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Research Article

Transactional Model of Electrical Energy Based on Emerging Technologies

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ABSTRACT

Introduction: Electricity is a vital resource today, but its reliance on fossil fuels including oil, coal, and natural gas. raises concerns about potential shortages and energy crises. The conventional centralized, one-way energy transaction system has several disadvantages, including dependence on non-renewable sources, inefficiency, and environmental pollution. Furthermore, it is costly, resistant to change, and faces security challenges and vulnerability to attacks, leading to a lack of transparency in energy transactions. Uncertainty slows the uptake of renewable energy and limits the involvement of small-scale local producers.

Objectives: This research paper proposes a transactional model for electric power based on emerging technologies. This represents a significant advance in the evolution of the current energy system, reducing dependence on centralized energy sources. The proposed model establishes a secure and reliable energy system between multiple agents, thereby reducing vulnerability to potential failures in traditional infrastructure. The elimination of centralized intermediaries and the implementation of emerging technologies guarantee a more reliable and transparent energy transaction system.

Methods: The research development process is divided into four main phases. First, a systematic literature review will be conducted to characterize emerging technologies used in electric power transactions. Next, the model's key components will be identified, analyzed, and integrated to define their roles and interactions. In the third phase, these components will be systematically integrated using the Rational Unified Process (RUP) methodology. Finally, the model will be applied to a test group of five entities, and its performance will be validated through a case study involving multi-agent electricity transactions.

Results: The exploration phase focused on identifying the technologies and components used in electricity transactions through a Systematic Literature Review (SLR). A total of 470 records were initially collected, from which 74 relevant studies were selected after applying inclusion criteria. The findings revealed that Blockchain technology is the most widely used, appearing in 85% of the studies due to its decentralized, secure, and transparent nature. The most common components identified include nodes (82.5%), smart contracts (57.5%), optimization algorithms (40%), and consensus mechanisms (32.5%). These elements were recognized as essential for enabling efficient, secure, and traceable energy transactions within decentralized systems.

Conclusions: The proposed transactional energy model presents an innovative solution to the limitations of traditional centralized systems by leveraging emerging technologies to facilitate decentralized energy generation and distribution. Its implementation in a peer-to-peer (P2P) network of educational and healthcare institutions in Nariño demonstrated strong expert approval, particularly for its security, transparency, and practical viability. The integration of Blockchain enhances trust and traceability, supporting user adoption and providing a foundation for future improvements and broader applications in decentralized energy networks.

Keywords: Blockchain, Systematic literature review, Components, Energy transaction

INTRODUCTION

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Electricity is essential to modern society, and significant energy sources, such as fossil fuels, have been the main energy sources for meeting society's energy needs. However, these sources are at risk of depletion due to high consumption, which could lead to an energy crisis due to eventual shortages.

Over the years, a single energy transaction model has been relied upon, relying on a conventional centralized system to carry out, manage, and distribute these transactions. This method involves a unidirectional energy flow from the grid, where electricity is generated, to the users who utilize it.

Today, the traditional energy system faces challenges that limit its efficiency and long-term sustainability. By adopting a centralized model, its operating core becomes susceptible to potential attacks, which could lead to the manipulation or loss of critical information. This vulnerability manifests as a lack of transparency, reliability, and traceability in energy transactions, which can be detrimental to the interests of system users. Conventional infrastructure can generate uncertainty regarding the integrity and security of energy transactions, acting as a disincentive to the adoption of more sustainable and decentralized sources.

In this sense, it is crucial to find new energy sources to meet energy demands. The distributed energy model is emerging as a novel approach to exchanging energy, shifting away from the conventional centralized model. In this approach, energy production takes place locally, typically through renewable resources including installations of solar panels or wind turbines in buildings, businesses, or communities. This entails decentralizing generation and increasing user participation. Furthermore, distributed generation facilitates direct transactions between users, eliminating the need for intermediaries and thereby contributing to a reduction in global pollution.

Unlike the conventional energy system, distributed energy allows individuals to manage and influence their energy supply while also encouraging the adoption of greener and more sustainable energy resources. The transformation and modernization of energy systems, driven by technological advancements, highlight the need to overcome the challenges inherent in traditional energy systems. Contemporary innovations in the electrical grid have effectively transformed energy production and consumption.

In this context, it is crucial to present a model that addresses the need to transform the current energy system. Emerging technologies represent innovation in multiple sectors, introducing novel approaches to addressing challenges and providing solutions that are more effective than existing technologies.

