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Ecological Shortcomings of Existing Methods for Substantiating the Number of Gas Distribution Stations (GDS)

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Annotation
Gas distribution stations (GDS) are key components of regional and urban energy infrastructure, ensuring the reliable supply of natural gas to households, enterprises, and industrial facilities. However, existing methods for substantiating the number of GDS emphasize only technical and economic indicators, while overlooking ecological risks. This study analyzes the ecological shortcomings of current approaches, focusing on the age structure of operating GDS, routine gas losses, and associated emissions. Results indicate that 40% of GDS have been in service for over 30 years, contributing to higher risks of technical failures, leakages, and increased maintenance demands. Methane emissions from individual stations reach 2.5–3.7 tons annually, representing a significant climate impact, while hydrogen sulfide and mercaptans, though smaller in mass, affect local air quality and public health. The findings emphasize the need for integrated justification methods that combine technical reliability, ecological monitoring, and modernization strategies to ensure sustainable gas distribution.

Keywords: Gas distribution station, natural gas infrastructure, methane emissions, ecological risks, pressure regulation, infrastructure aging, environmental safety.

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Introduction

Gas distribution stations (GDS) are essential infrastructure components ensuring the reliable and safe delivery of natural gas to industrial enterprises, energy facilities, and households. Their function is not limited to transportation; they also regulate pressure, remove mechanical impurities, and guarantee the quality of gas supplied to consumers [1]. In many countries, GDS form the backbone of urban and regional energy systems, linking high-pressure pipelines with local distribution networks. Despite their critical importance, the operation of such facilities is often associated with technical, ecological, and safety shortcomings that require a systematic scientific assessment [2].

The ecological shortcomings of existing methods for justifying the required number of GDS are directly linked to outdated technical standards and insufficient consideration of environmental factors [3, 4]. Current approaches often emphasize only technical and economic indicators such as throughput capacity, pressure stabilization, and contractual obligations between transmission operators and consumers [5]. However, they rarely account for ecological risks arising from technological failures, gas leakage, or insufficient monitoring of surrounding ecosystems.

Environmental safety of GDS is a multidimensional problem. On one hand, stations must maintain stable operation under fluctuating demand, but on the other hand, they generate risks associated with methane leakage, noise, and potential explosions [6-8]. Methane, as a greenhouse gas, has a global warming potential significantly higher than carbon dioxide. Therefore, even minor inefficiencies in gas distribution may have disproportionate ecological impacts [9]. Yet, many existing design and justification methods ignore these broader consequences.

Another shortcoming of current practices lies in the insufficient integration of modern ecological monitoring technologies [10]. While telemetric systems for pressure and temperature monitoring are increasingly being installed, ecological monitoring of air quality, soil contamination, and vegetation impacts near GDS sites is rarely implemented [11, 12]. The absence of such comprehensive assessment results in an incomplete understanding of the ecological footprint of gas distribution networks.

The criteria used to justify the number of GDS do not adequately reflect their service life. A significant share of existing stations has been in operation for over 30 years, leading to inevitable wear and reduced efficiency [13, 14]. Outdated GDS, if not properly modernized, pose elevated ecological and technological risks, yet their continued exploitation is often justified on purely economic grounds [15].

Therefore, there is an urgent need to develop scientifically based methods that integrate technical, economic, and ecological aspects for determining the optimal number of GDS. Such methods should provide not only reliable gas delivery but also minimize risks to human health, safety, and the environment. This article addresses the ecological shortcomings of existing justification approaches and outlines the necessity of introducing innovative, eco-efficient criteria into gas infrastructure planning.

Materials and methods

The research was conducted through a combination of analytical review, systematization of regulatory frameworks, and comparative evaluation of existing GDS operation practices. First, official technical standards such as O‘z DSt 948:2016, which define the requirements for gas odorization, pressure stabilization, and safety distances, were analyzed to assess their correspondence with international ecological safety principles.

Second, technical documentation and operational reports from line production management units (LPU of main gas pipelines) were examined to determine the average service life, structural composition, and failure frequency of GDS. The distribution of stations by age groups (up to 10 years, 10–20 years, over 30 years) was used as a basis for evaluating ecological risks associated with aging infrastructure (Figure 1).

