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SYSTEM ANALYSIS OF SERVICE-ORIENTED TRANSFORMATION METHODS AND MODELS OF REGIONAL ENERGY SYSTEMS IN THE CONTEXT OF EFFICIENCY, PROFITABILITY, AND RESILIENCE

Abstract. *This paper presents the results of a system analysis of theoretical and applied approaches to the transformation of service-oriented activities of economic agents in the energy sector. Four complementary layers of knowledge are summarized: (1) Service-Dominant Logic (SDL); (2) Product-Service Systems (PSS) and Energy-as-a-Service (EaaS); (3) Peer-to-Peer (P2P) and cooperative markets; and (4) Energy services and Demand-Side Management models. It is noted that SDL provides a unified framework for aligning the technical, economic, and social aspects of energy system transformation; PSS/EaaS approaches increase asset productivity and energy efficiency while reducing capital costs through outcome-based rather than resource-based contracts; P2P and cooperative architectures foster local energy autonomy, which is crucial for Ukraine's post-war energy recovery. Energy service markets are becoming the institutional mechanism of digital transformation by involving communities in flexibility markets, while the regional meso-level plays a key integrating role, ensuring coherence among technical, economic, and digital processes. Its function lies in coordinating cross-sectoral and inter-level interactions, promoting energy efficiency and innovation, ensuring resilience, security, and flexibility, and forming a new service-oriented architecture of the national energy complex. It is shown that Ukraine's regional energy systems will require: the development of EaaS platforms based on Datahub technology enabling smart contracts among consumers, ESCO companies, and system operators; the creation of local flexibility markets within communities; the use of service-oriented models for sustainable microgrids, especially for critical infrastructure (hospitals, educational institutions, military facilities); and the inclusion of value co-creation principles in new editions of the Law "On Energy Efficiency" and ESCO regulations.*
Keywords: service-dominant logic, product-service systems, energy-as-a-service, energy services, energy efficiency, system resilience.

1. Introduction

Regional energy systems (RES) play a key role in achieving Ukraine's energy sector recovery and sustainable development goals, actively contributing to energy supply security, maximizing energy efficiency, integrating renewable energy sources (RES), and utilizing local energy resources. As decentralized systems, they face a fundamental transformation driven by the increasing adoption of advanced technologies, digitalization, and new business models. Technically, these systems must optimize the integration of renewables, ensure resilient infrastructure with distributed generation units, and enhance flexibility through effective coupling of multiple energy carriers and local storage systems coordinated via supply and demand-side control. They should provide a system of integrated services that support business processes with a large number of participants and allow the implementation of business models that serve various market participants, such as individual consumers and/or their associations, system regulators, energy and service providers and aggregators. The latter are objects of the multi-product RES infrastructure that perform the functions of management (coordination, balancing) of distributed energy sources of various types, often located in different

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sectors of the regional economy (cross-sectoral integration). The implementation of an energy supply management model that directly connects producers and consumers of RES on a service platform open to finding partners (technology, investment, marketing), products and services is fundamental. A service-oriented management model directly linking energy producers and consumers on open digital platforms, where actors can find partners, technologies, investments, and services, is essential. The transformation requires a paradigm shift from commodity-based markets (where energy quantities are traded) to value- and outcome-based markets (where comfort, efficiency, and resilience are traded). The theoretical foundation of this transition includes SDL, PSS, and EaaS models that foster co-creation of value among producers, consumers, and intermediaries. Additionally, P2P and cooperative models reduce transaction costs and enhance local system adaptability. ESCO, EPC, and DSM frameworks provide practical tools for implementing service contracts and optimizing energy use amid digital and climate challenges.

2. Methods and Materials

2.1. Theoretical Foundations of Service-Dominant Logic

SDL views service as the fundamental basis of exchange, while products act as carriers of service propositions. Its axioms (value co-created in use, actors as resource integrators, institutions shaping interactions) form the foundation of energy service markets [1–9]. In the energy context, SDL shifts focus from "generation and sale" to value outcomes such as reliability, comfort, and sustainability. Research shows SDL integrates technical, economic, and institutional systems [1, 2, 8], bridging the gap between "technical efficiency" and "customer value" by emphasizing co-creation through digital and organizational institutions.