This research paper proposes an emerging technology-based transactional model for the electric power industry. This represents a significant advance in the evolution of the current energy system, reducing dependence on centralized energy sources and advancing the utilization of clean energy. The emerging technology-based transactional model establishes a reliable energy system between multiple agents, thereby reducing vulnerability to potential failures in traditional infrastructure. The elimination of centralized intermediaries and the implementation of emerging technologies ensure a more secure, reliable, and transparent energy transaction system. The emerging technology-based model for multi-agent electric power transactions is validated in a peer-to-peer (P2P) network environment. This validation process ensures that the proposed model is reliable, secure, and transparent and adapts to the current energy environment. Thus, an innovative and effective solution for conducting electric power transactions is offered.

The paper structure is as follows: A concise overview is provided in Section 1; Section 2 outlines the research methodology employed; Section 3 discusses the findings; and Section 4 offers the conclusions. Lastly, the references are listed.

OBJECTIVES

This research paper proposes a transactional model for electric power based on emerging technologies. This marks a major step forward in the development of today's energy system, reducing dependence on centralized energy sources. The proposed model establishes a secure and reliable energy system between multiple agents, thereby reducing vulnerability to potential failures in traditional infrastructure. The elimination of centralized intermediaries and the implementation of emerging technologies guarantee a more reliable and transparent energy transaction system.

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METHODS

The research development process is structured into four key phases. In the first phase, the emerging technologies applied in electric power transactions will be characterized using a systematic literature review.

In the subsequent phase, the key components of the model will be identified and analyzed, and their functions and relationships will be examined. Then, the systemic integration mechanisms will be defined, specifying how these components interact to ensure the system's coherent and effective operation.

In the third phase, a detailed process will be carried out to systematically integrate the various components that comprise the model, following the disciplines established by the Rational Unified Process (RUP).

Lastly, the fourth phase of the research will involve testing the developed model on an experimental group of five entities. This group will undergo the application of the new technology-driven model for multi-agent electricity transactions. The model's validation will be conducted through a case study, enabling a thorough and practical assessment of its performance.

RESULTS

1. EXPLORATION PHASE

In this phase, we examine how various authors represent and describe electricity transactions. So, we initially conducted a Systematic Literature Review (SLR) to identify relevant studies for the research.

To conduct this RSL, the methodology for creating conceptual syntheses in software engineering, as proposed by Zapata and Barón [19], is adapted. This approach is grounded in the systematic literature review process outlined by Kitchenham and Charter [20]. The phases and activities of this adapted methodology are described in detail below [21] (see Fig. 1).

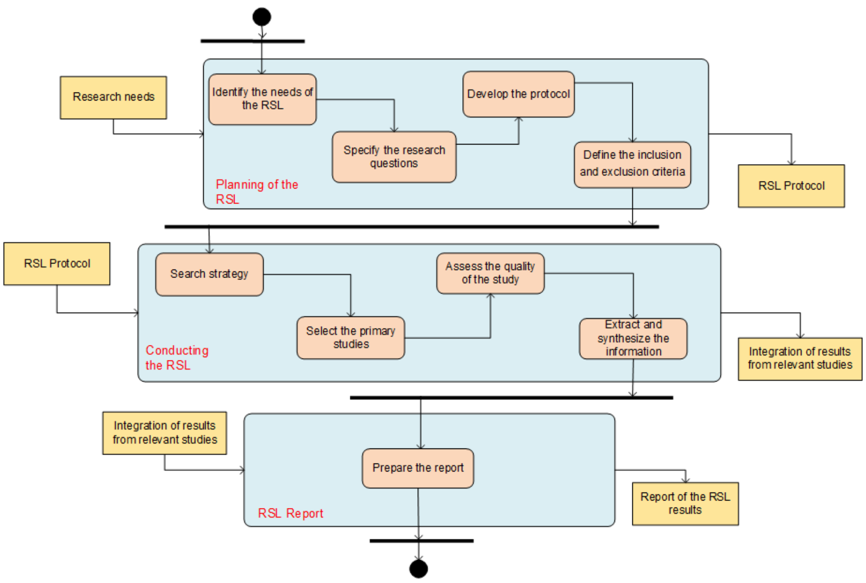

Fig 1. RSL process adapted for this research
Source: adapted from [19].

In conducting an RSL, formulating research questions is a key step. These questions direct the search for primary studies and guide the extraction and synthesis of the necessary information to answer them [22]. For this RSL, two research questions have been established, as outlined below.

