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Advanced Engineering Schools as Strategic Actors in the National Innovation System: Institutional Roles, Structural Interactions and Contributions to Sustainable Development Goals (SDGs)

Valery Vladimirovich Glushchenko[1,2], Olga Andreevna Zhdanovich[1], Pablo Iturralde[1]*

[1]Moscow Polytechnic University, Moscow, Russia
[2]Russian State University of Social Technologies, Moscow, Russia
*Correspondence: E-mail: valery.v.glushchenko@gmail.com

ABSTRACT

This study examines the Advanced Engineering School (AES) as a strategic institutional actor within the National Innovation System (NIS) in the context of post-industrial development and technological transformation. A conceptual and analytical research design was used, integrating institutional, organizational, systems, ontological, situational, and behavioral approaches to clarify the roles, functions, and interaction mechanisms of AES. AES strengthens innovation systems through customized research, applied innovation development, creativity-oriented engineering education, and cross-sectoral partnerships. AES also operates through cooperative and competitive relationships with universities, research institutes, competence centers, industrial enterprises, and analytical organizations. AES can support innovation system transformation, technological sovereignty, and sustainable development goals (SDGs).

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1. INTRODUCTION

In the context of post-industrial development and the emergence of a new technological paradigm, National Innovation Systems (NIS) play a crucial role in determining a country's capacity for sustainable economic growth and technological competitiveness. Innovation is no longer limited to isolated technological advances; rather, it has become a systemic process involving interactions among universities, research institutions, industry, and government actors. Previous studies have emphasized that innovation increasingly influences various dimensions of economic and social life, requiring institutional structures capable of integrating scientific knowledge, technological development, and human capital formation into coherent innovation ecosystems (Magrupova *et al.*, 2021). Within this framework, universities are expected to move beyond their traditional educational functions and contribute more actively to innovation-driven development through research, technology transfer, and strategic partnerships.

Despite the growing recognition of universities as key actors in innovation systems, higher education institutions often face structural and financial constraints that limit their capacity to participate in large-scale and breakthrough research and innovation projects. In response to these challenges, many countries have introduced targeted institutional mechanisms to strengthen the role of universities in national innovation agendas. In Russia, this policy orientation has been reflected in the federal project "Priority 2030," which supports the establishment of the Advanced Engineering School (AES) within leading technical and polytechnic universities. AES are designed as specialized organizational units that enhance technological sovereignty, accelerate scientific and technological progress, and align engineering education more closely with the needs of the real economy (Neretin and Ilyina, 2024; Popova, 2024). However, the conceptual distinction between AES and previously existing scientific or educational schools remains insufficiently clarified, and their systemic role within the NIS requires further examination (Aetdinova, 2024).

Existing research on National Innovation Systems has primarily focused on conceptual frameworks, institutional configurations, and methodological approaches for analyzing innovation dynamics at the national and sectoral levels (Ashurov, 2023; Belomestnov, 2019). Other studies on competence centers, think tanks, and specialized innovation institutions have highlighted the growing importance of organizational forms that support cooperation, competition, and knowledge diffusion within innovation ecosystems (Gurtov and Stasevich, 2020; Ivchenkova, 2019; Savage, 2015). Nevertheless, limited attention has been given to AES as distinct institutional actors within the NIS, particularly in relation to their interaction mechanisms with other innovation system elements and their potential contribution to sustainable development goals (SDGs) through education, innovation, and partnership-building.

This study aims to analyze Advanced Engineering Schools as structural and institutional elements of the National Innovation System. Specifically, it examines the roles, functions, and interaction mechanisms of AES within the NIS and evaluates their contribution to innovation system transformation and SDGs. Particular attention is given to their relevance to SDG 4, which concerns quality education; SDG 9, which focuses on industry, innovation, and infrastructure; and SDG 17, which emphasizes partnerships for the goals. By addressing these issues, this study contributes to a clearer conceptualization of AES and provides analytical foundations for innovation policy design and strategic planning in national innovation systems.

2. METHODS

This study employed a conceptual and analytical research design to examine AES as structural and institutional elements of the NIS. Since the research object is systemic, multi-actor, and non-empirical in nature, the study did not use statistical or experimental methods. Instead, it applied qualitative analytical approaches commonly used in institutional and innovation system research (Ashurov, 2023; Belomestnov, 2019).

The methodological framework integrated several complementary approaches:

(i) The institutional approach was used to analyze AES as innovation-related institutions formed through stable relationships among actors involved in education, research, and innovation activities. This approach helped explain how AES interacts with universities, research institutes, competence centers, and industrial partners through mechanisms of cooperation and competition (Belomestnov, 2019).

(ii) The organizational approach was applied to examine the structural position of AES within universities and the broader NIS. This approach focused on AES as organizational units established under state innovation policy, particularly the federal project "Priority 2030," and assessed their functions in relation to governance structures, policy objectives, and technological sovereignty (Neretin and Ilyina, 2024; Popova, 2024).

(iii) The systems approach was used to conceptualize the NIS and AES as complex hierarchical systems involving multiple levels of interaction, feedback, and functional differentiation. This approach enabled the analysis of AES contributions to NIS transformation through interconnections among research, innovation, and education domains.

