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DRIVING THE DEVELOPMENT OF ENERGY COMMUNITIES IN COLOMBIA: CHALLENGES AND OPPORTUNITIES FOR A DECENTRALIZED ENERGY TRANSITION

IMPULSANDO COMUNIDADES ENERGÉTICAS EN COLOMBIA: RETOS Y OPORTUNIDADES PARA UNA TRANSICIÓN ENERGÉTICA DESCENTRALIZADA

ESTÍMULO AO DESENVOLVIMENTO DE COMUNIDADES ENERGÉTICAS NA COLÔMBIA: DESAFIOS E OPORTUNIDADES PARA UMA TRANSIÇÃO ENERGÉTICA DESCENTRALIZADA

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ABSTRACT

Energy communities represent a transformative paradigm for democratizing access to renewable energy, decentralizing power systems, and fostering economic sustainability. This study analyzes their global development, with an emphasis on developing countries such as Colombia. The research employs a systematic literature review in Scopus and a keyword co-occurrence analysis to identify trends; in addition, Colombian regulatory documents were examined to contextualize the findings. The discussion addresses distributed generation, peer-to-peer (P2P) energy trading, and regulatory frameworks that drive local energy transitions. Although the opportunities are significant in Colombia, challenges persist in infrastructure, regulation, and social acceptance, particularly in the Caribbean region. The article proposes context-specific strategies from international experiences to overcome these barriers and consolidate decentralized energy systems that accelerate the country's energy transition and sustainable development.

Keywords
electricity, energy policy, energy resources

RESUMEN

Las comunidades energéticas representan un paradigma transformador para democratizar el acceso a energías renovables, descentralizar los sistemas energéticos y fomentar la sostenibilidad económica. Este estudio analiza su desarrollo global, con énfasis en países en vías de desarrollo como Colombia. La investigación utiliza una revisión sistemática en Scopus y un análisis de co-ocurrencia de palabras clave para identificar tendencias; además, se revisaron documentos regulatorios colombianos para contextualizar los hallazgos. Se abordan la generación distribuida, el comercio entre pares (P2P) y los marcos regulatorios que impulsan transiciones energéticas locales. En Colombia, aunque las oportunidades son significativas, persisten retos de infraestructura, regulación y aceptación social, especialmente en el Caribe. Este artículo propone estrategias adaptadas basadas en experiencias internacionales para superar dichas barreras y consolidar sistemas descentralizados que aceleren la transición energética y el desarrollo sostenible del país.

Palabras clave
energía eléctrica, política energética, recursos energéticos

RESUMO

As comunidades energéticas representam um paradigma transformador para democratizar o acesso à energia renovável, descentralizar os sistemas energéticos e promover a sustentabilidade econômica. Este estudo analisa seu desenvolvimento global, com ênfase em países em desenvolvimento, como a Colômbia. A pesquisa emprega uma revisão sistemática da literatura no Scopus e uma análise de coocorrência de palavras-chave para identificar tendências. Além disso, documentos regulatórios colombianos foram examinados para contextualizar os resultados. A discussão aborda a geração distribuída, o comércio de energia ponto a ponto (P2P) e os marcos regulatórios que impulsionam as transições energéticas locais. Embora as oportunidades sejam significativas na Colômbia, persistem desafios em infraestrutura, regulamentação e aceitação social, particularmente na região do Caribe. O artigo propõe estratégias específicas para o contexto, a partir de experiências internacionais, para superar essas barreiras e consolidar sistemas energéticos descentralizados que acelerem a transição energética e o desenvolvimento sustentável do país.

