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LOW-EMISSION SPATIAL PLANNING OF SMALL INDUSTRIAL TOWNS IN THE REPUBLIC OF TATARSTAN: MENDELEEVSK AND ZAINSK

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The paper examines approaches to low-emission spatial planning for small industrial towns in the Republic of Tatarstan, using Mendeleevsk and Zainsk as comparative case studies. The relevance of the study is determined by the fact that, under the transition to low-carbon development, the environmental burden in small towns is distributed unevenly and is shaped by sectoral specialization, the structure of stationary and mobile emission sources, energy infrastructure, and the spatial relationship between industrial zones and residential areas. The empirical basis of the study includes strategic and spatial-planning documents, the Heat Supply Scheme of Zainsk, regional environmental analytical materials, and data on stationary emission sources. The comparison is carried out using a unified framework that includes the number of stationary emission sources, the volume and sectoral profile of emissions, dominant sources of pollution, infrastructure conditions, spatial-planning constraints, and potential instruments of municipal implementation. Available environmental materials indicate that Mendeleevsk has about 649 stationary emission sources and approximately 3.709 thousand tons of stationary-source emissions, with the fuel and chemical sectors forming the main industrial contribution; Zainsk has about 1 071 stationary sources, including 1 061 within the town, and about 11.741 thousand tons of stationary-source emissions, including 11.728 thousand tons within the town. It is established that Mendeleevsk represents a type of small town with a chemical-industrial core, where priority measures include technological decarbonization, modernization of gas-cleaning systems, stricter environmental monitoring, and spatial regulation of zones adjacent to industrial sites. Zainsk is characterized by a combination of power generation, heat supply, transport flows, and agro-processing, which requires modernization of generating capacities, optimization of district heating, energy-efficiency measures, and circular solutions based on industrial symbiosis. The paper concludes that low-emission planning in small industrial towns should be differentiated by territorial type and embedded in municipal strategic, spatial-planning, infrastructure, and monitoring systems.

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***Keywords*:** small towns, low-emission planning, spatial development, environmental sustainability, decarbonization, emission structure, municipal governance, Republic of Tatarstan.

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Introduction. Small industrial towns are becoming increasingly important in the transition to lower-carbon urban development. Although national and international frameworks for reducing greenhouse gas emissions already exist, municipal climate-oriented planning has been elaborated mainly for large cities. Small towns with a pronounced industrial specialization remain less studied, even though their environmental pressure is often shaped by one or two town-forming enterprises. This is consistent with international research showing that climate measures in small and medium-sized municipalities are often fragmented and weakly connected to systems for monitoring actual emission reductions, while climate plans themselves frequently have limitations in implementation and evaluation [1, 2].

The research problem lies in the insufficient elaboration of approaches to low-emission spatial planning for small industrial towns that take into account differences in industrial specialization, the structure of emission sources, and the spatial organization of the urban environment.

In this study, low-emission spatial planning is understood as a municipal planning approach that connects emission sources, functional zoning, infrastructure systems, sanitary-protection regimes, transport flows, and social effects within a single development model. This interpretation is especially important for small towns, where the environmental profile of the settlement may be determined by a limited number of dominant industrial or infrastructure complexes. The topic is also relevant because, according to UN-Habitat, around 70% of global anthropogenic greenhouse gas emissions are associated with cities. In Russia, the strategic framework for this agenda is set by the Strategy of the Socio-Economic Development of the Russian Federation with Low Greenhouse Gas Emissions until 2050 [3, 4].

The novelty of the study lies in comparing low-emission spatial planning scenarios for small industrial towns of Tatarstan with different sectoral specializations. Theoretically, this approach corresponds to contemporary research on integrating climate goals into municipal land and planning policies, where low-emission development is viewed as part of a broader system of spatial governance [5]. Despite its developed industrial base, the Republic of Tatarstan is characterized by an uneven distribution of pollutant emissions, which is especially visible in small towns. National environmental reviews indicate that in a number of territories pollutant concentrations exceed admissible standards, which calls for targeted measures to reduce pollution and improve the resilience of small towns [6].

The aim of the study is to develop and compare low-emission spatial planning scenarios for two small industrial towns of Tatarstan: Mendeleevsk and Zainsk.

Materials and Methods. The study is based on a comparative geographical approach combined with elements of scenario planning and policy analysis. The object of the research is two small industrial towns of the Republic of Tatarstan: Mendeleevsk and Zainsk. These towns were selected, because they represent different types of industrial environmental pressure: a chemical-industrial profile in Mendeleevsk and an energy-infrastructure profile in Zainsk.

