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Global ammonium perchlorate market: Environmental challenges and imperatives of sustainable resource use

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Abstract. The relevance of this study is driven by the expanding use of ammonium perchlorate in the aerospace and defence industries, which is accompanied by increasing anthropogenic pressure on the environment and the need to implement the principles of sustainable resource use. The aim of the study was to analyse the dynamics, structure, and development factors of the global ammonium perchlorate market, taking environmental risks into account. The research employed methods of generalisation, comparative and economic analysis, as well as market trend analysis based on analytical reports and scientific publications. The results showed that the global ammonium perchlorate market is characterised by steady growth with an average annual rate of approximately 5.37%, driven by the development of the aerospace and defence sectors. It was established that the market exhibits a pronounced inertial development pattern and depends on state funding of strategic programmes. Key growth drivers were identified, including technological innovation, geopolitical tensions, and an increasing number of space launches. It was demonstrated that environmental risks associated with water contamination and the toxic effects of perchlorates create additional constraints on market functioning and contribute to stronger regulatory frameworks. Structural analysis revealed that the largest share by volume is held by the extractive industry and construction sector (43.65%), while the aerospace and defence sector provides the most stable strategic demand. It was substantiated that the environmental factor is transforming into an innovation driver, stimulating the development of safer production and utilisation technologies. The practical significance of the findings lies in their potential use for developing market strategies that account for environmental requirements and improving the efficiency of production processes

Keywords: solid rocket propellant; aerospace industry; environmental safety; water contamination; perchlorates; market dynamics; environmental regulation

Introduction

The global development of high-technology industries, particularly the aerospace and defence sectors, sustains steady growth in demand for specialised chemical components, among which ammonium perchlorate occupies a key position. This compound is widely used as an oxidiser in solid rocket propellants, which determines its strategic importance for ensuring the functioning of modern space launch systems and defence technologies. In the context of intensifying space programmes, a growing number of launches, and the modernisation of military-technological capabilities of leading nations, the ammonium perchlorate market demonstrates stable positive growth dynamics. At

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the same time, the expanding scale of production and use of this substance is accompanied by a range of environmental risks associated with its toxic properties, its ability to accumulate in natural environments, and its potential impact on water resources and human health. In the context of tightening environmental regulation and growing requirements for the safety of chemical production, the issue of minimising the negative impact of perchlorates on the environment is becoming highly relevant. This necessitates a rethinking of traditional approaches to organising production processes and the introduction of more environmentally oriented technological solutions.

According to B. Zhang *et al.* (2022), perchlorates are widely distributed water contaminants that are regularly detected in groundwater and surface waters in various regions of the world, including drinking water supply systems. The researchers emphasised that their presence in the aquatic environment has a global character and is associated with the high migratory capacity of these compounds, which determines their long-term persistence and dispersal even beyond the immediate sources of contamination. E.N. Pearce (2024), analysing the biomedical aspects of perchlorate exposure, noted that these compounds act as competitive inhibitors of the sodium-iodide symporter in the thyroid gland, leading to reduced iodine uptake and potential disruption of thyroid hormone synthesis. The author stressed that the greatest risk is observed in vulnerable population groups, particularly pregnant women and young children, for whom even low levels of chronic exposure may have significant consequences for endocrine development. B. Predieri *et al.* (2022), in their study, examined perchlorates as persistent inorganic pollutants of anthropogenic origin and emphasised that their environmental hazard is determined by the combination of toxicity and stability in natural environments. The authors concluded that effective risk management requires a comprehensive approach encompassing monitoring, regulatory control, and the implementation of remediation technologies.

