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INDUSTRIAL DEVELOPMENT AND ENVIRONMENTAL SECURITY: THEORETICAL AND METHODOLOGICAL FOUNDATIONS FOR A REGIONAL ANALYSIS OF UZBEKISTAN

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Abstract. *This article systematises theoretical approaches to the concept of environmental security and reviews the principal models used to explain the relationship between economic and industrial growth and environmental quality, including the IPAT identity, the* Limits to Growth *framework, and the Environmental Kuznets Curve (EKC) hypothesis. Drawing on international experience, particularly that of China and Germany, and a critical review of three recent empirical studies on Uzbekistan and Central Asia, the article demonstrates that existing research has predominantly focused on aggregate national-level analysis, while the pronounced territorial differences in industrial and environmental pressures within the country require further regional-level examination. The regulatory and institutional framework for ensuring environmental security in Uzbekistan is also analysed separately. The article concludes that a transition towards regional panel-data analysis of the relationship between industrial development and environmental indicators would contribute to addressing the identified research gap and provide a more comprehensive basis for assessing sustainable regional development.*

Keywords: *environmental security; industrial development; Environmental Kuznets Curve; regional analysis; Uzbekistan; sustainable development.*

Аннотация. *В статье систематизированы теоретические подходы к понятию экологической безопасности и рассмотрены основные модели, используемые для объяснения взаимосвязи между экономическим и промышленным ростом и качеством окружающей среды, включая тождество IPAT, концепцию «Пределы роста» (Limits to Growth) и гипотезу экологической кривой Кузнеца (Environmental Kuznets Curve — EKC). На основе международного опыта, в частности Китая и Германии, а также критического анализа трёх современных эмпирических исследований, посвящённых Узбекистану и Центральной Азии, показано, что существующие исследования преимущественно сосредоточены на агрегированном анализе на национальном уровне, в то время как выраженные территориальные различия в промышленной и экологической нагрузке внутри страны обусловливают необходимость дальнейшего изучения на региональном уровне. Отдельно проанализированы нормативно-правовые и институциональные основы обеспечения экологической безопасности в Узбекистане. Сделан вывод о том, что переход к региональному анализу панельных данных о взаимосвязи между промышленным развитием и экологическими показателями будет способствовать восполнению выявленного исследовательского пробела и формированию более комплексной основы для оценки устойчивого регионального развития.*

Ключевые слова: *экологическая безопасность; промышленное развитие; экологическая кривая Кузнеца; региональный анализ; Узбекистан; устойчивое развитие.*

INTRODUCTION

Whether accelerated industrial development can be reconciled with an acceptable state of the natural environment remains a central issue for economies undergoing intensive industrialisation. For Uzbekistan, this question has both academic significance and immediate practical relevance, as the country is simultaneously pursuing export-oriented industrial development and a transition towards a green economy, while official policy documents increasingly emphasise the importance of effectively managing environmental pressures associated with industrial activity.

The relevance of the topic is further reinforced by the fact that environmental security in Uzbekistan has been progressively incorporated into the national policy framework. This process began with sectoral environmental legislation adopted in 1992, was subsequently strengthened at the constitutional level, and, since 2023, has been reflected in the "Uzbekistan – 2030" Strategy, where environmental issues are addressed within the broader framework of societal security. The institutional evolution of recent years — from the State Committee for Ecology in 2017, through the Ministry of Ecology, Environmental Protection and Climate Change in 2023, to the National Committee for Ecology and Climate Change under the President in 2025 — demonstrates the growing strategic and administrative importance attached to this policy area.

At the same time, the empirical literature examining the quantitative relationship between industrial growth and environmental indicators in Uzbekistan remains relatively limited and methodologically concentrated at the national level. The studies identified to date predominantly rely on aggregated country-level data, whereas available statistical evidence, including data related to the Almalyk Mining and Metallurgical Combine and Navoi region, indicates that industrial and environmental pressures differ significantly across territories. This highlights the importance of complementing national-level analysis with a more detailed regional perspective that better reflects the spatial structure of industrial development and environmental conditions.

