for SMEs. It provides scalable and energy efficient digital MRV solution by integrating various methods such as hybrid PoS-PBFT consensus, AI enabled anomaly detection, IoT based data acquisition and smart contracts. While the framework has shown various technical and economic performance simulations, real world deployment is still a major challenge. Real world deployment and field validation are necessary before large scale adoption.

Review of “An efficient tool for real-time global carbon neutrality with credibility of delicacy management: A Modelx + MRV + O system”

Authors: Qingqing Li , Jinbo Shi , Wenxiang Li , Siyun Xiao , Ke Song , Yongbo Zhang , Zhenqi Wang , Jie Gu , Bo Liu , Xiaoming Lai (2026)

Nowadays, proving that a batch of bioethanol was produced sustainably relies heavily on separate, fragmented databases and paper records. Auditing is expensive, that is slow, and it is very hard for anyone outside the process to confirm the accuracy of the statistics. This is particularly true for smaller producers, who often struggle to defend the cost of certification when compared to larger refineries. By creating a digital verification system that complies with laws like RED II, CORSIA, and GDPR and is quick, hard to hack, and reasonably priced for small and mid-sized businesses to use, this article essentially seeks to bridge that gap.

The system comprises a three-tiered architecture integrated into a unified framework. IoT sensors sit at the source and pull in production data automatically, so nobody's typing numbers into a spreadsheet by hand. Before anything gets locked in, a machine-learning model — a random forest, specifically scans the incoming readings for anything that looks off, catching errors or suspicious entries early. Once the data passes that check, it's committed to a blockchain, which is what gives the whole record its permanence and makes it visible to whoever needs to audit it. To avoid the usual complaint about blockchains being slow and power-hungry, they didn't use Proof-of-Work; instead they ran a mix of Proof-of-Stake and Practical Byzantine Fault Tolerance. Heavier files don't even sit on the chain itself those go into IPFS, with only a hash of each file kept on-chain as a fingerprint.

The testing wasn't a single experiment, it was more of a layered approach, roughly four parts:

- They surveyed about 200 industry stakeholders first, just to get a real sense of who's actually ready to go digital, what's holding people back, and what infrastructure gaps still exist.
- Then came blockchain simulations pitting PoS against PBFT, mainly to see which held up better on throughput and consistency.
- Smart contracts were benchmarked next, how much gas they burn, how fast they execute with the IoT feed and the anomaly-detection model running alongside before data hit the ledger.
- Finally, a Monte Carlo simulation handled the money side, working out NPV, ROI, and payback period, with the off-chain storage trick factored in to keep costs realistic.

What was its consequence?

At least on paper, the figures appear to be reliable. The simulated network pushed around 1,960 transactions per second and confirmed them almost instantly, gas fees stayed manageable, and moving the bulk of the data off-chain slashed storage costs by more than 99.9 percent compared to storing everything directly on the blockchain. The financial modeling landed on roughly a 20 percent return on investment — enough, the authors argue, to make a case that this isn't just technically sound but actually worth the money for the businesses that would use it.

This study is primarily intended for

- Digital verification for bioethanol and similar biofuels made sustainably.
- Tracking carbon emissions and issuing renewable-fuel certificates.
- Staying compliant with RED II, CORSIA, and GDPR without drowning in paperwork.
- Broader IoT monitoring use cases: smart agriculture, renewable energy setups.
- Carbon-credit checks and sustainability certification, especially scaled to fit SMEs.

A rigorous examination reveals that, none of this ran on a real production line. Every result comes out of simulation, so the real world — messier networks, inconsistent connectivity, actual bad actors — could easily behave differently than the models predict. There's also no cybersecurity testing in this study, which is a significant lack given how much trust the system asks people to place in it. It appears that the writers are cognizant of this, and they list some clear next steps: actually, deploying the thing across blockchain nodes spread out geographically, connecting it to real carbon-credit registries and tokenization systems already in use, adding privacy protections like Decentralized Identifiers and Zero-Knowledge Proofs, and eventually stress-testing it under genuine industrial traffic rather than simulated load.

Key Findings and Implications:

It is an acceptable effort to make bioethanol certification faster and cheaper without shutting out smaller producers, and pairing sensors with an anomaly filter and a lighter blockchain setup makes practical sense. The issue that arises is whether the promising throughput and ROI numbers hold up once the system meets a real deployment and real adversarial conditions.