C. Fang & R. Naidu (2023) conducted a systematic review of perchlorate contamination and concluded that the high mobility of these compounds in natural environments significantly complicates the processes of their localisation and remediation. K.S. Kumar *et al.* (2022) analysed the environmental occurrence, toxicity, and remediation methods for perchlorates across various natural environments, emphasising the need for comprehensive approaches. R. Acevedo-Barrios *et al.* (2025) examined the global extent of perchlorate distribution, including their detection in Antarctica, demonstrating the transboundary nature of the contamination. R. Acevedo-Barrios & J. Olivero-Verbel (2021) systematised the sources of perchlorate contamination and the available remediation technologies, pointing to significant gaps in the regulatory framework. C.-Y. Lai *et al.* (2021) investigated mechanisms of biological perchlorate reduction and established that microbial remediation is a promising approach for the treatment of contaminated groundwater. O.A. Pivovarov & M.M. Cheltonov (2020) examined technological approaches to extracting ammonium perchlorate from solid rocket fuel disposal products. M.E. Gilbert *et al.* (2024) demonstrated that ammonium perchlorate exerts neurotoxic effects on thyroid development in neonatal rats. C. Serrano-Nascimento & M.T. Nunes (2022) investigated the effects of perchlorate and other NIS inhibitors on thyroid function and human health, concluding that there is a significant risk for pregnant women and children.

Alongside environmental aspects, significant importance attaches to the effective use of resources in the production of ammonium perchlorate. In this context, the concept of sustainable resource use entails optimising production cycles, reducing resource expenditure, and introducing innovative technologies. Thus, the available scientific base primarily covers the environmental and toxicological dimensions of the perchlorate issue. Market processes remain insufficiently studied: a comprehensive analysis of the structural factors driving the development of the ammonium perchlorate market – accounting for the interaction of environmental, technological, and institutional factors – is absent, and this gap provided the rationale for the present study. The aim of the study was to analyse contemporary trends in the development of the global ammonium perchlorate market, taking into account environmental risks and the operational features of the relevant production processes. To achieve this aim, the following objectives were defined: to analyse the dynamics and structure of the global ammonium perchlorate market; to identify the key factors that influenced its development; to investigate the environmental consequences of perchlorate production and use.

Materials and Methods

The study employed a comprehensive analytical approach combining methods of economic, comparative, and environmental analysis. The object of the study was the global ammonium perchlorate market; the subject was the trends in its development and the environmental aspects of its functioning. The information base of the study was formed from two categories of sources. The first category comprises scientific publications indexed in the international databases Scopus and Web of Science, dedicated to the environmental impact of perchlorates, their toxicity, and their technological applications (Motzer, 2001; Urbansky, 2002; Kucharzyk *et al.*, 2009; Lai *et al.*, 2021; Kumar *et al.*, 2022; Serrano-Nascimento & Nunes, 2022; Zhang *et al.*, 2022; Fang & Naidu, 2023; Gilbert *et al.*, 2024; Pearce, 2024; Acevedo-Barrios & Puentes, 2025). The second category consists of analytical reports from leading research agencies on the development of the ammonium perchlorate market (MarketsandMarkets, 2024; Research and Markets, 2025), which are compiled using an approach that integrates information from open sources, corporate reporting, industry surveys, and expert assessments. This approach ensures a sufficient level of reliability and representativeness of the results for further scientific generalisation. To analyse market dynamics, the compound annual growth rate (CAGR) calculation method was applied according to the formula:

$$CAGR = \frac{V_n{}^{\frac{1}{n}}}{V_0} - 1, \tag{1}$$

where V_0 is the market volume in the base year; V_n is the market volume in the final year; n is the number of years in the period under analysis. Based on available market data for 2018-2024 and projected values through to 2030, a compound annual growth rate of 5.37% was calculated. The projections presented in the analytical reports of Research and Markets (2025) and MarketsandMarkets (2024) are based on methods of trend extrapolation, regression analysis, and scenario modelling, taking into account the dynamics of government defence expenditure, the number of space launches, and the state of the regulatory environment.

