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Article

The analysis of urbanization drivers in Kazakhstan: A regional assessment from 2010–2022

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Abstract: Urbanization process affects global socio-economic development. Originally tied to modernization and industrialization, current urbanization policy is focused on productivity, economic activities, and environmental sustainability. This study examines impact of urbanization in various regions of Kazakhstan, focusing on environmental, social, labor, industrial, and economic indicators. The study aims to assess how different indicators influence urbanization trends in Kazakhstan, particularly regarding environmental emissions and pollution. It delves into regional development patterns and identifies key contributing factors. The research methodology is based on classical economic theories of urbanization and modern interpretations emphasizing sustainability and socio-economic impacts and includes two stages. Shannon entropy measures diversity and uncertainty in urbanization indicators, while cluster analysis identifies regional patterns. Data from 2010 to 2022 for 17 regions forms the basis of analysis. Regions are categorized into groups based on urbanization levels leaders, challenged, stable, and outliers. This classification reveals disparities in urban development and its impacts. Findings stress the importance of integrating environmental and social considerations into urban planning and policies. Targeted interventions based on regional characteristics and urbanization levels are recommended to enhance sustainability and socio-economic outcomes. Tailored urban policies accommodating specific regional needs are crucial. Effective management and policy-making demand a nuanced understanding of these impacts, emphasizing region-specific strategies over a uniform approach.

Keywords: urbanization; emission; ecology; industry; cities; policy

1. Introduction

The process of growth and development of urban areas significantly impacts the socio-economic development of regions and countries (Abdel-Rahman, 1990; Henderson, 2003). The main effects are associated with agglomeration, including increased productivity and specialization of economic activities (Fehrenbach et al., 2022; Ki, 2001; Peng et al., 2017; Sharma et al., 2019; Wei et al., 2022). Urbanization acts as a powerful transformative factor globally, reshaping economies, societies, and the environment (Kwiatkowski, 2019; Teran et al., 2020;). Urbanization was initially viewed as a process associated with modernization and industrialization, leading to the transformation of rural areas into urban settings (Arrow, 1962; Glaeser et al., 1992; Huang et al., 2020; Liu et al., 2020; Romer, 1986). Economic theories emphasize the advantages of agglomerations, such as creating more efficient labor markets and reducing transportation costs. In particular, SMEs often act as the backbone of local economies, driving job creation and fostering community development. Thus, integrating SME development into urbanization policies can significantly contribute to the overall sustainability of urban environments, enhancing the economic inclusivity of cities (Akhtar et al., 2022; Bomani et al., 2022; Liang et al., 2019; Mukherjee et al., 2023).

Urbanization significantly impacts the socio-economic aspects of life as improvements in education and healthcare system, and can affect economic growth (Byerlee, 1974; Bitner and Fialkowski, 2021; Cattaneo et al., 2022; Mazumdar, 1987; Mundia and Murayama, 2010; Sun et al., 2023; Shakibayev et al., 2024; Yao et al., 2021; Zhang et al., 2022). In low-income countries, the process of urbanization often exacerbates environmental issues due to inadequate infrastructure and insufficient adherence to environmental regulations (Abaje et al., 2020; Lu et al., 2017; Lin and Zhu, 2018; Wang et al., 2019).

In Kazakhstan, urbanization is actively transforming regions, affecting various aspects of population life. A comprehensive analysis of these processes is essential to develop effective urban planning and regional development policy strategies.

The primary objective is to analyze the impact of environmental, social, labor, industrial, and economic factors on urbanization processes, with a focus on identifying critical aggregate indicators that contribute significantly to these trends. The research design is grounded in a comprehensive literature review and expands upon fundamental approaches previously described, using the concept of entropy to analyze urban systems (Bitner and Fialkowski, 2021; Lu et al., 2017; Pacheco and Mera, 2022; Sansyzbayeva et al., 2020; Wang et al., 2019; Yao et al., 2021; Zhong et al., 2020). This methodology has been significantly adapted to meet the specific goals and objectives of this study, shifting the focus towards socio-economic parameters.

The extensive research on urbanization highlights its multifaceted impacts encompassing economic, environmental, and social dimensions. Economically, urbanization is linked to agglomeration economies, where the geographical concentration of industries leads to more efficient labor markets, reduced transportation costs, and enhanced innovation and productivity, as discussed in the theories of Marshall, Arrow, and Romer.

Environmentally, the relationship between urbanization and pollution is complex. As cities grow, emissions increase, leading to significant environmental challenges, particularly in lower-income countries with inadequate infrastructure and regulatory frameworks. Socially, urbanization improves access to services such as education and healthcare, which are pivotal for enhancing the quality of life. Despite these insights, there are notable gaps in understanding the long-term sustainability of urban growth. The studies often do not sufficiently address how cities can manage the dual challenge of ensuring environmental sustainability while fostering economic growth. Another gap lies in the actionable policy frameworks needed to manage these dynamics effectively.

