Solchain : A Blockchain Based P2P Solar Energy Sharing Microgrid System

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***Abstract*—** SolChain is a decentralized solar microgrid platform that leverages blockchain, IoT, and AI to enable secure, peer-to-peer (P2P) energy trading in regions with unstable grid infrastructure. Built on a Proof-of-Stake (PoS) sidechain, SolChain ensures low-latency and high-throughput transaction processing while periodically anchoring Merkle roots to a Layer-1 blockchain (e.g., Ethereum) for auditability and regulatory compliance. Smart contracts manage tokenized microtransactions denominated in SolarTokens (ST), enabling real-time settlement and enforcement of trade agreements. Zero-knowledge proofs (ZK-proofs) ensure user data privacy, while smart meters with LPWAN (e.g., LoRa) connectivity allow low-cost deployment in off-grid or weak-grid rural areas. Integrated AI/ML modules perform decentralized pricing, anomaly detection, and demand forecasting using distributed edge intelligence. This paper details SolChain's technical architecture, decentralized governance (via DAO), and deployment strategy, establishing a robust, scalable model for community-driven clean energy access in emerging markets.

I. Introduction

The global energy sector is at a pivotal juncture, transitioning from a reliance on centralized fossil fuel-based power generation to a more distributed and sustainable model. This shift is driven by increasing energy demand, environmental concerns, and the desire for greater energy independence and resilience. Solar power, as a clean and abundant renewable energy source, is at the forefront of this transition, offering a viable alternative to conventional energy sources. However, the effective integration and management of solar energy, particularly in decentralized settings, present unique challenges that traditional grid infrastructures are often ill-equipped to handle.

Solar Power and Energy Sharing- Solar energy provides a clean, sustainable, and increasingly affordable alternative to centralized power generation. Its decentralized nature reduces transmission losses, enhances local energy security, and enables microgrids to operate independently or integrate with the main grid. A key innovation is **peer-to-peer (P2P) energy sharing**, where households or communities with solar PV systems ("prosumers") not only use their own electricity but also sell or share surplus power directly within a local network. This shifts consumers into active energy market participants, improving reliability, lowering costs, and fostering resilience in regions prone to instability.

Why Blockchain? Blockchain technology offers a secure, transparent, and decentralized ledger system that eliminates the need for intermediaries. In energy systems, its core features—immutability, distributed consensus, and **smart contracts**—enable automated, tamper-proof, real-time transactions. This makes it ideally suited for managing decentralized P2P energy trading, reducing costs, increasing trust, and simplifying the integration of renewable sources.

II. Problem Statement

Despite the growing deployment of renewable energy systems, many communities face significant challenges in accessing, managing, and benefiting from locally generated power. Conventional centralized energy distribution models often limit local participation, obscure pricing mechanisms, and reduce transparency.

Moreover, technological and infrastructural barriers further hinder the effective utilization of distributed energy resources. Key problems observed in rural and semi-urban areas include:

Lack of control over energy resources In many rural or semi-urban regions, even when renewable energy plants like hydroelectric or solar farms exist locally, the electricity is routed to major cities. Local people have no say in how energy is distributed.

Pricing controlled by government/large corporations Energy prices are dictated by central authorities or large corporations, ignoring local production costs or surplus.

Possibility of hacking or tampering with credits/prices Centralized systems can be manipulated—people may lose credits, or prices can be unfairly adjusted.

No visibility of energy ownership/distribution People can't track how much energy they produce, consume, or share—leading to disputes or inefficiencies.

High internet/implementation cost Continuous internet access for smart energy systems can be expensive in remote areas.

Need for flexible deployment One-size-fits-all energy systems don't work well across different regions.