Comparative analysis was conducted across three dimensions. The first stage involved a comparison of regional markets (Asia-Pacific, North America, Europe) by share and relative growth dynamics in order to identify differences in development rates. This was followed by a comparison of industry segments by consumption volume – specifically, the aerospace and defence sector, the extractive industry and construction, and pyrotechnic production. Finally, an analysis was conducted of the overall impact of environmental constraints and regulatory pressure on market development. The method of generalisation was applied to form a holistic picture of the interaction between economic, environmental, and technological factors of market development. For a visual representation of this interaction, the method of systematisation was employed, followed by the development of an environmental factor impact matrix. In addition, the analysis of biomedical and toxicological data (in particular, relating to the effects of perchlorates on the endocrine system) was used in the study not as an independent research object, but as a qualitative indicator for assessing the regulatory environment. The depth of the negative health impact of chemicals was considered a key criterion explaining the formation of market constraints and stimulating innovation in treatment technologies. A limitation of the study was the absence of a unified system of indicators of environmental loading from ammonium perchlorate production in the public domain, which precludes quantitative assessment of the energy intensity and material consumption parameters of production cycles. This determined the predominantly qualitative character of the analysis of the resource aspect of market functioning.

Results and Discussion

The functioning of the global ammonium perchlorate market is determined by its critical role in supplying the aerospace and defence industries, where this substance is used as the primary oxidiser in composite solid rocket propellants. Ammonium perchlorate is an inorganic compound characterised by high oxidising capacity and efficient combustion, which accounts for its widespread application in the production of rocket engines. This functional specificity generates a highly specialised demand for the product (Sutton & Biblarz, 2016). Analysis of the dynamics of the global ammonium perchlorate market reveals an overall growth trend in the medium term (Fig. 1). In particular, the market volume in 2023 was estimated at approximately USD 812.21 million, and in 2024 at USD 854.77 million, while by 2030 it is projected to reach USD 1,171.80 million. The CAGR amounts to approximately 5.37% (Research and Markets, 2025). These data are consistent with the estimates for the solid rocket motor market contained in the MarketsandMarkets (2024) report, which confirms the representativeness of the database used.

