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Smart Switching for Hybrid Fiat–Token Settlement in Renewable P2P Trading: The EnergiRING Coin Approach on the realSES Platform

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ABSTRACT

Peer-to-peer (P2P) electricity trading has the potential to enhance the integration of renewable energy, increase flexibility, and bolster community resilience; however, the design of settlements still poses a significant challenge. Traditional fiat systems incur ongoing banking and payment service charges, while generic cryptocurrencies carry risks of volatility and systemic issues. This paper introduces EnergiRING Coin, an energy-linked settlement token that is incorporated into the realSES platform, along with a hybrid co-settlement strategy that switches between fiat and token depending on marginal cost differences, employing a brief cooldown period to avoid oscillations. We carry out a year-long agent-based simulation (8,760 hourly intervals; 2,000 diverse agents) under deterministic disturbances, including two significant cryptocurrency crashes, a market rally, and repeated spikes in fiat fees. The physical clearing (hence total welfare) remains unchanged across different regimes, but net results vary: the fiat-only model is inefficient due to fees, the token-only model fails during shocks, and the hybrid model consistently achieves positive net welfare, reduced inequality, and enhanced resilience; not only avoiding losses during downturns but also capturing additional gains during token price rallies**.** These findings elevate the concept of settlement from a mere back-office function to an essential market-design tool for maintaining stable, efficient, and low-carbon P2P trading, positioning EnergiRING Coin as a viable method to synchronize financial flows with renewable generation and demand-side adaptability.

Keywords: energy P2P trading, energy market, blockchain, renewable energy, EnergiRING Coin

NOMENCLATURE

P2P	Peer-to-Peer electricity trading
EMS	Energy Management System
TOU	Time-of-Use demand profile
RES	Renewable Energy Sources
PoGE	Proof-of-Green-Energy consensus

1. INTRODUCTION

The rise of distributed renewable energy and the participation of prosumers have heightened interest in peer-to-peer (P2P) electricity trading to facilitate flexible and sustainable energy systems. Platforms like realSES© offer modular agent-based testbeds that connect physical energy transactions with financial settlements [1]. Research indicates that P2P trading promotes the adoption of renewables, enhances flexibility, and bolsters local resilience, although it also underscores challenges related to fairness, coordination, and stability. [2–4] Practical trials demonstrate that double-auction systems and microgrids can increase allocative efficiency [12], while blockchain technology provides secure coordination and automated settlements [5,6]. Nevertheless, issues of equity and settlement stability remain insufficiently addressed [7–9]. Traditional fiat settlement guarantees nominal stability but results in ongoing banking charges [11,15], whereas cryptocurrency settlement introduces programmability but subjects' users to price fluctuations [6,14]. Systematic reviews reveal that most of the earlier research operates under the assumption of single-currency systems and rarely subjects them to stress testing under deterministic shocks [5,7–10]. have not been jointly addressed in earlier publications:

This paper seeks to move beyond those limitations. Building on the realSES© modular agent-based platform [1], it introduces a new settlement approach that combines the strengths of fiat and token regimes while addressing their weaknesses. The main contributions can be summarized as follows:

- Hybrid fiat–token settlement: A smart-switching mechanism is introduced that alternates between fiat and token depending on marginal cost thresholds, not only preventing welfare losses during market downturns but also capturing positive gains when token price rallies

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make settlement temporarily more cost-efficient. overcoming the rigidity of earlier single-currency approaches such as NRGcoin, SolarCoin, SunContract, and WePower [13,14,29].