III. Proposed Solutions

To address the challenges of decentralized energy access and management, we propose a blockchain-enabled system that empowers local communities and prosumers. The solutions focus on enhancing control, transparency, security, affordability, and flexibility in energy distribution. Each solution directly targets the problems identified, leveraging smart contracts, traceable energy credits, modular deployment, and optional local communication networks to create a resilient, fair, and scalable energy-sharing ecosystem. The system employs distributed consensus protocols to validate energy transactions, ensuring tamper-proof auditability. IoT-enabled smart meters capture real-time generation and consumption data, feeding into on-chain settlement mechanisms. Tokenized micro-payments are executed automatically through smart contracts, enabling seamless P2P trading. A sidechain architecture ensures low-latency operation while anchoring state checkpoints to a public blockchain for regulatory compliance.

Problem	Proposed Solution
Lack of control over energy resources	Give people direct control over their energy (e.g., via smart contracts/grid)
Pricing controlled by government/large corporations	Implement decentralized pricing mechanisms to ensure fairness
Possibility of hacking or tampering with credits/prices	Ensure tamper-proof pricing and credit systems using blockchain security
No visibility of energy ownership/distribution	Enable traceability — system tracks how much energy each person has
Need for flexible deployment	Design system to be modular and scalable

Table 1: Problem vs Proposed Solutions

A. Proposed Blockchain Based Architecture & Governance

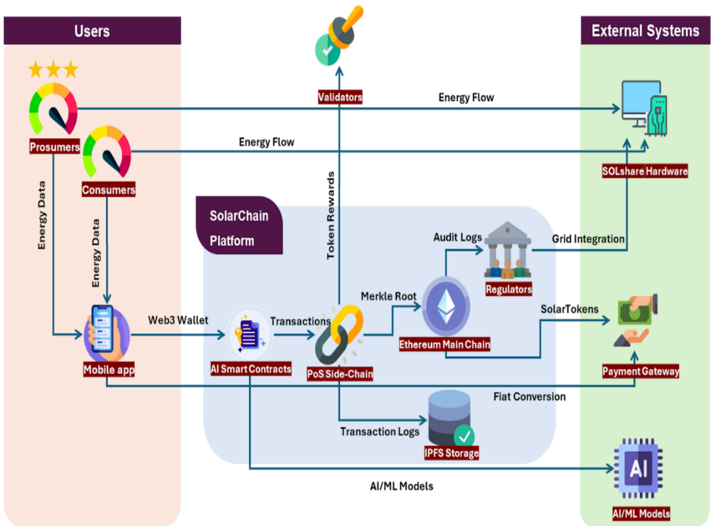


Fig: Solchain Architecture

B. Working Principal: Solchain Operational Flow

1. **Energy Generation & Measurement**
   Prosumers generate electricity via solar PV systems. Smart meters and IoT devices capture real-time production and consumption data, which is securely collected for SolChain transmission.

2. **Data Transmission & Recording**
   Real-time data is sent to SolChain, where each DER connects to a blockchain node. Transactions—including energy metrics and device diagnostics—are recorded immutably on the PoS Side-Chain. Privacy is ensured via entity mapping, zero-knowledge proofs, and digital certificates. Logs are stored on IPFS for integrity and access.

3. **P2P Energy Trading via AI Smart Contracts**
   - **Surplus Detection**: Smart meters detect generation exceeds consumption.
   - **Market Listing**: AI Smart Contracts list surplus energy on a local marketplace, accessible via mobile app.
   - **Demand Matching**: AI matches supply with demand using rules like dynamic pricing, quantity, and priority.
   - **Transaction & Settlement:** Trades are executed and settled automatically using SolarTokens, reducing costs and eliminating intermediaries.
   - **Energy Flow Control**: Smart contracts manage energy flow to storage or high-demand areas, ensuring efficient use.

4. **Consensus & Validation**
   Transactions are validated by PoS Validators, who earn SolarTokens. This permissioned blockchain ensures efficient, secure validation with high throughput.