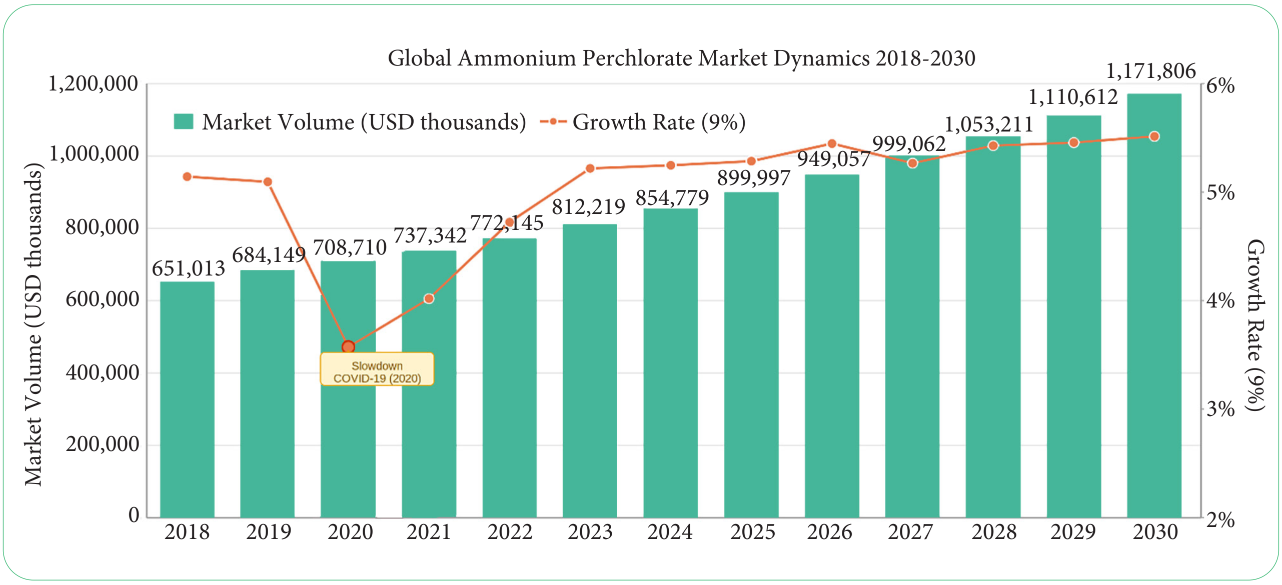

Figure 1. Dynamics of the global ammonium perchlorate market, 2018-2030

Source: compiled by the authors based on Research and Markets (2025)

It should be noted that the overall growth trend is not entirely uniform. An analysis of data for 2018-2022 reveals a noticeable short-term decline associated with a reduction in government orders and disruption to supply chains during the COVID-19 pandemic. This is consistent with general trends in the aerospace and defence industries in 2020-2021. After 2022, the market demonstrates recovery and accelerated growth, linked to geopolitical escalation and increased defence spending. This aspect is important for understanding the inertial character of market development, which is determined primarily by government funding cycles.

Analysis of the presented dynamics allows several structural characteristics of market development to be identified. The rate of market expansion remains moderate, due to the limited scope of application of the product and the high degree of specialisation of production. A dependence of market development on long-term programmes in the field of defence and space exploration is also observed, forming an inertial type of growth characteristic of sectors dominated by government funding. The growth of the ammonium perchlorate market is driven by a combination of technological and geopolitical factors. The key driver is the development of the aerospace industry, accompanied by an increase in the number of launches and an expansion of the range of space programmes. Simultaneously, defence budgets are growing in many countries, stimulating demand for rocket systems and, accordingly, for solid rocket propellants. Technological innovations aimed at improving the efficiency of rocket engines also sustain demand for ammonium perchlorate as a key component of such systems (Fig. 2).

Structural analysis of the ammonium perchlorate market reveals its sectoral diversification (Fig. 2). According to the data presented, the largest segment in 2023 is mining and construction (43.65%), where ammonium perchlorate is used primarily as a component of explosives. The aerospace and defence sector occupies the second position, yet generates the most stable and strategically predictable demand. Thus, the ammonium perchlorate market is commercially diversified: while the aerospace and defence industries determine the strategic significance of the product, the predominant consumption volume in 2023 falls on the extractive and construction sectors. Growing demand for high-purity ammonium perchlorate (concentration above 99%) is driven by the needs of the aerospace industry, where the stability of characteristics and predictability of material behaviour are of critical importance. This stimulates the development of more complex and energy-intensive production technologies, in particular electrochemical synthesis (Fig. 3).