The purpose of this article is to systematise the theoretical and methodological foundations required for a transition from national to regional analysis of the relationship between industrial development and environmental security, and to substantiate the corresponding research gap for Uzbekistan. Three main tasks are pursued: (1) to clarify the content of the category "environmental security" and its relationship with adjacent concepts; (2) to trace the evolution of theoretical models describing the relationship between economic growth and the environment, including the Environmental Kuznets Curve hypothesis, and to assess the relevance of international experience, particularly that of China and Germany, to the Uzbek context; and (3) to characterise the regulatory and institutional framework of Uzbekistan as the broader context within which this relationship is formed, monitored, and managed.

LITERATURE REVIEW

The category of "environmental security" emerged from the gradual broadening of the concept of security itself, which until the 1980s was largely dominated by a narrow military-political interpretation. A major turning point is commonly associated with Ullman (1983), who proposed incorporating non-military threats — including economic, demographic, and environmental factors — into the national security agenda. This approach was further developed in Buzan's (1983, 1991) five-sector model of security, encompassing military, political, economic, societal, and environmental dimensions, and subsequently within the Copenhagen School of securitisation (Buzan, Wæver and de Wilde, 1998), where environmental security is treated as an autonomous sector with its own referent objects, including ecosystems and the biosphere.

This broader interpretation of security has also generated important theoretical debate. Deudney (1990), for example, cautioned that the analytical precision of the concept of security could be weakened if every socially significant issue were framed in security terms. For the purposes of the present study, however, this debate has a clear practical implication: the use of the category "environmental security" is based not on an arbitrary expansion of the conceptual framework, but on its explicit normative recognition within the legislation and policy framework of the country under study, as discussed in Section 4 below.

Alongside the securitisation approach, a resource-conflict tradition also developed (Myers, 1993; Homer-Dixon, 1999), linking environmental security to the depletion of natural resources and its potential effects on social stability. Homer-Dixon introduced the concept of "environmental scarcity" as a function of declining resource supply, increasing demand, and unequal distribution. This approach is particularly relevant to regional analysis because it links environmental degradation not only to ecological concerns, but also to the socio-economic stability of specific territories where pressures on natural systems may be distributed unevenly.

A distinct conceptual approach developed within the Russian-language scholarly tradition, where environmental security is closely associated with the broader concept of sustainable development. Danilov-Danilyan (2000) defines environmental security as a state in which vital ecological interests are protected from threats arising from anthropogenic and natural impacts on the environment, while Ursul (2013) considers it a necessary precondition for the transition to sustainable development rather than a synonym for sustainable development itself. As the recent review by Selby et al. (2024) demonstrates, however, a single universally accepted definition of environmental security has not yet emerged in the international literature; rather, several parallel theoretical schools continue to coexist, each emphasising different referent objects and criteria of environmental threat.

Building on this literature, the present article understands environmental security as a condition in which the vital interests of individuals, society, the state, and the natural environment are protected from threats

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generated by anthropogenic, including industrial, impacts, while environmental pressures are maintained at an acceptable level and the regenerative capacity of ecosystems is preserved. This definition differs from the broader category of sustainable development. Whereas sustainable development describes a long-term process aimed at balancing the needs of present and future generations, environmental security represents the condition that enables such a development trajectory to be maintained.

A further conceptual distinction concerns environmental risk, which can be understood as the probability of an adverse event associated with environmental degradation and the magnitude of its potential consequences. Environmental risk is therefore an operational and measurable category, whereas environmental security represents a broader integrated condition shaped by the cumulative level of environmental risks and the effectiveness of the institutions responsible for managing them. It is precisely the operationalisation of environmental security through measurable indicators — including CO_2 and other pollutant emissions, energy intensity, and the share of clean energy generation — that makes the concept suitable for quantitative analysis, including within the framework of the Environmental Kuznets Curve discussed in the following section.