5. **Grid Integration & Resilience**
   - **Grid-Connected Mode:** Through SOLshare hardware, the microgrid sells surplus to or draws power from the national grid, enhancing energy balance and renewable integration. Bidirectional inverters synchronize voltage and frequency with the grid, while blockchain-based settlement records surplus exports and imports transparently.
   - **Islanded Mode:** Operates independently when disconnected, ensuring local resilience. A local control algorithm manages load–generation balance using IoT-enabled smart meters.

6. **Autonomous Operation & Resilience**
   When disconnected from the grid, the microgrid operates independently, ensuring uninterrupted power. This boosts energy security—critical in disaster-prone, grid-unstable regions like Bangladesh.

7. **Auditability & Regulatory Oversight**
   Aggregated data (Merkle Roots) is periodically committed to Ethereum Main Chain, creating a transparent, tamper-proof record for regulators. This ensures oversight without revealing sensitive user-level data.

8. **AI/ML for Optimization & Security**
   AI/ML models analyze energy and transaction data to forecast demand, optimize dispatch, detect anomalies (e.g., theft), and enhance cybersecurity across the microgrid.

9. **Payments & Fiat Conversion**
   A payment gateway enables seamless conversion of SolarTokens to local currency, letting prosumers earn from surplus and consumers pay using familiar fiat methods.

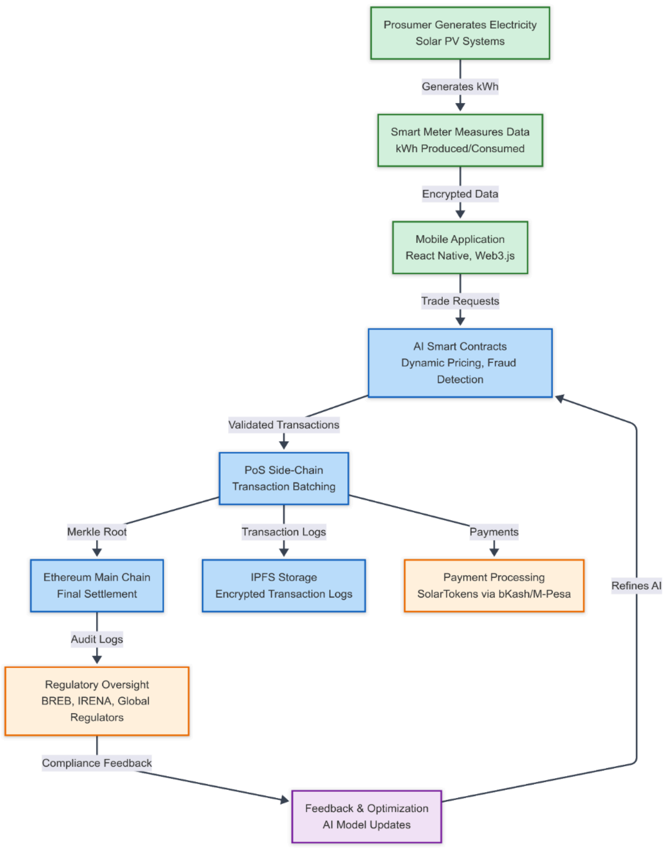


Fig: Solchain Operational Flow

C. SolChain AI/ML Models

SolChain deploys four AI/ML models – Demand Forecasting, Dynamic Pricing, Anomaly Detection, and Energy Optimization. These models leverage PyTorch neural networks. These are integrated for real-time grid stability, trading efficiency, and anomaly mitigation, they process 10-12 features each, achieving targets like <10% MAPE for forecasting and >0.85 F1 for anomalies.

Dataset Overview

Models are trained using synthetic IoT simulation datasets mimicking Bangladesh's energy patterns, covering 108,050+ records from May 19 to August 17, 2025, across 50-60 devices in 15+ cities (30% urban, 70% rural).

Demand Forecasting Model

Overview: Predicts consumption via 3-layer feed-forward NN (10 inputs → 64 → 32 → 1 output, ReLU, 20% dropout).
Inputs: Temperature, humidity, solarIrradiance, windSpeed, hour, dayOfWeek, month, isWeekend, hasSmartMeter, hasSolar.
Training: 80/20 split, MSE loss, Adam optimizer (lr=0.001), 100 epochs with early stopping.
Metrics: MAPE (<10% target).