This research is unique in that it offers a comprehensive approach to urbanization analysis, integrating economic, environmental, and social aspects. It not only highlights existing problems but also outlines strategic directions for developing effective policy measures aimed at balancing economic development with environmental sustainability. Importantly, this approach is particularly relevant for low-income countries, where urban policy must be adapted to local specificities. Thus, the findings of this study can serve as a foundation for forming long-term urban policy, taking into account the unique characteristics of different regions.

This study aims to evaluate the influence of various indicators on urbanization trends across different regions in Kazakhstan. How does the degree of urban development within various regions influence the level of environmental emissions and pollution, and what are the specific characteristics of the process of urbanization that contribute to these environmental impacts.

2. Literature review

Initially, urbanization was regarded as the process of population migration from rural to urban areas, usually due to modernization and industrialization. Alfred Marshall (1890) laid the foundation for understanding agglomeration economies highlighting the benefits of geographical concentration of industries including creating more efficient labor markets and reduction of transportation costs. Lewis (1954) identified that migration from rural area to urban is stimulated by a wage gap that emerges in the early stages of industrialization. As urban sectors (manufacturing and services) expand, they absorb surplus labor from the less productive rural (agricultural) sector. Further Arrow (1962) emphasized the importance of knowledge and technological innovations in economic growth. Romer (1986) expanded the theory of endogenous growth, focusing on the role of accumulating knowledge and ideas. Later, economists Glaeser, Kallal, Scheinkman, and Shleifer explained how specialization and concentration of industries in specific regions can create positive external effects, enhancing innovative activity and economic growth and introduced the term "MAR" (Marshall-Arrow-Romer) concepts of Marshal, Arrow and Romer (Glaeser et al., 1992). In the literature, two main types of agglomeration effects are distinguished. Urbanization economies is characterized by increased overall productivity in large cities, and localization or specialization economies typical of smaller cities where high levels of productivity are achieved by concentrating certain types of industries (Abdel-Rahman, 1990; Henderson, 2003; Huang et al., 2020; Ki, 2001; Liu et al., 2020; Peng et al., 2017; Pacheco and Mera, 2022). Thus, urbanization promotes the concentration of enterprises and workers in cities, leading to increased productivity, high employment and specialization of economic activities. These dynamics necessitate responsive urban policy frameworks to manage growth effectively and ensure equitable development across regions.

Research from the 1960s and 1970s began to acknowledge the importance of non-economic motives for migration, such as social prestige, the desire to escape social constraints, and gender discrimination (Byerlee, 1974; Mazumdar, 1987; Mundia and Murayama, 2010), which contribute to urbanization regardless of economic opportunities. Wheras studies, such as Bitner and Fialkowski (2021) and Yao et al. (2021), analyz the effects of urban development on population well-being, identified that demographic urbanization, characterized by increasing urban populations, generally results in benefits such as improved education, living standards, and infrastructure.

Certain studies explore that degree of urbanization impact on economic growth and environmental pollution, which affects countries differently based on their economic status. Lu et al. (2017) introduced the concept of an inverse correlation between economic growth and environmental pollution, suggesting that while economic activities typically increase pollution, these adverse effects might decrease after reaching a certain income level. Lin and Zhu (2018) noted that pollution levels initially rise with increases in income but start to decline once a specific threshold is surpassed, showing that economic progress can initially worsen but eventually contributes to environmental degradation reduction. This dynamic necessitates adaptive environmental policy measures that evolve as economic conditions change. Wang et al. (2019) found that in lower-income countries, increased urbanization often worsens pollution issues due to insufficient infrastructure and lax environmental regulations.

Recent studies put emphasis on industrial development and complex interdependencies between industrial activities and environment pollution, particularly concerning the deterioration of air quality. Lighter industries and high-tech sectors, while less overtly damaging, still notably contribute to environmental degradation by raising energy use and vehicular traffic in urban area (Khurshid et al., 2023; Sansyzbayeva et al., 2020; Zhou et al., 2018). Wei et al. (2022) stated that various industrial sectors, including heavy industry, light industry, and high technology are significant producers of air pollutants. Sharma et al. (2019) highlight that increase in agriculture production and pesticide use have led to significant environmental damage. Heavy industries, including metallurgy and chemical manufacturing, are principal sources of air pollution (Kwiatkowski, 2019; Teran et al., 2020) emitting dioxide (SO_2), particulate matter (PM_{10} and $PM_{2.5}$), and carbon dioxide (CO_2) contributing to smog formation and overall degradation of air quality in urban areas (Abaje et al., 2020; Liang et al., 2019; Sun et al., 2023). Fehrenbach et al. (2022) highlighted that pharmaceutical production industry, release active pharmaceutical ingredients as by-products of manufacturing processes.

Others focused on the role of small and medium-sized enterprises (SMEs) in urbanization putting it as fundamental and highlighting both economic contributions and environmental challenges. Bomani et al. (2022) and Mukherjee et al. (2023) discussed the significant role of small and medium enterprises (SMEs) in promoting the process of urbanization and enhancing economic metrics like GDP and employment. However, Akhtar et al. (2022) also pointed out a concerning shortfall, noting that these enterprises frequently overlook environmental standards, largely due to insufficient environmental compliance expertise.