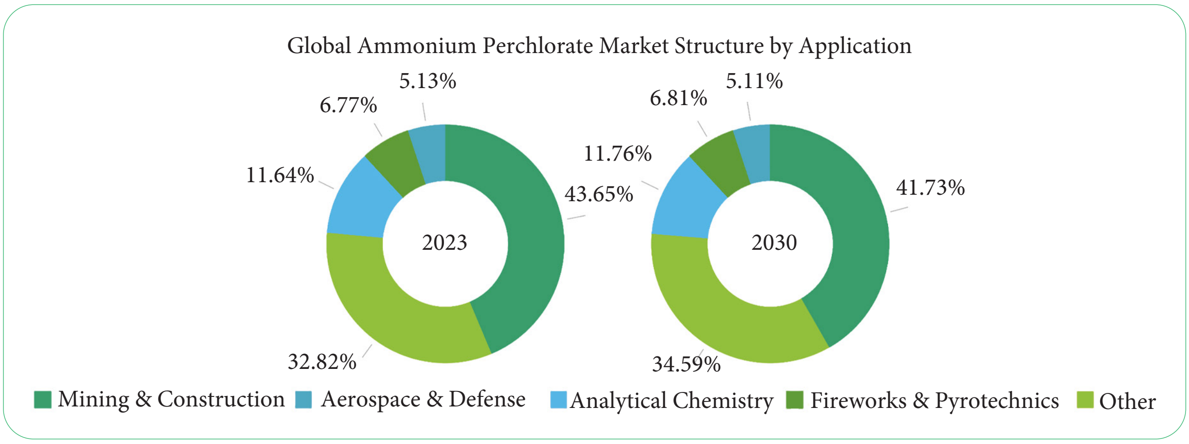

Figure 2. Structure of the global ammonium perchlorate market by application segment
Source: compiled by the authors based on MarketsandMarkets (2024), Research and Markets (2025)

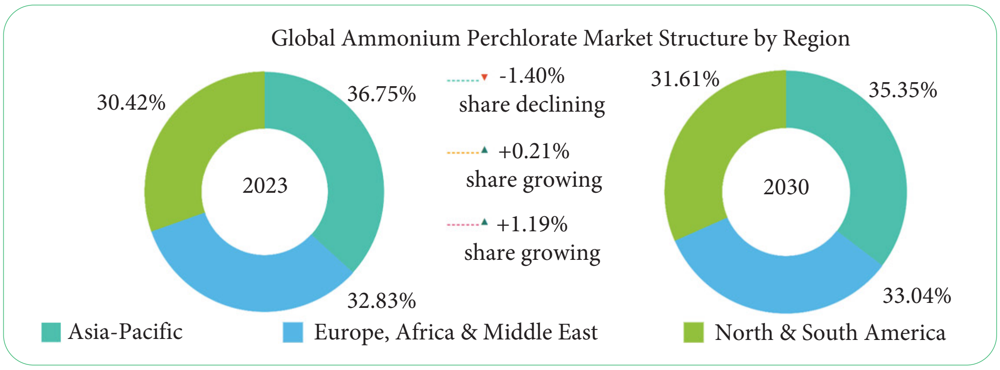

Figure 3. Geographic structure of the global ammonium perchlorate market by region
Source: compiled by the authors based on Research and Markets (2025)

The geographic structure of the market reveals important spatial differences in growth dynamics (Fig. 3). In terms of absolute volumes, the Asia-Pacific region leads; however, an analysis of market shares over time reveals a gradual decline in its relative share – from 36.75% in 2023 to 35.35% in 2030. Meanwhile, the shares of North America (from 30.42% to 31.61%) and Europe (from 32.83% to 33.04%) show an upward trend. This means that the markets of North America and Europe are growing in relative terms more rapidly than the Asia-Pacific market. Such dynamics may be associated with increased investment in rocket programmes in the United States and Europe after 2022, against the backdrop of geopolitical escalation.

The intensification of demand for ammonium perchlorate brings environmental safety issues to the fore. The entry of perchlorates into groundwater and surface waters can lead to their accumulation and subsequent inclusion in trophic chains, creating risks for ecosystems and human health. The impact of perchlorates on thyroid function is confirmed by contemporary toxicological research. C.-Y. Lai *et al.* (2021) emphasise that microbial remediation is one of the most promising approaches for reducing the environmental load of perchlorates in groundwater. The strengthening of environmental risks directly affects the regulatory environment. In a number of countries, strict requirements have been introduced with respect to the production, transportation, and disposal of perchlorates, which complicates the activities of manufacturers (Kucharzyk *et al.*, 2009). At the same time, the environmental factor is gradually transforming into an additional driver of innovative development: safety requirements stimulate the introduction of new treatment technologies and the development of alternative oxidisers with a lesser environmental impact. A systematic representation of environmental factors and their market impacts is provided in Table 1.

