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DEVELOPING A DRONE ECONOMY: A METHODOLOGICAL FRAMEWORK

Abstract. *The emergence of the drone economy represents a transformative element of modern digitalized national economies, integrating unmanned aerial vehicles (UAVs) into strategic industries such as energy, agriculture, logistics, infrastructure, and defense. This study proposes a comprehensive methodological framework for assessing the development of the drone economy, addressing its technological, economic, regulatory, industrial, and sustainable development dimensions. The research employs a systems approach, combining literature review, system-structural analysis, comparative assessment, statistical normalization, and expert judgment to construct an integral index of drone economy development (DEI). In addition, a sector-specific efficiency indicator is introduced to evaluate the impact of UAV implementation on productivity, cost reduction, safety, and environmental, social, and governance (ESG) outcomes. The proposed indicators enable a holistic assessment of UAV integration, capturing both direct and indirect effects, as well as structural and institutional constraints. The framework also facilitates cross-country and cross-sectoral comparisons and provides guidance for policymakers, industry stakeholders, and investors in identifying priority areas for fostering the drone economy. The findings highlight the importance of combining technological adoption with ESG principles to achieve sustainable, efficient, and socially responsible industrial transformation. By integrating drone technologies into strategic sectors, countries can enhance competitiveness, optimize resource utilization, and promote digital and green growth. The study contributes to the literature by offering a systematic tool for evaluating the multi-dimensional impact of UAV adoption and establishing a foundation for further research on the role of drones in economic development and sustainable industrial ecosystems.*

Keywords: *drone economy, UAV integration, strategic industries, sustainable development, ESG framework, digital transformation, technological innovation*

1. Introduction

The formation of the drone economy is one of the key components of the digital transformation of modern national economies, which is especially relevant in the context of global challenges related to ensuring sustainable development, increasing resource efficiency and strengthening economic security. The use of UAVs in strategic industries contributes to the optimization of production processes, reducing costs, increasing safety and minimizing negative environmental impacts.

In modern conditions, the drone economy is considered not only as a technological phenomenon, but as a complex socio-economic ecosystem that integrates digital technologies, institutional mechanisms, innovative business models and principles of sustainable development [1].

It should be noted that global processes of technological transformation are significantly changing approaches to the development of strategic industries in leading countries of the world. Under the influence of digitalization, automation and the introduction of intelligent systems, the role of traditional production factors is being rethought and new models of industrial policy are being formed. In these conditions, strategic industries, in particular the defense-industrial complex, energy, transport and logistics infrastructure, agro-industrial and mining and



metallurgical sectors, are increasingly considered as platforms for the implementation of high-tech solutions capable of ensuring the long-term competitiveness of national economies.

One of the key elements of modern technological transformation is unmanned aircraft systems, which in foreign practice go beyond military use and are actively integrated into civil and industrial processes. In countries with a developed innovation infrastructure, UAVs are used as a tool for increasing the efficiency of production facility management, monitoring critical infrastructure, ensuring security and optimizing resource use [2]. Thus, unmanned technologies are becoming a component of broader industrial ecosystems that combine physical assets with digital platforms for data collection and analysis [3].

In recent years, the scientific literature has seen a significant increase in the number of studies devoted to the use of unmanned aerial vehicle (UAV) in various industries, in particular in the context of technological transformation of strategic sectors. An important source of generalization of current trends are thematic special issues of the international journal “Drones”, which focus on critical industrial applications of UAVs, including inspection, maintenance, safety monitoring and assessment of the environmental condition of facilities with increased risk to people and equipment (for example, nuclear or oil facilities) — this direction emphasizes the importance of unmanned technologies in ensuring the safety and efficiency of industrial systems in foreign practice.

Separate review works focus on the technical aspects of the introduction of UAVs into industrial operations. Thus, works analyzing the architecture of systems for real-time surface inspection using drone swarms demonstrate that the coordination of several UAVs using the Internet of Things (IoT) and optimization algorithms allows you to automate complex processes of monitoring the state of infrastructure, which is important for large-scale industrial facilities — from energy networks to buildings [4]. This approach corresponds to the global trends of digital transformation of production and Industry 4.0, where automated systems and drone platforms act as a source of operational data for management decisions. Another area of research is devoted to the inspection and monitoring of large infrastructure facilities in industrial conditions. Comprehensive literature reviews show that unmanned systems can significantly reduce time and financial costs of inspection, increase occupational safety, and improve the quality of technical diagnostics compared to traditional methods — such conclusions are contained in reviews of works investigating unmanned inspections and non-destructive testing of large industrial facilities and structures [5].

