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Solar Credit Transaction System using Blockchain

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Abstract:

The accelerating global transition toward renewable energy—particularly solar power—has shifted from a strategic objective to an environmental and economic necessity. Despite remarkable progress in solar energy generation, the mechanisms for managing surplus energy and its associated credits remain inefficient and centralised. Existing Renewable Energy Certificate (REC) systems often involve high administrative costs, accessibility barriers for small producers, and risks of data duplication or double-counting (Andoni et al., 2019). This research proposes a decentralised Blockchain-based Solar Credit Transaction System (B-SCTS) that converts verified solar generation data into digital tokens, allowing transparent peer-to-peer trading between producers and consumers. By leveraging blockchain's transparency, immutability, and smart-contract automation, the proposed model establishes an open, cost-effective, and inclusive marketplace for energy credit exchange. This approach supports equitable participation in the clean-energy economy while addressing inefficiencies in existing credit mechanisms.

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I. INTRODUCTION

The global community continues to face the dual challenge of increasing energy demand while reducing greenhouse gas emissions. Solar energy has emerged as one of the most promising renewable sources due to rapidly declining photovoltaic costs, improved efficiency, and supportive governmental policies (WePower, 2021). However, generating solar energy alone is insufficient; robust systems must exist to fairly compensate producers and encourage adoption at all scales.

Conventional REC mechanisms, while effective in principle, are typically administered through centralised authorities that process and verify energy credits. Such dependence introduces high transaction costs, long processing times, and limited accessibility for individual or small-scale producers (Andoni et al., 2019). Consequently, clean-energy contributions from distributed sources remain undervalued.

Blockchain technology provides an opportunity to overcome these challenges. A blockchain ledger ensures transparent, tamper-resistant, and verifiable transaction records. Combined with smart contracts, it enables automatic credit issuance and exchange without relying on intermediaries (Power Ledger, 2021). This study proposes an innovative blockchain-based Solar Credit Transaction System that empowers prosumers—entities that both produce and consume solar power—to tokenise surplus generation and trade it directly in a secure peer-to-peer (P2P) marketplace.

II. LITERATURE REVIEW

3.1 Traditional Energy Credit Systems

In most jurisdictions, RECs are managed by regulatory bodies or energy utilities that certify renewable generation. Although these systems aim to ensure accountability, they rely heavily on manual processes and third-party verification, resulting in administrative inefficiencies. Small-scale solar producers frequently encounter entry barriers due to complex registration and verification procedures, reducing inclusivity in clean-energy markets (Andoni et al., 2019).

3.2 Blockchain Applications in the Energy Sector

Several pioneering projects have demonstrated blockchain's potential in renewable-energy trading. The Brooklyn Microgrid Project in the United States showcased how neighbourhood prosumers could trade surplus energy locally using blockchain (Mengelkamp et al., 2018). Similarly, Power Ledger in Australia and WePower in Europe established tokenised renewable-energy trading platforms that enhanced transaction transparency and accountability (Power Ledger, 2021; WePower, 2021).
More recently, projects such as Energy Web Chain (2022) and SunContract (2023) have focused on developing interoperable and scalable blockchain frameworks for national-level energy markets. These initiatives highlight blockchain's potential to democratise renewable-energy transactions but also underscore challenges related to scalability, regulation, and integration with existing grid systems.
3.3 Research Gap
Although multiple blockchain pilots exist, few provide a unified framework that integrates blockchain, IoT-based verification, and user-friendly wallet systems for broad public participation. This study addresses that gap by proposing a scalable, transparent, and inclusive model suitable for both community microgrids and larger-scale implementations.

III. SYSTEM ARCHITECTURE AND WORKFLOW

The proposed Blockchain-based Solar Credit Transaction System (B-SCTS) comprises interconnected technological and user components that enable seamless verification, tokenisation, and trading of solar energy credits.
4.1 System Components
Prosumers: Households, industries, or institutions that generate solar power and may consume part of it.
Consumers: Entities that purchase verified solar credits to meet sustainability targets or offset carbon footprints.
Blockchain Network: A decentralised ledger (e.g., Ethereum or Energy Web Chain) used to record and validate all energy transactions.
Smart Contracts: Self-executing digital agreements automating the issuance, transfer, and settlement of solar credits.
Digital Wallets: Secure interfaces allowing users to store and trade energy tokens.
IoT Smart Meters: Devices that collect real-time energy production data, ensuring transparency and preventing falsification.
4.2 Workflow Overview
Prosumers generate solar electricity through photovoltaic installations.
Smart meters record production data and send verified metrics to the blockchain via secure IoT protocols.
The blockchain converts verified units into Solar Credits (SCs) through an automated smart contract.
SCs are listed on a decentralised marketplace accessible to all registered users.
Consumers purchase SCs using fiat-linked stablecoins or digital currency, and ownership is automatically transferred through blockchain verification.
All transactions are stored immutably, ensuring auditability and eliminating double-counting.