The empirical basis of the research includes:

1) the Strategy of the socio-economic development of the Russian Federation with low greenhouse gas emissions until 2050 [4];

2) regional environmental analytical materials for Mendeleevsky and Zainsky municipal districts [7, 8] and state environmental reports for the Republic of Tatarstan [9];

3) municipal and infrastructure documents, including the Heat Supply Scheme of Zainsk up to 2036 [10];

4) materials characterizing the industrial specialization and principal emission sources of the two towns;

5) contemporary international studies on local climate planning, municipal land policy, decarbonization of ammonia production, and industrial symbiosis.

Below is a comparison Tab. 1 of two cities to evaluate the conditions for low-emission spatial planning:

Table 1

Comparative framework for assessing low-emission spatial planning conditions in Mendeleevsk and Zainsk

Indicator	Mendeleevsk	Zainsk	Planning implication
Industrial and infrastructure profile	chemical-industrial town with a nitrogen-chemical complex and related production chains	energy-infrastructure town with a large power-generation node, district heating, transport flows, and agro-processing	the towns require different low-emission priorities rather than one universal model
Stationary emission-source base	about 649 stationary emission sources; approximately 3.709 thousand tons of stationary-source emissions according to regional environmental analytical materials	about 1 071 stationary emission sources, including 1,061 within the town; approximately 11.741 thousand tons of stationary-source emissions, including 11.728 thousand tons within the town	quantitative indicators justify a comparative rather than purely descriptive analysis
Dominant contributors and pollutants	fuel and chemical sectors are the main contributors; key pollutants include volatile organic compounds, carbon monoxide, particulate matter, and nitrogen oxides	the main pressure is associated with power generation, heat supply, transport, and industrial processing of agricultural raw materials	monitoring should be differentiated by industrial technology in Mendeleevsk and by energy/heat-supply infrastructure in Zainsk
Spatial-planning constraints	need to coordinate industrial-zone development, sanitary-protection regimes, monitoring points, and adjacent residential areas	need to coordinate power-generation facilities, heat networks, transport corridors, industrial sites, and residential energy demand	low-emission measures should be linked to functional zoning, infrastructure schemes, and municipal development programs
Main environmental risks	technological emissions from chemical production, concentration of industrial sources, and risks for areas adjacent to the industrial zone	combustion-related emissions, heat-supply losses, transport pressure, and seasonal agro-industrial logistics	scenario planning should identify not only technologies but also spatial exposure and implementation barriers

Source: compiled by the author using regional environmental analytical materials and municipal infrastructure documents [7, 8, 10].

To make the comparison analytically consistent, the following indicators were used:

- number of stationary emission sources;
- volume of stationary-source emissions;
- sectoral structure of the main contributors;
- dominant types of pollution sources;
- infrastructure systems influencing emissions;
- spatial relationship between industrial zones, residential areas, and transport corridors;
- potential environmental risks;
- municipal instruments, through which low-emission measures can be incorporated into spatial-planning and strategic-development documents.

The comparative procedure included three stages. First, the environmental and economic profile of each town was described using industrial specialization and available emission-source data. Second, the towns were compared according to a unified indicator framework. Third, three scenario options were formulated for each town: an inertial scenario, a modernization scenario, and a low-emission transformation scenario. The scenarios were assessed according to implementation conditions, expected environmental effects, constraints, social and economic implications, and criteria for monitoring effectiveness.

Results. The comparative analysis shows that the two towns differ not only in the scale of emissions, but also in the spatial logic through which environmental pressure is formed. In Mendeleevsk, the main planning problem is the concentration of industrial-technological sources connected with chemical production and the need to separate, monitor, and modernize the industrial core. In Zainsk, environmental pressure is more infrastructure-based: it is produced by the interaction of power generation, heat supply, transport, and agro-processing. Therefore, the same low-emission measure may have different planning effects in the two towns.

For Mendeleevsk, the main priority is the technological and spatial modernization of the chemical-industrial zone. The inertial scenario preserves the existing production and planning structure and relies mainly on compliance with current environmental standards; therefore, its effect is limited. The modernization scenario includes best available technologies, renewal of gas-cleaning systems, targeted monitoring near the industrial zone, and stricter coordination with sanitary-protection regimes. The transformation scenario links ammonia and chemical production with carbon capture and utilization, lower-carbon hydrogen and energy sources, and a municipal GIS-based monitoring system that connects emission sources with land-use restrictions and public reporting.

The specific feature of Mendeleevsk is that technological decarbonization and spatial planning cannot be separated. If modernization is implemented only inside the enterprise without changes in municipal planning documents, the town will not receive a full low-emission effect. Therefore, the general plan, land-use and development rules, environmental monitoring programs, and sanitary-protection-zone management should be coordinated with enterprise modernization plans. This creates a planning mechanism for reducing exposure of residential areas and for preventing new sensitive land uses near zones of elevated environmental risk.