2.2. Theoretical Foundations of Product-Service Systems and "Energy-as-a-Service"

PSS describe business models ranging from product-oriented to result-oriented, promoting circularity and resource efficiency [10–29]. They combine tangible products with services to meet user needs. Applied to the circular economy, PSS and EaaS enable "servitization" of the energy sector – transforming suppliers into service operators [10–16]. Implementing PSS in distributed renewables reduces investment costs and improves demand control. EaaS contracts extend this model, where payment depends on achieved effects (e.g., heating, lighting, cooling) rather than energy volume [20–22].

2.3. Theoretical Foundations of P2P Models

P2P energy transforms consumers into prosumers, able to trade energy without a centralized intermediary. This reduces transaction costs for coordination, increases local efficiency and resilience through distributed decision-making and stimulating consumer participation [30–39]. The use of P2P models allows for increased efficiency and fairness in resource allocation, reduces risks of vulnerability to external threats, and ensures resilience, adaptability, and transparency in the face of cyber challenges [30–31]. Hierarchical and multi-agent optimization P2P schemes [35, 36] allow for the scaling of local platforms to the level of microgrids and regional clusters, where cooperative models extend this approach by forming system-agreed contracts for results.

2.4. Theoretical foundations of energy services

Service approaches to energy (ESCO, EPC, EaaS) form the basis for the transition from energy supply to energy efficiency management [40–83]. The economic foundations of energy efficiency policy are considered [40], the EaaS concept is formulated [41], it is shown [44] that district heating systems can provide balancing services, thereby becoming key elements of local flexibility markets, game models for DSM are used [50], which allow reducing peak loads and increasing network stability, and it is shown [59, 73] how national energy services markets are formed, where digital technologies (AI, blockchain, DataHub) increase transparency and trust between participants. In the article [82], the SDL approach is considered, which opens up new possibilities for implementing energy services in hybrid microgrid systems, and in [83], the role of artificial intelligence in increasing the efficiency, sustainability, and resilience of energy systems is investigated.

2.5. System Analysis of Ukraine's Energy Complex

A separate section should be noted numerous studies of the Institute of General Power Engineering of the NAS of Ukraine, devoted to the systematic analysis of structural changes in the functioning of the fuel and energy sector and its component subsystems in the conditions of rapid growth of the share of renewable energy sources and their reflection in the structure of the country's energy balance. Thus, the study [84] considers the key goals of low-carbon development adopted by Ukraine at the international and national levels, which affect the development of the national power industry and provides estimates of structural changes in the generating capacities of the Unified Power System of Ukraine for two key years – 2030 and 2035. The work [85] considers the potential of a holistic approach to the power system, district heating and municipal infrastructure, which is implemented at the local, regional and national levels.

3. Results and discussion

3.1. Integrative Framework of Service-Oriented Methods and Models

From the point of view of system analysis, the selected set of service-oriented methods and models [1–83] considered above is representative, as it connects the functional relationships and mutual influence of these methods and models, conventionally depicted in Fig. 1 by the Venn-Euler diagram, and the structural relationships of the components (participants, agents) of the multi-level energy system, conventionally depicted in Fig. 2 as their P2P interaction at the national, regional and local levels.