Table 1. Impact of environmental factors on the functioning of the ammonium perchlorate market

Environmental Factor	Manifestation	Market Impact
Water resource contamination by perchlorates	Accumulation in groundwater and surface waters	Tightening of environmental controls and restrictions on use
Emissions from rocket propellant combustion products	Release of toxic compounds into the atmosphere	Growing requirements for environmental standards
Environmental risks of production	Generation of waste and wastewater	Increased expenditure on purification and production modernisation
Strengthened regulatory frameworks	Introduction of environmental norms and standards	Creation of market entry barriers and stimulation of innovation

Source: developed by the authors

The findings indicate stable growth of the ammonium perchlorate market at a CAGR of approximately 5.37%, characterised by pronounced inertia and critical dependence on government funding for strategic programmes. The identified growth trend is fully consistent with the general trends in the development of the aerospace and defence industries (in particular, the increase in the number of space launches and geopolitical tensions) documented in the analytical reports of Research and Markets (2025) and MarketsandMarkets (2024). From a technological perspective, these market indicators are explained by the fundamental work of G.P. Sutton & O. Biblarz (2016), which confirms the central role of ammonium perchlorate as the primary oxidiser in solid rocket propellants, and provides a detailed analysis of its unique physicochemical properties that currently make it practically irreplaceable in this field.

At the same time, the study demonstrates that the expanding use of ammonium perchlorate is accompanied by increased anthropogenic pressure on the environment. The identified environmental constraints of the market (in particular, water resource contamination) are reliably confirmed by the conclusions of K.S. Kumar *et al.* (2022) and C. Fang & R. Naidu (2023) regarding the high mobility and persistence of perchlorates in natural environments. The problem of accumulation of these persistent anthropogenic contaminants in aquatic systems was conceptualised in the studies of W.E. Motzer (2001) and E.T. Urbansky (2002), where the lack of unified standards for risk assessment and sources of the chemical's entry into the environment was highlighted. In the contemporary context, the scale of the problem is illustrated by the study of B. Zhang *et al.* (2022), which identified high-risk zones in drinking water sources near industrial agglomerations in China.

An important aspect that creates additional pressure on producers and stimulates stricter regulatory frameworks is the impact of perchlorates on human health. The conclusions of the present work regarding toxic risks resonate with substantive biomedical research. C.M. Steinmaus (2016) detailed the pathways of perchlorate exposure via water supply systems and health consequences, while R.C. Pleus & L.M. Corey (2018) provided a comprehensive toxicological assessment of the effects of these compounds on the human body. A key mechanism of this impact – disruption of thyroid function – is described by R.E. Tarone *et al.* (2010) in an epidemiological review. These risks are particularly critical for vulnerable population groups: B. Predieri *et al.* (2022) classified perchlorates as serious endocrine disruptors that are among the key factors causing hormonal imbalance in children. Awareness of these threats earlier prompted K.H. Kucharzyk *et al.* (2009) to substantiate the need to establish strict drinking water quality standards in the United States.

The most significant conclusion of the analysis conducted is that environmental risks not only create constraints but are also transforming into a powerful driver of innovation, stimulating the development of safer production technologies and treatment systems. The development of water treatment technologies for perchlorates has progressed from the basic methods reviewed in detail by L. Ye *et al.* (2012) to modern high-technology solutions. M.R. Sijimol & M. Mohan (2014) examined pyrotechnics – in particular the production and use of fireworks – as a significant source of perchlorate environmental contamination. It was established that following fireworks launches, perchlorate concentrations in water rise sharply within a few hours and can exceed background levels tens or even thousands of times, before gradually declining over several weeks. The authors stress that the health and environmental consequences of this contamination source remain insufficiently studied, necessitating further research. In contrast to most existing works, which are narrowly specialised and focus either on economic and technical aspects and ballistics, or exclusively on epidemiology and ecology, the present study examines the ammonium perchlorate market as a unified ecological-economic system. This approach makes it possible to identify the dual role of the environmental factor: simultaneously as a rigid regulatory constraint on an inertial market and as the primary catalyst for structural and technological change within the paradigm of sustainable resource use.

