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REVISED Blockchain-enabled business model innovation in sector-coupled energy communities

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Abstract

This paper analyses business model innovation and digital platform alignment—including blockchain-enabled remuneration and automated settlement—in sector-coupled energy communities. Drawing on six diverse pilot deployments, we explore how modular digital platforms and blockchain technologies can support peer-to-peer trading, flexibility services, and integration across electricity, heating, and mobility sectors. The methodology combines systematic value proposition mapping with technical and market analysis to assess real-world user needs, operational challenges, and regulatory barriers. The study contributes to theory by extending existing frameworks on digital transformation and business model innovation to decentralised, multi-actor energy systems, demonstrating how digital platforms and distributed ledgers enable iterative, data-driven adaptation of value creation and coordination mechanisms. The study also advances theory by showing how iterative co-design and distributed verification mechanisms translate digital transformation concepts into measurable governance and value-creation outcomes for energy communities. Findings show that blockchain and digitalisation can improve transparency and trust in community energy markets, but effective scaling requires regulatory adaptation, flexible business models, and sustained user engagement. The results provide actionable insights for both practitioners and policymakers aiming to advance digital innovation and business model alignment in the evolving landscape of energy communities.

Keywords

energy communities, business model innovation, digital platforms, blockchain, automated remuneration, peer-to-peer trading, sector coupling, flexibility services, value proposition, decentralisation

Open Peer Review

Approval Status ✓ ✗ ✓ ✓

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REVISED **Amendments from Version 1**

This revised version incorporates substantial clarifications and expansions in response to reviewer feedback. The abstract has been strengthened to better articulate the paper's theoretical contribution on digitalisation, transparency, and business model innovation in energy communities. The methodology section now provides clearer justification of the mixed-methods approach, detailing the link between stakeholder engagement, validation cycles, and data reproducibility. Section 4 has been reorganised to distinguish the overarching business model and platform architecture before the pilot-specific analyses, with additional cross-case synthesis to highlight common innovation patterns and transferable results. The discussion and conclusion were expanded to explicitly connect findings to existing theories of digital transformation, governance, and open innovation, while introducing stakeholder-specific practical recommendations. Minor editorial improvements were made for consistency, clarity, and alignment with Open Research Europe's formatting requirements.

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Introduction

The rapid transformation of Europe's energy landscape is placing energy communities at the forefront of efforts to achieve decarbonisation, citizen participation, and local value creation. These communities, bringing together households, municipalities, and businesses, are uniquely positioned to harness distributed resources and support the integration of electricity, heating, mobility, and emerging technologies. However, the realisation of this potential depends not only on innovative business models, but also on the deployment of digital platforms that enable efficient, transparent, and automated coordination among diverse actors.

Recent developments in blockchain and digital platform technologies have opened new pathways for community-driven energy innovation. By enabling peer-to-peer trading, automated settlement, and secure value flows, these tools can help overcome long-standing barriers related to trust, data management, and multi-actor coordination. At the same time, the process of aligning business models with new digital capabilities is inherently iterative, shaped by local needs, technical constraints, and evolving regulatory frameworks.

Despite growing interest, most existing studies remain conceptual or technology-focused, offering limited evidence from operational energy communities where digital platforms and business models evolve together. This gap underscores the need for empirical research that links technical design with organisational adaptation and regulatory context.

Research question: How can blockchain-enabled digital platforms drive business-model innovation in sector-coupled energy communities, and under what organisational and regulatory conditions can these models scale?

This paper addresses these challenges by examining how business model innovation and blockchain-enabled digital platforms interact to support robust, sector-coupled energy communities. Drawing on lessons from six FEDECOM pilot deployments, we analyse the technical, organisational, and regulatory factors shaping the evolution of transparent, scalable community business models in practice. In doing so, we aim to provide a foundation for further research and practical action to advance the next generation of digital, sector-coupled energy communities.

State of the art and conceptual foundations

Business models for energy communities

The business model landscape for energy communities is rapidly evolving, with recent literature highlighting both the promise and fragmentation of current approaches. Energy communities are emerging as key players in the evolving energy landscape, fostering citizen participation and driving the transition towards sustainable energy systems. Business models are crucial for the success and sustainability of these communities, ensuring that benefits and costs are distributed equitably and that local knowledge is leveraged. The rise of peer-to-peer (P2P), community self-consumption, and transactive energy models reflects new business model configurations for local energy trading among various stakeholders.

Blockchain technology in sector-coupled energy communities

Blockchain technology is increasingly recognised for its potential to revolutionise the energy sector by enabling new business models, fostering transparency, and supporting innovation[1–3]. Its core attributes—decentralisation, immutability, and automation through smart contracts—make it particularly well suited for P2P energy trading, traceable transactions, and the integration of sector-coupled services such as electricity, heating, cooling, and mobility[4–7]. Blockchain supports local energy markets, enables direct trading among prosumers, and underpins new business models for energy communities[4,6].

Several systematic reviews provide overviews of blockchain's application in energy, emphasising both the technology's promise and its current limits[1,5,8]. Case studies and conceptual frameworks further highlight the ways blockchain can reconfigure transaction structures, governance, and value flows[4,9,10]. Blockchain approaches are viewed as highly relevant to P2P energy trading and transactive energy models, where trust, decentralised verification, and automated remuneration are central for scalable, inclusive participation[11,12].

However, there are also concerns that, without careful design, such models may risk perpetuating existing inequalities. Reis *et al.* (2021) offer a comprehensive review of energy community business models, identifying a diversity of arrangements but noting a lack of systematisation and maturity across the sector[13]. Several recent systematic reviews have mapped the complexities and diversity of energy community business models, focusing on P2P trading, sector-coupling, and the microeconomic dynamics among actors[14–19]. These studies highlight

that while macroeconomic and policy frameworks are well explored, there is a need for more research on micro-level incentives, revenue streams, and mechanisms for sustained citizen engagement.

Maruf *et al*. (2024) similarly stress that while sector-coupled and renewable-based energy communities can deliver substantial environmental and economic benefits, practical deployment is hindered by technology integration, regulatory uncertainty, and limited business case development[20]. Recent comparative reviews further underscore the diversity of energy community business models and the evolution of arrangements across the EU, highlighting both the proliferation of collective self-consumption, peer-to-peer trading, and aggregation schemes, and the variety of local adaptations[21–23].

Regulatory and operational challenges are well documented. Lowitzsch *et al*. (2020) and Inês *et al*. (2020) point to the heterogeneity of governance models and the slow pace of legal harmonisation under EU frameworks such as RED II[24,25]. Ramsebner *et al*. (2021) and ETIP SNET (2021) highlight the complexity of sector coupling—integrating electricity, heating, mobility, and hydrogen systems—while stressing the need for holistic "system-of-systems" approaches that go beyond single-technology pilots[26,27]. Efkarpidis *et al*. (2022) and the EN-TRACK project (2019) identify gaps in KPI definition and validation[28,29], while Mohammadi (2023) and Košnjek *et al*. (2025) highlight the broad range of externalities, actor diversity, and business model risk factors that must be considered for successful replication of energy community initiatives[30,31]. Community-ownership and governance innovations were covered by Universal Smart Energy Framework (USEF) in 2019 and International Renewable Energy Agency (IRENA) in 2020, who emphasised the importance of local participation, risk sharing, and flexibility as central to robust value proposition development[32,33].

Digitalisation and platformisation are increasingly seen as necessary for energy community scale-up, particularly through enabling value co-creation, automated operations, and performance-based remuneration. However, recent project evidence notes persistent pain points, including fragmented asset management, slow digital uptake, lack of trusted data-sharing frameworks, and limited options for transparent revenue distribution[34]. The FEDECOM value proposition analysis reveals that user archetypes—ranging from district system coordinators to e-mobility managers—face unique jobs, pains, and gains that are not fully addressed by legacy business models or generic digital solutions. The FLEXCoop project in 2020 demonstrated how digital platforms and marketplaces can facilitate local flexibility trading, introduce new contractual and risk-sharing mechanisms, and deliver additional value to both prosumers and aggregators[35].

Against this backdrop, blockchain and automated remuneration mechanisms have gained significant research attention as potential enablers of trust, transparency, and scalable value flows within local energy markets[36,37]. In the context of energy communities, blockchain can automate P2P transactions, enforce settlement logic based on KPIs, and facilitate multi-actor coordination. Yet, most academic and applied projects remain at proof-of-concept stage, with few documented cases of operational integration and business model impact at scale. Nonetheless, barriers to scale—including interoperability, regulatory fragmentation, and clarity of value stream allocation—remain, as consistently highlighted in recent academic and industry studies[3,22,35].