Considerable attention is paid to the integration of UAVs with data processing systems, in particular in combination with electronic sensor systems and artificial intelligence. An analysis of recent research with an emphasis on automatic data processing and

autonomous control demonstrates that the use of predictive navigation algorithms, deep learning and complex controllers can significantly improve the efficiency and accuracy of industrial missions performed by drones — this is important for complex sectors such as energy and manufacturing [6; 7; 8]. It should be noted that a number of scientific works consider the monitoring of energy infrastructure — from photovoltaic and wind power plants to thermal networks and power lines. Aviation platforms with multi-sensor sets allow for regular inspections of the technical condition of energy system elements, which meets the priorities of the digital transformation of the energy sector in the EU and the USA and contributes to increasing its reliability and resilience to man-made threats [9]. However, a review of foreign research also indicates the existence of significant technological and regulatory barriers. Thus, the issues of flight autonomy in complex industrial conditions, localization within facilities, processing of large data sets in real time, and integration with existing control systems stand out as the main technical challenges that require standards for the widespread implementation of UAVs in industrial sectors.

Foreign experience in the development of strategic industries shows that unmanned aerial vehicle are considered an important element of technological transformation aimed at increasing the efficiency, safety and sustainability of production systems [10]. In leading countries of the world, UAVs are integrated into long-term industrial development strategies as a component of digital infrastructures that combine physical assets with analytical and management platforms.

In general, it should be noted that the formation of the drone economy is a complex and multi-level process that encompasses not only the introduction of unmanned aerial vehicles (UAVs) into production and service processes, but also the creation of an appropriate institutional, technological and regulatory ecosystem. In leading countries of the world, drones are already transforming the functioning of strategic industries, in particular energy, the agricultural sector, transport and logistics, the defense industry, infrastructure and environmental monitoring.

The analysis of contemporary research indicates that comprehensive approaches to the formation of the drone economy are still in the early stages of development. Existing studies are predominantly focused on assessing the efficiency of unmanned aerial vehicles (UAVs) within specific sectors. In particular, the literature demonstrates significant economic effects from the application of UAVs in agriculture, logistics, and infrastructure, as evidenced by analytical reports of international organizations and consulting companies. At the same time, there is a clear lack of integrated methodological tools for assessing the overall level of development of the drone economy. Most current studies tend to concentrate on isolated dimensions of UAV implementation — technological, economic, or regulatory — which limits the ability to form a holistic understanding of the drone economy as a systemic

phenomenon. In contrast, the drone economy should be considered as a multidimensional ecosystem characterized by the interaction of technological solutions, market mechanisms, institutional frameworks, and sustainable development factors. This perspective is consistent with the modern paradigm of digital transformation, where value creation is driven by the integration of heterogeneous components into a unified system.

Given the above, this study employs a methodological approach aimed at developing a composite indicator for assessing the level of development of the drone economy. The proposed approach is based on the integration of multiple dimensions and is designed to:

- provide a comprehensive assessment of the drone economy development level;
- enable cross-country and cross-sectoral comparisons;
- identify structural weaknesses and priority areas for development;
- account for the contribution of drone technologies to the achievement of sustainable development goals.

2. Materials and Methods

This study develops a methodological framework for assessing the formation and development of a drone economy as an emerging component of modern economic systems. The research is based on a combination of theoretical, empirical, and quantitative methods aimed at identifying key structural elements of the drone economy and constructing an integrated assessment tool.

The research adopts a systems approach, which allows the drone economy to be considered as a complex, multi-level ecosystem integrating technological, economic, social, environmental, and infrastructural components. This approach is complemented by the principles of sustainable development, ensuring that the proposed framework captures the interdependence between economic efficiency, social responsibility, and environmental sustainability. In addition, a comparative analysis of existing economic concepts (including digital economy, Industry 4.0, and green economy) is applied to justify the positioning of the drone economy as a distinct and integrative development paradigm.