RQ1: Which computing technologies are utilized in electricity transactions?

RQ2: What components are involved in electrical energy transactions?

The main goal of the inclusion criteria is to select literature relevant to the research. For this review, the criteria include studies published between 2019 and 2023 that focus on technologies applied to electric power transactions,

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with document titles related to technologies or electric power transactions. The exclusion criteria omit studies not published in English, duplicate articles, and literature reviews or mappings [21].

The research protocol specifies the use of search strings. For the RSL on technologies applied to energy transactions, the following query is employed: ("computer technology" OR "information technology") AND ("energy trading" OR "energy transaction" OR "energy exchange") [21].

Digital databases used for the literature search include Scopus, ACM Digital Library, IEEE Xplore Digital Library, and Google Scholar [21] (see Fig. 2).

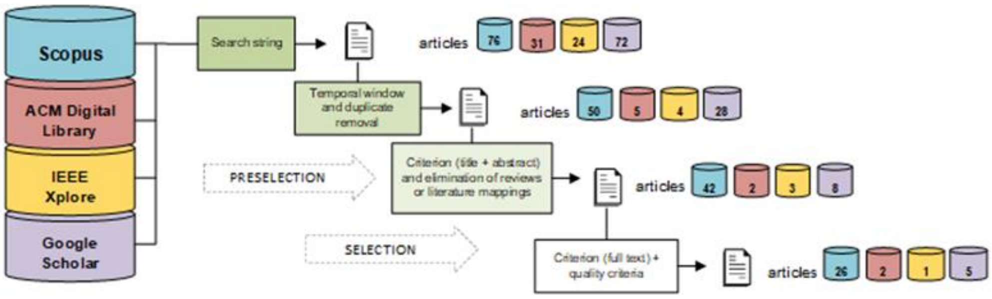

Fig. 2. Results of the study sources
Source: adapted from [23].

By applying the search string defined in Activity 2.1, 470 potentially relevant records were retrieved from the four selected bibliographic sources. After removing duplicates and filtering for publications from 2019 to 2023, 183 records remained. Titles and abstracts were then reviewed to identify studies focusing on models and technologies used in electric power transactions, resulting in 74 records selected for detailed analysis.

During the information extraction phase, emphasis was placed on the technologies utilized in electricity transactions and the components involved. The majority of studies concentrate on the use of Blockchain technology within decentralized networks for electricity transactions, also highlighting the specific components used in these energy exchanges [21] (see Fig. 3 and Fig. 4).

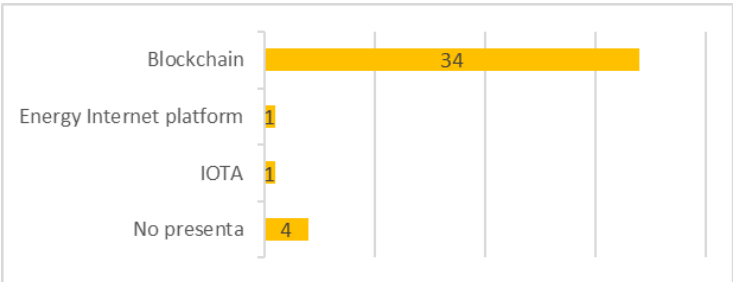

Fig. 3. Technologies for the transaction of electrical energy
Source: own elaboration

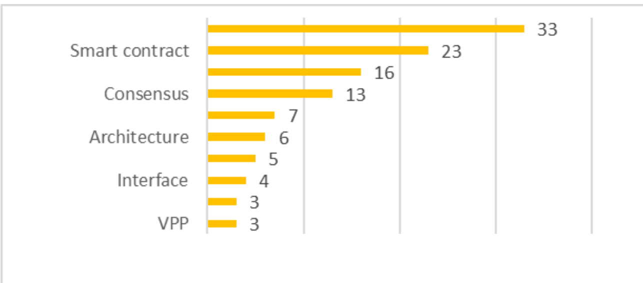

Fig. 4. Components
Source: own elaboration

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Among the studies reviewed, 85% employ blockchain technology due to its decentralized nature, which creates immutable and transparent records for all electrical energy transactions [21].

Additionally, 82.5% of the studies highlight the use of nodes as connection points within the network, allowing resource sharing among nodes. Nodes support decentralized, scalable network operations, enhancing user autonomy and resilience by eliminating the need for a central server.