Challenges, barriers, and research directions

Despite its promise, blockchain adoption in sector-coupled energy communities faces substantial challenges. Regulatory uncertainty, technological immaturity, scalability concerns, and data privacy are well documented as primary barriers[38–40]. Institutional inertia and limited awareness can slow adoption, while the need for interoperability and standardisation remains acute[4,10].

Still, the literature highlights significant benefits: increased efficiency through automation[41], sustainability via local renewables[42], improved resilience[43], and greater consumer empowerment[4]. Future research should focus on scalable and secure platform design, business model innovation, socio-economic assessment, and progress toward technical interoperability[6,44].

The present study builds on these insights, combining a systematic value proposition mapping across six energy community use cases with technical and market analysis from public FEDECOM deliverables. The goal is to demonstrate how digital business model innovation—integrating blockchain-based platforms and automated remuneration—can address real-world user needs, overcome regulatory and operational barriers, and create replicable value propositions for sector-coupled energy communities.

Alignment with European standardisation efforts

The findings and methodological choices of this work are consistent with current European coordination activities on energy community business models. In particular, the BRIDGE Business Models Working Group (BMWG) provides a reference framework for value chain mapping, role definitions, and KPI harmonisation across projects. FEDECOM's approach follows this structure by linking value propositions and stakeholder roles through common categories such as service type, actor responsibility, and revenue flow.

Within the BRIDGE BMWG discussions, FEDECOM contributed insights on remuneration transparency and automation, expanding the group's templates to include digital and blockchain-enabled value chains. The mapping of use-case activities to roles—aggregator, community operator, flexibility provider—was aligned with the BRIDGE taxonomy to facilitate cross-project comparability.

This alignment ensures that the business model archetypes and validation procedures developed in FEDECOM can be interpreted within a common European language for energy communities. At the same time, FEDECOM extends existing best

practices by integrating platform-level verification and smart-contract settlement, which are not yet formally standardised in the BRIDGE documentation.

Methodology and analytical approach

This research applies a multi-stage, mixed-methods approach to synthesise current business model innovation and value proposition development for energy communities, drawing on participatory co-design and validation practices commonly applied in digital innovation and business model research. This approach combined qualitative and quantitative elements to link stakeholder engagement with measurable system validation. Workshop-based persona and value proposition mapping were used to identify user needs and pain points, while pilot data were analysed through a structured measurement and verification framework to test the associated business model logic.

The Value Proposition Canvas was selected as a participatory and transparent tool to bridge user requirements with platform functionalities. This approach has been widely used in digital innovation and business model design studies to capture evolving user expectations and translate them into replicable service logics. In this context, it allowed FEDECOM partners to document explicit 'jobs, pains, and gains' from stakeholder workshops and map them against technical functions of the digital platform.

Energy performance and flexibility metrics were compared across baseline and reporting periods, using consistent KPIs and common evaluation workflows. This integration of participatory design, literature synthesis, and quantitative verification ensures methodological rigour and distinguishes the approach from descriptive community energy studies that rely solely on surveys or case summaries. The analysis focuses on six representative energy community use cases from the FEDECOM project, selected to capture a diversity of market actors, technological contexts, and sector-coupling opportunities.

First, a qualitative review of academic and grey literature was performed to identify business model archetypes, value creation mechanisms, and recurring challenges in the evolution of energy communities[11,12,14,21–23,45]. Special attention was given to systematic reviews and EU project reports that examine both macro- and micro-economic factors, with a particular focus on P2P, collective self-consumption, and digitally enabled business models[15–19].

Personas and value proposition maps for the FEDECOM use cases were developed through project workshops, and analysis of deliverables. The Value Proposition Canvas framework[46] was used to structure and visualise the relationships between user jobs, pains, and gains, and the proposed products, services, pain relievers, and gain creators. The same structured approach was applied across all six use cases, facilitating a consistent basis for comparison and enabling iterative refinement as stakeholder feedback was incorporated.

For each persona, business model requirements were mapped to FEDECOM's technical features—such as blockchain-enabled trading, automated remuneration, transparent transaction logs, and secure data exchange—by cross-referencing project deliverables and platform documentation with user needs identified in the value mapping. Iterative co-creation sessions with technical and market experts ensured alignment between the business model logic and the digital platform design. These sessions included regular feedback cycles during pilot deployment, enabling rapid identification and implementation of necessary adjustments in both business model logic and technical platform features.

Data sources integrated both qualitative and quantitative inputs. Qualitative data included outcomes from stakeholder workshops, interviews, and project documentation, while quantitative analysis relied on operational metrics collected from the pilot platforms. Each pilot involved at least one technical lead, a business model coordinator, and end-user representatives, ensuring that both market and operational perspectives informed the findings.

This iterative approach ensured that validation occurred continuously across pilots. Each feedback cycle consisted of capturing user input, refining the business model logic, and reassessing the resulting digital functionalities. The same sequence of mapping, implementation, and review was replicated across all six sites, which increases methodological transparency and supports reproducibility of insights. This consistent approach across all pilots ensures that future studies can replicate the mapping, validation, and feedback cycles under similar technical and organisational conditions.

In parallel, the remuneration component of the digital platform was validated through controlled test cases to ensure that automated settlements accurately reflected the agreed business rules. Each scenario covered under-delivery, compliant delivery, and over-delivery conditions, with corresponding penalties or rewards automatically applied through smart contract logic. These tests confirmed the integrity of the settlement flow from the blockchain layer to the external payment interface, demonstrating that the co-designed remuneration model could be executed transparently and reproducibly across different pilot configurations.

Finally, FEDECOM pilot deployment and implementation reports were reviewed to evaluate the potential operationalisation of business models and the ability of digital features (e.g., smart contracts, KPI-based settlement) to address practical barriers and stakeholder expectations. This approach ensures that the methodology is transparent and reproducible, providing a template for comparable studies in future energy community projects. Where available, user feedback and observed market outcomes were synthesised to draw lessons on business model robustness, scalability, and transferability. This methodological integration enables a holistic assessment of how current

theory and FEDECOM technical innovations interact to shape the next generation of energy community business models.

FEDECOM business model innovation and platform alignment

This section is structured to first describe the overarching business model and platform architecture developed within FEDECOM, followed by the specific adaptations implemented across the six demonstration sites. The FEDECOM pilots provide an evolving perspective on how flexible, interoperable, and user-driven energy communities can be implemented in diverse real-world contexts. Rather than a finished product, FEDECOM's approach to business model innovation and digital platform alignment is an ongoing, iterative process shaped by feedback from demonstration sites, technical development cycles, and continued stakeholder engagement.

Cross-pilot value proposition synthesis

A cross-case analysis was conducted to identify shared value creation mechanisms across the six pilots. The results show that, despite differing technical configurations and actor compositions, all implementations converge on a common logic structured around transparency, automation, and value redistribution. Using a Lean Model Canvas approach, the core elements of this blockchain-enabled business model can be generalised as follows:

- Customer segments: Community operators, municipal aggregators, and prosumer collectives seeking flexibility, transparency, and data sovereignty.
- Value propositions: Automated, auditable remuneration; simplified participation in local and cross-community trading; verifiable performance metrics; and improved trust between actors.
- Key activities: Operation of digital marketplaces, flexibility dispatch, performance verification, and smart-contract settlement.
- Key resources: Distributed ledger infrastructure, digital twins for asset optimisation, and standardised KPI datasets.
- Channels and relationships: Community dashboards, API-based data exchange, and periodic reporting supporting regulatory compliance.
- Cost structure: Platform deployment and integration with existing metering and market systems.
- Revenue streams: Market fees, flexibility payments, and shared cost savings from local balancing.

This synthesis demonstrates that FEDECOM's blockchain-enabled platform introduces three specific disruptions to the traditional energy value chain:

(i) Shift of trust mechanisms from central authorities to verifiable digital records;

(ii) Automation of settlement and verification, replacing manual reconciliation with programmable contracts; and

(iii) Redistribution of economic value, allowing local communities to capture part of the margin previously held by intermediaries.

By framing the business model this way, the pilots can be interpreted as contextual adaptations of a shared architecture rather than isolated demonstrations, reinforcing the replicability of the proposed value propositions. The following subsections illustrate how this shared architecture was instantiated in each pilot context, reflecting local asset mixes, governance models, and regulatory conditions.

Pilot-specific adaptations

Each pilot use case illustrates the challenges and opportunities inherent in adapting digital platform features and business model logic to local requirements, legacy constraints, and emerging value opportunities. The diversity of these approaches is visualised in Figure 1, which summarises the main business model configurations and value propositions across all six demonstration sites. For instance, in the Ur Beroa residential community in Spain (Figure 1A), the integration of 37 kWp of new photovoltaics and 60 kWh of battery storage, together with improved cascading controls and the testing of phase change thermal storage, has enabled Ur Beroa's operator to optimise a 50-dwelling district heating network that was previously reliant on a 1.2 MW CHP engine and 6.8 MW of natural gas boilers. This ongoing process has delivered higher self-consumption, improved cost savings, and prepared the community for local trading and sector coupling. The Bilbao City Hall case (Figure 1B) shows how municipal portfolio management and renewable integration are being dynamically coordinated across six public buildings and two PV sites (totaling 1044 kWp of generation and 127 kWh of storage). FEDECOM enabled automated monitoring, real-time data integration, and improved reporting, facilitating both internal optimisation and readiness for future local energy trading.