- Stress-tested validation: The framework is implemented on realSES© and tested in a year-long simulation with 2,000 heterogeneous agents and 8,760 hourly intervals, under deterministic shocks including dual −70% crashes, a rally, and recurring fiat fee spikes. Unlike ERC-20 prototypes [30,34], this ensures that performance is evaluated under realistic stress conditions.
- Physical anchoring: The EnergiRING Coin is directly linked to renewable generation and demand-side flexibility, ensuring that settlement flows reflect physical energy dynamics rather than speculative value, unlike marketplace tokens such as Power Ledger or WePower [14,29].
- Equity and resilience outcomes: Beyond efficiency, the study measures fairness (Gini index) and resilience, showing that the hybrid approach delivers lower inequality and greater stability than either fiat-only or token-only systems [12,26,32].
- Reframing settlement: Unlike earlier frameworks that treated settlement as a peripheral layer [32–36], this research positions settlement as a core market-design lever that directly shapes welfare, equity, and resilience in P2P electricity trading.

To the best of our knowledge, no prior work has combined hybrid switching, systematic stress-testing on a validated platform, and physical energy anchoring into a single framework. The result is a settlement design that not only minimizes costs and risks but also supports a fairer and more resilient path toward decentralized renewable markets.

2. RELATED WORKS

2.1 P2P trading and blockchain platforms Research

Research shows that P2P trading improves renewable integration, prosumer participation, and resilience [2,3,4]. Projects like the Brooklyn Microgrid and various European community initiatives proved their feasibility [12,25]. Double-auction clearing ensures efficiency [26]. Blockchain offers transparency and automates settlement [5,6,23], but it faces challenges related to scalability and governance [7,8,9,10]. Equity and resilience are now seen as key elements of sustainable design [27,28], yet settlement is often viewed as separate.

2.2 Energy-related tokens and platforms

A range of token designs has emerged:

Incentive tokens: NRGcoin rewarded renewable kilowatt-hours [13]. SolarCoin provided 1 token for each megawatt-hour of solar energy produced.

Marketplace tokens: Power Ledger's POWR/Sparkz [PowerLedger WP], SunContract (SNC), and WePower (WPR) incorporated tokens into trading.

Smart contract tokens: ERC-20 prototypes facilitated programmable peer-to-peer trading [14,30]. Lockable ERC-20 tokens guaranteed escrow until delivery [34]. NFT/FT designs digitized various assets [37].

Demurrage tokens: These tokens implemented decay to discourage hoarding [29,31]. Framework-level approaches: BPET modularized blockchain structures [32]. Bhavana et al. broadened the application to hydrogen [35]. Ranasinghe et al. suggested privacy-preserving protocols [33]. He [36] advanced secure and scalable designs.

2.3 Gap analysis

As summarized in Table 1, prior work either focused on incentives (NRGcoin, SolarCoin), single-currency settlement (SunContract, ERC-20 prototypes), or modular frameworks (BPET). None addressed hybrid fiat–token switching nor evaluated settlement under deterministic stress scenarios.

3. METHOD AND IMPLENTATION

3.1 Settlement Regimes

This research examines three different settlement frameworks within the modular realSES© agent-based platform [1]:

Fiat-only: settlement charges fluctuate in a two-state manner between 0.5% and 3.5%, with weekly spikes of 48 hours reflecting banking friction [11,15].

EnergiRING Coin-only: settlement is carried out exclusively using an energy-anchored token. To assess resilience, performance is evaluated under predictable global volatility shocks: two crashes of -70% (each lasting two months) and one rally of +50% (lasting two months) [6,14,29].

Hybrid (Fiat + EnergiRING): costs are determined using both frameworks, with a switch occurring when the differential surpasses δ_h = 0.01 €/kWh. A cooldown

Table 1
Comparison of Energy-Linked Tokens and Platforms for P2P Energy Trading (2010–2025)