Smart contracts are used in 57.5% of the studies to facilitate electricity transactions between nodes, automating and decentralizing the process while providing transparent records that build trust and ensure traceability.

Furthermore, 40% of the studies incorporate optimization algorithms focused on energy trading among network participants, improving operational efficiency and reducing costs, which leads to increased profitability and competitiveness [21].

Answers to the research questions posed in the RSL are as follows:

RQ1: Technologies used in electric power transactions aim to optimize efficiency and enhance security. Blockchain stands out as the most prevalent technology due to its decentralization benefits. It enables the creation of tamper-proof and transparent transaction records, ensuring traceability and data integrity. By eliminating central authority, blockchain reduces risks of tampering and system failures. Each transaction forms a secure, verifiable chain accessible to all network members, marking a significant innovation in the energy sector [21].

RQ2: Electricity transactions require high levels of trust and security among participants to ensure reliable and efficient energy supply. Nodes serve as vital network hubs for communication and transaction synchronization. Consensus mechanisms verify transaction integrity, reinforcing system security and trustworthiness. Smart contracts automate and enforce agreements, facilitating smooth, intermediary-free energy exchanges that simplify the transaction process for all parties involved [21].

2. ANALYSIS PHASE

The model components are identified to recognize the common elements potentially forming part of the proposed model. To provide an overview of the relevant studies obtained in the RSL, the categorized components are presented in Table 1.

TABLE I
Components of energy transactions

Components	Frequency	Reference
Nodos	33	[24], [25], [26], [15], [16], [27], [28], [29], [30], [31], [17], [32], [9], [33], [34], [18], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [7], [47], [48], [49], [50]
Smart contract	23	[25], [26], [28], [29], [51], [31], [17], [18], [35], [52], [39], [41], [42], [43], [44], [53], [54], [5], [45], [46], [7], [47], [55]
Optimization algorithm	16	[24], [27], [30], [9], [33], [34], [35], [36], [38], [39], [41], [54], [46], [48], [49], [50]
Consensus	13	[25], [29], [51], [30], [37], [39], [42], [43], [44], [56], [5], [7], [50]
Energy trading	7	[16], [37], [52], [40], [44], [56], [50]
Layered architecture	6	[27], [51], [52], [44], [56], [5]

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Centralized energy system	5	[15], [9], [33], [37], [38]
User interface	4	[18], [5], [46], [44]
Wallet	3	[16], [29], [32]
Virtual power plant	3	[26], [35], [39]

A comparative study is conducted to analyze and compare the various components used in electricity transactions. This study considers the relevant studies obtained from the literature review (See Fig. 5).

Componentes / Referencia	Nodos	Contrato inteligente	Algoritmo de optimización	Consenso	Comercio de energía	Arquitectura en capas	Sistema de energía centralizado	Interfaz de usuario	Billetera	Planta de Energía Virtual
[20]	✓	x	x	✓	✓	x	✓	x	x	x
[39]	x	✓	x	✓	x	✓	x	✓	x	x
[14]	✓	x	✓	x	x	x	✓	x	x	x
[30]	✓	✓	x	✓	x	x	x	x	x	x
[2]	✓	x	✓	x	x	x	x	x	x	x
[3]	✓	✓	x	✓	x	x	x	x	x	x
[4]	✓	✓	x	x	x	x	x	x	x	✓
[5]	✓	x	x	x	x	x	✓	x	x	x
[6]	✓	x	x	x	✓	x	x	x	✓	x
[7]	✓	x	✓	x	x	✓	x	x	x	x
[8]	✓	✓	x	x	x	x	x	x	x	x
[9]	✓	✓	x	✓	x	x	x	x	✓	x
[35]	x	✓	x	✓	x	✓	x	x	x	x
[10]	✓	x	✓	✓	x	x	x	x	x	x
[11]	✓	✓	x	x	x	x	x	x	x	x
[12]	✓	✓	x	x	x	x	x	x	x	x
[13]	✓	x	x	x	x	x	x	x	✓	x
[15]	✓	x	✓	x	x	x	✓	x	x	x
[16]	✓	x	✓	x	x	x	x	x	x	x
[17]	✓	✓	x	x	x	x	x	✓	x	x
[18]	✓	✓	✓	x	x	x	x	x	x	✓
[19]	✓	x	✓	x	x	x	x	x	x	x
[21]	✓	x	✓	x	x	x	✓	x	x	x
[36]	x	✓	x	x	✓	✓	x	x	x	x
[22]	✓	✓	✓	✓	x	x	x	x	x	✓
[23]	✓	x	x	x	✓	x	x	x	x	x
[24]	✓	✓	✓	x	x	x	x	x	x	x
[25]	✓	✓	x	✓	x	x	x	x	x	x
[34]	✓	x	✓	✓	✓	x	x	x	x	x
[31]	✓	✓	x	x	x	x	x	x	x	x
[26]	✓	✓	x	✓	x	x	x	x	x	x
[27]	✓	✓	x	✓	✓	x	x	✓	x	x
[32]	✓	x	✓	x	x	x	x	x	x	x
[37]	x	✓	x	x	x	x	x	x	x	x
[33]	✓	x	✓	x	x	x	x	x	x	x
[41]	x	x	x	✓	✓	✓	x	x	x	x
[38]	x	✓	✓	x	x	x	x	x	x	x
[28]	✓	✓	x	x	x	x	x	x	x	x
[29]	✓	✓	✓	x	x	x	x	✓	x	x