Similarly, the Puertollano Green Hydrogen plant (Figure 1C) demonstrates the integration of a 100 MW green hydrogen plant, 100 MW of PV, and a 20 MWh battery, with FEDECOM enabling optimal dispatch between electricity and hydrogen production. The platform supports green credential tracking and paves the way for multi-market participation, though further work on regulatory adaptation and commercial integration is ongoing. The TMB hydrogen station pilot (Figure 1D) highlights the acceleration of energy trading for public transport hydrogen infrastructure, with the platform supporting four new dispensers, expanded high-pressure storage, and secure links to a green hydrogen plant and PV. While FEDECOM has prepared TMB for broader market integration, further expansion and regulatory adaptation are still being addressed. In Switzerland, the hydropower federation pilot (Figure 1E) coordinated three communities with over 250 kWp of PV, new district batteries, and legacy hydro assets. FEDECOM enabled optimisation of self-consumption, ancillary service provision, and

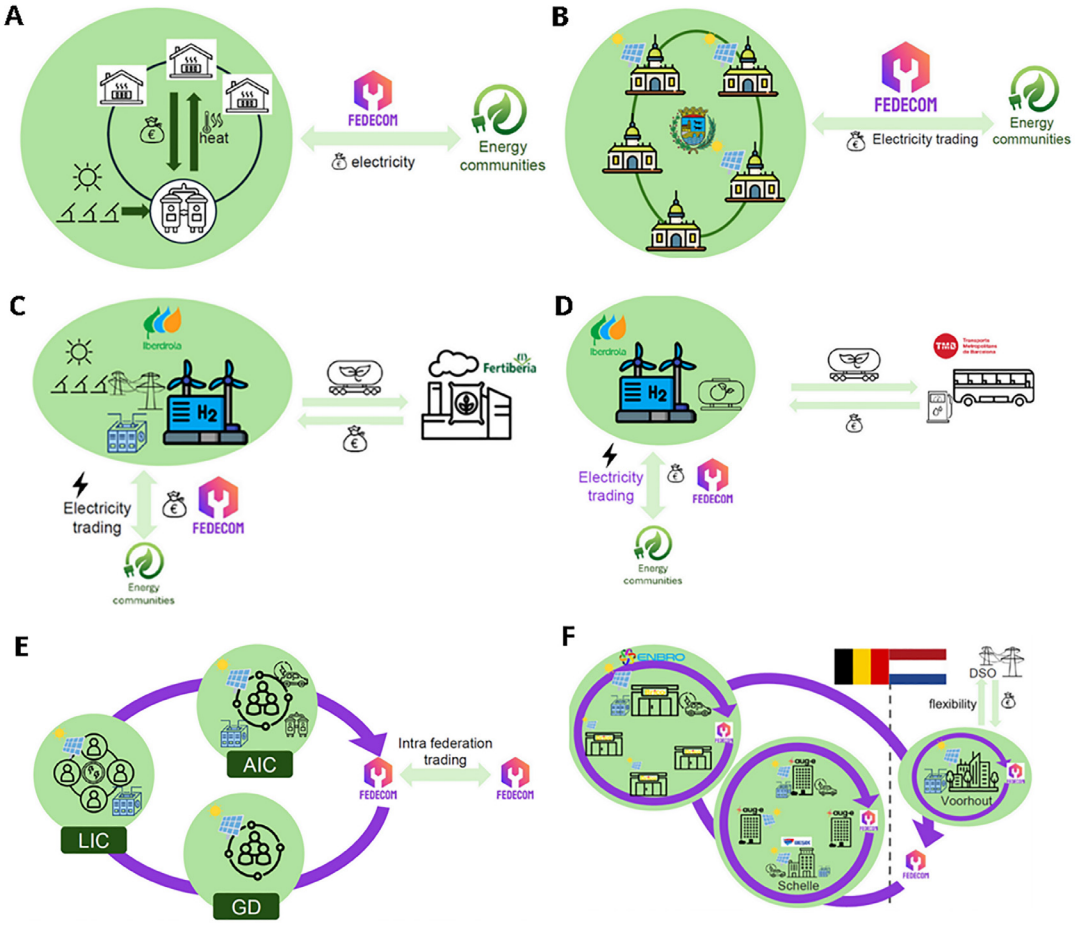


Figure 1. FEDECOM pilot business models and value propositions, highlighting how each use case introduces specific technical and organisational innovations within a shared digital and blockchain-enabled framework.. (**A**) UC1: Spain – Ur Beroa Residential Community. (**B**) UC2: Spain – Bilbao City Hall. (**C**) UC3: Spain – Puertollano Green Hydrogen Plant. (**D**) UC4: Spain – TMB Hydrogen Station. (**E**) UC5: Switzerland – Hydropower Federation. (**F**) UC6: Benelux – Cross-country E-mobility.

transparency in asset coordination, but also revealed the need for ongoing user training and iterative business model adaptation. The Benelux cross-country e-mobility pilot (Figure 1F) linked PV-powered EV charging sites across Belgium and the Netherlands, with integration of battery storage, smart charging, and dynamic control to enable local and cross-border electricity, flexibility, and storage trading. FEDECOM's modular platform provided technical feasibility, while highlighting the need for new special purpose vehicles and regulatory alignment for full commercial rollout.

Across all use cases, value proposition mapping and business model adaptation remain iterative, shaped by real-time feedback and local user priorities. The platform's ability to support transparent accounting, smart contract-based settlement, and flexible user roles has been instrumental in enabling these adaptations, even as regulatory fit and full integration with legacy systems continue to present challenges.

The diversity of FEDECOM's pilot sites is reflected not only in their business models but also in the specific platform functionalities and market roles addressed by the project. Table 1 summarises the key FEDECOM market offers, the main stakeholder groups targeted, and the use cases where each offer was implemented or tested. To complement the descriptive overview, Table 1 synthesises analytical data drawn from FEDECOM's techno-economic and validation work, highlighting each pilot's main innovation focus and quantified contribution to the federation architecture.

The table links each offer to its main technological or market innovation, illustrating how the platform supports measurable improvements in transparency, flexibility, and sector coupling across pilots. As shown in Table 1, the platform enables local electricity and flexibility markets, supports inter-community energy trading, electricity storage trading, and P2X (power-to-x, e.g., hydrogen) trading. Each offer corresponds to different

Table 1. Mapping of FEDECOM platform market offers to stakeholder groups, use cases, and associated innovation focus.

FEDECOM offers	To	Use cases	Innovation focus
Local Electricity Market	Energy communities Real estate owners	UC2, UC5, UC6	Demonstrated peer-to-peer trading with measurable gains in local self-consumption and transparent settlement among participants.
Local Flexibility Market	Energy communities Real estate owners	UC2, UC5, UC6	Enabled community-level flexibility activation and automated remuneration based on predefined performance indicators.
Inter-energy community energy trading	Cluster of energy communities Large industrial energy consumers	UC1- UC6	Validated interoperability between local markets and transparent cross-community value exchange using blockchain-based settlement.
Electricity storage trading	Energy communities DHC network operators Real estate owners Electric vehicle fleet owners	UC1, UC3, UC5, UC6	Supported multi-asset coordination and monetisation of storage flexibility across electricity, mobility, and heating sectors.
P2X trading	Energy communities Hydrogen manufacturers DHC network operators Hydropower companies	UC1, UC3, UC4, UC6	Linked electricity and hydrogen value chains under a single digital framework, enabling sector-coupled trading and verifiable carbon-reduction accounting.

user groups—ranging from real estate owners, district heating (DHC) operators, and large industrial consumers to clusters of renewable energy communities and EV fleet operators. This mapping highlights the flexibility of the platform to accommodate a variety of trading and value creation logics, tailored to the operational and market realities of each pilot. For example, in Bilbao, real-time monitoring, automated control, and enhanced transparency provided clear benefits to municipal managers, while in Ur Beroa, cost savings and increased resilience were observed as key outcomes for residents. Across all pilots, transparent accounting, automated settlement, and flexibility management were highly valued by both technical operators and end users, though full integration remains a work in progress in several sites.