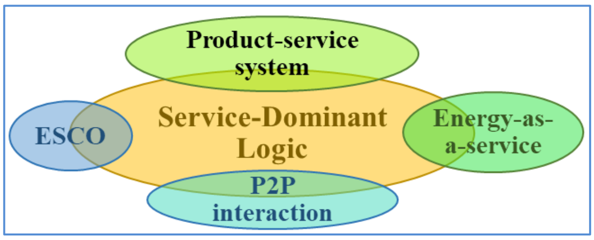

Figure 1. Venn-Euler diagram

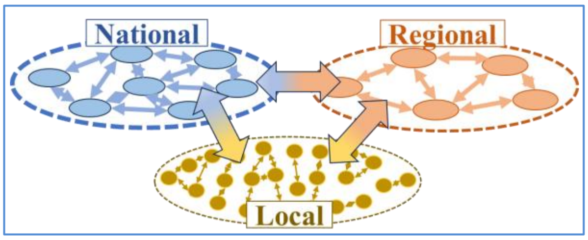

Figure 2. Multi-level P2P interaction

Three key directions of transformation are identified:

1. Creation of service-oriented institutions aligning state, business, and community interests.
2. Development of PSS/EaaS business archetypes for electricity, heat, and combined systems.
3. Application of hierarchical and multi-agent optimization models integrating local solutions into system-of-systems (SoS).

Fig. 3 presents a generalized three-tier energy system model of marketplace integrating energy service functions across all levels:

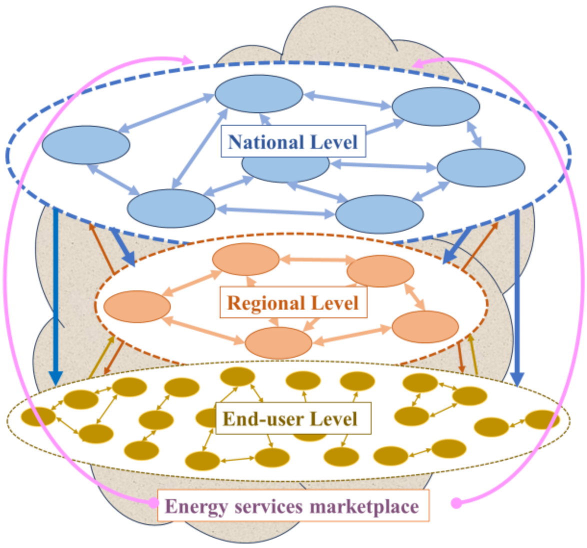

Figure 3. Generalized structure of the energy service marketplace of the energy system

I. National level (macro level):

- Enterprises and networks of national subordination: NNEGC Energoatom, NJSC Naftogaz of Ukraine, NEC Ukrenergo, Ukrgazvydobuvannya, Centrenergo). Spheres: oil, gas, coal, electric and thermal energy;
- Energy services:
  - strategic energy audit and monitoring;
  - digital platforms (Energy-as-a-Service);
  - integration of RES into national networks;
  - efficiency management and balancing of systems.

II. Regional level (mesolevel):

- Regional enterprises and networks (oblenergo, oblgaz, oblteplokomunenergo, local CHP). Tasks: energy distribution, accounting, balancing supply and demand;
- Energy service:
  - development of regional energy plans and development programs;
  - implementation of ISO 50001;
  - creation of regional energy markets;
  - demand management (DSM);
  - ESCO contracts with municipalities;
  - development of Smart Grid/Heat technologies.

III. End-user level (micro-level):

- Individual and cooperative energy supply systems that form distributed microgrids of energy production, storage and consumption (households with RES (solar, wind, bioenergy installations), small businesses and municipal facilities with local energy sources, communities operating as energy cooperatives or microgrids). Objectives: increasing efficiency, productivity, safety and comfort;
- Energy service:
  - conducting energy audits;
  - developing local energy plans and development programs;
  - creating active consumers;
  - peer-to-peer energy trading (local energy markets);
  - demand management (DSM);
  - energy service contracts with housing and communal services;
  - implementing ISO 50001;
  - implementing Smart Grid/Heat Home technologies.

The integrative role of the energy service marketplace, which covers all levels of the energy system, lies in the system-coordinated implementation of innovations not as a “product distribution” service, but as an institutional process, where each actor (company, consumer, community) does not simply accept innovation, but transforms it in accordance with its own resources and values.