To achieve the research objectives, the following methods are employed:

- *literature review and content analysis* — to identify existing approaches to defining and measuring technology-driven economic systems and to conceptualize the notion of a drone economy;
- *system-structural analysis* — to determine the key components and internal relationships within the drone economy ecosystem;
- *comparative analysis* — to assess similarities and differences between the drone economy and related economic paradigms;
- *statistical normalization methods* — to ensure comparability of heterogeneous indicators;

- *index method* — to construct an integrated indicator reflecting the overall level of drone economy development;
- *expert judgment* — to determine weighting coefficients for individual indicators.

The proposed methodology is subject to certain limitations, including data availability constraints, potential subjectivity in assigning weights, and differences in national statistical systems. However, these limitations do not undermine the applicability of the framework but indicate directions for further refinement.

3. Results and Discussion

In contemporary academic discourse, the concept of the “drone economy” does not yet have a universally accepted definition, but it is actively emerging through research on the unmanned aerial vehicle (UAV) market and its impact on economic processes. Most international studies focus not on the term itself, but on the economic effects of drone adoption across various industries. Market reports emphasize that UAVs are transforming traditional business models, creating new economic segments and generating significant economic benefits [11]. The commercial drone sector, including logistics, agriculture, and infrastructure monitoring, is rapidly expanding, forming new service markets and digital solutions [12].

Several researchers [13] regard UAVs as a disruptive technology capable of radically changing operational processes in multiple economic sectors. In particular, their role in enhancing efficiency, automating processes, and creating competitive advantages for enterprises is highlighted. At the same time, a practical dimension of the so-called “drone ecosystem” [14; 15; 16] is emerging, encompassing not only drone manufacturing but also software, data analytics, service provision, and flight management infrastructure. Analytical reports also note that drones significantly increase business process efficiency, reduce costs, and improve data quality for managerial decision-making [17]. For example, in agriculture, drones optimize resource usage and increase crop yields, while in infrastructure sectors, they reduce maintenance and inspection costs. Moreover, research highlights the creation of new labor markets and professions associated with drone development, maintenance, and data analytics [18].

From the authors’ perspective, the “drone economy” can be defined as the set of economic relations, institutions, and activities arising from the development, production, implementation, and utilization of UAVs, as well as the processing and commercialization of the data they generate, aimed at enhancing efficiency, competitiveness, and sustainable development of economic systems.

As a new direction in economic development, the drone economy is characterized by a complex, multi-level structure that integrates technological, production, service, and institutional components into a single system. Its formation occurs within the context of

digitalization, Industry 4.0, and the increasing role of data as a key economic resource. Unlike traditional sectoral models, the drone economy exhibits a pronounced ecosystemic nature, encompassing a wide range of interconnected actors and processes. We propose an ecosystemic approach to the structure of the drone economy, whose main components are:

- UAV manufacturing;
- Service sector (Drone-as-a-Service, DaaS);
- Data analytics and processing;
- Infrastructure;
- R&D sector.

The first fundamental element is UAV manufacturing, which includes enterprises engaged in the development and production of hardware: drones, sensors, cameras, navigation systems, and flight control software-hardware complexes. This segment defines the technological level of the drone economy, as it is the source of key innovations ensuring global market competitiveness. Drone manufacturing is increasingly integrated with other high-tech sectors, such as microelectronics, artificial intelligence, and telecommunications.

The second critical component is the service sector, encompassing UAV-based services. Currently, this segment demonstrates the fastest growth, developing new business models such as Drone-as-a-Service (DaaS). Services include infrastructure inspection, agricultural monitoring, aerial imaging, logistics operations, search and rescue missions, among others. Its development enhances the operational efficiency of enterprises in strategic sectors, reducing costs and minimizing risks.

The third structural element is the data analytics and processing sector, which gains importance in the context of the digital transformation of the economy. Drones serve not only as operational tools but also as sources of large datasets requiring processing, analysis, and interpretation. Artificial intelligence, machine learning, and geographic information systems are extensively applied in this segment, transforming collected data into valuable managerial decisions that improve enterprise and sector performance.