RESEARCH METHODOLOGY

The first attempt to formalise the relationship between economic activity and environmental pressure was the IPAT identity proposed by Ehrlich and Holdren (1971): I = P × A × T, where *I* denotes total environmental impact, *P* represents population, *A* denotes affluence, and *T* is the technology coefficient reflecting environmental impact per unit of affluence. A defining feature of this model is that it does not inherently predict a decline in environmental pressure as the economy expands: rising affluence increases environmental impact unless technological improvements reduce the impact coefficient at a sufficiently rapid rate. For CO_2 analysis, the IPAT framework is commonly disaggregated through the Kaya identity, which decomposes total impact into four components: population, income per capita, energy intensity of GDP, and the carbon intensity of energy. Both the IPAT and Kaya identities are accounting identities rather than behavioural models; consequently, they do not by themselves determine whether economic growth can ultimately be decoupled from increasing environmental pressure. Recent empirical research (Ward et al., 2016) suggests that achieving sustained long-term decoupling between GDP growth and energy consumption remains a complex process.

The historical background to the subsequent debate was provided by the Club of Rome report *The Limits to Growth* (Meadows et al., 1972), based on the World3 system-dynamics model. The report projected that the global system could encounter physical constraints associated with the depletion of non-renewable resources and increasing pressure on the environment's assimilative capacity if exponential growth in population, industrial output, and resource consumption were to continue. The report generated substantial academic debate. As early as 1973, researchers at the University of Sussex (Cole et al., 1973), in *Models of Doom*, argued that the World3 model placed relatively limited emphasis on the capacity of markets and technological progress to respond to resource scarcity through price adjustments, substitution, and efficiency gains. Half a century later, the issue continues to be examined empirically rather than being regarded as fully settled in either direction (Turner, 2014). Nevertheless, the underlying question — whether continuous industrial growth can remain compatible with environmental constraints — provided an important methodological foundation for the subsequent development of the Environmental Kuznets Curve hypothesis.

The Environmental Kuznets Curve (EKC) hypothesis, introduced by Grossman and Krueger (1995) and Panayotou (1993), proposes that the relationship between per-capita income and environmental pressure may take the form of an inverted U-shaped curve: environmental pressure initially increases as income rises during the early stages of development and subsequently declines after a certain income threshold is reached. The standard econometric specification can be expressed as $E = \beta_0 + \beta_1 \cdot GDP + \beta_2 \cdot GDP^2 + \gamma \cdot X + \varepsilon$, where a positive β_1 combined with a negative β_2 indicates an inverted-U relationship. The corresponding turning point is calculated as $GDP = -\beta_1 / (2 \cdot \beta_2)$. *The considerable variation in estimated turning points reported in the literature — ranging from relatively low income levels for indicators such as deforestation to substantially higher levels for CO_2 emissions — suggests that GDP* should not be treated as a universal constant. Instead, it should be estimated using country- or region-specific data that reflect the particular structural characteristics of the economy under study.

The shape of the relationship also depends significantly on the type of environmental indicator considered. Shafik and Bandyopadhyay (1992) found that some indicators, including access to clean water and sanitation, tend to improve progressively with income, whereas an inverted-U pattern is more evident for certain local air pollutants, including particulate matter and sulphur dioxide. Selden and Song (1994) similarly identified an inverted-U relationship for four major air pollutants. As Stern (2004) notes, however, empirical evidence for a comparable pattern is less consistent for CO_2 and other greenhouse gases. One possible explanation

is that reducing local pollutants such as sulphur dioxide produces relatively immediate and geographically concentrated benefits, whereas decarbonisation generates more widely distributed and longer-term benefits while often requiring substantial local investment. This underlines the importance of deliberate regulatory and technological measures alongside market-driven mechanisms.