Fig. 5. Comparative study of components

Following the comparative study, the common and differentiating elements among the reviewed proposals were analyzed to identify the most relevant components for electricity transactions.

- Common components: Those present in at least 50% of the studies are considered common. Nodes (82.5%) stand out, enabling a decentralized and scalable network; smart contracts (57.5%), which automate and ensure the traceability of transactions; and consensus mechanisms (32.5%), which are essential for confirming transaction authenticity and maintaining system security.
- Differentiating components: Although less prominent in the studies, these components are equally valuable, including route optimization (40%), peer-to-peer energy trading (17.5%), and layered architecture (15%). Also featured are virtual plants (7.5%), centralized control systems (12.5%), user interfaces (10%), and digital wallets (7.5%), each with specific roles in grid efficiency, security, and accessibility.

Based on the analysis, the proposed model integrates all the common elements, in addition to incorporating some differential components that provide key functionalities:

a. Energy trading: enables direct exchanges between users, fostering a more participatory and sustainable system.
b. Centralized system: leverages existing infrastructure to ensure efficient supply and rapid response to failures.
c. User interface: Enhances the experience and facilitates access for even non-technical users.
d. Digital wallet: ensures the safekeeping and secure management of energy assets in the form of tokens.

- Proposed additional components: Although not identified in the review, it is recommended to integrate functionalities such as controlling supply and demand to maintain energy balance and maximize the efficiency of renewable sources. It also highlights the need to strengthen security and trust in transactions by ensuring transparent, verifiable, and tamper-resistant records, which are essential for the evolution toward a reliable and decentralized energy system.

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To summarize the key studies reviewed in the RSL on energy traction technologies, the categorized technologies are presented in Table III.

TABLE III
Technologies used for energy transactions

Technology	Frequency	Reference
Blockchain	34	[25], [26], [16], [27], [28], [29], [51], [30], [31], [17], [32], [33], [34], [18], [35], [37], [38], [52], [39], [40], [41], [42], [43], [44], [53], [56], [54], [5], [45], [46], [7], [47], [55], [49]
IOTA's Directed Acyclic Graph (DAG)-based ledger	1	[50]
Energy Internet platform	1	[15]
It does not present	4	[24], [9], [36], [48]

The review of studies identified that only 15% used alternative technologies such as IOTA or other platforms, while some did not specify the technology used. These options were ruled out due to their low adoption or a lack of evidence regarding their effectiveness, security, or scalability.

On the contrary, 85% of the studies analyzed choose Blockchain to manage electricity transactions, highlighting its decentralized, transparent, and secure approach. This technology allows transactions to be recorded immutably, ensuring data traceability and reducing the risk of manipulation.

Blockchain was selected as the foundation for integrating the model's components due to its multiple advantages. These include its ability to facilitate energy trading between nodes without intermediaries, implement smart contracts to automate processes and validate transactions through trusted consensus mechanisms. Furthermore, the use of user interfaces and digital wallets enhances the end-user experience and facilitates the secure management of energy assets.

Selecting the appropriate protocol is key to ensuring system efficiency. Therefore, a comparative analysis of the main Blockchain protocols used in the business environment was conducted. This evaluation allowed us to identify which best suits the technical requirements of the proposed module. The documents analyzed include comparisons between Bitcoin, Hyperledger Fabric, and other platforms applied in energy contexts, both locally and internationally.