Palavras-chave:
energia elétrica, política energética, recursos energéticos

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INTRODUCTION

In the global energy transition context, clean energy sources have emerged as a fundamental solution to challenges associated with climate change, energy security, and sustainable development. Characterized by minimal environmental impact, these sources aim to reduce greenhouse gas emissions and promote more resilient and decentralized energy systems. According to Andoni et al. (2019), blockchain and other advanced technologies are transforming traditional energy models by enabling decentralized management and peer-to-peer (P2P) energy trading. Mollah et al. (2021) highlight that blockchain-enabled smart grids address security concerns in transactions and facilitate the integration of renewable resources into decentralized systems. The integration of distributed energy resources (DERs) has further catalyzed the adoption of renewables and the creation of energy communities, fostering prosumer participation in local energy markets (Morstyn et al., 2019). These innovations contribute not only to environmental sustainability but also to social cohesion and local economic development (Siano et al., 2019), marking a clear path toward the global energy transition.

The transition toward sustainability requires not only renewable sources but also advanced technologies that optimize resource use. In this context, P2P energy has emerged as a key mechanism, enabling direct transactions between prosumers and consumers within energy communities. This approach democratizes access and facilitates a decentralized, flexible energy market (Wang et al., 2019). P2P systems reduce energy costs and promote efficient use of renewables. For instance, Zia et al. (2020) show how local transactions facilitate renewable integration into microgrids, while Siano et al. (2019) demonstrate how distributed ledger technology (DLT) enables secure energy transactions through smart contracts, optimizing supply-demand balance. Mollah et al. (2021) note that decentralization is central to future smart grids, integrating Blockchain to overcome technical barriers.

However, adopting these systems presents regulatory and technical challenges, especially in regions where centralized structures still dominate. Andoni et al. (2019) and Soto et al. (2021) emphasize the need for regulatory clarity and robust infrastructure to implement P2P models in emerging regions effectively.

Energy communities play a crucial role in this transition, serving as catalysts for renewable technologies and autonomous governance mechanisms. They unite prosumers and consumers in dynamic markets, leveraging technologies like blockchain to ensure secure, transparent transactions (Gu et al., 2023; Wang et al., 2019). European implementation has shown that these initiatives can enhance energy resilience and reduce carbon emissions. where the integration of smart contracts enables process automation, improving both economic and environmental performance (Andoni et al., 2019; Mollah et al., 2021). Mollah et al. (2021) argue that combining Blockchain and smart grids is key to managing growing energy transactions efficiently.

Despite these benefits, energy communities still face regulatory, technical, and infrastructural barriers in developing countries. This underscores the need for further research to design adaptive models that reflect local conditions and ensure long-term viability (Gu et al., 2023; Siano et al., 2019).

OBJECTIVES OF THE LITERATURE REVIEW AND CONTRIBUTION TO THE FIELD

In the Colombian context, energy communities represent a strategic approach to addressing persistent challenges such as energy poverty, unreliable electricity supply, and regulatory barriers. The current legislative framework, promoted by the Ministry of Mines and Energy and the Energy and Gas Regulatory Commission (Comisión de Regulación de Energía y Gas – República de Colombia, 2011; Ministerio de Minas y Energía – República de Colombia, 2023b), allows the establishment of collective self-generators (AGRC, in Spanish) and collective distributed generators (GDC, in Spanish), fostering the adoption of non-conventional renewable energy sources (NCRES), including solar, wind, and biomass. These regulations, together with targeted incentives for projects in the Caribbean region, offer significant potential to improve energy access in areas affected by high tariffs and limited infrastructure.

At the global level, advanced technologies such as blockchain and smart contracts have transformed energy markets, permitting secure and transparent transactions between prosumers and consumers. Studies by Andoni et al. (2019) and Siano et al. (2019) have demonstrated how P2P trading democratizes access to renewable energy, reduces carbon emissions, and enhances local governance. These international experiences provide valuable insights for Colombia, particularly regarding integrating digital platforms that improve energy management and encourage community participation.

This literature review aims to analyze how energy communities, supported by technological innovations and adaptive regulatory frameworks, can contribute to a decentralized energy transition in Colombia.