Bitner and Fialkowski (2021), Shakibayev et al. (2024) and Yao et al. (2021) analyzed the effects of urban development on population well-being. They discovered that demographic urbanization, characterized by increasing urban populations, generally results in benefits such as improved education, living standards and infrastructure. Moreover, Zhang et al. (2022) reveled that regions with higher educational attainments and better healthcare accessibility, as indicated by the number of hospital beds per capita, tend to urbanize more rapidly by attracting individuals seeking improved employment opportunities and quality of life available in urban settings. According to Cattaneo et al. (2022) education and healthcare have direct impact on quality of life, attracting populations to urban centers, and reflecting regional development progress define functional areas and play a key role in economic and social development, directly impacting.

The process of urbanization varies significantly across regions, influenced by both economic and social factors. In low-income countries, urbanization process often challenges existing infrastructures, whereas in high-income regions, it is better managed due to more robust policy frameworks. The role of industries, both heavy and high-tech, is crucial as they shape the economic landscape and influence urban development patterns.

Effective urban management requires integrated strategies that consider economic activities like small and medium-sized enterprise operations, and social infrastructure improvements, including education and healthcare. Thus, it is essential to analyze clusters based on key metrics such as economic indicators (e.g., SME activity, employment rates, self-employment levels) and social indicators (e.g., access to education and healthcare). Clustering regions by these metrics allows for tailored policy interventions that address specific local needs, focusing on enhancing urban planning and regional development.

3. Methodology

The research design for the current study is based on the conducted literature review and was built on the fundamental approach proposed by Bitner and Fialkowski (2021) and Yao et al. (2021) using the concept of entropy to analyze urban systems. However, in the current study, this methodology has significantly expanded and adapted to specific goals and objectives. The focus of this research was shifted to socio-economic parameters. Thus, the aim was to analyze and examine the impact of environmental, social, labor, industrial, and economic factors on urbanization processes. Therefore, the methodology included several steps. **Figure 1** illustrates the research steps.

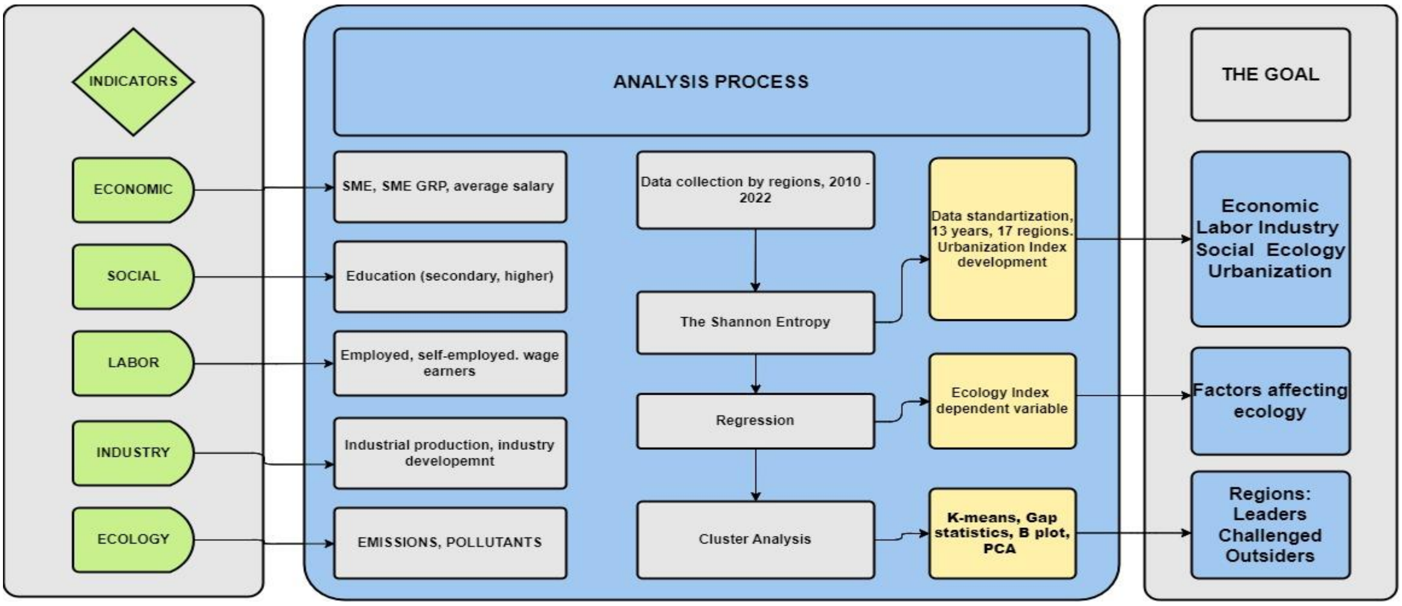


Figure 1. Research design.

The initial objective was to identify critical aggregate indicators which contribute to the urbanization process. The literature review showed that based on the context of the research, the authors give preference to the dichotomous approach and analyze two main factors. It was identified that social, industrial, and economic factors play crucial roles in the process of urban development.