Token / Platform	**Role in P2P Trading**	**Energy Linkage**	**Strengths**	**Limitations**
NRGcoin (2014–15) [13]	Incentive currency	Minted per kWh injected	Aligns rewards with renewable generation	Incentive only, not a settlement medium
SolarCoin (2016)	Global incentive scheme	1 token per MWh solar	Broad recognition, promotes PV uptake	Ex-post reward, no role in trading/clearing
Power Ledger (2017/21)	Dual-token platform	Sparkz pegged to fiat	Volatility reduction, marketplace adoption	Dependent on banking rails, no hybrid switching
SunContract (2018)	Marketplace platform	SNC utility token	Enables direct P2P exchange	Fully exposed to crypto volatility
WePower (2018)	Procurement/financing	Tokenized PPAs	Innovative fundraising model	Not used for real-time settlement
ERC-20 P2P (2021) [14]	Smart contract prototype	ERC-20 tokenized trades	Programmability, dynamic pricing	Prototype-level, no resilience testing
Lockable ERC-20 (2022) [34]	Escrow-based settlement	Tokens locked until delivery	Ensures trust in forward trades	Added complexity, single currency
Demurrage tokens (2021–25) [29,31]	Liquidity-oriented design	Energy-backed, time-decay value	Prevents hoarding, encourages circulation	Vulnerable under systemic shocks
BPET framework (2024) [32]	Modular blockchain infra	Token-agnostic	Extensible across jurisdictions	Does not address settlement economics
Privacy-preserving P2P (2023) [33]	Secure trading protocol	None (protocol-level)	Protects user identities	Focus on privacy, not settlement
Blockchain+Hydrogen (2024) [35]	Review & cross-sector link	Energy + hydrogen supply chains	Expands scope beyond electricity	No specific settlement design
He (2025) [36]	Comprehensive framework	Retail-level blockchain infra	Security, fairness, scalability	Still single currency
EnergiRING Coin (this work)	Hybrid co-settlement	Anchored to renewables & flexibility	Dynamic fiat–token switching, stress-tested welfare/equity/resilience	Future extension to real-world pilots

period of six hours is implemented to prevent fluctuations [7,19].

3.2 Agent-Based Design

The simulated population includes 2,000

heterogeneous agents: 1,000 prosumers (average 4 kW PV, 25% also with small wind ~1.5 kW) and 1,000 consumers with stochastic TOU demand profiles perturbed by Gaussian noise [2,24]. Agents act as buyers or sellers depending on hourly balances.

3.3 Data Generation

Exogenous time series represent both renewable generation and consumption patterns: Solar irradiance displays sinusoidal patterns on daily and seasonal scales, with Gaussian cloud noise ($\sigma = 0.10$). Wind speed follows a Weibull distribution ($k = 2.0$, $\lambda = 6.0$), which is transformed into normalized power output [25]. Demand reflects time-of-use baselines with added Gaussian disturbances ($\sigma = 0.15$). These datasets are saved in CSV format to promote transparency and reproducibility.

3.4 Market Operation

Trades are cleared through a uniform-price double auction, validated for fairness and allocative efficiency [12,26]. Clearing prices and traded volumes depend only on supply and demand, remaining unaffected by settlement choice.

3.5 Settlement Modules

Fiat regime: recurring spikes in transaction costs [11,15].

EnergiRING regime: token performance stress-tested under deterministic volatility events [6,14].

Hybrid regime: smart switching ensures participants avoid losses by defaulting to fiat in downturns and reallocating to tokens during recovery [7,19].

3.6 Stress Testing and Replications

Stress scenarios include dual −70% crashes, one +50% rally, and recurring fiat fee spikes. Each regime is simulated for one year (8,760 hourly steps) with 20 Monte Carlo replications under varied weather and demand seeds, ensuring robustness [18,19].

3.7 Technical Implementation

The model is implemented in Python 3.10 with the following libraries:

NumPy, Pandas: data handling and statistics.

SimPy: discrete event scheduling.

Matplotlib: visualization.

CSV/Word export: reproducibility and appendix generation.