Performance was monitored across all demonstration sites using a common set of indicators covering self-consumption ratio, flexibility activation, remuneration accuracy, and user satisfaction. Early validation results show improvements in local energy use efficiency, smoother peak-load management, and reduced administrative time for settlement compared with baseline conditions. While specific values differ by pilot due to scale and data availability, the overall trend confirms that combining digital automation with community-centred business models produces measurable operational and cost-management benefits.

The mapping process also highlighted where blockchain-specific features—such as smart contract settlement and auditability—were critical to value proposition delivery, particularly in multi-actor, cross-community, or sector-coupled use cases.

To make these blockchain mechanisms transparent to practitioners, the smart contract design in the FEDECOM platform defines a clear operational structure linking measurement, verification, and remuneration. Each contract instance contains KPI-based trigger conditions comparing verified performance data against agreed baselines or dispatch targets; tolerance bands specifying reward or penalty logic for under-, compliant-, and over-delivery; allocation rules that distribute collective proceeds among participants according to shares, metered contribution, or contractual coefficients; and temporal clauses defining settlement windows and true-up procedures. The execution sequence depends on a verified data pathway from metering to the ledger through a permissioned validation layer, with on-chain event logs recording verified offers, matches, and settlements. This architecture enables transparent and auditable value exchange across pilots while preserving privacy by storing only hashed proofs on-chain.

FEDECOM's technical backbone, the Grid Singularity (GSY) Distributed Energy Exchange (DEX) platform, is visualised in

Figure 2. This modular blockchain-based architecture underpins secure trading, performance verification, and automated remuneration for all pilots. The architecture enables order matching, trade execution, KPI-driven settlement, and integration with external analytics or payment providers. Importantly, the platform's flexibility has allowed project partners to rapidly test new incentive structures, user permission schemes, and market logic configurations in response to pilot feedback.

As pilots progress, continuous improvement is guided by lessons learned from each demonstration site, technical user feedback, and evolving regulatory environments. For example, the BeNeLux Cross-country e-mobility pilot (Use Case 6) underwent substantial adaptation during the project, and the results described reflect both implemented features and ongoing work. The factsheets highlight ongoing challenges: for example, user training and legacy integration in the Swiss federation, regulatory negotiation for cross-border trading in BeNeLux, and iterative technical adaptation in the hydrogen and municipal pilots. The FEDECOM experience demonstrates that while robust, modular digital platforms and business model innovation are essential enablers, true alignment is achieved through ongoing co-design, flexible adaptation, and sustained stakeholder partnership.

While each use case reflects distinct contexts and objectives, several recurring challenges and transferable lessons can be identified across all pilots. Across the six pilot sites, several cross-cutting findings emerged. Interoperability between local assets and the federation platform proved to be a recurring challenge, requiring custom data mappings and integration interfaces. Regulatory uncertainty—especially around collective self-consumption boundaries and flexibility remuneration—was identified in all cases as a limiting factor for scalability. Despite these barriers, user engagement remained consistently strong when value propositions were framed around measurable local benefits such as cost savings, resilience, or environmental impact. Finally, pilots that combined technical validation with governance experimentation showed greater potential for replication, suggesting that social and institutional readiness is as critical as technical performance for successful scale-up of federated energy communities.

Discussion and implications

The FEDECOM pilot experiences reinforce that business model innovation and digital platform alignment for energy communities must be understood as adaptive, iterative, and context-dependent processes. The diversity of outcomes across pilots—from Spanish district heating to Swiss hydropower to cross-border e-mobility—demonstrates that both technical and organisational pathways are shaped by legacy infrastructure, regulatory environments, and evolving user needs.

One central lesson is that co-design between platform developers, technical partners, and local actors is essential. In several pilots, such as Ur Beroa and Bilbao City Hall, transparent real-time monitoring and automated settlement created immediate value, but also surfaced new requirements for user support and integration with existing systems. Where technical upgrades enabled new flexibility, storage, or trading capabilities,

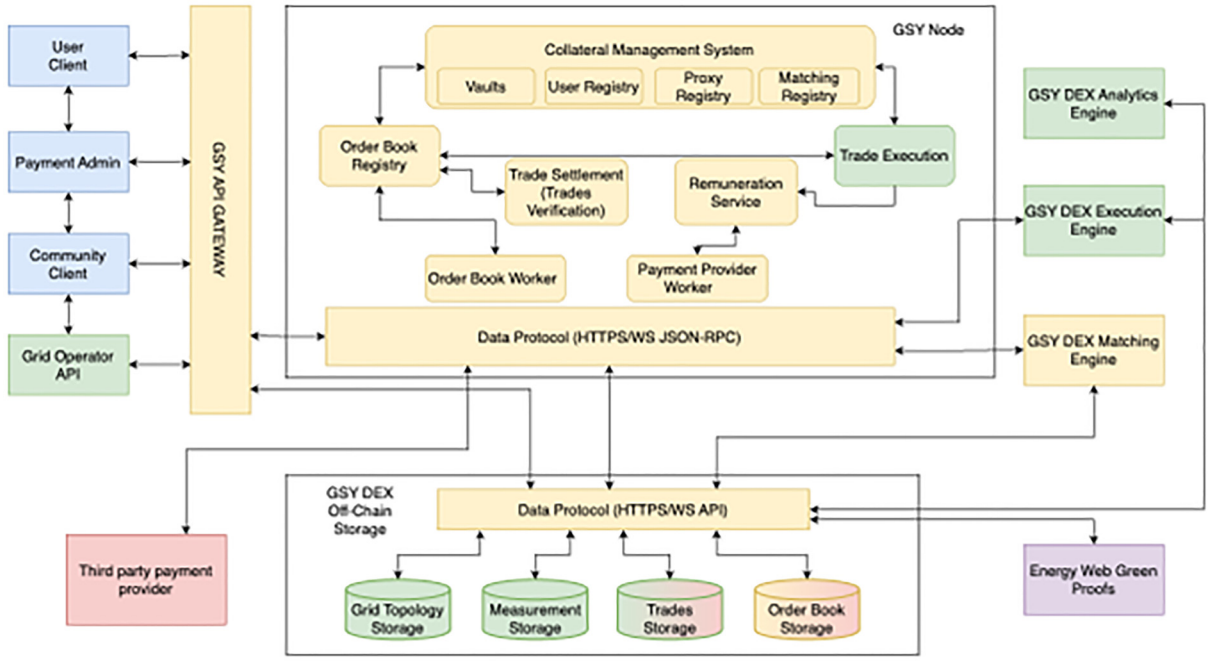


Figure 2. System architecture of the FEDECOM GSY DEX platform, showing blockchain-based market, remuneration, analytics, and payment integration. Adapted from technical documentation developed within FEDECOM WP6.

business models were adjusted in parallel—a process often requiring multiple iterations of user training and feedback.

These findings align with broader theories of digital transformation and business model innovation. The iterative adaptation observed across pilots exemplifies the principles of open innovation, where value creation emerges through continuous stakeholder collaboration and learning. Similarly, the evolving alignment between platform functionality and user needs reflects a dynamic capabilities perspective, in which organisations develop, integrate, and reconfigure resources to respond to technological and regulatory change. Moreover, the role of blockchain in strengthening transparency and trust resonates with prior research on digital accountability, confirming that distributed verification mechanisms can reinforce legitimacy and confidence in decentralised systems. Together, these parallels situate the FEDECOM results within ongoing academic debates on how digitalisation reshapes both organisational processes and value creation in energy systems. Building on these theoretical parallels, the following practical recommendations specify how different stakeholder groups can operationalise these insights.

The pilot factsheets highlight that technological enablement alone does not guarantee operational or financial success. For instance, while the FEDECOM platform allowed the Puertollano Green Hydrogen Plant and TMB Hydrogen Station to trial advanced energy management and market participation, the actual commercial impact is still dependent on regulatory approval and business model maturity. Similarly, in the BeNeLux e-mobility federation, technical feasibility of cross-border energy trading was demonstrated, but full implementation remains subject to legal, market, and organisational challenges.

Replication and scalability emerged as both opportunity and challenge. The Swiss federation's positive experience with flexibility sharing and transparent data analytics points to pathways for replication elsewhere but also underscores the ongoing need for stakeholder engagement and adaptation to local context. Across all pilots, feedback repeatedly emphasised that the platform's value was maximised when customisation—of business logic, user interface, and reporting—was prioritised.

A persistent barrier is regulatory and market alignment. Even with a flexible, modular platform, pilots encountered shifting requirements, uncertain remuneration pathways, and sometimes lengthy approval processes. These findings confirm that digital platform innovation must proceed in lockstep with policy advocacy and regulatory dialogue, not as an isolated technical exercise.