METHODOLOGY

This study is grounded in identifying key trends and emerging patterns related to energy communities and their integration with advanced technologies such as

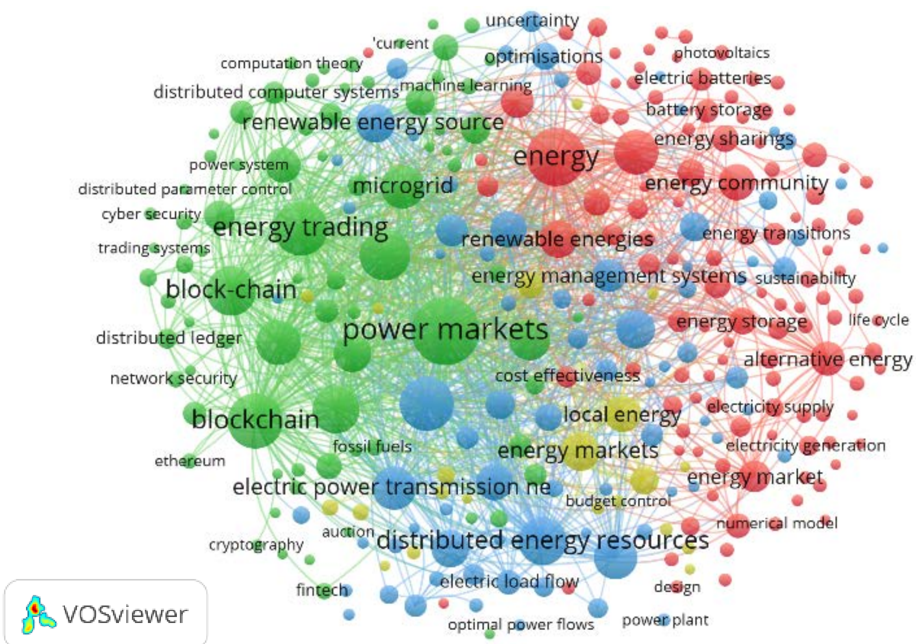

Figure 1. Co-occurrence map of keywords in the field of energy communities and associated technologies. Source: Prepared by the authors.

Blockchain and Smart Contracts. The Scopus database was used to ensure rigorous and representative analysis, as it includes peer-reviewed literature from high-impact journals (Codina, 2005). Search terms included "Energy communities", "Blockchain", "Smart contracts", and "Distributed energy markets."

The analysis followed several stages:

1. Initial screening and temporal delimitation. Titles and abstracts were assessed to identify studies aligned with the research focus. Articles had to include at least one of the predefined terms in the title, abstract, or keywords, using the Boolean operator OR. The timeframe extended from a seminal work (Andoni et al., 2019) to the most recent full year (2025), yielding 1,232 documents.
2. Application of exclusion criteria. Documents not in English, or not classified as scientific articles or reviews, were excluded. Publications unrelated to Engineering, Energy, or Computer Science were also removed, reducing the dataset to 609 documents.
3. Keyword co-occurrence analysis. To explore the conceptual structure of the literature, we used VOSviewer to identify relationships among frequent terms and uncover thematic clusters.
4. Thematic classification and prioritization. The remaining studies were classified into four key thematic categories to support a more focused and organized analysis: (i) implementation of digital technologies in energy communities (25 documents), (ii) regulatory and policy barriers (25), (iii) community governance models (25), and (iv) specific cases of renewable energy integration (25). Within each category, the most relevant studies were identified, prioritizing those with higher citation counts as an indicator of academic impact.
5. Final selection and in-depth analysis. A final subset of 13 scientific articles was selected for detailed review. The selection was based on their thematic alignment, methodological rigor, and scholarly influence. This final stage provided a robust foundation for the critical analysis of the most significant contributions in the field.

Additionally, the study incorporated regulatory and institutional perspectives to enhance contextual relevance. A distinctive feature was the inclusion of key regulatory documents (Ministerio de Minas y Energía – República de Colombia, 2023a) and reports (Comisión de Regulación de Energía y Gas – República de Colombia, 2011), which helped situate international trends within Colombia's context, especially in the Caribbean region, known for its high potential in non-conventional renewable energy sources.