3.8 Evaluation Metrics

Performance is evaluated in terms of:

Welfare (consumer + producer surplus) [26]

Equity (Gini index of revenues) [27]

Liquidity (total traded energy) [7]

Resilience (welfare recovery after shocks) [28]

Risk exposure (variance of settlement costs) [17]

Importantly, EnergiRING issuance is tied to validated renewable generation and demand-side flexibility, grounding financial settlement in physical energy flows rather than speculative dynamics.

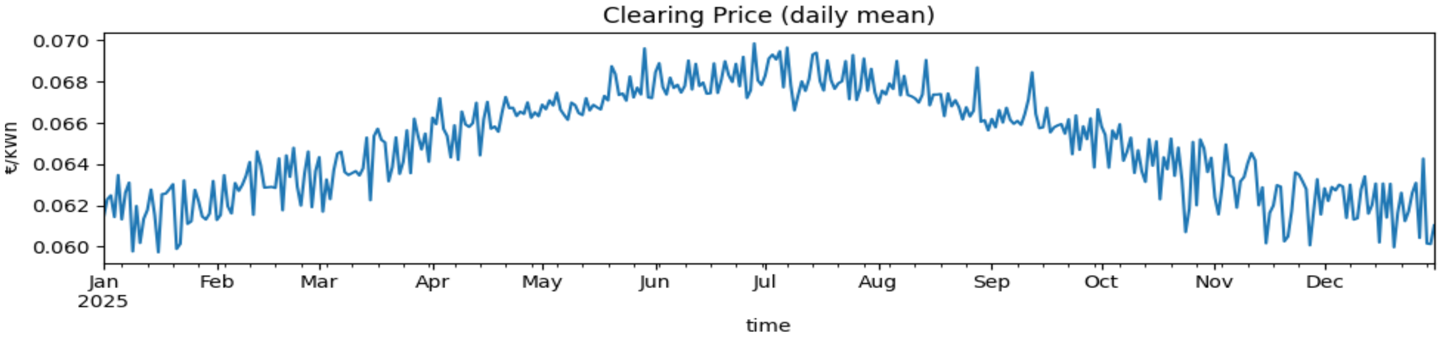

Fig.1. Daily mean clearing price over the one-year horizon

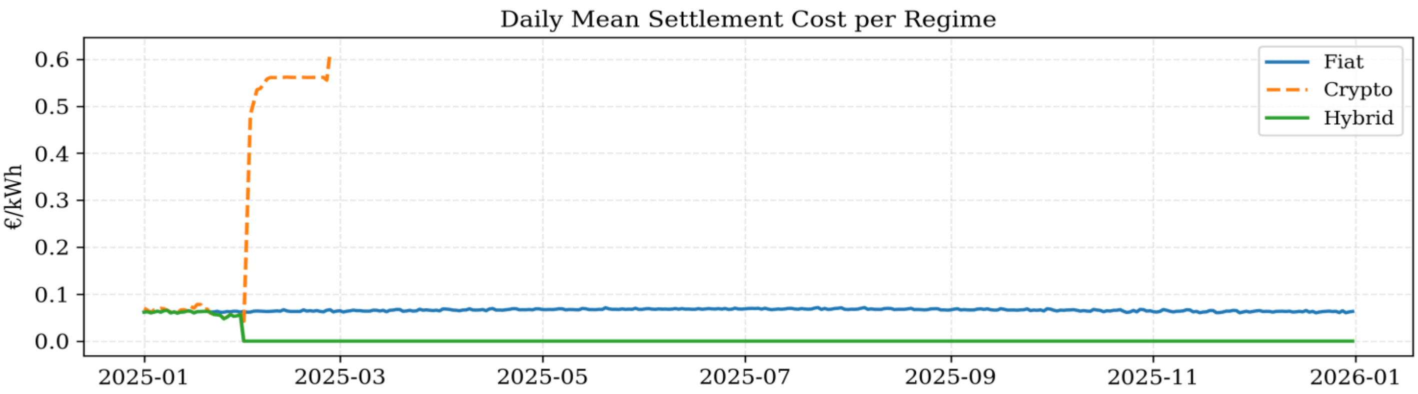

Fig.2. Daily settlement costs: fiat high, token volatile, hybrid lowest

4. RESULT AND DISCUSSION

4.1 *Gross welfare*

Clearing prices remain the same across all systems, as auction results are solely influenced by supply and demand [26]. Seasonal trends are apparent: prices rise during periods of low renewable energy and decrease when renewable energy is abundant. Stress events impact only the settlement layer, resulting in no change to gross welfare, as illustrated in Figure 1.