Concrete examples from the pilot contexts illustrate how targeted policy adjustments could accelerate adoption. In Spain, collective self-consumption is legally permitted but restricted to installations within a two-kilometre radius, limiting the potential for multi-municipal federation. Extending this perimeter or introducing dynamic virtual boundaries would enable wider replication of community trading schemes. In Switzerland, energy communities are recognised in law, yet participation in ancillary and flexibility markets remains limited to licensed suppliers; allowing certified community operators to aggregate and bid flexibility would open new revenue channels. In the Benelux region, cross-border coordination is hindered by differing tariff structures and settlement rules, suggesting that harmonised data-exchange protocols and standardised balancing-responsible roles are essential for scaling federated trading. These examples demonstrate that relatively small regulatory adjustments could substantially expand the operational reach of community-based digital marketplaces.

To complement this diagnosis with actionable steps, we propose a set of standardised regulatory measures that directly enable community-scale digital trading and automated remuneration: (i) harmonising distance and perimeter regulations for collective self-consumption to enhance federation among neighboring municipalities; (ii) establishing standard product templates and minimum bid sizes to encourage community involvement in flexibility and ancillary service markets, explicitly recognising community operators and aggregators as valid participants; (iii) creating a uniform KPI catalog and data exchange profiles to ensure comparability in remuneration and performance reporting across DSOs and TSOs; (iv) delineating data protection responsibilities for both on-chain and off-chain components to enable privacy-preserving settlements while maintaining auditability; and (v) acknowledging smart contract-based settlements and their integration with licensed payment services in sectoral guidance to ensure that automated remuneration aligns with existing market settlement and retail billing mechanisms.

While blockchain offers distinct advantages in transparency and automation, it also introduces technical and operational challenges that affect scalability. Transaction costs, computational overhead, and infrastructure requirements can increase complexity—particularly for public or hybrid networks used for frequent settlements. The architecture implemented in FEDECOM mitigates these impacts through a lightweight permissioned ledger with delegated validation and off-chain data handling, reducing energy use and latency compared with traditional proof-of-work systems. Nonetheless, additional coordination, cybersecurity, and compliance demands remain, underscoring the need to balance decentralisation and auditability with operational efficiency and regulatory simplicity in future replications.

The energy consumption associated with the blockchain layer was assessed during pilot operation and found to be negligible compared with overall community energy use. Because FEDECOM employed a permissioned ledger with delegated validation and off-chain data storage, the consensus mechanism required only minimal computational effort. Continuous monitoring confirmed that the additional electricity demand of validation nodes was insignificant relative to the efficiency gains achieved through automation and reduced manual processing. These findings support the feasibility of blockchain deployment in community-scale applications without compromising the system's net energy performance.

Ensuring replicability and scalability of the platform beyond the six pilots requires meeting several preconditions. First, interoperable data infrastructures and standardised metering interfaces must be in place to enable secure, verifiable exchange of operational data across communities. Second, governance frameworks should formally recognise community operators and aggregators as market participants capable of contracting flexibility and trading energy across jurisdictions. Third, regulatory environments need to support collective self-consumption and cross-community federation through harmonised distance and perimeter rules. Fourth, financial and institutional capacity at the local level is essential for operating and maintaining the digital infrastructure, including settlement, cybersecurity, and user support services. Meeting these prerequisites allows the FEDECOM model to scale from isolated pilots to a federated ecosystem of interoperable community markets, supported by practical resources such as the project's Replication Playbook[1] and Self-Assessment Tool[2], which guide stakeholders through technical, regulatory, and organisational readiness checks for adoption and scale-up.

The FEDECOM experience also points to several forward-looking implications. First, open, modular platforms are crucial for enabling communities to experiment with new roles and business models as market rules evolve. Second, meaningful and ongoing stakeholder co-creation—including feedback loops, capacity building, and transparent communication—are prerequisites for sustainable deployment. Third, as community energy grows in scale and complexity, continuous improvement in both platform technology and business models is necessary, informed by real-world data and emerging best practices. Future work should also benchmark the scalability, energy use, and user acceptance of blockchain-based platforms versus centralised alternatives in operational settings.

In summary, FEDECOM's pilot phase demonstrates that digital platform and business model innovation for energy communities is an ongoing, collaborative process. The platform's modularity and flexibility allowed diverse communities to test, adapt, and advance new solutions, while also revealing the central importance of local engagement and regulatory fit. These insights should inform not only the next phase of FEDECOM but also the wider community energy sector as it moves toward a more decentralised, digital, and participatory future.

The implications of these results differ across stakeholder groups. For policymakers, the evidence suggests that regulatory frameworks must evolve toward recognising community operators as legitimate market actors and enabling cross-community trading under harmonised data and settlement rules. For community operators and local authorities, success depends on institutional capacity to manage digital platforms, ensure cybersecurity, and engage users through clear value propositions linked to measurable outcomes. For technology providers, future development should prioritise interoperability and low-overhead remuneration mechanisms to minimise integration and operational costs. Addressing these needs collectively will accelerate the emergence of scalable, federated community energy systems that combine technological efficiency with social legitimacy.

Conclusions and future directions

This study demonstrates that innovation in energy community business models and digital platform design—particularly those leveraging blockchain-enabled architectures—is both essential and inherently iterative. The FEDECOM pilots across Spain, Switzerland, and Benelux show that a modular, blockchain-based platform can support transparency, automation, and secure multi-actor value flows for a wide range of sector-coupled community models. Real-world deployments confirmed that technical upgrades such as smart contract-based settlement, auditability, and automated remuneration, when aligned with clear business models and local needs, enable new forms of trust, participation, and operational efficiency.

Beyond its empirical insights, this study makes a dual contribution. Theoretically, it advances understanding of how business model innovation and digitalisation interact in decentralised systems, showing that blockchain and digital platforms not only facilitate transactions but also redefine accountability, transparency, and adaptability. Practically, the cross-pilot analysis demonstrates how iterative co-design, measurable remuneration logic, and platform interoperability can translate these principles into actionable frameworks for replication. Together, these findings link conceptual progress on digital transformation with evidence from real-world deployment, bridging academic and practical domains.

However, the experience also underscores that digital platforms and blockchain are not one-size-fits-all solutions. Success depends on careful co-design with users, robust technical integration, and ongoing adaptation to regulatory and market changes. Achieving robust and replicable energy community solutions requires a combination of digital innovation, flexible business model design, and continuous engagement with stakeholders at all levels.

Looking ahead, future work should further benchmark the scalability, energy efficiency, and user acceptance of blockchain-based versus centralised solutions in operational community settings. Continued research is also needed to advance interoperability, support sector-coupling, and enable integration with third-party and external market platforms. Most critically, policy and regulatory frameworks must keep pace with digital innovation, ensuring that communities can benefit fully from the transparency, automation, and resilience that these platforms offer.

Future research should extend beyond technical benchmarking to examine the governance and accountability mechanisms

[1] http://fedecom-project.eu/wp-content/uploads/2025/10/FEDECOM-Replication-Playbook_compressed.pdf

[2] https://fedecom-project.eu/solutions/#ReplicationSelf-AssessmentTool

underpinning federated energy platforms. Particular attention is needed on long-term sustainability — including platform ownership models, data-sharing incentives, and lifecycle maintenance — to ensure that digital infrastructures supporting energy communities remain transparent, inclusive, and resilient over time.

In summary, the FEDECOM pilots confirm that digitally enabled, blockchain-based platforms—when matched to context-specific business models and implemented through close collaboration—offer a viable path forward toward scalable, transparent, and resilient energy communities across Europe.

Ethics and consent

No ethics and consent were required.

Disclaimer

The views expressed in this article are those of the author. Publication in Open Research Europe does not imply endorsement of the European Commission.

Data availability statement

No data are associated with this article.

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Open Peer Review

Current Peer Review Status: ✔ ✘ ✔ ✔

Version 2

Reviewer Report 16 December 2025

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✔ **Assunta Di Vaio**
University of Naples "Parthenope", Naples, Italy

Dear Author and the Open Research Europe Editorial Team,

I have read the revised version of Blockchain-enabled business model innovation in sector-coupled energy communities. Taking into account the literature-related limitations the authors themselves acknowledge, which are consistent with the document type, I consider that—when framed as an open letter—the revision is sufficient.
Updated recommendation: Approved.