Unlike existing studies, current work employed data for five aggregate leading indicators for 17 regions during 13 years (2010–2022). The data utilized in this study were carefully collected from official sources to ensure the robustness and reliability of the findings. The primary data sources are open-access datasets from the Bureau of National Statistics and the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, which provide comprehensive and official statistical data across various socio-economic dimensions. The Bureau of National Statistics, a reputable governmental agency, is responsible for compiling and disseminating essential statistical information, encompassing a wide array of socio-economic indicators crucial for analyzing urbanization trends.

The dataset includes a range of indicators such as economic measures (Small and Medium Enterprises, Gross Regional Product of SMEs, and average salaries), social metrics (levels of secondary and higher education), labor statistics (employment status including employed, self-employed, and wage earners), industrial data (industrial production and industry development), and ecological indicators (emissions and pollutants). The data span from 2010 to 2022 and cover 17 regions, providing an extensive temporal and spatial scope for a comprehensive analysis of urbanization processes.

A key element of the methodological approach is the use of Shannon entropy to assess the degree of diversity or uncertainty of each urbanization indicator. Shannon entropy estimates how unexpected or diverse the data is for each indicator. High entropy values indicate greater diversity and less predictability of data distribution. Wang et al. (2019) applied a comprehensive approach and relied on data on four critical aspects of urbanization - demographic (population growth and density), spatial (land use changes and urban expansion), economic (GDP growth and changes in economic structure) and social (level of education, health care, and other social indicators). Lu et al. (2017) proposed a comprehensive approach to analyzing the relationships between economic development, environmental quality, and public health, significantly contributing to these problems' study.

In the context of urban development, the application of Shannon entropy offers several advantages over other methods. Shannon entropy allows for assessing the diversity or uncertainty of a system and quantifying the heterogeneity and unpredictability of various urban indicators such as social, economic, and industrial factors. This method helps in understanding how diverse or concentrated the urbanization factors are across different regions. The process of data standardization using the max-min approach ensures that all indicators are comparable, which is crucial for accurate entropy calculation. By differentiating between positive and negative indicators, the methodology maintains the integrity of the data's meaning.

The extensive dataset, based on aggregate indicators over a span of 13 years across 17 regions, ensures the comprehensiveness of the analysis and accounts for temporal and spatial variations in urbanization. Unlike the Kuznets curve, which primarily focuses on the relationship between economic development and income inequality, Shannon entropy provides a more nuanced and multifaceted analysis of urban systems by incorporating a broader range of socio-economic parameters. Kuznets curve can illustrate the general trajectory of economic development and inequality, it may not adequately capture the complex and detailed interaction between various urbanization factors. Shannon entropy, on the other hand, excels in highlighting the diversity and variability within the data, offering insights into the multifactorial nature of urbanization. This comprehensive approach allows for a deeper understanding of the complexities and dynamics of urbanization processes for analyzing urban development trends.

Next, cluster analysis is effective for identifying regions with similar urbanization patterns. This method allows grouping regions based on the similarity of their socio-economic parameters. By clustering regions, the analysis can provide data-driven insights into the factors driving urbanization in different contexts. The method of clustering can be adjusted to focus on different socio-economic parameters, ensuring relevant and comprehensive analysis.

The methodology for classifying regions into Leader group, Challenged group, and Stable regions is based on their economic resilience and adaptive capacities, following the works of Simmie and Martin (2010) and Zhou et al. (2018). Leader group regions have high adaptive capacity and continuous innovation, effectively managing growth, stability, collapse, and reorganization. Challenged group regions struggle with adaptation, often depending on external factors like foreign direct investment. Stable regions maintain steady development without significant shocks, but lack the dynamism to become leaders without policy interventions promoting innovation and diversification.

The foundation of the research methodology is the preliminary standardization of data using the max-min approach, which allows for bringing various indicators to a comparable form. For standardizing data before calculating entropy, two different formulas are used depending on whether the indicator is considered "positive" or "negative". A positive indicator means that higher values indicate a better outcome (social, economic, industrial, and labor force) and are calculated according to the following Equation (1):

$$X'_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \tag{1}$$

whereas a negative indicator means that lower values present better outcomes (ecological) and are calculated according to the following Equation (2):

$$X'_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)} \tag{2}$$

where:

X_{ij}—is the original value,

$\max(X_j)$ and $\min(X_j)$—the maximum and minimum values of the *j*-th indicator among all the regions considered.

X'_{ij}—is the normalized value of the indicator.

This approach of data standardization was used to scale all indicator values to a unified scale from 0 to 1 to compare different indicators and simplify subsequent data analysis. After data standardization, the Shannon entropy Equation is used to assess each indicator's degree of diversity or uncertainty. The Shannon entropy for the *j*-th indicator is calculated as follows Equation (3):

$$E = -\sum_{i=1}^{N} p_i \ln(p_i) \tag{3}$$

where:

E—the entropy of the system;

p_i—the probability of the i-th state of the system (in the context of data analysis, the share of the normalized value of indicator i, divided by the sum of all normalized values for that indicator);

N—the total number of states (or indicators under consideration);

ln—the natural logarithm.