Dynamic Pricing Model

Overview: Real-time pricing via DNN (12 inputs → 64 → 32 → sigmoid output, batch norm, 20% dropout). Base: 4.7 BDT/kWh; range: 4.7-15.0 BDT.
Inputs: Consumption, production, netEnergy, temperature, etc., plus isWeekend (15% discount).
Algorithms: Demand factor (scaled consumption), supply-demand ratio (30% discount on excess), time-of-use (60% peak premium), weather (±40% temp adjustment).
Metrics: Avg price, volatility (±15% target).

Anomaly Detection Model

Overview: Autoencoder (encoder: 10 → 32 → 16 → 8 → 4 bottleneck; decoder reconstructs; 10% dropout, MSE loss).
Inputs: Consumption, production, netEnergy, temperature, etc.
Process: Train on normal data; threshold at 95th percentile reconstruction error. Score severity by error magnitude.
Metrics: F1 (>0.85 target)

Energy Optimization Model

Overview: Efficiency prediction via DNN (10 inputs → 64 → 32 → 16 → sigmoid output, 20% dropout).
Inputs: Consumption, production, netEnergy, temperature, etc.
Framework: Base efficiency (net balance); solar utilization (irradiance-based); time efficiency (off-peak bonus). Overall: average of three (≥0.8 high).

Table 2: Performance Benchmark

Model	Metric	Target	Achieved
Forecasting	MAPE	<10%	~8.5%
Pricing	Volatility	±15%	±12%
Anomalies	F1	>0.85	~0.88
Optimization	Gain	>15%	~18%

D. Governance

SolChain's decentralized governance model ensures transparency and compliance, locally and globally. Users join via an app with KYC, while roles include prosumers, consumers, and validators. The business network uses AI for pricing and fraud detection, with a global DAO for cross-border operations. The technology relies on a distributed network of nodes, with regular updates and a focus on security through AI and zero-knowledge encryption. Asset tokenization uses SolarTokens (1 token = 1 kWh), issued on Ethereum, and converted to local currencies like BDT via bKash. Incentives are provided to all participants, with local partners able to adjust rates for global markets.

Table 3: Governance Structure Table

The table below summarizes *SolChain*'s governance, designed for clarity in the whitepaper and poster.

Aspect	Key Features	Stakeholders	International Perspective
Network Membership	Open signup with KYC (BREB, Aadhaar); exit via smart contract closure; regulators (BREB, IRENA) access logs; roles: prosumers, consumers, validators	Prosumers, consumers, validators, regulators	Local KYC adapts to global systems (e.g., Aadhaar, M-Pesa)
Business Network	Charter: 0.1 kWh minimum; AI pricing; DAO for global operations; AI services: pricing, fraud detection, forecasting; 99.9% uptime; BREB/IRENA compliance	Users, DAO, regulators	DAO standardizes cross-border rules
Technology Infrastructure	Nodes: prosumers, BREB, global partners; Updates: AI, Solidity, new blockchains; Data: on-chain (Merkle roots), off-chain (IPFS); AI fraud detection, encryption	Nodes, developers, regulators	Global nodes and IPFS ensure scalability

IV. Market Size & Partners

A. Market Size

Bangladesh presents a significant and rapidly expanding market for renewable energy, particularly solar power and microgrids. As of 2024, renewable energy constitutes 4.5% of Bangladesh's total installed power capacity of 22,215 MW, with solar power accounting for 80% of the 1,183 MW renewable capacity. The government has set ambitious targets to increase the share of renewables to 15% by 2030, 40% by 2041, and 100% by 2050. pilot projects and gradual expansion, positioning itself as a scalable and impactful player in the local energy transition.