(iv) The ontological approach was applied to clarify the conceptual boundaries between AES and other innovation actors by comparing key concepts related to innovation activities, innovation objects, and stages of innovation development.

In addition, situational and behavioral approaches were used to analyze the innovation behavior of AES and other NIS actors under changing technological and geopolitical conditions. Within the situational approach, innovation processes were examined as combinations of system states, available managerial decisions, and their potential effectiveness. The data sources consisted of peer-reviewed literature, policy documents, and analytical studies on national innovation systems, advanced engineering education, and institutional innovation mechanisms. The study used comparative analysis, logical reasoning, and synthesis to integrate the findings from these sources. This methodological combination provided a comprehensive basis for examining the contribution of AES to innovation system transformation and SDGs, particularly in relation to SDG 4, SDG 9, and SDG 17.

3. RESULTS AND DISCUSSION

The emergence of AES represents not only an organizational reform in higher education but also a structural transformation within innovation governance in the post-industrial economy (Ashurov, 2023). Unlike traditional university faculties or isolated research units, AES are designed as innovation-oriented institutional actors that integrate education, applied research, and technological development within a unified organizational framework. This integrated structure enables AES to function as a knowledge producer, innovation intermediary, and facilitator of cooperation among academia, industry, and the state (Belomestnov, 2019).

From a systems perspective, AES occupies a hybrid institutional position within the NIS. They remain structurally embedded in universities and retain academic functions related to education and research, while also being oriented toward applied technological problems defined by industrial partners and national innovation priorities. This dual position allows AES to connect fundamental research with industrial application and to reduce fragmentation among heterogeneous innovation actors within the NIS (Magrupova *et al.*, 2021; Neretin and Ilyina, 2024).

The analysis further indicates that AES influences the NIS through both cooperative and competitive mechanisms. Cooperation may occur through joint research projects, shared innovation infrastructure, and coordinated innovation activities involving universities, research institutes, and competence centers (Gurtov and Stasevich, 2020). At the same time, AES may compete with existing research institutes, competence centers, and analytical organizations for funding, highly qualified personnel, project leadership, and strategic influence within innovation networks (Ivchenkova, 2019). This coexistence of cooperation and competition does not necessarily weaken the NIS; rather, it may stimulate innovation dynamics by encouraging specialization, efficiency, and differentiation of institutional roles (Savage, 2015). The position of AES in relation to major NIS actors is summarized in **Table 1**. AES occupies an integrative position within the NIS. Their strongest cooperative relationships are found with universities and research institutes, where AES serves as a platform for transforming fundamental knowledge into applied technological solutions (Belomestnov, 2019). Interactions with competence centers and analytical organizations may involve competitive elements, particularly in relation to project coordination, analytical expertise, and access to innovation funding. However, these competitive interactions remain embedded within broader institutional coordination mechanisms shaped by national innovation policy (Ivchenkova, 2019; Neretin and Ilyina, 2024).

Table 1. Position of advanced engineering schools within the national innovation system.

NIS ELEMENT	CORE FUNCTION	INTERACTION WITH AES	DOMINANT RELATIONSHIP MODE
Universities	Education and fundamental research	Organizational integration and joint programs	Cooperation
Research institutes	Fundamental and applied research	Knowledge transfer and joint R&D	Cooperation
Competence centers	Applied innovation and skills development	Project coordination and specialization	Cooperation/ competition
Industrial enterprises	Commercialization and production	Joint innovation projects and technology testing	Partnership
Analytical centers	Policy and technology analysis	Overlapping analytical functions	Competition

A key finding of this study is the identification of three core functional domains through which AES contribute to NIS transformation: customized research, applied innovation development, and creativity-oriented engineering education. Customized research refers to scientific activities directed toward concrete technological problems defined by industrial demand and strategic state priorities. Unlike traditional academic research, which often prioritizes disciplinary advancement, customized research within AES is problem-driven and outcome-oriented. This orientation increases the practical relevance of research outputs and accelerates their diffusion into innovation processes.

Applied innovation development constitutes the second functional domain of AES. In this domain, AES supports the development, testing, and refinement of technological solutions, prototypes, and engineering systems. The close integration of research, education, and innovation enables rapid feedback between theoretical knowledge and practical application, thereby reducing the time required to move from concept to implementation. This function strengthens national technological capabilities and supports industrial modernization.

The third functional domain is creativity-oriented engineering education. Educational models implemented within AES emphasize project-based learning, interdisciplinary collaboration, and sustained interaction with industrial partners (Aetdinova, 2024). Through these approaches, AES contributes to the development of a creative engineering workforce capable of responding to complex and uncertain innovation environments. This function is closely related to human capital development and aligns with the broader goal of improving the quality and relevance of engineering education.

The effectiveness of AES within the NIS depends not only on the number of activities they conduct but also on the degree of functional integration among research, innovation, education, and partnership-building. In this regard, AES differs from traditional university units, where education, research, and innovation often operate as parallel rather than integrated functions. AES are more strongly characterized by a concentration strategy, in which resources, competencies, and managerial attention are focused on selected priority innovation areas defined by national policy and industrial demand (Popova, 2024). This strategy strengthens organizational coherence, reduces dispersion of effort, and improves alignment with industry needs.