The urbanization index is calculated as the weighted sum of entropy values across all indicators and calculated according to the following Equation (4):

$$\text{Urbanization Index} = \sum_{i=1}^{n} (\text{Weight}_j \times e_i) \tag{4}$$

where:

Weight_j—the weight of the j-th indicator, reflecting its relative importance;

N—the number of indicators;

e_i—entropy.

Weights can be determined through expert evaluations or evenly distributed if all indicators are assumed to be equally important. In our study on urbanization levels across various regions, we proceed from the premise that all considered indicators hold equal significance for analysis. This assumption simplifies the process of assessing and comparing urbanization processes across different territories. Following this approach, we assign an equal weight of 1 to each indicator, reflecting their equal importance in the context of our analysis.

Within the scope of this study, the weights of indicators are utilized to ascertain their contribution to the overall urbanization index. Viewing all indicators as equivalent, we assign a weight of 1 to each. Consequently, the urbanization index is calculated as the sum of entropy values for all indicators without accounting for an additional weighting coefficient, enabling us to evaluate the level of urban development based on evenly weighted components. Applying this method to our study allows us to quantitatively assess and compare urbanization process degrees across various regions, thereby identifying areas with high urbanization levels and potentially higher environmental emissions and pollution levels.

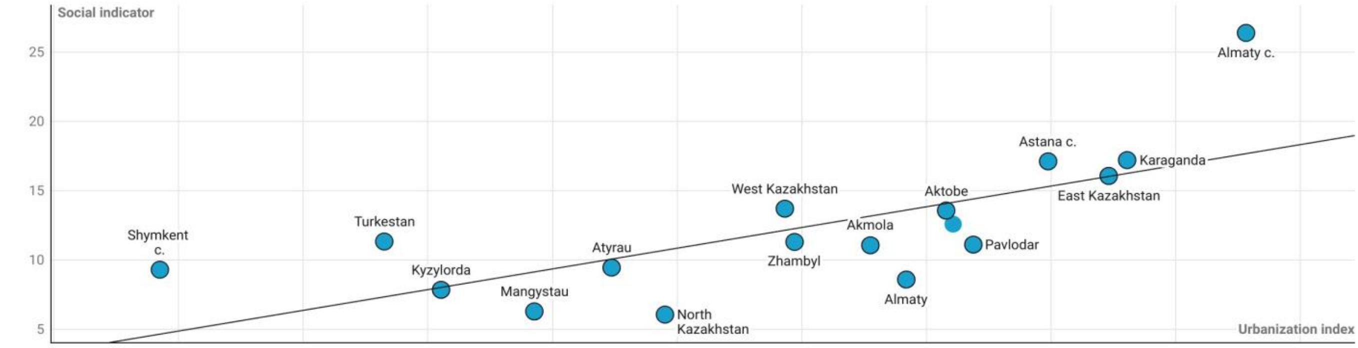
4. Results and discussion

4.1. Urbanization index

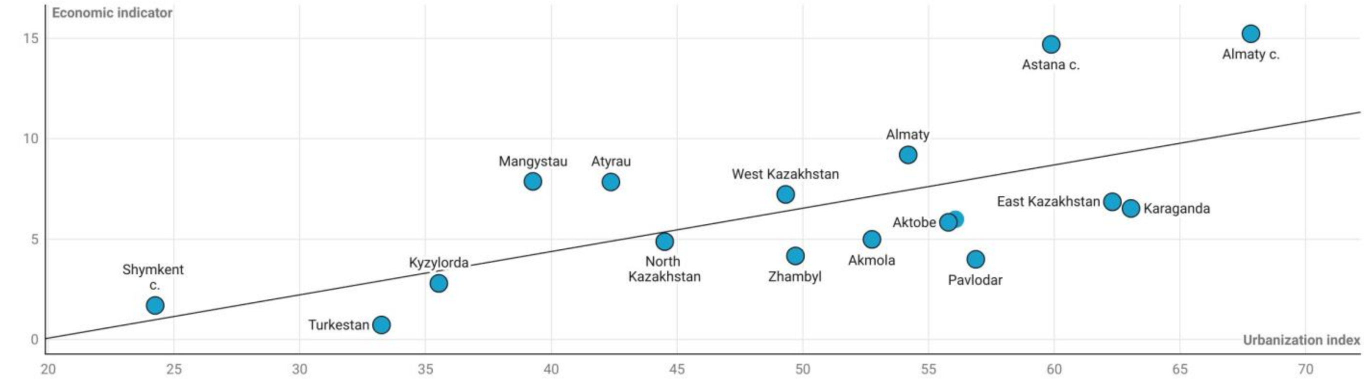
Indices were calculated in socio-economic, industrial production, and regional emissions. For each region, the socio-economic development index can reflect the general state of the economy, level of education, healthcare, and other social indicators.