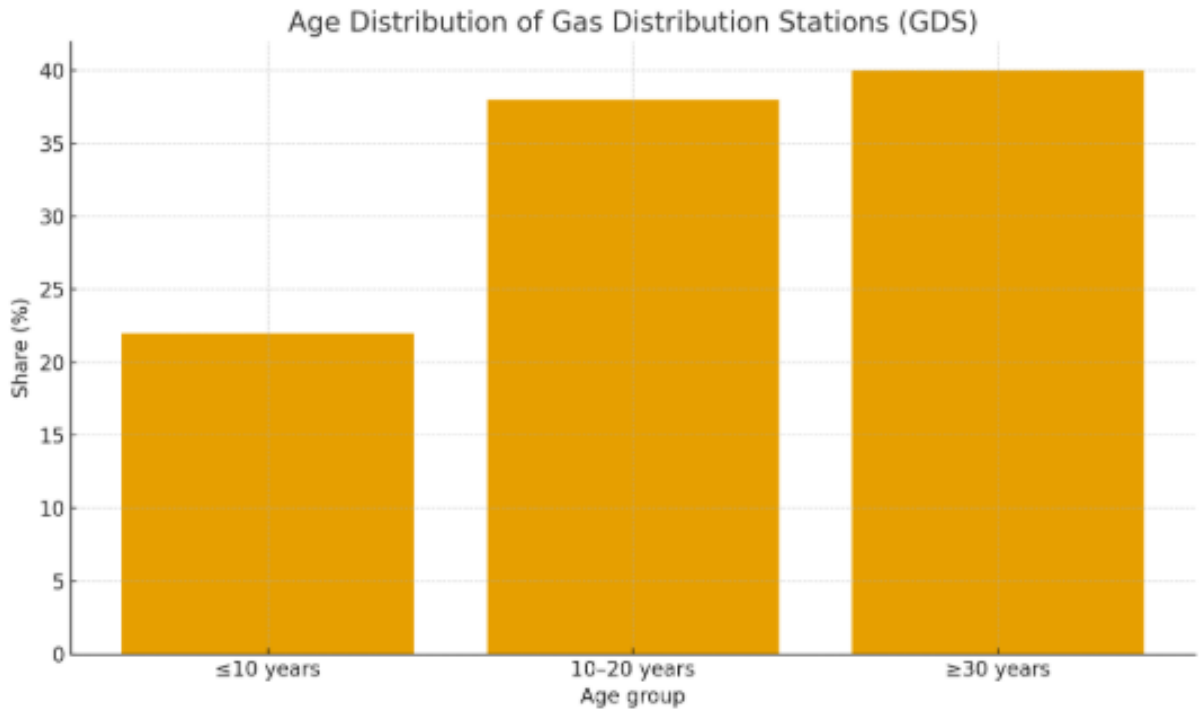

Figure 1. Age distribution of GDS (with absolute counts and risk notes).

Third, case studies of existing GDS configurations (single-line, multi-line, ring, and dead-end systems) were analyzed to identify how different schemes influence ecological reliability and emergency response. Emphasis was placed on the efficiency of pressure regulators, safety valves, and telemetric control systems in reducing ecological risks, particularly methane emissions and safety hazards.

Finally, the methodological framework included a comparative analysis between traditional justification methods (focused primarily on gas throughput and pressure control) and ecologically oriented approaches. This comparison highlighted the degree to which current methods fail to account for environmental safety, providing the basis for discussing new integrative strategies.

Results

The gas distribution station (GDS) must reliably supply consumers (enterprises and settlements) with a specified amount of gas at a defined pressure, level of purification, and odorization. It must also create branches from the pipelines transporting gas to distribution networks for delivery to residential and industrial areas.

Gas with pressures of 3×10^5 Pa and 6×10^5 Pa is supplied to city distribution networks and consumer gas regulating points, while gas with pressures of 1.2×10^6 Pa and 2×10^6 Pa is supplied to special consumers such as thermal power plants, large power stations, and gas-filling compressor stations. At the GDS outlet, the specified quantity of gas must be supplied in accordance with contractual agreements between the line production management units of main pipelines and the consumer, while maintaining working pressure accuracy within 10%. Ensuring the reliability and safety of GDS includes: (1) periodic monitoring of technological equipment, (2) regular maintenance to sustain performance, (3) timely modernization and renovation of worn-out systems, (4) compliance with minimum distance requirements to settlements and industrial sites, and (5) prevention and elimination of failures.