Another essential component is infrastructure, ensuring the functioning of the drone economy. It includes airspace management systems, charging and service stations, telecommunications networks, and regulatory frameworks governing UAV usage. Infrastructure plays a key role in scaling drone technologies, as wide adoption is limited without adequate regulatory and technical support.

A separate and significant component is the research and development (R&D) sector, which ensures the continuous advancement of technology, development of new solutions, and adaptation of UAV systems to the specific needs of different industries. Universities, research institutes, startups, and large tech companies interact in this segment. The role of R&D increases under global market competition, where innovation becomes the key to leadership.

Thus, the structure of the drone economy is a complex integrated system that combines manufacturing, services, analytics, infrastructure, and research, enabling the formation of new economic relations and the transformation of traditional industrial sectors. It is worth noting that the development of the drone economy generates a wide spectrum of effects across economic, social, and environmental dimensions. Their integrated nature underlines the importance of drone technologies as a tool for promoting sustainable development.

The results of the study are aimed at substantiating a comprehensive approach to assessing the development of the drone economy as a multi-dimensional and dynamically evolving system. Thus, traditional evaluation methods do not fully capture the complexity and cross-sectoral nature of drone technologies. In particular, the fragmented use of individual indicators limits the ability to assess the systemic impact of unmanned aerial vehicles on economic transformation processes. In this context, there is a need to develop an integrated analytical tool that would allow for a holistic assessment of the drone economy, taking into account its economic, technological, social, environmental, and infrastructural dimensions. Such an approach ensures the consideration of both direct and indirect effects of drone technologies, as well as their role in shaping new value chains and innovation ecosystems.

Given this, it is proposed to use an integral index of drone economy development, which aggregates the key components of its functioning and reflects the level of UAV integration into strategic sectors of the economy, taking into account the ecosystem approach.

It is proposed to calculate the integral indicator of drone economy development based on the following formula:

$$DEI = w_1T + w_2E + w_3R + w_4S + w_5ESG \quad (1)$$

where all components are normalized in the interval [0;1], which ensures their comparability:

DEI — integral index of drone economy development;

T — technological component (level of UAV implementation, digitalization);

E — economic component (productivity, cost reduction);

R — regulatory component (normative and legal support);

S — industry component (level of integration into strategic industries);

ESG — indicator of sustainable development (environmental, social and management effects);

w_i — weighting factors.

In order to ensure correct aggregation of indicators, a normalization procedure is used. For development-stimulating indicators, the following formula is used:

$$X_{norm} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (2)$$

In turn, for development disincentive indicators, it is advisable to use the following calculation formula:

$$X_{norm} = \frac{X_{max} - X_i}{X_{max} - X_{min}} \quad (3)$$

This allows all indicators to be brought to a single scale.

In turn, the technological component (T) characterizes the level of implementation of unmanned technologies and digitalization of production processes. Its formation is based on an assessment of the intensity of UAV use, the level of automation and integration of modern digital technologies. The technological component should be calculated using the formula:

$$T = \frac{1}{n} \sum_{j=1}^n T_j \quad (4)$$

where:

- T — integral technological indicator;
- T_j — normalized partial indicators;
- n — number of technological indicators.

The main technological indicators can be:

- number of UAVs per unit of manufacturing enterprises;
- level of process automation;
- share of AI/IoT use;
- investment in drone technologies.

The economic component (E) reflects the effectiveness of the implementation of drone technologies in terms of productivity, costs and financial results.

$$E = \frac{1}{n} \sum_{j=1}^n E_j \quad (5)$$

where:

- E — economic indicator;
- E_j — normalized economic indicators.
- n — number of economic indicators.

The main technological indicators are:

- productivity growth;
- cost reduction;
- return on investment (ROI);
- revenue growth.

The regulatory component (R) reflects the level of institutional support for the development of the drone economy.

$$R = \frac{1}{n} \sum_{j=1}^n R_j \quad (6)$$

where:

- R — regulatory indicator;
- R_j — normalized indicators of the regulatory component;
- n — number of indicators of the regulatory component.

The main regulatory indicators are:

- availability of a regulatory framework;
- development of UTM systems (a comprehensive network security solution that combines the functions of a firewall, antivirus, intrusion prevention system (IPS), VPN, and web content filtering in a single device or software);

- availability of certification;
- government support.