Next, the scatter plots for indicators depict the relationship between various indicators—social, economic, industrial production, and labor- and the urbanization index across different regions in Kazakhstan are provided in **Figure 2**. Analyzing the association between urban development and various development indicators across

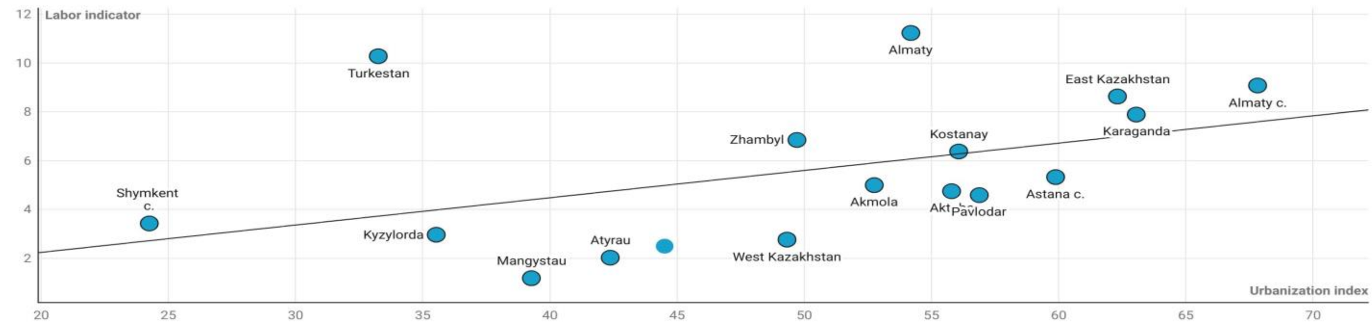
Kazakhstan, trends and developments that contradict regional development's overall direction and outliers warranting detailed examination could be observed.



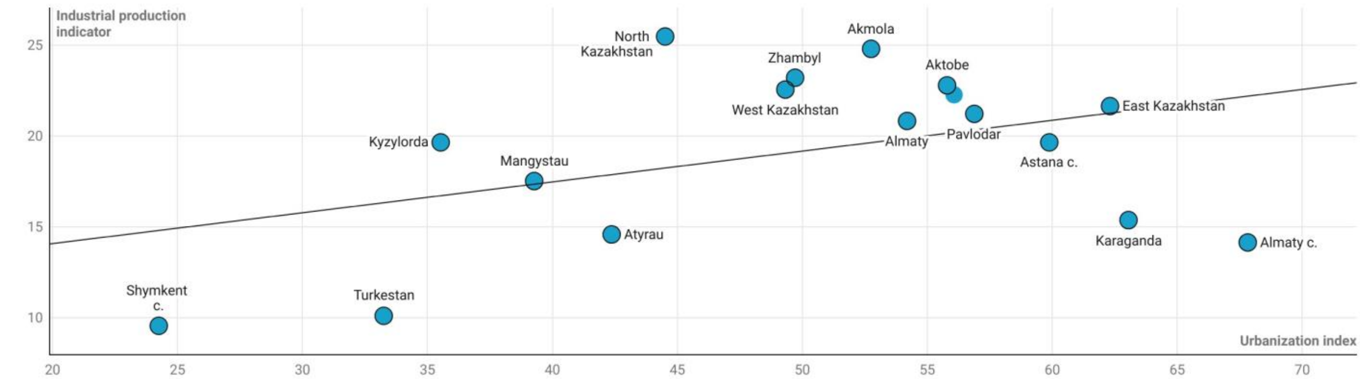
(a)



(b)



(c)



(d)

Figure 2. Scatter plot. **(a)** social urbanization; (**b)** economic urbanization; **(c)** labor force urbanization; **(d)** industrial urbanization.

The results will classify regions based on their level of urban development. The following groups were identified: leaders (require support to sustain their growth), challenged (need tailored strategies to address the disparities), stable (will benefit from diversification to boost their development), and outliers warrant in-depth analysis to replicate their unique successes elsewhere.

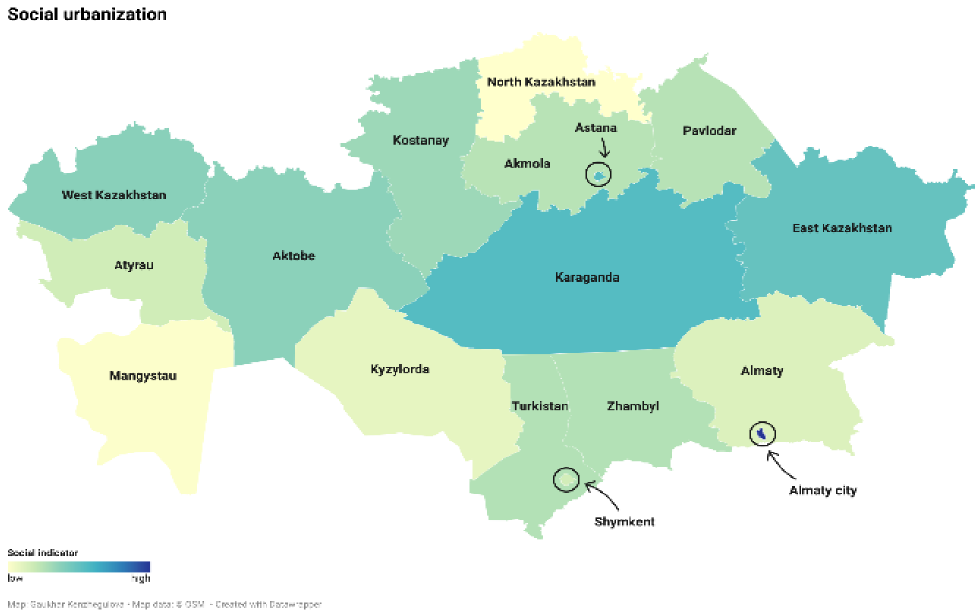
Leader group regions are defined by regions that exhibit high values across most indicators in conjunction with a high urbanization index, suggesting an effective urban development influence on socio-economic benefits. Almaty city, the area with the highest indicators, showcased a particularly strong performance in social (above 25) and economic (around 16) areas, with urbanization close to the apex at 70. Astana city is also a part of this leader group, with similarly high performance, although slightly trailing Almaty city.