3.2. Methods and models

Key analytical tools include:

– Game-theoretic DSM models for peak-load reduction.
– Multi-agent optimization for P2P networks.
– Morphological analysis of PSS/EaaS business archetypes.
– System dynamics and diffusion models for ESCO adoption.
– Top-down and bottom-up modeling linking macroeconomic scenarios with consumer behavior.
– Local flexibility market models for heat and electricity.

4. Conclusions

1. SDL provides a unified framework aligning technical, economic, and social aspects of energy transformation. PSS/EaaS enhance asset productivity and efficiency through outcome-based contracts. P2P and cooperative architectures promote local autonomy essential for Ukraine's post-war energy recovery.

2. Energy service markets institutionalize digital transformation by engaging communities in flexibility markets. The regional level serves as the integration core, ensuring coherence of technical, economic, and digital processes. Energy service thus acts as the integrator of Ukraine's energy complex, enhancing resilience, innovation, and security while shaping a new service-oriented energy architecture.

3. Ukraine's RES will require: the development of Datahub-based EaaS platforms with smart contracts among consumers, ESCOs, and operators; establishment of local flexibility markets; adoption of service-oriented models for sustainable microgrids (especially for critical infrastructure); and the inclusion of co-creation principles in energy efficiency legislation.

4.

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Author contributions: Tatyana Evtukhova – methodology and system analysis, text and figures preparation, editing; Oleksandr Novoseltsev – scientific consulting, conceptualization, review, and editing.

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СИСТЕМНИЙ АНАЛІЗ МЕТОДІВ І МОДЕЛЕЙ СЕРВІС-ОРІЄНТОВАНОЇ ТРАНСФОРМАЦІЇ РЕГІОНАЛЬНИХ ЕНЕРГЕТИЧНИХ СИСТЕМ В КОНТЕКСТІ ЕФЕКТИВНОСТІ, ПРИБУТКОВОСТІ ТА БЕЗПЕКИ

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Анотація. *Представлено результати системного аналізу теоретичних і прикладних підходів до трансформації сервіс-орієнтованої діяльності економічних агентів в енергетиці. Узагальнено чотири взаємодоповнюючі пласти знань: (1) Сервіс-домінантна логіка (SDL), (2) Продуктово-*

сервісні системи (PSS) та Енергія-як-сервіс (EaaS), (3) Взаємодії кожен з кожним (P2P) та кооперативні ринки, (4) Енергетичні послуги і керовані попитом моделі. Відзначено, що SDL формує єдину рамку для узгодження технічних, економічних і соціальних аспектів трансформації енергетичних систем, PSS/EaaS-підходи підвищують продуктивність активів і енергоефективність, зменшують капітальні витрати завдяки контрактам на результат, а не на ресурс, P2P і кооперативні архітектури створюють локальну енергетичну автономію, ключову для післявоєнного відновлення енергетики України. Енергосервісні ринки стають інституційним механізмом цифрової трансформації, залучаючи громади до участі у ринках гнучкості, а регіональний мезорівень стає ключовим, де енергосервіс грає інтегруючу функцію, забезпечуючи єдність технічних, економічних і цифрових процесів. Його роль полягає у координації між секторами і рівнями, стимулюванні енергоефективності та інновацій, забезпеченні стійкості, безпеки і гнучкості системи, формуванні нової сервісно-орієнтованої архітектури паливно-енергетичного комплексу країни. Показано, що регіональні енергетичні системи України потребуватимуть: розвитку EaaS-платформ на базі DataHub з можливістю смарт-контрактів між споживачами, ЕСКО-компаніями та операторами систем; створення локальних ринків гнучкості у громадах; застосування сервісно-орієнтованих моделей для стійких мікромереж, особливо для критичної інфраструктури (лікарні, навчальні заклади, військові містечка); включення принципів спільного створення цінності до нових редакцій Закону «Про енергетичну ефективність» і положень про ЕСКО.

Ключові слова: сервіс-домінантна логіка, продуктово-сервісні системи, енергія як послуга, енергосервісні послуги, стійкість системи.

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