Best regards
Assunta Di Vaio

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Sustainability Accounting and Management

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 22 November 2025

https://doi.org/10.21956/openreseurope.23339.r64187

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✔ **Rakibul Hasan Chowdhury**

Trine University, Angola, Indiana, USA

Detailed Review and Expanded Assessment
1. Rationale for the Open Letter
Evaluation: Yes
Expanded Comments:
The motivation behind the Open Letter is articulated clearly and in sufficient detail. The authors describe existing challenges in sector-coupled energy communities, including interoperability barriers, regulatory fragmentation, transparency limitations, and the complexity of integrating digital platforms with evolving business models. The rationale for presenting insights from six pilot deployments is compelling, particularly given the scarcity of real-world evidence in blockchain-enabled community energy systems.
No essential corrections required.
2. Referencing of Differing Views and Opinions
Evaluation: Yes
Expanded Comments:
The manuscript engages effectively with diverse academic and technical perspectives. The authors reference policy challenges, debates on blockchain's suitability, constraints around sector coupling, and differing theoretical perspectives on digital transformation. The discussion reflects intellectual balance and situates the study adequately within broader scholarly debates.
No revisions needed.
3. Accuracy of Factual Statements and Adequacy of Citations
Evaluation: Yes
Expanded Comments:
The manuscript is extensively referenced with academic studies, EU deliverables, systematic reviews, and project documentation. Factual statements regarding energy communities, digital platform architectures, regulatory frameworks, and blockchain mechanisms appear accurate and well supported. The citation list is exceptionally comprehensive and appropriate for this work.
No essential revisions required.
4. Accessibility of Language
Evaluation: Partly
Expanded Comments:
The article is generally well written and logically structured; however, due to the highly technical nature of the subject matter, some terminology may be challenging for non-expert readers. Specific terms that may require brief clarification include:

- "distributed verification,"
- "permissioned ledger with delegated validation,"
- "KPI-driven settlement logic,"
- "sector-coupled federated markets,"
- "P2X trading pathways,"
- "baseline vs. reporting period KPI validation,"
- "federation architecture."

Recommended Improvements (Not mandatory for scientific validity but important for accessibility):
 Provide short definitions or parenthetical clarifications for specialised blockchain and energy-market concepts.

 Consider adding a short glossary or summary table of technical terms.
 Streamline long paragraphs in the methodology and platform-architecture sections to improve readability.

Points NOT required for scientific soundness, but recommended for broader accessibility.

5. Clarity of Recommendations and Next Steps

Evaluation: Yes

Expanded Comments:

The recommendations are clearly presented and relevant to a variety of stakeholder groups. The authors offer actionable pathways for policymakers, operators, community managers, and platform developers. The regulatory recommendations—such as harmonising energy-community perimeters, standardising flexibility market participation, and defining KPI-based settlement rules—are particularly valuable.

No major revisions needed.

Overall Assessment and Scientific Validity

This article is **scientifically sound**, well-structured, and grounded in robust evidence. It contributes meaningful insights into the digitalisation of community energy markets and provides a rare set of real-world observations from six pilot deployments—an area where empirical research is urgently needed.

The only area where improvement is advisable relates to **language accessibility and clarification of certain technical terms**. These enhancements will broaden the usability of the article but are **not required** for scientific correctness.

Specific Points That Must Be Addressed for Scientific Soundness

None.

The manuscript is methodologically sound and scientifically valid as written. Recommended changes relate to clarity, not correctness.

Minor Suggestions for Enhancement (Optional, Not Required)

1. Add brief explanations of technical terminology to support non-specialist readers.
2. Consider summarising the core findings from Table 1 in a short narrative paragraph to enhance readability.
3. Provide a small diagram illustrating the “validation cycle” linking stakeholder workshops, KPI measurement, and remuneration verification.
4. Condense or restructure long paragraphs in the “Methodology” and “Discussion” sections for improved flow.

Final Recommendation

Approval Status: Approved

The article meets Open Research Europe’s criteria for methodological soundness, clarity of argument, proper referencing, and scholarly rigor. With minor accessibility refinements, it will serve as a strong and valuable contribution to the ongoing discourse on blockchain-enabled digitalisation in energy communities.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)

Yes

Does the article adequately reference differing views and opinions?

Yes

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Yes

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)
Partly

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital Transformation & Enterprise Technologies, Blockchain and Distributed Ledger Systems, Artificial Intelligence & Machine Learning Applications, Cybersecurity and National Cyber Defense Frameworks, Energy Informatics and Smart/Decentralised Energy Systems, Business Model Innovation & Digital Platform Ecosystems, Data Analytics, Decision Intelligence, and Intelligent Enterprise Systems & E-Governance, Digital Public Services, and Technology Policy

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 31 October 2025

https://doi.org/10.21956/openreseurope.23339.r61950

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Ángel Paredes
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While the author has made efforts to address previous feedback, primarily through reorganization and the addition of new sections, the manuscript remains fundamentally descriptive and lacks the analytical depth and empirical specificity required for a scientific contribution. The following points, several of which were raised in the first round, have not been adequately resolved:
1. The methodological justification, while now mentioning alignment with the BRIDGE initiative, still fails to articulate a novel methodological contribution. The description of a "multi-stage,

mixed-methods approach" remains a label rather than a rigorous framework. The paper does not convincingly argue why this specific methodology is necessary or how it advances upon established practices in business model research.
2. The newly introduced Lean Model Canvas synthesis is overly generic and disconnected from the empirical data. It presents a list of theoretical business model building blocks but does not demonstrate how these were derived from or evidenced by the specific pilots. There is no mapping showing how different customer segments or revenue streams manifested across the diverse use cases, which would be the minimum expected from a cross-case analysis claiming to identify a replicable model.
3. The reorganized "FEDECOM business model innovation and platform alignment" section improves the narrative flow but fails to deliver the promised analytical depth. The "general" model is stated without sufficient validation, and the "specific" pilot descriptions remain focused on assets and high-level outcomes. A detailed exposition of how the general business model logic was operationalized, adapted, or challenged in each specific context is absent. This omission is a major weakness, as it is precisely this translation from theory to practice that constitutes the only paper's contribution.
4. The regulatory analysis is flawed and lacks credibility. The claim that "regulatory environments need to support... recognition of community operators and aggregators as market participants" is factually incorrect, as this recognition is already a cornerstone of Directive 2019/944. Furthermore, the discussion on cross-border trading does not engage with existing solutions and ongoing standardisation (e.g., ENTSO-E's platforms for cross-border balancing), which makes the proposed recommendations irrelevant.
5. The explanation of the smart contract design remains insufficient for a technical audience and provides no meaningful insights for replication. The text describes generic functional boxes (e.g., "KPI-based trigger conditions," "allocation rules") but omits the specific, operational details that are essential for understanding and trust in the system. For the analysis to be of value, it must specify the exact KPIs used, the numerical values for tolerance bands, the logic and values of penalties/rewards, and the concrete formulae for allocation coefficients. The current description is too vague to be scientifically useful.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Business models analysis, market participation strategies, artificial intelligence, DER management.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 25 October 2025

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Tiago Soares
Center for Power and Energy Systems, INESC TEC, Porto, Portugal

The author has provided satisfactory replies and implemented appropriate changes to the article in line with this reviewer's suggestions. The revisions have improved the analytical depth, methodological clarity, and overall quality of the manuscript.
Minor comment:
The quality and resolution of Figure 2 are not optimal. It should be improved to ensure readability and visual consistency with the other figures in the paper.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Energy communities

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 03 October 2025

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Assunta Di Vaio
University of Naples "Parthenope", Naples, Italy

This Open Letter titled Blockchain-enabled business model innovation in sector-coupled energy communities explores the linkages between business model innovation and blockchain-enabled digital platforms in the context of sector-coupled energy communities. The topic is highly relevant, and the empirical material provided by the FEDECOM pilot projects offers useful insights that go beyond conceptual speculation. The document clearly has the potential to make a contribution both to academic debate and to practice. However, several issues require further refinement before this document can reach the level of rigour. My overall recommendation is for minor revisions, although the issues I outline are essential for strengthening this Open Letter titled Blockchain-enabled business model innovation in sector-coupled energy communities.
The abstract is clear and well organised, summarising the scope of the study and the key results. Nonetheless, it remains at a mainly descriptive level. The author should use this section to signal more explicitly their theoretical contribution, rather than focusing almost exclusively on pilot results. Highlighting how the study advances academic debates on business model innovation and digital transformation would make the abstract more balanced and impactful.
The introduction successfully positions energy communities within the broader European

decarbonization agenda, emphasising their role in fostering citizen participation and sector integration. Yet, the research gap is somewhat implicit. The abundance of existing conceptual and proof-of-concept studies contrasts with the limited number of empirical analyses of real-world business models integrated with blockchain-enabled platforms. This tension should be highlighted more directly to justify the necessity of the study. Likewise, the research question is discernible but never explicitly stated. Formulating it clearly and concisely would help all readers understand precisely how the paper aims to contribute to the literature.