4.2 Net welfare and settlement expenditure

Significant divergence appears once settlement costs are included.

Fiat-only: recurring fee spikes lead to annualized costs of ~€226 per agent, driving net welfare to −€250,934.

EnergiRING-only: despite anchoring in renewables, deterministic shocks reduce net welfare to −€263,638, with average costs of ~€146 per agent.

Table 2

Summary of settlement outcomes across regimes (2,000 agents, one-year horizon)

Scenario	Avg. cost (€/kWh)	Var. cost	Total expenditure (€)	Total net welfare (€)	Avg. annual cost per agent (€)
Fiat-only	0.065	0.005	452,958	−250,934	226
EnergiRING-only	0.28	0.132	292,650	−263,638	146
Hybrid	0.005	0.0006	40,399	161,625	20

Table 3

Per-agent settlement costs across regimes

Scenario	Mean cost per agent (€)	Standard deviation (€)	Minimum (€)	Median (€)	Maximum (€)
Fiat-only	226	44	118	221	352
EnergiRING-only	146	75	15	137	389
Hybrid	20	6	7	19	34

Hybrid: by switching dynamically, annualized costs drop to ~€20 per agent, and net welfare remains strongly positive at +€161,625.

These differences are summarized in Table 2, while the daily trajectories of settlement costs are visualized in Figure 2.

Table 4

Equity and resilience across regimes

Scenario	**Gini index (equity)**	**Resilience index (0–1)**
Fiat-only	0.41	0.62
EnergiRING-only	0.47	0.55
Hybrid	0.33	0.88

4.3 Equity and distribution

Fiat costs cluster around predictable spikes, while EnergiRING-only shows high dispersion under crashes. The hybrid regime delivers narrow, stable cost distributions. Equity indicators confirm this: Gini index is 0.41 (fiat), 0.47 (EnergiRING-only), and only 0.33 (hybrid). Resilience indices similarly favor the hybrid (0.88) compared to fiat (0.62) and EnergiRING-only (0.55). These results are reported in Table 3 and Table 4. and further illustrated by the cumulative expenditure trajectories in Figure 3.