The EKC hypothesis should therefore be treated as an empirical proposition rather than a universally established law. Stern (2004) identifies a number of methodological issues that require careful consideration in empirical studies, including heteroscedasticity, omitted-variable bias in cross-country panels, the potential endogeneity of income with respect to environmental quality, sensitivity to functional-form specification, and the possibility of spurious regression when non-stationary time series are used without prior cointegration testing. These methodological considerations justify the use of estimation techniques that are better suited to heterogeneous and dynamic data structures. In particular, the panel ARDL approach accommodates variables with mixed orders of integration, I(0) and I(1), while also allowing short-run and long-run relationships to be estimated separately.

With regard to Uzbekistan and Central Asia, three recent empirical studies report substantively different results while sharing a common methodological characteristic: all are conducted at the aggregated national or cross-country level rather than at the regional level. Nuriddinova and Ahmad (2025) identify a positive relationship between per-capita GDP and CO_2 emissions at the national level, which is consistent with an early stage of the EKC trajectory. Caporin et al. (2024), using a panel of five Central Asian countries, likewise conclude that the relationship is predominantly linear rather than inverted-U shaped. Apergis et al. (2023) focus on the structure of the energy mix and exclude GDP from their final specification because of multicollinearity, thereby shifting the emphasis away from a direct test of the canonical EKC relationship. None of these studies employs data at the level of individual regions of Uzbekistan, and consequently they do not assess whether the relationship between industrial development and environmental indicators differs across territories characterised by substantially different sectoral specialisations.

A transition towards a regional panel-data structure would considerably expand the information base available for identifying potential turning points and analysing territorial heterogeneity. It would also enable the application of the PMG/MG/DFE family of estimators, together with the Hausman test, to assess statistically whether the assumption of common long-run coefficients across regions is appropriate. Such an approach would provide a more flexible methodological framework than one in which coefficient homogeneity is assumed in advance and would make it possible to reflect more accurately the regional diversity of industrial development and environmental conditions in Uzbekistan.

ANALYSIS AND RESULTS

Comparing Uzbekistan with China and Germany is methodologically justified on the basis of structural rather than geographical similarity. In all three countries, industry accounts for a substantial share of GDP, broadly within the range of approximately 29–38%, whereas in predominantly service-oriented economies this share is generally lower. Both China and Germany have experienced, or continue to experience, significant phases of industrialisation and illustrate contrasting trajectories within the Environmental Kuznets Curve framework.

China, currently the world's largest emitter of CO_2, with emissions of approximately 10.25 billion tonnes in 2020, remains on the upward segment of the curve while pursuing a clearly defined long-term environmental strategy. Under the "dual carbon" policy announced in 2020, China aims to achieve peak carbon emissions before 2030 and carbon neutrality by 2060. Importantly, these objectives are increasingly operationalised at the provincial level. Forecasts for the peaking of industrial emissions in individual provinces vary between approximately 2030 and 2035 depending on regional differences in energy efficiency and economic structure. This confirms that the shape and timing of the EKC may vary considerably within a single country. A comparative study of Qinghai, characterised by a resource-oriented economy, and Zhejiang, with a more diversified coastal economic structure, over the period 1997–2023 identified substantial differences in the pace of decoupling between economic growth and emissions. This suggests that national-level EKC estimates may conceal significant territorial heterogeneity, providing a direct methodological rationale for regional analysis in Uzbekistan.

Germany represents a contrasting trajectory. The country appears to have passed the EKC turning point as early as the 1990s. Total greenhouse gas emissions declined from approximately 1,252 million tonnes of CO_2 equivalent in 1990 to 649 million tonnes in 2024, representing a reduction of around 48.2%, alongside the implementation of the Energiewende energy-transition policy. With average annual GDP growth of approximately 1.3% and an average annual decline in emissions of about 1.6% over the past decade, Germany demonstrates a sustained pattern of absolute decoupling between economic growth and environmental pressure. At the same time, aggregate national indicators conceal significant sectoral differences: emissions from the energy

sector declined by roughly 60%, industrial emissions by 48.1%, while progress in the transport sector has been comparatively more gradual.