After analyzing various options, Hyperledger Fabric was identified as the most suitable protocol for the proposed model. Its modular structure, use of Docker containers, and efficient consensus mechanism enable an agile and adaptable network that does not rely on cryptocurrencies.

This protocol offers a secure environment, ideal for energy transactions, by minimizing risks and enabling transparent participation of multiple actors in decentralized networks. Its flexibility allows the implementation of smart contracts, integration of user interfaces and digital wallets, and the efficient management of energy supply and demand.

In short, Hyperledger Fabric facilitates transaction automation, security, and traceability, making it the most robust option aligned with the requirements of the proposed transactional model.

3. CONSTRUCTION PHASE

The components are integrated using Hyperledger Fabric as the primary facilitator for interaction between the various elements of the system. Additionally, the computational solution that will serve as the fundamental foundation for implementing and supporting the proposed energy trading model has been developed.

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The objective is to demonstrate how Hyperledger Fabric facilitates integration between the various elements that comprise the energy transaction model, including nodes, smart contracts, consensus mechanisms, trading interfaces, wallets, and supply and demand management.

a. Nodes: Hyperledger Fabric enables secure interaction between nodes classified as:

- Committing: Send transactions and queries.
- Ordering: group transactions into blocks.
- Endorsing: Validates transactions and stores the ledger.

In the proposed model, nodes are referred to as agents, and an ordering agent and an endorsing agent are specifically configured to ensure integrity and functionality.

a. Organization: Organizations manage nodes and their permissions, promoting a structured and secure network that enables efficient cooperation between participating entities.

b. Smart Contract: Smart contracts automate agreements once certain conditions are met. In the model, they are assigned to endorsing agents, optimizing the execution of energy transactions.
c. Consensus: The protocol implements its consensus mechanism by endorsing agents, validating transactions, and guaranteeing their immutability.

d. Wallet: Each agent is assigned a digital wallet through a smart contract. This ensures security, traceability, and efficient control of energy assets.

e. User Interface: An intuitive interface is developed for agents to manage, view, and execute their transactions. This interface connects directly to the Blockchain network, facilitating interaction with the system.

f. Energy Exchange: The network enables transparent energy trading between agents. Offers are displayed on the interface, streamlining the process and improving decision-making.

g. Interconnector: The model includes a centralized energy system as a physical interconnector, enabling connection and coordination between agents for efficient distribution.

h. Supply and Demand Manager: This component enables agents to adjust and accept energy offers in real time, optimizing the functioning of the energy market on the grid.

i. Component Articulator: For the model to function correctly, several key elements are configured within Hyperledger Fabric:

- Containerization (Docker): All system components run as containers.
- Domain and channel: group organizations and allow secure communications between them.
- Ordering Service: Organizes transactions and maintains network integrity.
- Certification Authority (CA): Issues and manages digital certificates for agent authentication.
- CLI (Command Line Interface): a container that manages the network, manages identities and executes commands necessary for its operation.

A detailed description of the visual representation of the model is presented from both a structural and functional perspective. The structural composition of the model is achieved using a conceptual-level UML class diagram, which enables the description of model components and their structural relationships. The functional composition of the model is achieved through a sequence diagram, which allows the description of model components and their respective functional contributions. This approach offers a systemic perspective, highlighting how elements interact over time to contribute to the overall functioning of the model.

The construction of a computational solution will provide support for the model, enabling the theoretical model to

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be put into practice. This computational solution enables the simulation of scenarios, facilitates data analysis, and supports decision-making based on the results obtained.

For the construction of the computational solution, the RUP methodology has been employed. This methodology aims to organize and structure software development, encompassing a collection of processes essential for turning user requirements into software. Use cases direct RUP, which is focused on architecture; it is iterative and incremental, fundamental for software development [57].

An iteration is a full development cycle producing a product version that progressively evolves with each cycle, eventually forming the final system. Using iterations brings several benefits to product development, such as risk mitigation and greater ease in adapting to changes [58].

Considering the information obtained during the analysis phase of this thesis and the first activity carried out in the construction phase, Hyperledger Fabric was selected as the component integration protocol to be used in developing the solution. For the back end, Angular was chosen as the framework. Ultimately, PostgreSQL was chosen as the database management system.

There are several models for performing the requirements engineering process. SWEBOK proposes a structure for defining the software requirements engineering process, among which the activities of requirements elicitation, analysis, specification, and validation stand out [59].

Requirements engineering is a key discipline in software engineering that focuses on identifying, documenting, and managing the needs of users and other stakeholders, transforming them into precise specifications to guide system development [59].