The industry component (S) characterizes the degree of integration of UAVs into strategic industries.

$$S = \frac{1}{m} \sum_{i=1}^m S_i \quad (7)$$

where:

- S — the industry indicator;
- S_i — the level of UAV uses in the i -th industry;
- m — the number of strategic industries.

In turn, the sustainable development component (ESG) reflects environmental, social and governance effects.

$$ESG = \frac{E_{env} + E_{soc} + E_{gov}}{3} \quad (8)$$

where:

ESG — an indicator of the sustainable development component;

E_{env} — an integral indicator of the environmental effect of UAV use, reflecting the level of reduction in negative environmental impact. Such indicators include:

- reduction in emissions CO₂ (through process optimization);
- reduction in resource use (fuel, water, fertilizers);
- efficiency of environmental monitoring;
- reduction in environmental risks (e.g. accidents).

E_{soc} — an integral indicator of social impact, characterizing the impact of UAV use on safety, employment and quality of life. Social impact indicators include:

- increased occupational safety;
- reduced injuries;
- creation of new jobs;
- improved quality of life (through effective services).

E_{gov} — an integral indicator of the quality of governance of UAV implementation processes, reflecting the level of institutional capacity and transparency.

Among the indicators:

- transparency of technology use;
- digital governance;
- level of regulatory coherence;
- availability of standards and controls.

Let us give a detailed description of the calculation of integral indicators.

1. Environmental component:

$$E_{env} = \frac{1}{k} \sum_{j=1}^k E_{env_j} \quad (9)$$

where:

- k — number of environmental indicators;
- E_{env_j} — normalized indicators.

2. Social component:

$$E_{soc} = \frac{1}{p} \sum_{j=1}^p E_{soc_j} \quad (10)$$

where:

- p — number of social indicators;
- E_{soc_j} — normalized indicators.

Table 1

Indicators of the environmental component E_{env}^*

Designation	Indicators	Decoding
E_{env_1}	Emission reduction CO ₂	Percentage of emission reductions due to the use of UAVs
E_{env_2}	Resource saving	Reduction in fuel, water, fertilizer use (%)
E_{env_3}	Environmental monitoring	Share of territories/objects monitored by UAVs (%)
E_{env_4}	Reduction of accident rate	Reducing environmental incidents (%)

*data sources: ESG reports, industry assessments

Source: compiled by the authors

Table 2

Indicators of the social component E_{soc}^*

Designation	Indicators	Decoding
E_{soc_1}	Occupational safety	Injury reduction (%)
E_{soc_2}	Workplaces	Drone employment growth (%)
E_{soc_3}	Access to technology	Share of businesses using UAVs (%)
E_{soc_4}	Quality of service	Quality improvement (logistics, inspections) (%)

*data sources: statistical data and expert assessments

Source: compiled by the authors

3. Governance component:

$$E_{gov} = \frac{1}{q} \sum_{j=1}^q E_{gov_j} \quad (11)$$

where:

q — the number of management indicators;

E_{gov_j} — normalized indicators.

The identification of three key components — environmental, social, and governance — is grounded in the widely recognized international ESG concept, which serves as a standard framework for assessing the sustainability of economic systems. This approach is extensively applied by international organizations, investors, and researchers to evaluate the impact of business activities and technological innovations on the environment, society, and governance structures. The use of these three components allows for:

- ensuring a comprehensive coverage of the key dimensions of sustainable development;

- avoiding duplication of indicators;
- maintaining a balance between methodological detail and practical applicability;
- ensuring comparability of results with international studies and benchmarks.