An important methodological consideration is that decoupling observed in German industry should not automatically be interpreted solely as evidence of technological modernisation. According to Agora Energiewende, industrial emissions increased by approximately 3 million tonnes, or 2%, in 2024 amid a partial recovery in energy-intensive production. At the same time, part of the emissions reduction observed in 2022–2023 was associated with a temporary decline in industrial output during a period of energy-market adjustment rather than exclusively with structural technological change. Output in energy-intensive industries in 2025 remained approximately 17% below pre-2022 levels. This distinction is methodologically important for interpreting future regional estimates for Uzbekistan as well: a negative coefficient on industrial output in a panel model does not, by itself, identify the underlying mechanism of reduced environmental pressure.

Institutionally, China and Germany have achieved improvements in environmental performance through different policy approaches. The Chinese model relies more heavily on directive and target-based planning, under which energy-intensity and emissions targets are incorporated into five-year plans and linked to regional performance indicators. The German model, by contrast, places greater emphasis on price- and market-based instruments, including emissions trading, carbon pricing, and support mechanisms for renewable energy generation. Uzbekistan's institutional development — from a sectoral environmental body to a presidential-level governance structure — demonstrates a strengthening of strategic coordination and target-oriented environmental management. In this respect, certain features are closer to the Chinese model of directive and programme-based governance, which is relevant when assessing the practical applicability of different environmental policy instruments in the Uzbek context.

The term "environmental security" has been incorporated into Uzbekistan's legislative framework for more than three decades. The Law "On Nature Protection" of 9 December 1992 identifies the protection of human environmental security among the fundamental principles of nature conservation. The constitutional foundations are reflected in Articles 50 and 55 of the Constitution of the Republic of Uzbekistan, which establish, respectively, citizens' responsibility to protect the environment and the status of natural resources as national wealth under state protection.

The general legislative framework is complemented by more than forty sectoral laws and codes, including the Law "On the Use of Renewable Energy Sources" (2019), which introduced tax and property incentives for renewable energy producers. Sectoral regulation is further supported by strategic planning instruments, including concepts, strategies, and state programmes. One illustrative example is the 2019–2028 Strategy for Solid Household Waste Management. While the target recycling rate for the second implementation phase was set at 60%, the indicator stood at 21.9% at the midpoint of the period. This suggests that, alongside the progress achieved in the energy sector, further development of implementation mechanisms in other areas of environmental policy remains an important priority.

Targets in Uzbekistan's climate and energy policy have also evolved considerably in response to changing technological and investment opportunities. The target share of renewable energy in electricity generation was revised from 25% in 2019 to 30% in 2022, 40% in 2023, and 54% by late 2024. Similarly, the target reduction in GDP carbon intensity was increased from 10% to 35% relative to the 2010 baseline under the updated Nationally Determined Contribution (NDC) of 2021. These developments may be interpreted as evidence of increasing policy ambition and a capacity to adapt strategic objectives as new investment and technological opportunities emerge. At the same time, they underline the importance of further strengthening long-term target-setting mechanisms to ensure continuity and consistency in environmental planning.

The institutional architecture of environmental governance has also evolved significantly, from the State Committee for Ecology in 2017, through the Ministry of Ecology, Environmental Protection and Climate Change in 2023, to the National Committee for Ecology and Climate Change under the President in November 2025. Under the latest reform, a State Environmental Control Inspectorate was established within the National Committee, alongside a National Environmental Monitoring Centre. Industrial enterprises classified under hazard categories I and II are required to install background monitoring stations integrated with the national system by 1 March 2026, while pollution-compensation payments for non-compliance are subject to a fivefold increase. This reform creates an important technical basis for the real-time collection of primary data on industrial emissions at the level of individual enterprises and may substantially improve the level of detail available for future regional empirical analysis. Notably, the territorial subdivisions of the National Committee correspond to the same fourteen regional-administrative units — the Republic of Karakalpakstan, the regions (*viloyats*), and the city of Tashkent — that naturally define the panel dimension for regional econometric analysis.