There are several models for carrying out the software design process. SWEBOK proposes a structure for defining the software design engineering process, among which the architectural design and detailed design activities are notable [59].

During this process, the overall structure of the system, the interactions between its parts, and the appropriate design patterns are considered to achieve a balance between quality, cost, and maintainability. The objective is to create a detailed plan that guides the implementation of the software in a coherent manner [59].

There are several models for carrying out the software construction process. SWEBOK proposes a structure for defining the software construction process, among which the planning, design, coding, and verification activities stand out [59].

Software construction encompasses various activities related to the effective and efficient creation of code that implements system requirements. Construction is not just about writing code but also about adopting practices and tools that improve quality, collaboration, and efficiency throughout the process [59]. These practices help ensure that the software is reliable, maintainable and meets the established requirements.

Coding, on the other hand, is responsible for transforming the specific requirements of the solution into concrete lines of code. Coding is a crucial phase in software development, as it represents how ideas and algorithms are expressed so that machines can interpret and execute them.

4. VALIDATION PHASE

The Transactional Model for Electric Power Based on Emerging Technologies is validated through consultation with experts in the electric power field. The expert consultation is based on the focus group method proposed by [60] and adapts the validation process proposed by Barón [61]. (See Fig. 6)

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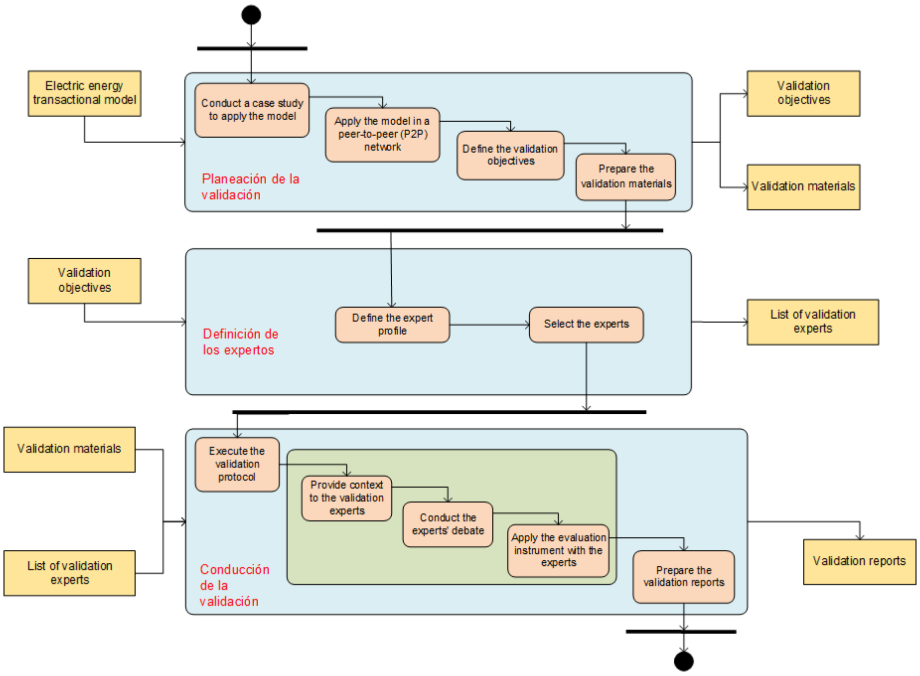

Figure 5. Model validation process
Fountain. Adapted from [61]

Validation of the transactional electric power model based on emerging technologies through its implementation in a specific operating environment. The selected peer-to-peer (P2P) network comprises five key entities within the Department of Nariño, participating in the project titled "Development of a multi-agent non-conventional energy transactional model for the Department of Nariño – BPIN 2021000100499."

The participating entities are:

- CESMAG University.
- Cooperative University of Colombia - Pasto campus.
- University of Nariño.
- Mariana University.
- Departmental University Hospital of Nariño.

These entities form a comprehensive network of agents responsible for carrying out decentralized energy transactions using a model based on emerging technologies.