Challenged group regions exhibit moderate to high urbanization indices but lag in one or more indicators. They signal a discrepancy between urban development levels and expected development outcomes. Shymkent city displayed moderate urbanization, but social and labor indicators linger at lower levels (nearly 10 for social and around 5 for labor, economic around 3), indicating that urbanization is not yet yielding the anticipated comprehensive benefits, raising concerns about the efficacy of urban growth.

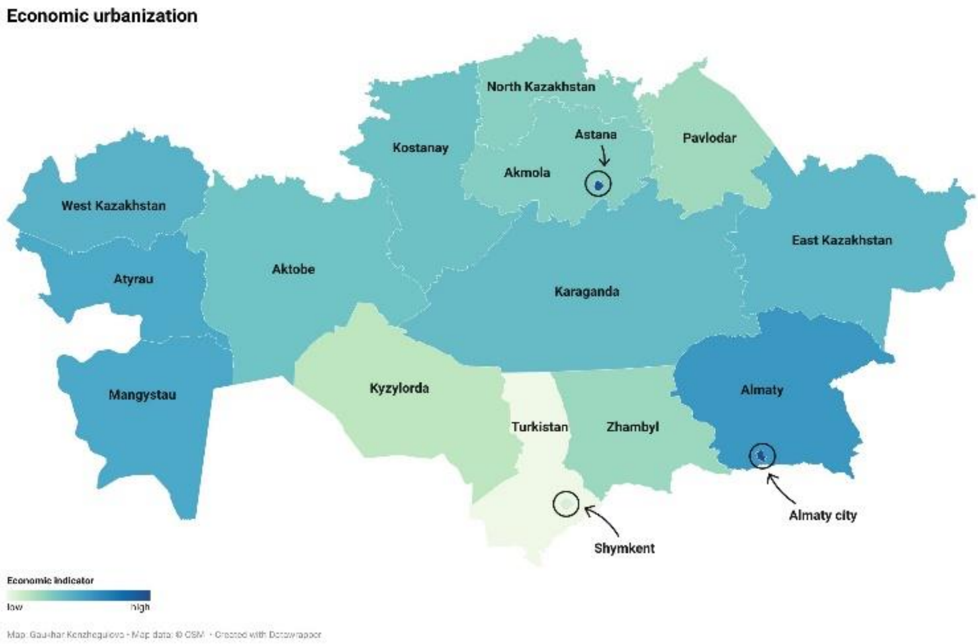
Stable group regions with moderate scores across all indicators regardless of their urbanization index include Mangystau and Atyrau regions, which showed consistent moderate indicator scores (approximately 7 in social indicators), showcasing stability that may be attributed to economic drivers beyond urban density and resource extraction. A few regions showed interesting trends that described the key characteristics of regional policy development. Turkestan exhibited a relatively high social indicator of about 20, implying that regional policies or specific socioeconomic conditions may successfully foster social development in less urbanized settings. At the same time, North Kazakhstan showed an interesting trend. Even though North Kazakhstan has an "industrial production indicator close to 18, which is comparatively high, the overall trend showed results reflected moderate urbanization. Thus, despite not being one of the most urbanized regions, North Kazakhstan has a high industrial output level that rivals or exceeds that of more urbanized areas. Kyzylorda showed an indicator above 10 in labor indicators, suggesting effective labor utilization or labor-intensive industries prevalent in the region.

These results differ based on the general trend observed and indicate the following. North Kazakhstan's industrial output is less dependent on the concentration of urban infrastructure and population. Industrial activity in North Kazakhstan is likely spread across the region, including rural areas, rather than concentrated in highly urbanized cities. Turkestan high social indicators (20) suggest successful socio-economic strategies not dependent on urban development, which the type of industry-specific developments could explain. One of the significant characteristics of modern tourism is that this business travels with customers and therefore does not provide long-lasting employment.