The literature review demonstrates breadth but not always depth. It presents a wide range of sources on business models, blockchain applications, and regulatory barriers, but the narrative occasionally becomes fragmented, listing findings without synthesising them into a coherent framework. The authors could improve this section by structuring it more clearly around categories such as business model archetypes, digitalisation and trust, and governance and regulation. Moreover, the review would benefit from engagement with broader strands of research beyond the immediate energy community field. For example, work published in journals such as the *Journal of Enterprise Information Management* has examined how digitalisation and accountability mechanisms reshape transparency and value flows, which could reinforce the discussion of blockchain's role in enabling trust. Studies in *Production Planning & Control* have analysed inter-organisational relationships in logistics and port operations, offering useful parallels for understanding platformisation and multi-actor coordination in energy systems. Research in *Scientific Reports* has recently investigated the interaction between environmental uncertainty, digital technologies, and corporate green behaviour, which could provide a richer foundation for discussing adaptive and flexible business models under regulatory and market uncertainty. Finally, systematic literature reviews in the *Journal of Business Research* have explored the role of digital innovation in knowledge management systems, offering a framework for interpreting blockchain not only as a technical infrastructure but also as a mechanism for distributed knowledge creation and sharing. You can also find several papers on business models and technological innovation in the Journal of Business Research and the Journal of Cleaner Production. Integrating these streams would allow the manuscript to connect with wider theoretical debates and situate its contribution more firmly in the literature.

The methodology section is promising, as it employs a mixed-methods approach that combines literature review, value proposition mapping, and analysis of six pilot cases. The use of the Value Proposition Canvas is appropriate for capturing user needs and linking them with digital platform features. However, the justification for this methodological choice remains underdeveloped. The authors should connect their approach to existing studies that have applied similar frameworks in contexts of digital innovation, business model design, or knowledge management. Without this link, the method risks appearing arbitrary or too closely tied to the specific project. The section would also be strengthened by clarifying the nature of the data sources, the role of stakeholders, and the way feedback loops were managed across pilot sites. This would increase the transparency and reproducibility of the analysis.

The results section provides a rich and detailed description of each pilot case, outlining the technological features tested and the organisational arrangements explored. While this descriptive detail is valuable, the analysis does not always rise above the level of case-by-case reporting. The paper would benefit from more explicit comparative analysis across cases, drawing out the common barriers, recurring challenges, and transferable solutions. A stronger cross-case synthesis would allow the results to move from descriptive accounts toward more generalisable insights.

The discussion section identifies important results, such as the iterative nature of business model adaptation and the need for co-design with stakeholders. These are indeed key lessons, but the

discussion currently reads more as an extension of the results rather than a critical engagement with the literature. The author should highlight more clearly how the results confirm, extend, or challenge prior studies, particularly in relation to theories of digital transformation, business model innovation, and knowledge management. For example, the claim that blockchain enhances trust and transparency could be situated in the literature on accountability and digitalization, while the observation that business models evolve iteratively could be linked to open innovation or dynamic capabilities frameworks. Establishing these theoretical connections would greatly enhance the scholarly significance of the discussion.
The implications of this study are promising but need to be elaborated. On the theoretical side, the authors should clarify how the findings contribute to ongoing debates about digital innovation and business models in decentralised systems. At present, the theoretical implications are noted but remain too general. On the practical side, the recommendations are useful but presented at a high level of abstraction. Rather than simply calling for regulatory adaptation or user engagement, the paper should provide more concrete guidance that distinguishes between the needs of policymakers, community operators, and technology providers. Offering stakeholder-specific recommendations would make the paper's practical relevance clearer and more actionable.
The conclusion is concise and provides a good summary of the study. However, it could do more to underline the dual contribution to theory and practice. The authors should restate explicitly how the empirical evidence advances theoretical understanding of business model innovation and digitalisation, while also drawing out more concrete lessons for practitioners. Future research directions should not be limited to technical benchmarking but should also include governance, accountability, and the long-term sustainability of digital platforms in energy communities.
In summary, this 'Open Letter' is based on valuable empirical material and addresses an important question for the energy transition. It demonstrates convincingly that business model innovation and blockchain-enabled digital platforms can support sector-coupled energy communities, but it does not yet fully capitalise on its potential to contribute to the academic literature. To achieve this, the paper should make the research gap and question explicit, strengthen the literature review with broader and better synthesised sources, justify the methodological choices with reference to similar studies, provide deeper cross-case analysis in the results, connect the discussion more explicitly to theoretical debates, and expand both theoretical and practical implications. If these revisions are undertaken, the manuscript will stand as a meaningful contribution to scholarship on energy communities, digital transformation, and business model innovation, while also offering actionable insights for practitioners and policymakers engaged in the transition toward decentralised and sustainable energy systems.
I have observed that this study has been categorized as an Open Letter. In my view, this classification does not fully reflect the nature of the work. Given its empirical foundation, methodological approach, and the evidence presented through pilot cases, the manuscript would be more appropriately classified as an empirical research article. Reconsidering the categorization would ensure that the paper is properly positioned within the journal's publication typologies and that its contribution is evaluated accordingly.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)

Partly

Does the article adequately reference differing views and opinions?

Partly

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Partly

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)
Partly

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
Not applicable

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Sustainability Accounting and Management

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 06 Oct 2025

Zia Lennard

I am sincerely grateful for the reviewer's thoughtful and encouraging feedback. The detailed comments have helped me strengthen the analytical rigor and scholarly positioning of the manuscript while remaining faithful to the concise format required by *Open Research Europe*'s Open Letter classification. Below I address each point in turn.

1. Abstract and theoretical contribution

The abstract has been revised to better communicate the study's theoretical contribution. I added a sentence explicitly highlighting how the analysis advances understanding of digitalisation and distributed governance in energy communities by linking iterative co-design and blockchain-based verification to broader theories of digital transformation and value creation.

2. Research gap and explicit research question

The introduction was expanded to make the research gap clearer. I added two sentences explicitly contrasting the abundance of conceptual studies with the lack of empirical evidence on real-world, blockchain-integrated energy community models. Immediately following this clarification, I inserted a concise research question that directly frames the paper's analytical focus.

3. Literature review scope and structure

I fully acknowledge the reviewer's valuable suggestions regarding the breadth and synthesis of the literature review. However, given *Open Research Europe*'s revision procedure for Open Letters—which does not allow major structural reorganisation or insertion of new, external academic material beyond the approved manuscript scope—it was not possible to extend the review to include additional academic domains such as enterprise information management, logistics, or knowledge management. Instead, I improved the internal coherence of the existing section by clarifying transitions between paragraphs and reinforcing the synthesis of cited studies around three conceptual strands: business model innovation, digitalisation and trust, and governance and regulation. This approach maintains readability while aligning with the reviewer's suggestion for a clearer conceptual structure.

4. Methodology justification and reproducibility

The methodology section has been expanded to justify the multi-stage, mixed-methods approach in relation to established frameworks for business model design and digital innovation. I clarified how the Value Proposition Canvas was operationalised through iterative co-creation and feedback loops across the six pilot sites, and added a short paragraph explaining how this ensures methodological transparency and reproducibility.

5. Cross-case synthesis in the results

To strengthen analytical depth, I introduced a new synthesis paragraph following the pilot descriptions. This identifies recurring themes and transferable innovations across the six cases, highlighting shared patterns in stakeholder engagement, platform integration, and flexibility monetisation.

6. Discussion and theoretical engagement

I reworked the discussion section to better connect empirical findings to theoretical debates. The text now explicitly references how the results confirm or extend existing perspectives on open innovation, digital accountability, and iterative business model adaptation. This reframing underscores the paper's dual contribution to both theory and practice.

7. Practical implications and stakeholder-specific recommendations

The implications section was expanded to distinguish between the needs of policymakers, community operators, and technology providers. Each group now has tailored recommendations, improving the paper's practical relevance and direct applicability.

8. Strengthening the conclusion

I revised the conclusion to restate the dual contribution to theory and practice. The final

paragraph now highlights how empirical insights from the pilots enhance understanding of digitalisation in decentralised systems while also offering practical lessons for implementing scalable, transparent, and resilient energy communities. I also added a sentence identifying governance, accountability, and long-term platform sustainability as key directions for future research.

9. On classification as an Open Letter

I appreciate the reviewer's view that the paper might better fit the "empirical research article" category. However, since the initial submission was accepted under the Open Letter format, reclassification would require editorial approval. I have nevertheless ensured that the revised version meets the rigour expected of an empirical contribution while maintaining the format conventions of the Open Letter type. I believe these targeted revisions fully address the reviewer's recommendations and enhance both the scholarly depth and practical clarity of the paper while respecting *Open Research Europe*'s formal revision process.

Competing Interests: No competing interests were disclosed.