Review of “Supporting building life cycle carbon monitoring, reporting and verification: A traceable and immutable blockchain-empowered information management system and application in Hong Kong” Authors: Ye Luo , Jieliang Shen , Hanwei Liang , Lu Sun , Liang Dong (2024)

It's become pretty clear from recent research that the building sector is one of the biggest contributors to global carbon emissions and actually, it's not all about the energy a building uses once it's up and running. Researchers keep pointing out that emissions creep in at almost every stage: manufacturing the materials, transporting them to site, the actual construction work, ongoing maintenance, and even what happens when a building is eventually torn down. That's part of why so many countries are now shifting their attention toward life-cycle carbon assessment, rather than just focusing narrowly on operational energy use like they used to.

To actually measure all of this, a number of Life Cycle Assessment (LCA) tools have been developed over the years. Tools like Tally, One Click LCA, and eToolLCD are fairly common among designers and engineers who want to compare materials and get a sense of a building's environmental footprint. These tools are genuinely useful, especially early on in the design process, but there is a twist different tools tend to follow different standards and draw their system boundaries in different places. So, when you try to compare carbon data across projects, messy things happen quite fast. On top of that, most of these systems still rely on centralized databases, which raises some real concerns around transparency, authenticity, and whether the data can actually be trusted over the long run.

This is where the idea of a proper Monitoring, Reporting, and Verification (MRV) system comes in. A building goes through a lot of hands over its lifetime material suppliers, manufacturers, contractors, owners, maintenance teams, waste management companies and keeping track of carbon-related information across all of these stakeholders is genuinely complicated. Traditional ways of managing this data just don't hold up well when it comes to full traceability.

That's part of why blockchain has started getting attention as a possible fix. At its core, blockchain works as a distributed ledger, once something is recorded, it's very difficult to alter, and because every authorized participant holds a copy of the same ledger, it naturally improves transparency and cuts down on the risk of tampering. A number of researchers have argued that this makes blockchain well-suited for secure information sharing, building a clear audit trail for carbon data, and generally improving trust between everyone involved in a construction project.

A good example of this idea being put into practice is the work of Luo et al. (2024), who developed a blockchain-enabled framework specifically for tracking building life-cycle carbon emissions in Hong Kong. They built the system around a consortium blockchain using Hyperledger Fabric, with the goal of capturing data at every stage of a building's life from construction right through to eventual demolition. The results were fairly encouraging, honestly. Blockchain

seemed to deliver exactly what it promises on paper: real traceability, transparency, and a level of immutability that traditional centralized systems just can't match, and it appeared to support the whole MRV process more effectively as a result. They didn't just test this in theory, either they ran it against real building-sector data from Hong Kong, and the results were solid enough to suggest the framework could genuinely work for carbon auditing and sustainability reporting in practice. To their credit, the authors were also honest about where things get difficult. Integrating the system with existing infrastructure, working out reliable ways to collect data, scaling the whole thing up, and actually getting stakeholders to buy in all of these came up as real, practical challenges that still need to be worked through.

When you pull all of this together, it's hard to escape the conclusion that life-cycle carbon assessment isn't really optional anymore it's fast becoming a basic requirement for anyone serious about sustainable construction. The existing LCA tools clearly have their place and do add real value, but they still struggle when it comes to managing and verifying data in a way people can actually trust. Blockchain, on the other hand, looks like a genuinely promising piece of the puzzle, offering a way to build carbon monitoring systems that are far more transparent and traceable than what we've had before. So, when you look at the literature as a whole, the message that comes through is fairly consistent: bringing LCA and blockchain-based MRV together could go a long way toward making building carbon data more accurate and more credible and in the process, help move the industry closer to its broader goals around green building and carbon neutrality.

Review of “A Blockchain-based Carbon Credit Ecosystem” Authors: Dr. Soheil Saraji and Dr. Mike Borowczak

Carbon credit was introduced to reduce carbon emissions. The idea behind this was: if carbon emissions are reduced by a company, carbon credits will be earned by the company, and then credits can be sold to companies that need to balance their carbon emissions.

After the Kyoto Protocol in 1997 this concept became popular, where carbon emissions started being treated as a tradable asset. Later, for controlling emissions different countries were allowed to create their own methods by Paris Agreement in 2015. Carbon taxes were used by some countries, while others developed carbon trading systems.

Many problems are faced by Carbon Market. The main issue is that there is no single global system. Own carbon trading platforms were created by different regions. such as the European Union Emission Trading System (EU ETS), New Zealand ETS, and California Cap-and-Trade Program. Different rules were followed by each system, which made it difficult to compare and exchange carbon credits between different markets.