The functional roles of AES and their contributions to NIS transformation and sustainable development are summarized in **Table 2**. The contribution of AES to sustainable development is multidimensional. Through advanced engineering education, AES supports SDG 4 by improving the quality, relevance, and innovation orientation of higher education. Through applied research and technological development, they contribute to SDG 9 by strengthening industrial innovation capacity and technological infrastructure. In addition, their partnership-oriented activities reflect the principles of SDG 17 by facilitating cross-sector collaboration and knowledge exchange within innovation ecosystems (Kickbusch and Hanefeld, 2017).

Table 2. Functional roles of advanced engineering schools and their contributions to the national innovation system and SDGs.

AES FUNCTION	CORE CHARACTERISTICS	CONTRIBUTION TO NIS TRANSFORMATION	RELEVANT SDGS
Research	Customized, problem-oriented scientific research	Accelerates knowledge-to-innovation transfer	SDG 9
Innovation	Development and testing of technologies and prototypes	Strengthens industrial innovation capacity	SDG 9
Education	Project-based, creativity-oriented engineering education	Develops advanced human capital	SDG 4
Partnership	Collaboration with industry, government, and research institutions	Enhances innovation ecosystems and networks	SDG 17

Another important dimension of AES influence concerns its analytical and forecasting functions. Successful AES may perform not only technical and educational tasks but also analytical roles related to monitoring scientific and technological trends, assessing innovation risks, and formulating strategic recommendations for institutional and policy-level decision-making. These capabilities are important for navigating uncertainty caused by rapid technological change and geopolitical volatility. However, the development of such functions requires dedicated organizational structures and specialized competencies, which may not yet be fully institutionalized across all AES.

From a governance perspective, the interaction between AES and other NIS elements highlights the importance of institutional coordination. Although AES requires a certain degree of organizational autonomy, its effectiveness depends on alignment with national innovation policy, regional development strategies, and sectoral priorities (Neretin and Ilyina, 2024). Weak coordination may result in fragmentation, duplication of efforts, or misalignment between AES outputs and real economic needs. Therefore, integrating AES into multi-level innovation governance frameworks is essential for maximizing their systemic impact.

AES can contribute to regional innovation development. In regions with industrial specialization or emerging technological clusters, AES may function as anchor institutions that support advanced training, applied research, and university-industry collaboration. This role can enhance regional absorptive capacity and contribute to more balanced territorial development. However, several risks should be acknowledged. AES may experience institutional overload if they are expected to deliver educational excellence, innovative outputs, analytical insights, and policy support simultaneously. In addition, unequal regional conditions, industrial partnerships, and institutional capacities may produce asymmetric outcomes among AES within the national innovation system.

To mitigate these risks, AES governance models, performance indicators, and strategic planning processes should be continuously refined. Evaluation frameworks should consider not only quantitative outputs, such as publications or patents, but also qualitative contributions to innovation ecosystems, human capital development, and partnership-building. AES constitutes a distinctive and increasingly influential institutional element of the NIS. Through integrated research, innovation, education, and partnership functions, AES contributes to innovation system transformation, technological sovereignty, and sustainable development. Their effectiveness, however, depends on strategic concentration, institutional coordination, and the development of analytical capacities.

Taken together, the strategic value of Advanced Engineering Schools lies not only in their ability to conduct research or deliver engineering education, but also in their capacity to integrate multiple innovation functions within a coordinated institutional framework. By linking universities, research institutes, industry, government, and analytical actors, AES can strengthen the coherence of the National Innovation System and support the transition from knowledge production to practical innovation outcomes. However, this role requires clear governance mechanisms, focused strategic priorities, and evaluation systems that capture both quantitative outputs and qualitative contributions to human capital development, institutional coordination, and partnership-building. Therefore, the long-term contribution of AES to innovation system transformation depends on its ability to balance educational, technological, analytical, and collaborative functions within national and regional innovation priorities.

4. CONCLUSION

This study examined AES as strategic institutional actors within the NIS in the context of post-industrial development and technological transformation. AES functions as a hybrid innovation actors that integrate education, applied research, innovation development, and partnership-building within a unified organizational framework. Through these integrated functions, AES helps reduce structural fragmentation within the NIS, accelerate knowledge-to-innovation transfer, and strengthen technological sovereignty. AES also operates through both cooperative and competitive relationships with other NIS actors, including universities, research institutes, competence centers, industrial enterprises, and analytical organizations. These interactions support specialization, institutional coordination, and innovation system effectiveness. In addition, AES contributes to sustainable development by supporting quality engineering education, industrial innovation capacity, and cross-sector partnerships, particularly in relation to SDG 4, SDG 9, and SDG 17. This study contributes to the conceptual understanding of AES as institutional innovation hubs within national innovation systems. Practically, AES effectiveness depends on strategic concentration, coordination with innovation policy, and the development of analytical and partnership capacities. Future policy and institutional planning should therefore support governance models that align AES functions with national, regional, and industrial innovation priorities.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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