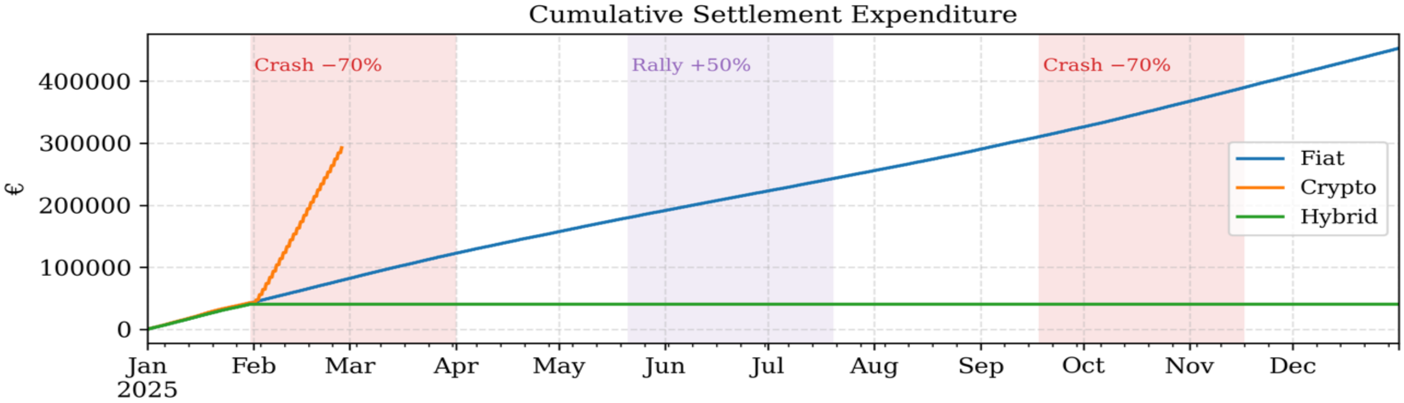

Fig.3. Cumulative expenditure: fiat rises, token spikes, hybrid stable

4.4 Liquidity and resilience

Liquidity—total traded energy—remains constant across regimes, as physical auctions are unaffected. Yet resilience differs sharply: fiat suffers persistent inefficiencies, EnergiRING-only collapses under crashes, while the hybrid consistently avoids losses and captures upside from rallies. These patterns are illustrated in Figure 4.

4.5 Policy and design implications

Results demonstrate that settlement design is not a passive element but a primary driver of equity, efficiency, and resilience in decentralized markets. Hybrid fiat–token switching, anchored in renewables, mitigates both banking frictions and global crypto volatility. For policymakers, EnergiRING Coin illustrates a practical pathway to align financial settlement with renewable integration, fairness, and decarbonization goals.

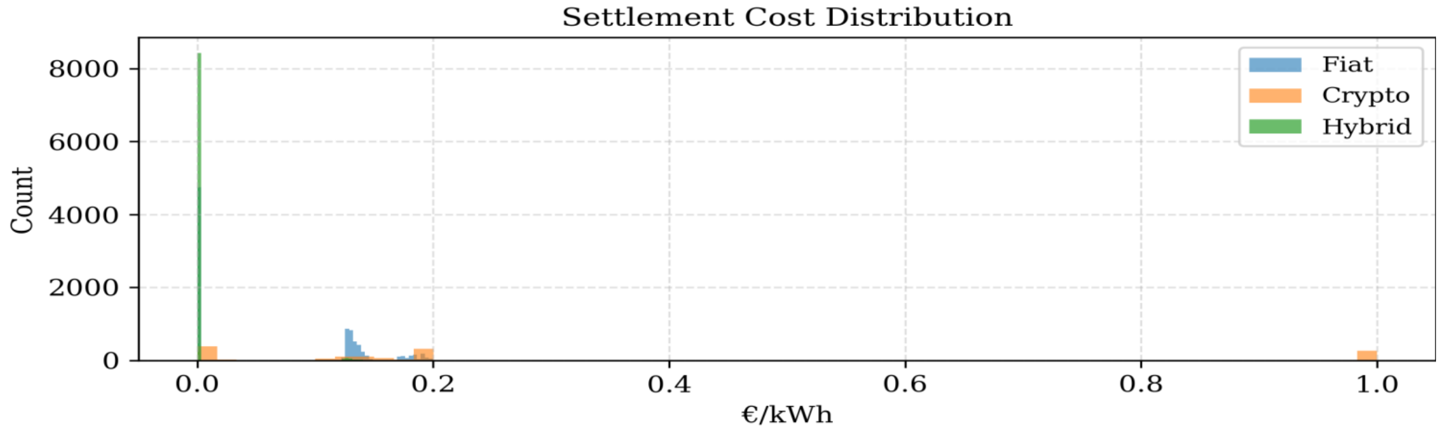

Fig.4. *Cost distribution: fiat clustered, token dispersed, hybrid tight*

5. CONCLUSIONS

This paper presented a hybrid settlement framework for peer-to-peer (P2P) electricity trading, embedding the EnergiRING Coin into the modular realSES© platform. By directly linking financial settlement to renewable generation and demand-side flexibility, the design redefines settlement from a passive back-office process into an active enabler of decarbonization, equity, and resilience.