Trust is another important problem. When there is real reduction in carbon emission then only the carbon credit is valuable. It is difficult to verify whether a project is actually reducing emissions. In some cases, the organizations responsible for checking projects may have connections with the companies developing those projects. This creates doubts about whether the verification process is completely fair.

Over crediting is another issue. It happens when sometimes the projects receive carbon credits for emission reductions which might have happened even without the project. This creates a situation where companies may try to reduce emissions, but the actual environmental impact is less than expected.

Carbon markets also face problems like:

Different rules are there in different countries.

- Lack of transparency.
- Difficulty while tracking carbon credits.
- There is Possibility of the same credit being used multiple times.
- There is High dependency on brokers and intermediaries.

Due to these limitations, researchers are looking for better technologies that can make carbon markets more secure, transparent, and reliable.

II. BLOCKCHAIN TECHNOLOGY FOR IMPROVING CARBON MARKETS

Blockchain technology is one of the technologies which has the potential to solve many problems in existing carbon markets. Blockchain is a decentralized system where information is stored across different computers instead of being controlled by one central authority.

The idea behind blockchain is connected to the Byzantine Generals Problem, which was introduced by Lamport, Shostak, and Pease in 1982. This problem explains how different users can agree on the same information even when some users cannot be fully trusted.

In 2008, Satoshi Nakamoto introduced Bitcoin, which showed that without depending on a bank or central organization digital record can be maintained. Users were allowed to store transactions in a way that makes changes very difficult, this happened because of Blockchain technology.

Proper tracking is required for carbon credits so this feature is useful for carbon markets. Carbon credit could be sold or claimed more than once without a secure system. So, this problem can be solved by Blockchain by creating a permanent record of every carbon credit transaction.

Later, Ethereum introduced smart contracts, which made blockchain more useful. When specific conditions are completed, Smart contracts are programs that automatically perform actions.

Many activities are performed manually in traditional carbon markets, such as:

- Carbon reduction projects are checked.
- Issuing carbon credits.
- Transferring credits between organizations.
- Removing used credits from the system.

The chances of errors and fraud can increase by manual processes. Reliability can be improved by smart contracts by automating the processes.

Transparency can also be improved by blockchain because all transactions can be recorded and tracked. Information about a carbon credit, such as where it was created, who owns it, and whether it has already been used, can be verified easily.

Automated Market Makers (AMMs) is another blockchain-based concept. Here without depending on traditional brokers, they allow users to trade digital assets. Carbon credit trading becomes more efficient and this reduces extra cost.

Review of “A blockchain-based carbon registry platform for credible climate action in transportation” Authors: Xinlai Liu, Tolkien Bagchi, Charlie Lee Sy & H. Oliver Gao (2026)

The idea of pricing carbon isn't some recent policy fad. It goes back to the Kyoto Protocol in 1997, which essentially treated CO₂ as a tradeable commodity something you could buy, sell, and speculate on like any other asset. That framing is the reason cap-and-trade looks the way it does today.

Paris, in 2015, took that further by leaving the method up to each country: hard caps, taxes, or trading systems. Trading ended up winning in most places, partly because it doesn't just penalize big polluters, it also rewards companies that were already running lean, low-emission operations.

Where it falls apart is in the execution. Gale, Langer, and Waterman noted back in 2010 that the EU ETS, New Zealand's scheme, and California's cap-and-trade program all grew up in isolation from each other. A credit issued in one system carries essentially no weight in another; there's no shared language between them.

Sovacool's 2011 review dug into why these markets keep underdelivering, and the answer is pretty mundane: money leaks out along the way. Brokers routinely take 3–8% per transaction, and the verifiers supposedly checking whether a

project's emissions cuts are real are usually paid by the very companies whose projects they're verifying. It's a conflict of interest baked right into the structure.

Haya and colleagues' 2020 look at California's program found the same pattern playing out loose accounting standards mean credits get handed out for reductions that were probably going to happen anyway. That's the over-crediting problem, and it's a big deal because it means the market can look productive on paper while doing very little for the atmosphere.

Put those threads together and you get a fairly bleak picture: carbon markets that are splintered across jurisdictions, difficult to audit from the outside, and steadily losing value to middlemen instead of channeling it into actual emissions reductions.

Getting a group of strangers to agree on one version of the truth with no referee is an old problem. Lamport, Shostak, and Pease laid out the Byzantine Generals problem back in 1982, and it's still the theoretical backbone of how blockchains reach consensus today.