RESULTS AND DISCUSSION

KEYWORD CO-OCCURRENCE ANALYSIS

This analysis uncovers the conceptual structure of the literature by identifying clusters of frequently co-occurring terms, thereby revealing key thematic relationships among the selected articles. Figure 1 presents a co-occurrence map, where nodes and links highlight thematic relationships among key concepts.

The keyword co-occurrence analysis identified three primary thematic clusters reflecting predominant research areas in energy communities and advanced technologies: Energy Transition and Energy Communities, Blockchain and Digital Technologies, and Energy Management and Efficiency. Below is a synthesis of the findings grouped by cluster, highlighting the main concepts and their context within the field.

- Energy Transition and Energy Communities (Red): This cluster focuses on research on creating sustainable energy generation and storage models. It emphasizes integrating renewable sources, active participation by energy communities, and the importance of decentralized energy markets. The strong connection between "energy sharing" and "energy community" highlights the crucial role of prosumers and local initiatives in the energy transition. The main concepts are "Energy community", "Alternative energy", "Energy storage", "Energy transitions", and "Energy sharing".
- Blockchain and Digital Technologies (Green): This group reflects the growing interest in deploying advanced technologies such as Blockchain and Smart Contracts. These tools enable decentralized energy trading, facilitate P2P transactions, and ensure local energy markets' security, transparency, and efficiency. The links between "Blockchain" and "Smart contracts" underscore their significant role as key enablers in developing modern, decentralized energy systems. The main concepts are "Blockchain", "Distributed ledger", "Peer-to-peer trading", "Energy trading", and "Smart contracts".
- Energy Management and Efficiency (Blue): This group reflects the growing interest in deploying advanced technologies. These tools allow decentralized energy trading, facilitate P2P transactions, and ensure local energy markets' security, transparency, and efficiency. The links between "blockchain" and "smart contracts" underscore their significant role as key enablers in developing modern, decentralized energy systems. The main concepts include "Renewable energy source", "Microgrid", "Distributed energy resources", and "Energy efficiency".

DEFINITION AND CHARACTERISTICS OF ENERGY COMMUNITIES

Energy communities are a transformative model for advancing sustainable and decentralized energy systems. They involve citizens, businesses, and local organizations that collaborate in producing, consuming, and trading renewable energy. Based on the principles of sustainability, local empowerment, and decentralized governance, these communities promote inclusive and participatory energy management (Soto et al., 2021).

A key feature of energy communities is their ability to operate autonomously within local markets, using technologies such as blockchain and smart contracts to enable secure and transparent peer-to-peer energy trading (Mollah et al., 2021; Wang et al., 2019). Many also implement microgrids to optimize distributed energy resources and improve resilience to environmental and regulatory risks (Zia et al., 2020).

Internationally, energy communities have helped address energy poverty and infrastructure deficits. In Europe, the 2019 Renewable Energy Directive has encouraged Renewable Energy Communities to enhance citizen participation and renewable adoption (Gjorgievski et al., 2021). In Latin America, particularly in rural and underserved areas, community microgrids offer reliable, sustainable electricity that supports social and economic development (Soto et al., 2021).

EVOLUTION OF THE CONCEPT OF ENERGY COMMUNITIES

The notion of Energy Communities has evolved significantly over recent decades, becoming a key driver in the shift toward more sustainable and decentralized energy systems. These communities, which bring together prosumers, local managers, and other stakeholders, aim to democratize energy production, consumption, and trading by implementing advanced technologies such as Blockchain and Smart Contracts. This model promotes environmental sustainability, strengthens social cohesion, and fosters local economic development (Gu et al., 2023; Stefan et al., 2020). Energy Communities leverage Non-Conventional Renewable Energy Sources (NCRES) such as solar and wind to reduce dependence on fossil fuels and increase resilience to climate and regulatory challenges (Zia et al., 2020).