Moreover, the integration of the ESG approach into the methodology for assessing the drone economy makes it possible to account not only for the economic outcomes of UAV implementation, but also for their long-term environmental and social implications. This is fully consistent with contemporary principles of sustainable development and responsible investment. Alongside the assessment of the overall level of drone economy development, particular importance is attached to the analysis of the effectiveness of UAV utilization at the level of individual strategic sectors. This is due to the fact that the impact of drone technologies is inherently heterogeneous and depends on sector-specific characteristics, including the level of technological maturity, investment capacity, and the

Table 3

Indicators of the governance component $E_{gov_i}^*$

Designation	Indicators	Decoding
E_{gov_1}	Transparency	Availability of open data/reporting (0–1)
E_{gov_2}	Digital governance	Level of use of data-driven solutions (%)
E_{gov_3}	Regulatory coherence	Coherence of policies and standards
E_{gov_4}	Institutional capacity	Level of governance development

*data sources: international indices and expert assessment

Source: compiled by the authors

institutional environment. An analysis of international experience demonstrates that the deployment of UAVs in sectors such as energy, agriculture, logistics, and infrastructure is associated with significant economic and operational benefits. In particular, there is evidence of increased productivity, reduced maintenance costs, improved safety levels, and a decrease in environmental impact. However, in most existing studies, these effects are evaluated in isolation, without considering their cumulative and systemic impact.

In this regard, there is a clear need to develop a generalized indicator that would enable the integration of the key outcomes of UAV implementation within a specific sector and facilitate the assessment of investment efficiency in drone technologies. Such an indicator makes it possible to combine economic, operational, and sustainability-related effects of UAV usage and to evaluate them in relation to investment costs, thereby providing a comprehensive assessment of the effectiveness of drone technology implementation in strategic sectors.

$$E_i = (\Delta P_i + \Delta C_i + \Delta S_i + \Delta ESG_i) / I_i \quad (12)$$

where:

- E_i — the effectiveness of UAV uses in industry i ;
- ΔP_i — productivity gain;
- ΔC_i — cost savings;
- ΔS_i — increasing security level;
- ΔESG_i — improving sustainable development indicators;

I_i — investments in the implementation of UAVs.

Productivity growth is defined as the relative change in production volumes or work performed:

$$\Delta P = \frac{P_a - P_b}{P_b} \quad (13)$$

where

P_a, P_b — productivity before and after the implementation of UAVs.

In turn, the cost reduction is calculated using the formula:

$$\Delta C = \frac{C_a - C_b}{C_b} \quad (14)$$

where

C_a, C_b — costs before and after the implementation of innovations.

The safety improvement indicator is defined as a reduction in the number of incidents or injuries:

$$\Delta S = \frac{S_a - S_b}{S_b} \quad (15)$$

where

S_a, S_b — the level of hazardous incidents before and after the implementation of innovations.

The change in the sustainable development effect is determined as the difference in the integral ESG indicator before and after the implementation of UAVs.

$$\Delta ESG_i = ESG_a - ESG_b \quad (16)$$

In turn, investments in the implementation of UAVs include capital and operating costs:

$$I_i = CapEx_i + OpEx_i \quad (17)$$

In order to ensure comparability of the components of the efficiency indicator, a normalization procedure is used. Since all components $\Delta P_i, \Delta C_i, \Delta S_i, \Delta ESG_i$ are stimulants (the larger the value, the higher the effect), their normalization is carried out according to the formula:

$$X_{norm} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (18)$$

where:

- X_i — actual value of the indicator;
- X_{min}, X_{max} — minimum and maximum values in the sample.

After normalization, all indicators acquire values in the range [0;1], which provides the possibility of their aggregation.

The proposed indicator of the effectiveness of UAV use is based on a combination of economic, technological and sustainable development effects and allows:

- to assess the feasibility of introducing UAVs in a specific industry;
- to compare the effectiveness of their use between different sectors;
- to identify areas for increasing investment efficiency;
- to take into account not only economic, but also environmental and social effects.

In order to integrate the assessment of the level of development of the drone economy and the effectiveness of the use of unmanned technologies in strategic industries, we propose a general indicator of the effectiveness of the development of the drone economy, which is defined as the product of the integral index of the development of the drone economy and the indicator of the effectiveness of the use of UAVs in the relevant industry:

$$DDE_i = DEI \cdot E_i \quad (19)$$

where:

DDE_i — efficiency of drone economy development in the i industry;

DEI — integral index of drone economy development;

E_i — the effectiveness of UAV uses in the industry.

The proposed indicator allows us to take into account both the general level of development of the drone economy and the effectiveness of the use of unmanned technologies in specific industries. Such integration provides a deeper understanding of the mechanisms of the functioning of the drone economy and allows us to identify imbalances between the potential and its implementation. In particular, the situation in which a high level of development of the drone economy is accompanied by low efficiency of the use of UAVs in industries indicates the presence of structural or institutional constraints. At the same time, high values of the indicator DDE_i characterize an effective combination of a favorable environment and effective use of technologies.