Nakamoto's 2008 Bitcoin paper was the first real proof that this could work at scale. Proof-of-work let a network of mutually distrustful strangers maintain a single, tamper-resistant transaction history, without a bank or any central authority calling the shots. It solved double-spending in digital currency and it's worth pointing out that carbon credits face almost the identical risk: without a watertight system, nothing stops the same credit from being sold or claimed twice.

Buterin pushed the idea further with Ethereum in 2016. Smart contracts code that executes automatically once certain conditions are met meant you no longer needed a human to sign off on every step. That maps unusually well onto what's broken in carbon markets right now, where verifying, issuing, and retiring credits are all manual processes, and manual processes are exactly where errors and manipulation creep in. Smart contracts could turn those steps into something automatic and auditable by anyone.

Kim and Huh's 2020 study is one of the earlier attempts to actually test this combination, examining how blockchain-based carbon trading might support UN sustainability goals by making credits traceable across borders and regulatory regimes.

Then there's the rise of automated market makers — trading mechanisms built directly into blockchain protocols that let people swap assets without a broker sitting in the middle. That's about as direct a fix as you can get for the commission problem Sovacool identified: fewer intermediaries taking a cut, and more visibility into how prices are actually set.

Taken together, this body of research suggests blockchain isn't just a shiny add-on bolted onto carbon markets for the sake of novelty. Its core features, a record that can't be quietly altered, rules that enforce themselves, no need for a trusted middleman line up almost point-for-point with the specific failures decades of carbon market research keep identifying.

III. CONCLUSION

Going through these five papers back-to-back, the same story keeps repeating itself in different industries. A bioethanol producer can't easily prove their fuel was made sustainably. A construction company loses track of a building's carbon footprint somewhere between the concrete supplier and the demolition crew. A country's carbon credit gets sold once, maybe twice, and nobody outside the transaction really knows. Different sectors, same broken trust. The paperwork is scattered, audits take forever and cost a fortune, and more often than not, the people checking whether a project is "green" are being paid by the same people who want it certified as green. That's not really a technology problem on its own — it's a trust problem that technology happens to be good at solving.

Blockchain is the piece that shows up in almost every paper for a reason. Saraji and Borowczak walk through it nicely, tracing it all the way back to the Byzantine Generals Problem and Nakamoto's original Bitcoin idea, and Liu et al. make the same point from a different angle: once you have a ledger that nobody can quietly edit, a lot of the classic carbon

market headaches — double-counting, over-crediting, credits from the EU ETS meaning nothing in California — start to look solvable. It's not magic; it's just record-keeping that can't be tampered with.

What's more interesting, though, is that the newer papers don't stop at blockchain. Both bioethanol studies pair the ledger with IoT sensors pulling data straight from the source and an AI layer that catches anomalies before anything gets written permanently — plus they push the heavy files off-chain onto IPFS so storage doesn't become its own problem. The Hong Kong building study does something similar in spirit, slotting a Hyperledger Fabric blockchain into an existing life-cycle assessment process rather than trying to reinvent everything from scratch. The takeaway across both: blockchain works best as part of a stack, not as a standalone hero technology.

None of this is quite finished, though, and the authors are pretty upfront about that. The bioethanol frameworks post genuinely impressive numbers — throughput near 1,960 transactions per second, storage costs cut by over 99%, a projected 20% ROI — but it's all simulation. Nobody's actually run this on a real supply chain yet, and cybersecurity testing is basically absent from both studies, which is a little unsettling given how much trust the system is asking people to place in it. Hong Kong at least tested against real building data, which is a step further, but the researchers themselves flag integration, data collection, and stakeholder buy-in as unresolved. And zooming out to the foundational papers, there's a bigger issue neither blockchain nor AI can fix by itself: without shared rules that different countries and industries actually agree on, a perfectly engineered ledger still can't make a credit issued in one place mean anything in another.

So where does that leave things? Honestly, it feels less like five separate ideas and more like pieces of the same solution. Blockchain gives you the tamper-proof backbone, AI and IoT feed it trustworthy real-time data, and smart contracts take over the manual, error-prone parts — issuing, verifying, transferring, retiring credits — where human error and conflicts of interest usually creep in. What's missing is the less thrilling stuff: actual field pilots, real security audits, privacy tools like zero-knowledge proofs, and above all, some kind of common language between registries that currently don't talk to each other at all. Whether blockchain-based MRV becomes the real backbone of a trustworthy global carbon market, or just another promising system that stayed in the lab, ultimately boils down to whether anyone puts in the work to close those gaps.

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