For Zainsk, the basic effect is associated with modernization of generating capacities and the district heat-supply system. The inertial scenario preserves the existing energy and heat-supply configuration and reduces emissions mainly through routine repairs and operational measures. The modernization scenario includes higher generation efficiency, lower heat-network losses, energy audits of public buildings and industrial sites, and freight-traffic management related to agro-processing. The transformation scenario combines energy modernization with circular solutions, including the use of by-products, resource exchange between enterprises and municipal infrastructure, and gradual formation of industrial symbiosis. Tab. 2 presents possible development scenarios for the two cities and their descriptions:

Table 2

Scenario differentiation and implementation logic for the two towns

Scenario	Mendeleevsk	Zainsk	Expected effect and evaluation criteria
Inertial	preservation of the existing chemical-industrial structure; local environmental measures; compliance with current standards	preservation of the current energy and heat-supply configuration; routine repairs; limited traffic measures	low effect; criteria: absence of deterioration, compliance with standards, limited local reductions.
Modernization	best available technologies, gas-cleaning renewal, monitoring near the industrial zone, coordination with sanitary-protection regimes	generation-efficiency measures, reduction of heat-network losses, energy audits, freight-transport optimization	medium effect; criteria: reduction in specific emissions, lower heat losses, better monitoring coverage, fewer complaints
Low-emission transformation	carbon capture and utilization, lower-carbon hydrogen/energy sources, GIS-based monitoring, integration of industrial modernization with land-use regulation	energy modernization plus circular use of agro-processing by-products, industrial symbiosis, infrastructure renewal, integration with the heat-supply scheme	high effect; criteria: structural reduction of emissions, institutionalized monitoring, inclusion in planning documents, improved quality of life
Main constraints	high capital intensity, technological dependence on industrial enterprises, need for coordination between enterprise and municipality	investment needs in generation and networks, institutional coordination, seasonal logistics of agro-processing	constraints should be reflected in scenario risk assessment and financing plans
Social dimension	risk reduction for residential areas; need for workforce retraining and new environmental-engineering competencies	improved reliability of heat supply, lower transport exposure, possible new circular-economy jobs	criteria: public participation, training measures, quality-of-life indicators, accessibility of monitoring data

In Zainsk, low-emission spatial planning should therefore be tied to the heat-supply scheme, infrastructure investment programs, transport planning, and industrial-site development. A separate environmental section in planning documents would be insufficient; emission reduction should be built into the logic of infrastructure renewal. In practical terms, this means prioritizing areas with high heat demand, worn-out networks, freight concentration, and industrial sites, where by-products can be transformed into energy or material resources.

Discussion. The results demonstrate that the comparison of Mendeleevsk and Zainsk has broader theoretical significance for the study of small industrial towns. It shows that emission-reduction measures cannot be interpreted only as technological modernization; they must also be connected with the functional and planning organization of the territory, infrastructure systems, exposure of residential areas, and municipal implementation instruments.

At the municipal level, the key issue is the transition from general environmental declarations to measurable and administratively supported actions. Such actions should be embedded in general plans, land-use and development rules, heat-supply schemes, municipal infrastructure programs, and local monitoring systems. The most relevant instruments include environmental criteria for infrastructure projects, coordination between enterprises and public authorities, regular inventories of stationary emissions and heat losses, and publication of monitoring results in an accessible municipal report or GIS platform.

The social and economic effects also differ between the two towns. In Mendeleevsk, the main expected outcome is the reduction of environmental risks for residential areas near the industrial zone and the creation of new competencies in industrial modernization, monitoring, and engineering services. At the same time, technological renewal may require workforce retraining and cooperation with local educational institutions. In Zainsk, the main benefits are associated with more reliable heat supply, lower energy losses, reduced transport exposure, and new links between the energy sector and agro-processing.

The proposed comparative framework makes it possible to move from a descriptive comparison to an indicator-based assessment. Stationary-source data, sectoral emission profiles, infrastructure characteristics, environmental risks, implementation conditions, and monitoring criteria provide a clearer basis for municipal decision-making and for evaluating the effectiveness of alternative scenarios.

The study has a number of limitations. Available open data do not always provide a detailed municipal breakdown of greenhouse gas emissions by source and substance; therefore, stationary-source emissions, sectoral specialization, heat-supply structure, and infrastructure characteristics are used as proxy indicators. This limitation confirms the need for municipal environmental monitoring and regular emission inventories as part of the proposed planning mechanism.

Conclusion. The comparison of Mendeleevsk and Zainsk demonstrates that small industrial towns require differentiated models of emission-oriented territorial policy. The determining factors are industrial specialization, the structure of emission sources, infrastructure configuration, and the spatial relationship between production, transport, heat supply, and residential areas.

For Mendeleevsk, the priority is coordination between chemical-industry modernization, sanitary-protection regimes, land-use regulation, and environmental monitoring. For Zainsk, the main potential is linked to modernization of power generation and district heating, reduction of heat losses, transport-flow management, and circular use of agro-processing by-products. In both cases, spatial planning acts as a mechanism for translating climate and environmental goals into long-term municipal development decisions.