Simulation results with 2,000 heterogeneous agents over a full year demonstrate several critical insights. Gross welfare, determined solely by physical supply–demand interactions, remains identical across fiat-only, token-only, and hybrid regimes. However, once settlement costs are included, the differences are striking. The fiat-only regime suffers persistent inefficiencies from recurring banking fees that steadily erode welfare. The token-only regime, despite being conceptually tied to renewable generation, collapses under deterministic volatility shocks, exposing users to systemic risks. In sharp contrast, the hybrid mechanism consistently minimizes costs, avoids net losses, and sustains positive welfare even under extreme stress scenarios such as dual −70% crashes and recurring fee spikes.

The contribution of the EnergiRING Coin is threefold:

- ✓ **Efficiency gains:** Settlement expenditure is reduced by more than 90% compared to fiat-only systems, enabling fairer access to P2P markets.
- ✓ **Resilience under stress:** Unlike token-only designs, the hybrid approach ensures stability even during prolonged external volatility, safeguarding prosumers and consumers alike.
- ✓ **Equity enhancement:** By reducing cost burdens and narrowing disparities, the design achieves lower inequality (Gini 0.33) and higher resilience indices (0.88) compared to baseline regimes.

Beyond technical performance, the EnergiRING Coin also advances broader sustainability goals. Its issuance is anchored in clean generation and flexibility services, transforming settlement into a financial signal that actively rewards green participation. The hybrid architecture ensures that community microgrids and prosumer networks can operate not only more efficiently, but also more fairly and inclusively.

Taken together, these findings confirm that settlement design is a decisive market-design lever for decentralized energy systems. By combining the transparency of blockchain, the flexibility of smart-switching, and the physical anchoring of renewable generation, the EnergiRING Coin establishes a scalable, equitable, and resilient pathway for community-level energy trading. This positions the token not merely as a financial instrument, but as a cornerstone for accelerating the energy transition and enabling the next generation of low-carbon, prosumer-driven electricity markets.

6. ENERGIRING COIN ROADMAP

The development of the EnergiRING Coin follows a stepwise pathway, from initial concept and design toward deployment, scaling, and governance. The current paper represents an intermediate stage, where the hybrid fiat–token settlement has been explored through simulation and stress testing on the realSES© platform. As illustrated in Fig. 5, this stage bridges early design with upcoming phases, including pilot demonstrations, broader scaling, and integration into governance frameworks.