Globally, Energy Communities have proven to be practical tools for addressing energy access issues and energy poverty. In local contexts, such as Colombia's Caribbean region, they present an opportunity to transform energy systems and advance social equity. Their development, propelled by technological advances and regulatory frameworks, allows citizen participation in energy markets. However, their implementation varies depending on each region's socioeconomic and climatic conditions, underscoring the importance of an adaptive approach to ensure success. Such adaptive approaches should be context-sensitive, integrating participatory governance, institutional collaboration, and appropriate technology selection based on local capacity. Successful models must consider not only technical feasibility but also cultural acceptance, affordability, and long-term community ownership to guarantee that energy communities are inclusive, resilient, and sustainable.

KEY STAKEHOLDERS: PROSUMERS, LOCAL MANAGERS, AND MARKET PARTICIPANTS

Key stakeholders in Energy Communities include prosumers, local managers, and market participants, each playing a critical role in ensuring the operation and sustainability of these systems.

- Prosumers: Individuals or entities that both produce and consume energy. According to Wang et al. (2019), prosumer engagement through decentralized platforms, such as those based on blockchain, facilitates reliable energy transactions and fosters the adoption of renewable energy technologies (Ariza et al., 2020).
- Local Managers: They coordinate the community's activities, including energy planning and mediation among members. Their role is crucial in implementing participatory governance models and ensuring compliance with regulatory standards. As Stefan et al. (2020) highlighted, this role is especially significant in local settings where energy needs and resources vary widely.
- Market Participants: This group comprises system operators, technology developers, and other actors providing critical infrastructure and services. They facilitate the integration of advanced technologies, such as Smart Contracts and real-time monitoring systems, to improve operational efficiency and transparency within the energy system (Mollah et al., 2021).

Figure 2 illustrates a conceptual model of P2P energy trading in Energy Communities. It highlights the main interactions among key actors: consumers, prosumers, and the utility company, all coordinated by an energy exchange manager.

These players can trade energy among themselves or with consumers, managing both generation and consumption. The utility company provides backup to the system, offering energy purchase and export prices to balance surpluses or shortages in community energy production. The energy exchange manager oversees energy transactions among participants, ensuring efficient fulfillment of energy needs while maintaining transparency and security in energy flows and financial agreements. Figure 2 highlights energy flows (represented by arrows) as well as energy trading transactions (labeled "Trading"). It underscores the significant role of prosumers in fostering a decentralized energy generation and consumption model.

ENABLING TECHNOLOGIES FOR ENERGY COMMUNITIES

The development of energy communities, driven by advanced technologies, facilitates the decentralization of energy systems and optimizes resource management. The leading tools used are Blockchain and Smart

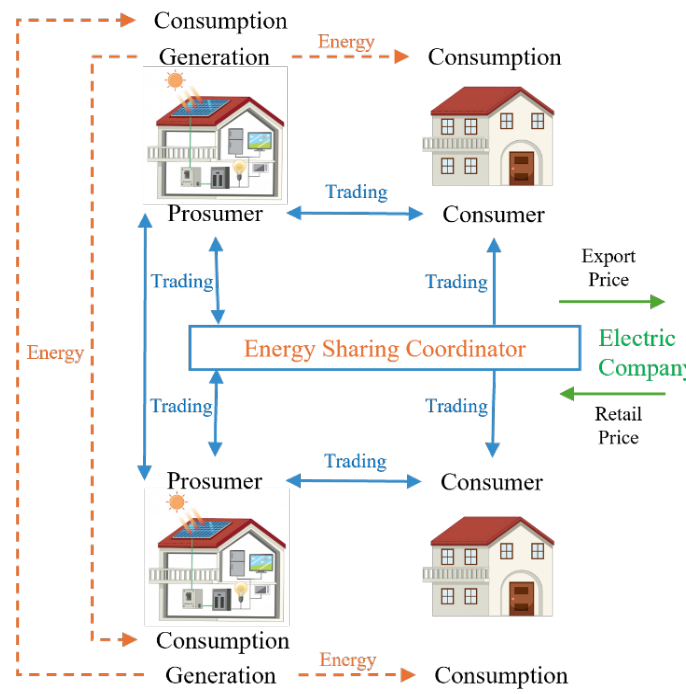

Figure 2. Conceptual Model of P2P Energy Trading in Energy Communities. Source: Adapted from Soto et al. (2021).