Equipment must be used in accordance with operating manuals and technical documentation, as well as instructions developed by specialized organizations. Gas supplied to consumers must be odorized in accordance with O‘z DSt 948:2016, except in cases defined by contractual

agreements. The main functions of GDS are pressure stabilization, purification from mechanical impurities, and pressure reduction according to standards for consumer use. Depending on pipeline configurations, pressure is reduced to medium (up to 3×10^5 Pa) or high (3×10^5–12×10^5 Pa). GDS can be central (for large groups of users) or stationary (for individual users).

The following GDS types exist: by pressure (low, medium, high), by stages (single-stage, multi-stage), by line configuration (single-line, multi-line), and by supply type (ring and dead-end). Natural gas supplied to the consumer passes through filters for purification and regulators for pressure reduction. In case of regulator malfunction, safety valves and relief devices are activated. Bypass lines are provided for manual pressure adjustment during maintenance. Manometers are installed at the inlet and outlet, and thermometers measure gas temperature. Industrial gas meters account for consumption centrally.

Stable gas pressure is ensured by direct-acting regulators. Depending on outlet pressure, the GDS chamber expands or contracts, maintaining constant supply pressure. In modern designs, combined GDS integrate safety shut-off valves and gearboxes. Telemetric systems are used for monitoring pressure, temperature, and door openings. Depending on outlet pressure, regulators are classified as low, medium, or high.

In terms of operation, single-stage systems reduce pressure in one step, while multi-stage systems lower it gradually. A two-stage system was described, where high-pressure gas (12×10^5 Pa) is filtered, then reduced to 5×10^4–3×10^5 Pa, and finally supplied to the consumer network. Multi-line systems increase reliability by parallel supply, while ring systems allow supply from several GDS simultaneously. Dead-end systems are less reliable and used mainly for small settlements.

Currently, 8,416 GDS units are in operation. Of these, 22% are under 10 years old, 38% are between 10 and 20 years, and 40% have been in operation for more than 30 years. This distribution demonstrates a significant share of outdated GDS infrastructure.

Table 1 presents the age distribution of gas distribution stations (GDS) currently in operation within the region. The analysis shows that 22% of GDS are relatively new (less than 10 years), which typically exhibit lower probabilities of failure and better compliance with modern technical standards. However, the majority of stations fall into the mid-life (10–20 years, 38%) and aged (over 30 years, 40%) categories. These older facilities are associated with increased maintenance needs, higher ecological risks due to wear and tear, and potential reliability issues. The large share of outdated GDS highlights the urgency of systematic inspections, modernization, or decommissioning programs to ensure ecological and operational safety.

Table 1. Age distribution of gas distribution stations (GDS)

Age group	Share (%)	Estimated count	Risk note	Remark
≤10 years	22	1,852	Newer assets; lower failure probability	Mostly compliant with modern standards
10–20 years	38	3,198	Mid-life; increasing maintenance needs	Likely candidates for targeted upgrades
≥30 years	40	3,366	Aged assets; highest ecological & reliability risk	Priority for audit, retrofit, or decommissioning

Table 2 summarizes the estimated gas losses and emissions for different types of GDS. Standard stations are associated with annual methane losses equivalent to approximately 2.55 tons per year, while high-pressure stations exhibit even higher losses of about 3.73 tons per year. Although emissions of hydrogen sulfide (H_2S) and mercaptans (RSH) are comparatively small in mass terms, their ecological significance is notable due to odor and toxicity effects. Methane emissions are of particular concern, given their high global warming potential, making aged or poorly

maintained stations disproportionately important contributors to greenhouse gas release. These data confirm that ecological risks from GDS extend beyond technical failures, emphasizing the need for improved monitoring and mitigation measures.