Dockerized components are established for deployment. Participating entities, known as organizations, collaborate to maintain and operate the network infrastructure, thus defining its structure and operation. These organizations include the University of Nariño, the Mariana University, the Cooperative University - Pasto Campus, the CESMAG University, and the Departmental University Hospital of Nariño. They deploy their domains in Docker containers, forming a comprehensive network for carrying out transactions and prioritizing privacy through a channel known as the marketplace. The nodes for the specific context are called agents, which collaborate to preserve the network's security and integrity, utilizing an ordering service that groups and distributes transactions into blocks. Ordering and endorsing agents are designated, along with a certification authority for each organization, to oversee enrollment and guarantee access security through digital certificates. Distributed smart contracts are implemented in each organization, and agents are linked to a CouchDB database to represent updated data and transactions. A Docker CLI container is used for network management and administration, hosting identities, certificates, and the necessary tools to interact with network components.

The expert evaluation instrument consists of 13 items. Each item allows the experts to establish their position regarding the model. The experts indicate their position regarding the items in the instrument by employing a Likert scale, quantitative data is gathered to assess experts' acceptance of the model. To obtain qualitative information, the evaluation instrument enables experts to supplement their responses regarding each item with open comments and,

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ultimately, make general observations [61]. The items are listed in Table III, and the Likert scale is presented in Table V. The ratings are provided in Table IV.

TABLE V
Expert assessments

Items
1. **The integration of Blockchain with the model facilitates the complete traceability of energy transactions carried out by the different agents in the P2P network.**
2. **The interface of the computing solution** is intuitive and user-friendly.
3. **The model** offers a high level of **security** for energy transactions.
4. **The model** ensures the **integrity and privacy of the data exchanged**.
5. **The proposed model facilitates more secure and reliable** energy transactions compared to conventional centralized systems.
6. **The model** facilitates the **integration of multiple agents** in a P2P environment without complications.
7. **The model** provides an adequate level of **transparency** in the transactions carried out.
8. **Consider that the model components are adequately integrated to ensure the model's operation.**
9. **The model** is **viable for implementation** in P2P networks.
10. Considers that the integration of the model's components with Blockchain technology is adequate to guarantee the security and transparency of energy transactions in the P2P network
11. **The technology used for the systemic integration of the model components is suitable for ensuring transaction security.**
12. **The use of Blockchain in the model facilitates interoperability between the different components of the transactional model in the P2P network.**

Table 1 Likert scale

Likert scale	Position assessment
Totally agree	5
OK	4
Indifferent	3
Disagree	2
Totally disagree	1

Source. [61]

The experts' overall position on the instrument's 11 items is in complete agreement. Most of the values associated with the indicators fall within the range of full agreement. This indicates the experts' high level of acceptance of the model, its components, and the research.

The validation process of a data collection instrument is determined by two fundamental characteristics: the capacity to truthfully measure the variable in question (validity) and the capacity to reproduce equal results (reliability) [62]

Reliability is determined by the degree to which a measuring instrument reproduces equal results after repeated application to the same objects or individuals [116]. Therefore, reliability indicates the ability to obtain stable and consistent results at different points in time when the instrument is applied [115].

The alpha coefficient, introduced by Lee J. Cronbach in 1951, is a measure used to assess the reliability of a scale by evaluating how closely the items within an instrument are correlated [117].

The minimum acceptable threshold for Cronbach's alpha coefficient is 0.70; values below this indicate low internal consistency of the scale. The maximum desirable value is 0.90, as values exceeding this suggest redundancy or duplication, meaning multiple items are measuring the same aspect of a construct [118]. Consequently, redundant items should be removed. Generally, alpha values between 0.80 and 0.90 are considered ideal [119].

The reliability of the instrument used was verified through analysis of variance of both the individual items and the overall score. To this end, the 12 items presented to the experts during the Focus Group session were considered for validating the proposed model. As a result of this validation process, the instrument's items demonstrated an acceptable internal consistency with a Cronbach's alpha coefficient of 0.74. This result supports the reliability of the transactional model developed.

DISCUSSION

The proposed transactional energy model proves to be an innovative solution that addresses the limitations of the traditional centralized energy system. By leveraging emerging technologies, it decentralizes energy generation and distribution, allowing for greater user and prosumer participation.

The implementation of the model in a peer-to-peer (P2P) network comprised of educational and healthcare institutions in the Department of Nariño enabled its practical validation. The results demonstrate a high degree of acceptance by experts, who highlight the model's security, transparency, and viability for real-world application in decentralized energy scenarios.

The model's integration with technologies such as Blockchain strengthens its security and traceability, encouraging its adoption among users. Furthermore, the case study provides valuable insights into areas for improvement, facilitating future implementations in broader peer-to-peer (P2P) networks and promoting the evolution toward a more innovative and more participatory energy system.

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