Conclusions

The results of the analysis indicate that the ammonium perchlorate market is shaped by a complex set of economic, technological, and environmental factors whose interaction is acquiring an increasingly systemic character. Whereas in the early stages of industry development the dominant factors were exclusively the functional and technical parameters of the substance as a rocket propellant component, there is a gradual shift of emphasis towards the integration of environmental constraints into the decision-making processes at all levels of market functioning. The global ammonium perchlorate market demonstrated an overall growth trend at a CAGR of 5.37% with a projected volume of USD 1,171.80 million in 2030, although this dynamic is not uniform and experienced a temporary decline under the impact of the COVID-19 pandemic. Structural analysis revealed that the largest segment by volume is mining and construction (43.65% in 2023), while the aerospace and defence sector generates the most stable strategic demand. Geographic analysis showed that the markets of North America and Europe demonstrate higher relative growth rates compared to the Asia-Pacific region. The environmental factor acquires a dual role: it simultaneously constrains the market through regulatory pressure and stimulates innovation in the field of safer production technologies.

At the same time, the study indicates that the environmental component is not yet fully institutionalised as an autonomous regulator of market development, and is manifested primarily through fragmented constraints and local monitoring practices. Ensuring the balanced development of the ammonium perchlorate market requires the integration of environmental criteria into the strategic management system of the industry, in particular through the improvement of production technologies, the strengthening of regulatory frameworks, and the stimulation of innovative solutions in the field of alternative materials. A promising direction for further research is the study of the relationship between the development of alternative oxidisers, the tightening of environmental requirements, and the transformation of the market structure, as well as the analysis of mechanisms for harmonising environmental standards across different jurisdictions and their impact on global ammonium perchlorate supply chains.

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Conflict of Interest

None.

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Глобальний ринок перхлорату амонію: екологічні виклики та імперативи збалансованого ресурсокористування

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Анотація. Актуальність дослідження зумовлена розширенням використання перхлорату амонію у ракетно-космічній та оборонній галузях, що супроводжується підвищенням техногенного навантаження на довкілля та необхідністю впровадження принципів збалансованого ресурсокористування. Метою дослідження став аналіз динаміки, структури та факторів розвитку глобального ринку перхлорату амонію з урахуванням екологічних ризиків. У роботі були використані методи узагальнення, порівняльного та економічного аналізу, а також аналіз динаміки ринку на основі аналітичних звітів і наукових публікацій. У результаті було встановлено, що глобальний ринок перхлорату амонію характеризується стабільним зростанням із середньорічним темпом близько 5,37 %, що обумовлено розвитком аерокосмічного та оборонного секторів. Було визначено, що ринок має виражений інерційний характер розвитку та залежить від державного фінансування стратегічних програм. Виявлено ключові фактори зростання, серед яких технологічні інновації, геополітична напруженість та збільшення обсягів космічних запусків. Було доведено, що екологічні ризики, пов'язані із забрудненням водних ресурсів і токсичним впливом перхлоратів, формують додаткові обмеження для функціонування ринку та сприяють посиленню нормативного регулювання. Структурний аналіз показав, що найбільшу частку за обсягом займають видобувна промисловість і будівництво (43,65 %), тоді як аерокосмічний та оборонний сектор забезпечує найстабільніший стратегічний попит. Обґрунтовано, що екологічний фактор трансформується у драйвер інновацій, стимулюючи розвиток безпечніших технологій виробництва та використання. Практичне значення отриманих результатів полягає у можливості їх використання для формування стратегій розвитку ринку з урахуванням екологічних вимог та підвищення ефективності виробничих процесів

Ключові слова: тверде ракетне паливо; аерокосмічна промисловість; екологічна безпека; забруднення водних ресурсів; перхлорати; ринкова динаміка; екологічне регулювання