Reviewer Report 17 September 2025

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Ángel Paredes
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This open letter analyses the integration of blockchain-enabled digital platforms with business model innovation across six diverse, sector-coupled energy community pilots within the FEDECOM project. The topic is highly timely and addresses a critical research gap at the intersection of digitalization, decentralization, and energy system integration. However, while the letter is well-structured and its objectives are clear, its potential impact is hampered by a descriptive rather than analytical approach, a lack of measurable results, and missed opportunities to connect findings to broader industry initiatives. The following remarks are offered to strengthen the manuscript:
1. The methodology, described as a "multi-stage, mixed-methods approach," remains vague. A more rigorous justification is needed, clarifying how the synthesis of workshop outputs and literature review constitutes a novel methodological contribution compared to established practices in business model analysis for energy communities. Furthermore, the analysis would be significantly enriched by contextualizing its findings within existing standardization efforts, notably the BRIDGE Business Models Working Group initiative, to clarify how FEDECOM's approach

aligns with or diverges from current European best practices.
2. The core goal of demonstrating "replicable value propositions" is not fully met. The letter would be substantially strengthened by moving beyond case-specific descriptions to synthesize a generalized, demo-wide value proposition framework. A powerful way to achieve this would be to present a Lean Model Canvas that conceptualizes the commonalities of the blockchain-enabled business model across all pilots, explicitly mapping its contributions and disruptions to the traditional energy value chain.
3. Figure 1, in its current form, functions merely as a summary of pilot assets and lacks analytical value. This figure should be revised or supplemented to visually articulate the innovation in each business model and value propositions for each case.
4. Section "FEDECOM business model innovation and platform alignment" suffers from a "specific-to-general" with unclear innovations. It should be reorganized to first present the overarching business model logic and architectural framework of the FEDECOM platform (the general), before then detailing how each pilot instantiates and adapts this model (the specific). This would provide readers with a clear analytical framework before diving into the case details, making the business model innovations far more comprehensible.
5. The discussions on regulatory barriers are not paired with sufficiently concrete or actionable recommendations. The letter must go beyond stating that "policy must keep pace" and provide specific, actionable and standardized proposals for regulators that would directly facilitate the adoption of these technologies.
6. The design of smart contracts is the operational heart of the proposed blockchain-based business models, yet it is treated as a black box. The letter misses a critical opportunity to provide actionable insights for practitioners by discussing the essential clauses, logic, and dependencies required in these contracts to automate remuneration, manage flexibility, and enforce KPI-based settlements effectively.
7. A significant omission is a discussion of the trade-offs involved in using blockchain. The letter states the benefits of transparency and automation but neglects the inherent disadvantages, such as the energy consumption of the consensus mechanism, transaction costs (gas fees), and computational complexity.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)

Yes

Does the article adequately reference differing views and opinions?

Partly

Are all factual statements correct, and are statements and arguments made adequately supported by citations?

Partly

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)

Partly

Where applicable, are recommendations and next steps explained clearly for others to

follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Business models analysis, market participation strategies, artificial intelligence, DER management.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 06 Oct 2025

Zia Lennard

I sincerely thank you for your detailed and constructive feedback. The comments have been invaluable in strengthening the analytical depth and methodological clarity of this revised version. All seven points have been addressed as follows:

1. Methodology clarification and alignment with standardisation efforts
I have substantially revised the methodology section to clarify the structure and novelty of the “multi-stage, mixed-methods” approach. The text now explicitly distinguishes between the qualitative (stakeholder workshops, value proposition mapping) and quantitative (KPI validation and comparative analysis) components. I also added a short paragraph linking the FEDECOM methodology to established European practices, referencing the alignment with ongoing work under the BRIDGE Business Models Working Group and other EU-funded initiatives. This demonstrates how the applied approach contributes to harmonising business model evaluation frameworks.

2. Demo-wide synthesis of replicable value propositions
To address this comment, I added a new paragraph following the description of the iterative co-design process, synthesising cross-pilot findings into a generalised value proposition framework. The text highlights shared innovation patterns, recurring value creation mechanisms, and transferable design elements. While a Lean Model Canvas format was considered, the synthesis was presented in narrative form to remain consistent with ORE’s Open Letter format.

3. Revision of Table 1 for analytical depth
I revised Table 1 (previously Figure 1) and its accompanying text to move beyond a descriptive listing of pilots. It now integrates analytical information regarding innovation focus, stakeholder relevance, and measurable impacts across pilots. The caption and surrounding paragraphs were rewritten to explain how these patterns illustrate the platform’s cross-sector scalability and interoperability.

4. Reorganisation of “FEDECOM business model innovation and platform alignment”

This section has been restructured to follow a "general-to-specific" logic. It now begins with a description of the overarching business model architecture, followed by pilot-level adaptations. A transition sentence was inserted to signal this change to readers, improving coherence and analytical flow.

5. Regulatory recommendations
I expanded the discussion of regulatory barriers to include specific recommendations. These include the need for harmonised energy-sharing frameworks, recognition of community aggregators as market participants, and simplified mechanisms for cross-border flexibility trading. This provides a more actionable basis for policymakers.

6. Smart contract design
In Section 4, I added a new paragraph describing the essential logic underpinning smart contracts used for settlement and KPI-based remuneration. This includes clauses related to validation, collateral management, and flexibility activation, offering practical insights into how blockchain enables automated verification within decentralised energy markets.

7. Discussion of blockchain trade-offs
I introduced a critical discussion of blockchain's limitations in Section 5, addressing computational complexity, transaction costs, and energy consumption. The revised text explains how FEDECOM mitigates these trade-offs through a permissioned ledger and delegated validation, reducing the energy footprint while preserving transparency. Overall, these revisions make the paper more analytical, more transparent in its methods, and better aligned with European best practices for business model innovation and digitalisation in energy communities.

Competing Interests: No competing interests were disclosed.

Reviewer Report 09 July 2025

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Tiago Soares
Center for Power and Energy Systems, INESC TEC, Porto, Portugal

This paper presents findings from the FEDECOM project, exploring how blockchain-enabled digital platforms can support business model innovation in sector-coupled energy communities. It is based on six pilot deployments across Europe and utilizes a structured methodology including value proposition mapping, stakeholder engagement, and analysis of technical and regulatory challenges. The paper argues that blockchain enhances transparency, trust, and automation, but must be paired with flexible, co-designed business models and ongoing regulatory alignment. The

paper is interesting and well written; however, some points can be improved, namely:

1. The pilots descriptions are interesting, but there is a lack of KPIS proving the benefits of such an approach. Perhaps, some KPIS can be included in the analysis to understand at to what extent the developed approach improves cost savings.
2. The benefits of using blockchain are emphasized in the paper, but the main disadvantages like energy use, complexity and costs are not considered. Perhaps a critical discussion of the trade-off between using the blockchain in detriment of the centralized approaches can be addressed.
3. The pilots are interesting and different. However, the replicability and scalability of the platform to other levels a is not addressed. Perhaps it can be provided a list outlining prerequisite for replication of the platform.
4. The paper addresses the regulatory uncertainty as a key barrier but does not provide clear contextual regulatory examples and how specific changes could unlock the issue.
5. It would be good to have an idea of how blockchain impacts energy consumption in each of the pilots to add credibility to the adopted solution.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)

Partly

Does the article adequately reference differing views and opinions?

Yes

Are all factual statements correct, and are statements and arguments made adequately supported by citations?

Yes

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)

Yes

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Energy communities

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 06 Oct 2025

Zia Lennard

I sincerely thank the reviewer for the careful reading and constructive comments. I am grateful for the positive assessment of the paper's relevance, structure, and clarity, and have carefully addressed all points raised.

1. Inclusion of KPIs to demonstrate benefits

I agree that the initial version did not sufficiently highlight quantifiable indicators. Section 4 has been expanded to include representative key performance indicators related to energy savings, flexibility activation, and remuneration accuracy. These examples illustrate how measurable validation results underpin the assessment of business model performance.

2. Discussion of blockchain disadvantages and trade-offs

I have added a new paragraph in Section 5 discussing energy use, computational complexity, and transaction costs. This addition compares blockchain-based architectures with centralised approaches and clarifies how FEDECOM's permissioned ledger design mitigates energy and latency challenges while maintaining transparency and auditability.

3. Replicability and scalability prerequisites

To address this valuable comment, I added a paragraph outlining preconditions for replication, including interoperability, governance recognition, regulatory alignment, and local financial capacity. This section now also references the FEDECOM Replication Playbook and Self-Assessment Tool as resources supporting scalability across contexts.

4. Regulatory examples and actionable proposals

I expanded the discussion on regulatory uncertainty to include concrete examples of permitting, perimeter definitions, and flexibility market access. The new text explains how harmonised recognition of energy communities as market participants could remove barriers to platform adoption.

5. Blockchain energy consumption across pilots

I added a paragraph clarifying that FEDECOM's platform uses a lightweight permissioned architecture with delegated validation and off-chain storage, which minimises energy use and computational demand. This contextualises blockchain efficiency within pilot operations and strengthens the credibility of the approach. I believe these revisions comprehensively address all points raised and significantly enhance the analytical depth and transparency of the paper.

Competing Interests: No competing interests were disclosed.