IV. SYSTEM DIAGRAMS

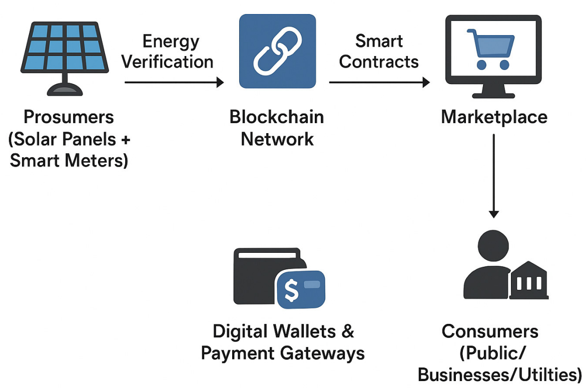

Fig. 1 High-Level Architecture

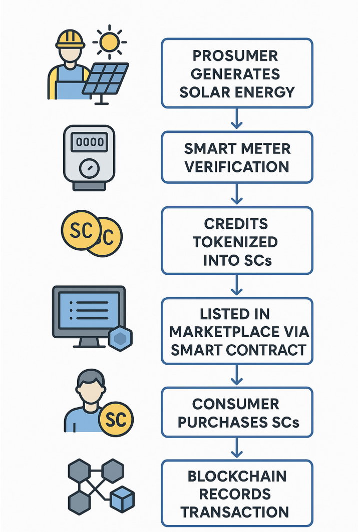

Fig. 2 Transaction Flow Diagram

V. BENEFITS AND CHALLENGES

Transparency:
Every transaction recorded on the blockchain can be traced back to its verified source, ensuring that each Solar Credit corresponds to a legitimate quantity of energy produced. This eliminates duplication and enhances consumer trust in credit authenticity.

Decentralization:
By removing intermediaries such as government registries or centralised authorities, the system minimises administrative overhead, reduces operational costs, and allows faster transaction settlement.

Security:
Blockchain's cryptographic protocols protect all records from tampering or unauthorised alteration, ensuring data integrity and immutability.

Accessibility and Inclusion: The system empowers small and medium producers—such as households and small enterprises—to directly participate in the renewable energy market, democratizing access to financial benefits previously limited to large-scale operators.

Sustainability: By monetising renewable generation, the model incentivises further investment in solar infrastructure, contributing to long-term environmental sustainability.

5.2 Challenges

Despite its promise, several practical challenges must be addressed:

Regulatory Constraints: Energy markets are subject to stringent national and regional regulations. Integrating blockchain transactions within existing legal frameworks remains a complex task requiring cross-sectoral collaboration.

Scalability: Public blockchains can experience performance limitations under heavy transaction loads, which may hinder real-time energy trading during peak demand periods.

Infrastructure Readiness: The successful deployment of the system depends on widespread IoT infrastructure adoption, standardised data formats, and reliable internet connectivity in all operational areas.

User Adoption and Awareness: Public understanding of blockchain-based energy systems remains limited. Extensive education, user training, and intuitive platform interfaces are essential for mainstream acceptance.

VI. GOVERNMENT CONCERNS AND POLICIES

Effective implementation of blockchain-based solar trading platforms requires supportive government policy frameworks. The following dimensions are particularly critical:

Regulatory Recognition: Governments must legally acknowledge tokenised energy credits as valid financial or environmental assets, establishing guidelines for their issuance, validation, and exchange.

Consumer Protection: Regulations must safeguard users from fraudulent activities, unfair pricing, and privacy breaches by enforcing data security and dispute-resolution mechanisms.

Taxation and Compliance: A clear taxation framework should govern earnings from energy-credit trading, preventing misuse while encouraging legitimate participation.

Data Privacy: Blockchain transparency must be balanced with privacy requirements under data-protection laws such as the GDPR. Appropriate cryptographic anonymisation and permissioned-ledger models can ensure compliance.

Market Integration: Policymakers should coordinate with grid operators to align blockchain credit systems with existing REC programs and renewable-energy targets.

Incentive Mechanisms: Governments can accelerate adoption by providing subsidies for IoT meter deployment, offering tax credits to prosumers, and funding pilot projects that integrate blockchain into national renewable portfolios.

Recent developments, such as India's Energy Blockchain Sandbox Initiative (2023) and the EU's Renewable Digital Markets Directive (2024), highlight growing institutional interest in decentralised green-energy solutions.

VII. CASE STUDY EXAMPLE

Imagine a sustainable smart city—"SolarVille"—where every residential building and commercial complex installs rooftop solar panels linked to a blockchain network via IoT smart meters.

A household generating surplus energy has its production automatically verified and converted into Solar Credits (SCs), stored securely in a digital wallet. A nearby company, aiming to meet sustainability targets, purchases these credits directly through the decentralised marketplace.

This peer-to-peer exchange forms a localised circular energy economy, reducing dependency on centralised utilities while allowing citizens to benefit financially from renewable-energy generation. The same framework can be extended to regional grids, facilitating transparent renewable-energy certificate management at scale.

VIII. FUTURE WORK

Further research could enhance system efficiency and adoption through the following directions:

Integration of Artificial Intelligence (AI): Implement AI-driven analytics for energy-demand forecasting, anomaly detection, and dynamic pricing strategies.

Interoperability and Cross-Border Trading: Develop standards that allow blockchain energy platforms in different countries to interoperate, supporting international credit exchanges.

Hybrid System Design: Combine blockchain frameworks with existing REC infrastructures to ensure regulatory continuity and market compatibility.

User-Centric Interfaces: Design intuitive mobile and web applications that simplify wallet management, smart-contract interaction, and transaction visualisation for non-technical users.

Energy Storage Integration: Explore linking blockchain-verified credits with decentralised storage networks to optimise energy distribution and usage.

IX. CONCLUSION

Blockchain technology represents a transformative step in achieving transparency, trust, and inclusivity within renewable-energy markets. The proposed Blockchain-based Solar Credit Transaction System (B-SCTS) empowers producers and consumers to interact directly in a secure and efficient marketplace. By removing intermediaries, it fosters equitable participation and reduces systemic inefficiencies.

Although regulatory, technical, and social barriers persist, the combination of blockchain, IoT, and smart-contract technologies offers a robust pathway toward sustainable and decentralised energy ecosystems. With continued innovation, government support, and public engagement, such systems could become foundational to the next generation of global energy-trading infrastructures.

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