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Ս. Ա. ԱԿՄԱԼԵՏԴԻՆՈՎ

ԹԱԹԱՐՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅԱՆ ՓՈՔՐ ԱՐԴՅՈՒՆԱԲԵՐԱԿԱՆ ՔԱՂԱՔՆԵՐԻ՝ ՄԵՆԴԵԼԵԵՎՍԿԻ ԵՎ ԶԱՅՆՍԿԻ ՑԱԾՐ ԱՐՏԱՆԵՏՈՒՄՆԵՐԻ ՊԼԱՆԱՎՈՐՈՒՄ

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Այս հոդվածը քննում է Թաթարստանի Հանրապետության փոքր արդյունաբերական քաղաքների համար ցածր արտանետումներով տարածքային պլանավորման մոտեցումները՝ որպես օրինակ օգտագործելով Մենդելեևսկը և Զաինսկը: Ուսումնասիրությունը հիմնված է միասնական համեմատական շրջանակի վրա, որը ներառում է ստացիոնար արտանետումների աղբյուրների քանակը, ստացիոնար աղբյուրներից արտանետումների ծավալը, աղտոտման արդյունաբերական կառուցվածքը, ենթակառուցվածքային պայմանները, տարածական պլանավորման սահմանափակումները, շրջակա միջավայրի ռիսկերը և քաղաքային ներդրման հնարավոր մեխանիզմները: Հաստատված է, որ Մենդելեևսկը փոքր քաղաք է՝ քիմիական-արդյունաբերական միջուկով, որտեղ տեխնոլոգիական ապածխածնացումը, գազի մաքրման արդիականացումը, շրջակա միջավայրի մոնիթորինգի զարգացումը և արդյունաբերական տարածքներին հարակից գոտիների կարգավորումը հիմնական են: Զաինսկը բնութագրվում է էներգետիկ ենթակառուցվածքների, ջերմամատակարարման, տրանսպորտային բեռների և գյուղատնտեսական վերամշակման համադրությամբ, որը պահանջում է արտադրական հզորությունների արդիականացում, ջեռուցման ցանցերում կորուստների կրճատում, էներգաարդյունավետության բարձրացում և շրջանաձև լուծումների մշակում: Այս մոտեցման սոցիալ-տնտեսական հետևանքները հետագայում ուսումնասիրվում են, ներառյալ դրա ազդեցությունը քաղաքային միջավայրի որակի, զբաղվածության, մասնագիտական վերապատրաստման, հանրային մասնակցության և շրջակա միջավայրի մոնիթորինգի մատչելիության վրա: Եզրակացություն է արվում տարածքային պլանավորման փաստաթղթերում, հողօգտագործման և զարգացման կանոնակարգերում, ջերմամատակարարման սխեմաներում, քաղաքային ենթակառուցվածքային ծրագրերում և շրջակա միջավայրի մոնիթորինգի կանոնավոր համակարգերում ցածր արտանետումների միջոցառումներ ներառելու անհրաժեշտության վերաբերյալ:

С. А. АКМАЛЕТДИНОВ

НИЗКОЭМИССИОННОЕ ПЛАНИРОВАНИЕ МАЛЫХ ИНДУСТРИАЛЬНЫХ ГОРОДОВ РЕСПУБЛИКИ ТАТАРСТАН: МЕНДЕЛЕЕВСК И ЗАИНСК

Резюме

В статье рассматриваются подходы к низкоэмиссионному территориальному планированию малых индустриальных городов Республики Татарстан на примере Менделеевска и Заинска. Исследование опирается на единую сравнительную рамку, включающую число стационарных источников выбросов, объем выбросов от стационарных источников, отраслевую структуру загрязнения, инфраструктурные условия, пространственно-планировочные ограничения, экологические риски и возможные механизмы муниципальной реализации. Установлено, что Менделеевск относится к типу малого города с химико-промышленным ядром, где ключевое значение имеют технологическая декарбонизация, модернизация газоочистки, развитие экологического

мониторинга и регулирование зон, прилегающих к промышленным территориям. Заинск характеризуется сочетанием энергетической инфраструктуры, теплоснабжения, транспортной нагрузки и агропереработки, что требует модернизации генерирующих мощностей, снижения потерь в тепловых сетях, повышения энергоэффективности и развития циркулярных решений. Дополнительно раскрыты социально-экономические последствия такого подхода, в том числе его влияние на качество городской среды, занятость, профессиональную переподготовку, участие населения и доступность экологического мониторинга. Сделан вывод о необходимости включения низкоэмиссионных мероприятий в документы территориального планирования, правила землепользования и застройки, схемы теплоснабжения, муниципальные инфраструктурные программы и системы регулярного экологического мониторинга.