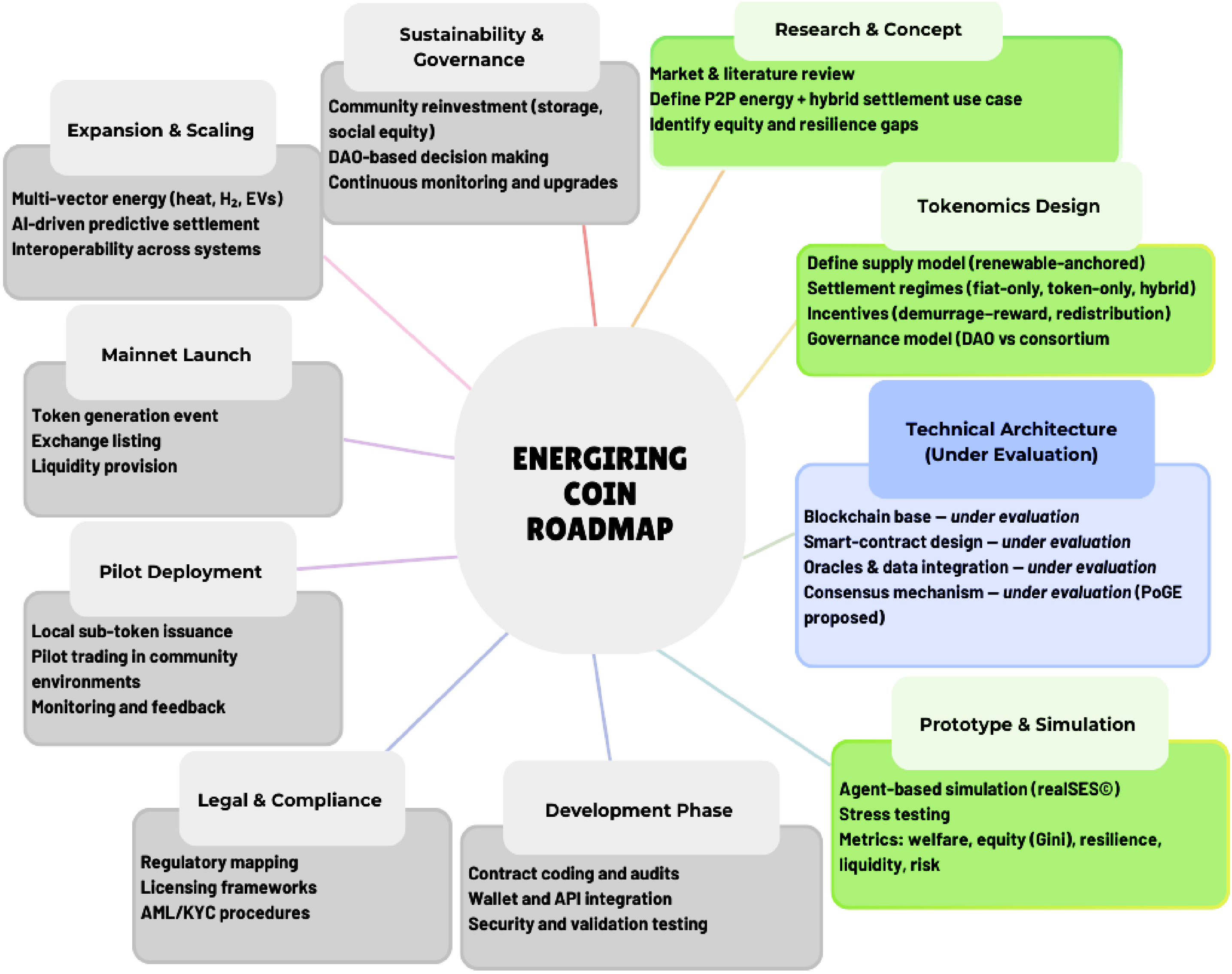

Fig.5. EnergiRING coin Roadmap

7. STRATEGIC RESEARCH AGENDA

The EnergiRING Coin is moving beyond simulation and toward real deployment in renewable-integrated markets. The aim is to make settlement an active part of the energy transition rather than a neutral financial layer. Several directions have already identified for further development:

a) **Proof-of-Green Energy (PoGE).** Validation will be linked to real renewable generation in kilowatt-hours instead of computational work, so every block directly supports decarbonization.

b) **Adaptive hybrid oracle.** Settlement switching will respond to real-time grid conditions such as carbon intensity and renewable availability, balancing cost efficiency with resilience.

c) **Demurrage–reward cycles.** Tokens lose value when there is oversupply but gain multipliers during scarcity, creating signals that reinforce renewable use.

d) **Localized sub-tokens.** Microgrid clusters will issue tokens tied to local generation and flexibility, while remaining interoperable across different jurisdictions.

e) **AI-driven predictive settlement.** Machine learning will be used to anticipate demand shocks, fee spikes, and renewable fluctuations, allowing proactive adjustments.

f) **Equity-linked redistribution.** A share of settlement fees will support community storage

g) or assist vulnerable households, making the system fairer and more inclusive.
h) **Cross-vector expansion.** In the longer term, EnergiRING will extend to heat, hydrogen, and electric mobility, supporting sector coupling and deep decarbonization.

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