Thus, the proposed approach provides a more comprehensive understanding of the impact of drone technologies on the development of strategic industries and meets the modern requirements of sustainable and inclusive economic development. In general, we note that the proposed approach provides a comprehensive assessment of the development of the drone economy, covering technological, economic, regulatory and environmental aspects of its functioning. Its use allows us to form a holistic picture of the level of integration of unmanned technologies into strategic industries. In addition, the proposed toolkit creates an analytical basis for making informed management decisions at the state and industry levels. It also helps identify key factors that constrain the development of the drone economy and determine priority areas for its stimulation. An important advantage of the approach is the possibility of adapting it to the specifics of individual countries and industries, taking into account their economic and institutional characteristics. In the context of sustainable development, it allows assessing not only economic results, but also environmental and social effects of the introduction of UAVs. Thus, the proposed approach forms a methodological basis for strategic management of the development of the drone economy in the context of digital transformation.

3.1. Strategic and Policy Implications of Drone Economy Development

The analysis of the integral indicators of the drone economy (DEI) and the effectiveness of UAV use (DDE) demonstrates that unmanned aerial technologies are not only a tool for operational optimization but also a strategic lever for national economic development. The deployment of drones in strategic sectors — energy, agriculture, logistics, infrastructure, and defense — creates systemic opportunities for enhancing productivity, reducing costs, increasing safety, and promoting sustainability. From a policy perspective, these outcomes carry several important implications.

First, the drone economy has the potential to strengthen economic resilience and competitiveness. High DEI and DDE values indicate sectors where UAV integration maximizes operational efficiency and return on investment, suggesting priority areas for targeted governmental support and incentives. Policymakers can use these indicators to identify structural bottlenecks, prioritize investment, and develop sector-specific roadmaps for drone adoption. In strategic industries such as energy and defense, timely adoption of UAV technologies can improve national security, ensure continuity of critical services, and reduce reliance on outdated, labor-intensive processes.

Second, the development of a drone economy has regulatory and institutional implications. Effective UAV integration requires coherent legal frameworks, safety standards, air traffic management, and certification systems. The DEI framework highlights the importance of regulatory maturity as a core component of drone ecosystem development. Countries that

proactively align drone policies with technological innovation are better positioned to attract foreign investment, foster public-private partnerships, and accelerate industrial modernization. Moreover, the integration of ESG metrics into UAV evaluation ensures that policy decisions consider long-term environmental and social outcomes, promoting responsible technological deployment.

Third, the drone economy supports sustainable development and environmental policy objectives. UAV deployment allows for precise monitoring of natural resources, early detection of environmental hazards, and optimization of resource use. This contributes to reducing emissions, minimizing industrial accidents, and improving ecological monitoring. Policymakers can leverage these capabilities to meet climate goals, enhance energy efficiency, and implement evidence-based environmental regulations. At the same time, the inclusion of social indicators, such as occupational safety and job creation, ensures that drone policies align with broader societal objectives, including workforce development and social inclusion.

Finally, the drone economy has strategic geopolitical and security dimensions. Countries that establish advanced UAV ecosystems gain technological sovereignty, enhance the competitiveness of domestic industries, and reduce dependency on foreign technologies. Strategic sectors, particularly defense and critical infrastructure, benefit from improved situational awareness, rapid data acquisition, and autonomous operational capabilities. In this context, the DEI and DDE indicators provide policymakers with a quantitative foundation for evaluating the national readiness for drone integration, allowing for informed decisions on technology acquisition, international collaboration, and defense modernization.

In summary, the development of the drone economy extends beyond technological and economic gains to encompass policy, regulatory, social, environmental, and strategic dimensions. The proposed integrated indicators provide a robust analytical tool for governments, industry leaders, and investors to assess sectoral readiness, prioritize strategic interventions, and align UAV deployment with long-term national objectives. By bridging operational effectiveness with policy and strategic planning, the drone economy becomes a critical instrument for fostering sustainable, resilient, and competitive industrial systems.