Contracts, which enable secure and transparent energy transactions while eliminating intermediaries and lowering operating costs (Andoni et al., 2019; Gu et al., 2023; Zia et al., 2020). These technologies allow prosumers and other market participants to actively engage in decentralized models, automating critical processes such as transaction settlements and energy asset management (Wang et al., 2019).

Transactive Energy is another key enabler, integrating economic and control mechanisms to balance supply and demand in real-time within microgrids and local energy markets (Siano et al., 2019; Zia et al., 2020). Such systems leverage digital and communication technologies to manage Distributed Energy Resources (DERs), fostering prosumer engagement in P2P markets. Successful examples include initiatives like Power Ledger and PROSUME, which demonstrate the transformative potential of these models in both local and international markets (Gjorgievski et al., 2021). Similarly, technologies such as the Internet of Things (IoT) and digitalization improve connectivity among smart devices in homes and businesses. Smart meters and real-time analytics platforms optimize energy generation and consumption, improving energy efficiency and promoting renewable energy adoption (Miglani et al., 2020; Mollah et al., 2021).

Finally, cases in Europe, Australia, and Latin America highlight how these technologies reshape energy markets. Pilot projects have demonstrated their capacity to integrate Renewable Energy, reduce emissions, and advance social cohesion in energy communities (Gjorgievski et al., 2021; Gu et al., 2023; Stefan et al., 2020).

Blockchain and smart contracts: the foundation of energy decentralization

Blockchain technology and Smart Contracts have emerged as pivotal elements in transforming and decentralizing modern energy systems. Blockchain provides a distributed, secure, transparent infrastructure for recording energy transactions, effectively removing intermediaries and reducing operating costs. On the other hand, smart contracts are digital tools that execute energy transactions automatically, reducing the need for intermediaries and minimizing errors (Kumari et al., 2022; Mollah et al., 2021).

In the energy context, these technologies facilitate the implementation of P2P markets, where prosumers can directly trade surplus renewable energy with other users. This encourages local community involvement and boosts economic and environmental sustainability. Examples like the Brooklyn Microgrid project in the United States and Power Ledger in Australia underscore the transformative impact of Blockchain in enabling decentralized energy resource management (Gjorgievski et al., 2021; Sousa et al., 2019). Blockchain also addresses critical challenges such as cybersecurity by employing advanced cryptographic mechanisms to protect user data and ensure the integrity of transactions.

Figure 3 illustrates the architecture of a decentralized energy management system comprising smart meters, data communication lines, and power infrastructure. Each household, including both consumers and prosumers, is equipped with a smart meter that monitors energy consumption or generation in real time. These meters are interconnected through secure digital networks with a central management platform, potentially supported by Blockchain and smart contracts, and communicate with the Distribution System Operator (DSO) infrastructure. The system allows peer-to-peer energy trading while maintaining coordination with the DSO to ensure grid stability and system reliability. Power flows are represented by orange dashed lines, while data flows are shown as solid blue lines. This integrated setup supports automated transactions, efficient load balancing, and increased resilience to local fluctuations in demand or supply. The figure highlights how physical infrastructure and institutional actors are connected through digital tools to activate secure and dynamic decentralized energy markets.

Transactive energy and P2P trading redefining local markets

Transactive Energy and P2P trading are reshaping energy markets by allowing direct exchanges between