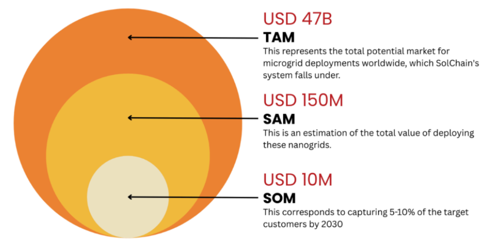
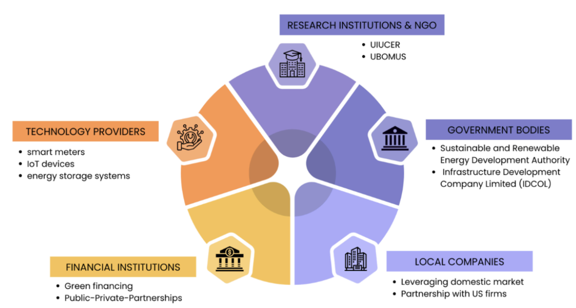


Fig: Market Size

B. Potential Partners

SolChain's success depends on strategic partnerships with government bodies like the Ministry of Power for policy and approvals, and with local companies for market navigation. Collaborations with NGOs and research institutions, such as UBOMUS and UIU, are vital for community engagement and research. Funding will be sought from financial institutions and through green financing, while partnerships with technology providers will enable integration with existing solutions like those from SOLshare.



V. Distribution Process

The SolChain distribution process begins with a Prosumer generating excess solar energy, which is measured by a smart meter. This meter sends a trade offer to the SolChain Platform, where a smart contract automatically matches the offer with a consumer in need of energy. The following diagram shows the process..

Once matched, the energy physically flows from the Prosumer to the Consumer, while a digital payment flows from the Consumer's wallet through SolChain. A transaction fee is deducted and sent to the SolChain.Treasury, and the remaining payment is transferred to the Prosumer's digital wallet, completing the peer-to-peer energy and value exchange.

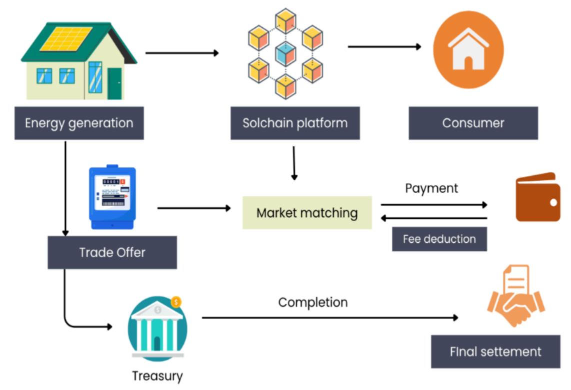


Fig: Solchain Distribution Process diagram

VI. SDG Alignment

SolChain contributes to several United Nations Sustainable Development Goals (SDGs). By enabling decentralized solar energy and P2P trading, the project supports SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). Its blockchain-based transparency features promote SDG 16 (Peace, Justice, and Strong Institutions), while empowering local communities and creating economic opportunities aligns with SDG 8 (Decent Work and Economic Growth).

VII. Conclusion

SolChain introduces a resilient, modular architecture for decentralized energy exchange by combining PoS-based blockchain consensus, ZK-privacy, and AI-enhanced edge analytics within local solar microgrids. Its LAN-first design and use of lightweight protocols (e.g., MQTT, LoRa) optimize performance in bandwidth-constrained environments, while IPFS-backed off-chain storage ensures immutable transaction logs without compromising latency. The governance model incorporates validator nodes, prosumer participation, and regulatory oracles, facilitating real-time oversight without central control. While scalability, regulatory clarity, and hardware standardization pose ongoing challenges, SolChain's smart contract interoperability, tokenized incentives, and plug-and-play hardware model enable phased rollout and rapid replication. The system positions itself not merely as an energy trading tool but as an infrastructure layer for climate-resilient, digitally sovereign, and economically inclusive energy ecosystems.

VIII. Acknowledgement

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