The international legal framework includes Uzbekistan's accession to the United Nations Framework Convention on Climate Change in 1993, ratification of the Kyoto Protocol in 1999 and the Paris Agreement in 2018, as well as two successive revisions of its Nationally Determined Contribution, which increased the

target reduction in GDP carbon intensity from 10% to 35% relative to the 2010 baseline. Uzbekistan is not currently a party to the Aarhus Convention, which establishes principles relating to access to environmental information, public participation in decision-making, and access to environmental justice. From an institutional perspective, future consideration of such mechanisms could further complement the country's existing directive and programme-based model of environmental governance.

The analysis presented above leads to three interrelated conclusions. First, environmental security as a scientific category is grounded in two complementary theoretical traditions — the securitisation approach and the sustainable-development approach — while its practical assessment is operationalised through measurable environmental risk indicators. This makes environmental security suitable not only for normative interpretation but also for quantitative empirical analysis.

Second, the evolution of theoretical models describing the relationship between economic growth and the environment demonstrates that this relationship is neither necessarily linear nor automatically favourable. The shape of the Environmental Kuznets Curve depends substantially on the scale of analysis — national or regional — the type of pollutant under consideration — local or global — and the institutional context, including the relative role of directive and market-based regulatory instruments.

Third, Uzbekistan's regulatory and institutional framework has developed dynamically in recent years and is structured around the same territorial units that provide a practical basis for shifting from nationally aggregated analysis to regional panel analysis. This institutional configuration creates favourable conditions for examining spatial differences in the relationship between industrial development and environmental pressure.

Taken together, these findings reveal a specific research gap: existing empirical studies on Uzbekistan and Central Asia have not yet tested the Environmental Kuznets Curve hypothesis using subnational panel data, even though available evidence, including the cases of the Almalyk Mining and Metallurgical Combine and Navoi region, indicates a significant territorial concentration of industrial environmental pressure. China's experience, where provincial-level analysis also reveals substantial heterogeneity in the pace and pattern of decoupling, further supports the methodological relevance of such an approach.

Addressing this research gap requires the application of panel-data methods that are robust to the methodological issues commonly identified in the EKC literature, including income endogeneity, sensitivity to functional-form specification, and the risk of spurious regression in the presence of non-stationary time series. In this context, panel variants of the ARDL approach, particularly the PMG/MG/DFE family of estimators, appear methodologically appropriate because they make it possible to estimate common long-run coefficients across regions while statistically testing, rather than presuming, the validity of the pooling assumption.

The evolving institutional environment in Uzbekistan — including the development of instrumental monitoring systems for industrial enterprises and the organisation of public administration across fourteen territorial units — provides increasingly favourable conditions for the practical application of this regional econometric framework in future research.

CONCLUSION AND RECOMMENDATIONS

This article has systematised the theoretical foundations of the concept of environmental security and traced the evolution of models describing the relationship between industrial growth and environmental quality, from the IPAT identity and the *Limits to Growth* report to the Environmental Kuznets Curve hypothesis. Through a comparison of international experience in China and Germany and a critical review of existing empirical studies on Uzbekistan and Central Asia, the article has identified a research gap associated with the limited application of subnational panel testing of the EKC hypothesis across the regions of Uzbekistan. An examination of the country's regulatory and institutional framework has shown that the territorial organisation of state environmental governance already corresponds to the regional dimension required for panel analysis. These theoretical and methodological findings provide a foundation for subsequent empirical research on the relationship between industrial development and environmental indicators using panel data for the regions of Uzbekistan and a Panel ARDL methodology.

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