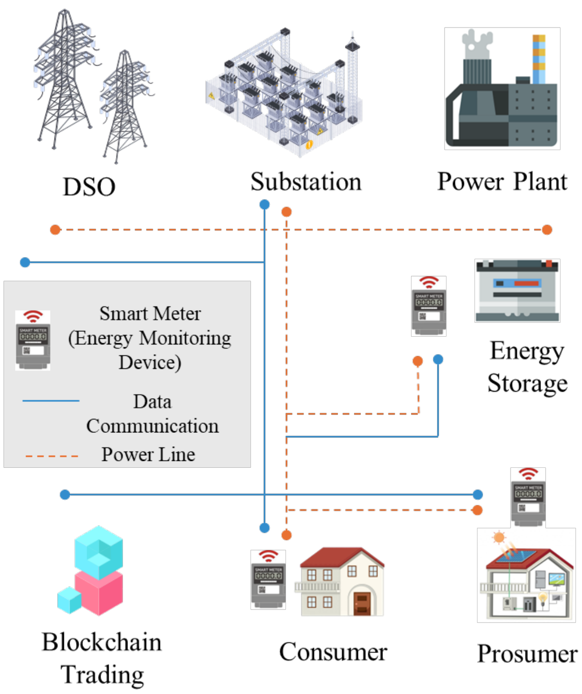

Figure 3. Concept of an Energy Trading System. Source: Prepared by the authors.

consumers and prosumers, eliminating traditional intermediaries, and fostering the decentralization of energy systems. These models harness technologies like blockchain and digital platforms, enabling efficient and transparent real-time trading of renewable energy (Soto et al., 2021). Transactive energy relies on advanced algorithms to dynamically balance supply and demand in local microgrids. These tools optimize energy flow, minimize losses, and support the integration of renewable sources such as solar and wind. Moreover, transactive controllers automatically adjust user consumption based on economic signals, enhancing system sustainability (Siano et al., 2019).

P2P trading, in turn, allows prosumers to maximize the use of their Renewable Energy resources and earn financial benefits by selling excess energy directly to other users. Studies in Colombia emphasize the potential of P2P trading to empower end-users and increase their engagement in the energy market. For instance, the "Transactive Energy Initiative Colombia" has identified user preference structures to design business models that integrate this type of transaction (Cárdenas-Álvarez et al., 2022). Nevertheless, these models face significant regulatory and technological challenges. In Colombia, the absence of specific legal frameworks to regulate decentralized energy transactions constitutes an obstacle to widespread implementation. Likewise, initial infrastructure costs, such as smart meters and digital platforms, limit adoption, particularly in rural and underdeveloped areas (González-Dumar et al., 2024).

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In summary, transactive energy and P2P trading offer a unique opportunity to decentralize energy markets and empower consumers. However, to fully realize their potential, adaptive policies and strategic partnerships are critical to overcoming technological and regulatory barriers, especially in emerging contexts like Colombia (Zia et al., 2020).

USE CASES AND INTERNATIONAL EXPERIENCES

The selection of developed countries with very different contexts from Colombia, such as Germany, Denmark, Japan, or Australia, allows us to highlight specific contributions in different decentralized energy systems, providing valuable ideas for Colombia's energy transition as models to follow.

In Europe, Germany is at the forefront of renewable energy governance and citizen-driven initiatives. Its *Energiewende* policy advocates collaborative energy models that involve all stakeholders. Using blockchain technology, Germany is improving transparency and reducing operational costs, setting a benchmark for participatory governance and regulatory adaptation (Mollah et al., 2021). On the other hand, Denmark excels in market-driven energy innovation, particularly through peer-to-peer (P2P) trading platforms. These platforms allow prosumers to trade surplus energy, optimizing supply and demand dynamics and ensuring grid stability. Denmark's success provides a replicable model for the integration of distributed renewable energy systems in Colombia (Wang et al., 2019).

An example from the Asian continent is Japan. This country has been successful in deploying microgrids that integrate solar and distributed storage. These systems ensure continuity of power during emergencies, mitigating the vulnerabilities inherent in centralized grids. This approach is particularly instructive for disaster-prone regions (such as Colombia), highlighting the need for robust and adaptive energy infrastructure (Siano et al., 2019).

Finally, Australia's P2P energy trading platforms, exemplified by initiatives such as Power Ledger, enable direct transactions between prosumers. This model promotes inclusive and sustainable energy markets while reducing reliance on centralized grids. The country's experience aligns with Colombia's goal of empowering local energy communities through decentralized solutions (Wang et al., 2019).