4. Conclusions

This study develops a comprehensive methodological framework for assessing the formation and development of the drone economy as a multidimensional, ecosystem-based phenomenon. The research demonstrates that UAV technologies are not merely technological tools, but integral components of modern economic systems, capable of transforming strategic industries such as energy, agriculture, logistics, infrastructure, and defense.

Key contributions of this study are as follows:

Holistic Conceptualization: The drone economy is conceptualized as a multi-level ecosystem integrating technological, economic, social, environmental, and regulatory components. This approach emphasizes the interdependence between efficiency, sustainability, and governance, highlighting that UAV adoption must be evaluated not only in terms of immediate economic gains but also through its broader systemic impact.

Integrated Assessment Tool: A novel integral index of drone economy development (*DEI*) is proposed, aggregating technological, economic, regulatory, industrial, and ESG-based sustainability indicators. This composite indicator enables cross-sectoral and cross-country comparisons, providing a unified framework for assessing UAV integration and the overall development of drone ecosystems.

Sectoral Efficiency Evaluation: Beyond the general development index, an effectiveness indicator for UAV deployment in individual strategic sectors is developed. This measure integrates economic, operational, and sustainability effects relative to investment costs, allowing stakeholders to identify the most productive and impactful applications of drone technologies.

Integration of ESG Principles: Incorporating environmental, social, and governance factors into

the evaluation ensures that drone economy development aligns with the principles of sustainable development and responsible investment. This enables long-term evaluation of UAV impacts, such as emission reductions, resource efficiency, improved occupational safety, job creation, and enhanced governance transparency.

Strategic Governance Insights: The combined use of DEI and sector-specific effectiveness indicators provides actionable insights for policymakers, industry leaders, and investors. The framework identifies structural or institutional constraints, guides investment priorities, and supports the development of regulations and digital infrastructures to facilitate UAV adoption.

Overall, the proposed framework bridges the current methodological gap in the assessment of drone economies, offering a rigorous, multi-dimensional, and practical tool for monitoring, benchmarking, and guiding UAV-driven technological transformations. Future research should focus on empirical validation of the index across multiple countries, the incorporation of real-time data analytics, and the exploration of dynamic feedback loops between UAV deployment, industrial performance, and ecosystem sustainability.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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РОЗВИТОК ДРОНОВОЇ ЕКОНОМІКИ: МЕТОДОЛОГІЧНА ОСНОВА

Анотація. Виникнення дрової економіки є трансформаційним елементом сучасних цифровізованих національних економік, інтегруючи безпілотні літальні апарати (БПЛА) у стратегічні галузі, такі як енергетика, агропромисловий сектор, логістика, інфраструктура та оборона. У дослідженні запропоновано комплексну методологічну рамку для оцінки розвитку дрової економіки, що охоплює технологічні, економічні, регуляторні, галузеві та аспекти сталого розвитку. Використано системний підхід, поєднуючи огляд літератури, системно-структурний аналіз, порівняльну оцінку, статистичну нормалізацію та експертну оцінку для побудови інтегрального індексу розвитку дрової економіки (DEI). Крім того, запропоновано секторний показник ефективності, що дозволяє оцінити вплив впровадження БПЛА на продуктивність, скорочення витрат, безпеку та результати у сфері екології, соціальної відповідальності та управління (ESG). Запропоновані індикатори забезпечують комплексну оцінку інтеграції БПЛА, враховуючи як прямі, так і непрямі ефекти, а також структурні та інституційні обмеження. Рамка методології сприяє порівнянню між країнами та галузями та надає рекомендації для політиків, представників промисловості та інвесторів щодо пріоритетних напрямів розвитку дрової економіки. Результати підкреслюють важливість поєднання технологічного впровадження з принципами ESG для досягнення сталого, ефективного та соціально відповідального розвитку промисловості. Дослідження робить внесок у літературу, пропонуючи системний інструмент для оцінки багатовимірного впливу впровадження БПЛА та створює основу для подальших досліджень ролі дронів у економічному розвитку та формуванні сталих промислових екосистем.

Ключові слова: дрова економіка, інтеграція БПЛА, стратегічні галузі промисловості, сталий розвиток, ESG-підхід, цифрова трансформація, технологічні інновації.