Table 2. Gas losses and emissions per GDS type

GDS type	Loss (m^3/year)	Loss (m^3/s)	CH_4 (g/s)	CH_4 (t/year)	H_2S (g/s)	H_2S (t/year)	RSH (g/s)	RSH (t/year)
Standard GDS	3,600	0.000114	80.94	2.552524	0.000002	0.000072	0.000004	0.000129
High-pressure GDS	5,256	0.000167	118.57	3.734804	0.000003	0.000106	0.000006	0.000190

Discussion

The analysis of gas distribution stations (GDS) reveals that aging infrastructure remains a critical challenge for the reliability and ecological safety of gas supply systems. As indicated in Table 1, nearly 40% of GDS have been in operation for more than 30 years, which significantly increases the likelihood of technical failures, leakages, and inefficient gas regulation. Older facilities are more prone to corrosion, mechanical wear, and outdated safety systems, creating not only technical but also ecological risks. This finding highlights the pressing need for systematic modernization and replacement programs to ensure compliance with current safety and ecological standards.

Methane emissions from GDS constitute one of the most serious ecological shortcomings of existing justification methods. Table 2 demonstrates that even under normal operating conditions, gas losses amount to 2.55–3.73 tons of methane per year per station, depending on pressure class. Methane's global warming potential, which is approximately 28–34 times greater than that of carbon dioxide, makes these losses ecologically significant. Current methods for substantiating the required number of GDS primarily consider throughput capacity and contractual obligations, while neglecting the broader climate implications of routine emissions and leakage.

The emissions of hydrogen sulfide (H_2S) and mercaptans (RSH), though minor in terms of mass compared to methane, also pose ecological and social concerns. These compounds are toxic and contribute to odor nuisance, negatively affecting air quality in nearby residential areas. Their presence, even in small concentrations, requires monitoring due to potential health effects and reduced public acceptance of GDS facilities. The absence of ecological criteria in the planning and justification of GDS overlooks these impacts, reinforcing the need for integrated environmental assessments.

Furthermore, the reliability of gas supply systems is undermined by the predominance of outdated pressure regulation schemes. While modern GDS incorporate telemetric control systems, combined safety valves, and multi-stage pressure reduction, many stations continue to operate with single-line or outdated schemes. This not only increases the risk of emergency shutdowns but also contributes to uncontrolled emissions during maintenance or equipment failure. The ecological shortcomings here stem from insufficient integration of modern ecological monitoring and automated emission control technologies into the justification framework.

Finally, the observed emission levels and infrastructure aging trends underscore the importance of adopting a more holistic methodology for substantiating the number of GDS. Such methodology must go beyond technical and economic indicators to include greenhouse gas emissions, toxic compounds, and the ecological footprint of long-term operation. Only through the integration of ecological criteria into decision-making can gas supply systems ensure both energy security and environmental sustainability.

Conclusions

The conducted analysis demonstrates that existing methods for substantiating the required number of gas distribution stations (GDS) have considerable ecological shortcomings. Current practices primarily emphasize technical performance indicators such as throughput capacity and pressure regulation, while ecological factors receive little systematic consideration. As a result, the planning and operation of GDS often fail to account for the risks of greenhouse gas emissions, toxic compounds, and long-term environmental impacts.

A significant proportion of GDS infrastructure is outdated, with 40% of stations operating for more than 30 years. These facilities represent the most critical sources of technical failures, unplanned emissions, and ecological risks. Modernization or replacement of such stations should therefore be prioritized to ensure the stability, safety, and environmental sustainability of gas supply systems.

Routine losses of natural gas, particularly methane, contribute to climate change impacts that are currently overlooked in GDS justification methodologies. Even a single station can emit several tons of methane annually, underscoring the importance of integrating greenhouse gas accounting into operational standards and decision-making frameworks.

Additional ecological concerns include the release of hydrogen sulfide and mercaptans, which, despite their relatively small volumes, degrade air quality and negatively affect surrounding communities. These emissions highlight the need for comprehensive monitoring systems that combine telemetric pressure control with ecological measurement of harmful compounds.

In conclusion, the ecological shortcomings of current justification methods for GDS can only be addressed through the development of an integrated approach. Such an approach should incorporate environmental monitoring, emission reduction strategies, and lifecycle-based modernization plans, ensuring that the gas supply system remains reliable while minimizing its ecological footprint.

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