By synthesizing Germany's governance framework, Denmark's market innovations, Japan's resilience strategies, and Australia's P2P systems, Colombia can formulate a comprehensive energy transition plan. This approach could address the country's regulatory, infrastructure, and socioeconomic challenges and open the door to a decentralized and sustainable energy future. International experiences have highlighted the effectiveness of combining advanced technologies, including blockchain and smart contracts, with cooperative models and inclusive regulations. These experiences also underscore the transformative role of emerging technologies in optimizing resource management and building trust among market stakeholders. For example, the use of blockchain in Europe has improved the traceability and security of energy transactions, reinforcing prosumer participation through peer-to-peer trading (Tkachuk et al., 2023).

CONCLUSIONS

Developing energy communities, including Colombia, has become a pivotal strategy for advancing sustainable and decentralized energy systems worldwide. This model democratizes energy access, reduces carbon emissions, and promotes socio-economic sustainability by integrating emerging technologies and adaptive regulatory frameworks.

In Colombia, energy communities offer a strategic opportunity to address long-standing challenges such as energy poverty and limited electrification in rural and non-interconnected regions. The Caribbean region has significant potential for distributed generation due to its abundant renewable resources (Ministerio de Minas y Energía – República de Colombia, 2024).

Nevertheless, the country faces regulatory, technical, and social barriers. Although Law 2099 of 2021 and CREG Resolution 701 of 2024 establish foundations for the creation of energy communities, greater regulatory clarity is needed, as are financing mechanisms to encourage the participation of small-scale prosumers (Ministerio de Minas y Energía – República de Colombia, 2023b). Pilot projects in the Department of Bolívar have demonstrated the viability of such initiatives, underlining the importance of adapting international models to local realities (Departamento Nacional de Planeación – República de Colombia, 2023; Molina et al., 2022). Based on this, we consider that the main strategies to achieve a sustainable energy transition in Colombia would be as follows:

- Strengthening the Regulatory Framework: Design inclusive regulations that incentivize private investment and reduce barriers to adopting emerging technologies.
- Fostering Education and Community Awareness Actions: Implement educational programs to raise awareness in local communities regarding the benefits of renewable energy and decentralized management.
- Developing Public-Private Partnerships: Encourage collaborations among universities, technology companies, and local governments to accelerate the adoption of innovative solutions. Universities

can play a crucial role in research, development, and technical training, ensuring communities have the tools and knowledge necessary to manage their energy resources.
- Investing in Infrastructure and Technology: Prioritize the deployment of smart meters, storage systems, and digital platforms to facilitate P2P trading and the efficient management of energy resources.

The transition toward energy communities in Colombia demands a comprehensive approach that combines technology, regulation, and citizen participation. Universities are called upon to spearhead technical training and public engagement initiatives, bridging technological development and local needs. Their involvement in pilot project design, alongside cooperation with the private and governmental sectors, will be pivotal for ensuring the feasibility and scalability of these initiatives.

In summary, energy communities are drivers of technological change and essential tools for strengthening social cohesion and cultivating a culture of sustainability. Their practical implementation requires a sustained commitment from all sectors, ensuring that the benefits of the energy transition are accessible for the entire Colombian population. Timely and decisive action remains essential to empower communities, strengthen institutional and technological capacities, and drive the transition toward a decentralized and inclusive energy future that guarantees long-term sustainability and social equity.

AUTHOR CONTRIBUTION CRediT

Conceptualization, M.F.M.R. & J.G.F.C.; Data Curation, M.F.M.R.; Formal Analysis, M.F.M.R.; Funding Acquisition, M.F.M.R.; Research, M.F.M.R.; Methodology, M.F.M.R.; Project Management, M.F.M.R. & J.C.M.S.; Resources, M.F.M.R.; Software, M.F.M.R.; Supervision, M.F.M.R. & J.C.M.S.; Validation, M.F.M.R. & J.G.F.C.; Visualization, M.F.M.R. & J.G.F.C.; Writing - review and editing, M.F.M.R., J.C.M.S. & J.G.F.C.

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