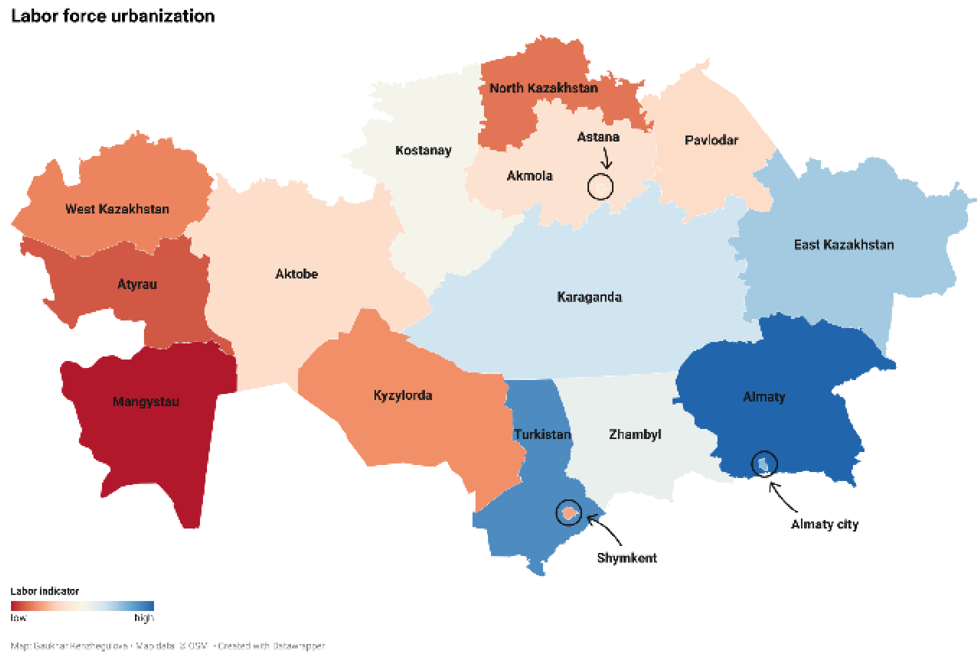
Next, in **Figure 3**, regional development indicators for Kazakhstan are presented between urbanization process and various development metrics across geographic locales.


Social urbanization
North Kazakhstan
Kostanay
Astana
Pavlodar
Akmola
West Kazakhstan
East Kazakhstan
Atyrau
Aktobe
Karaganda
Mangystau
Kyzylorda
Almaty
Turkistan
Zhambyl
Almaty city
Shymkent
Social indicator
low
high
Map: Gaukhar Kenzhegulova · Map data: © OSM · Created with Datawrapper

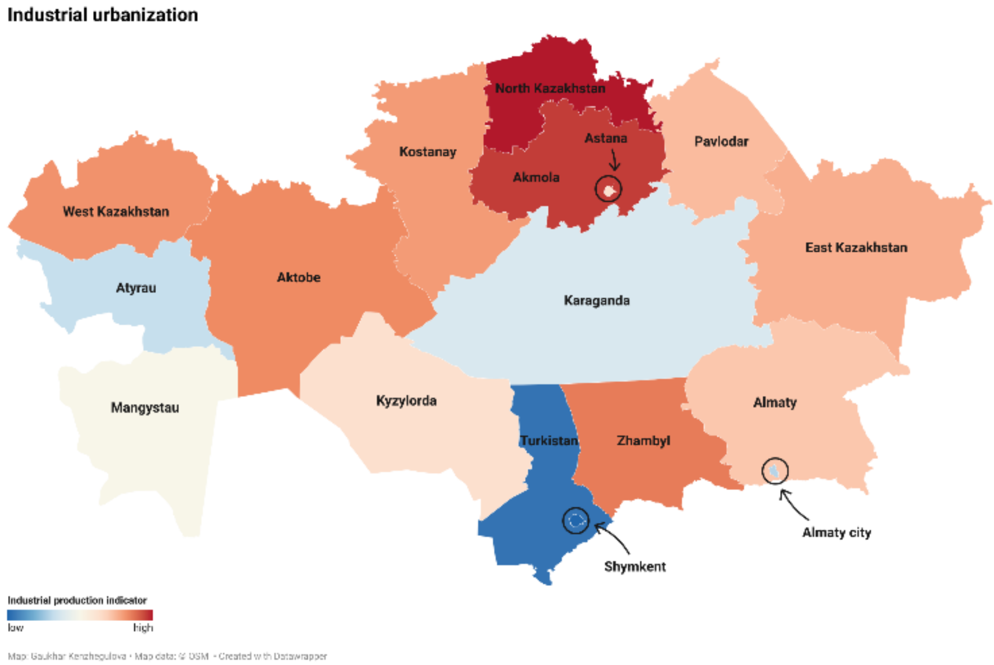
(a)


Economic urbanization
North Kazakhstan
Kostanay
Astana
Pavlodar
Akmola
West Kazakhstan
East Kazakhstan
Atyrau
Aktobe
Karaganda
Mangystau
Kyzylorda
Almaty
Turkistan
Zhambyl
Almaty city
Shymkent
Economic indicator
low
high
Map: Gaukhar Kenzhegulova · Map data: © OSM · Created with Datawrapper

(b)



(c)



(d)

Figure 3. Urbanization by indicators. **(a)** social urbanization; **(b)** economic urbanization; **(c)** labor force urbanization; **(d)** industrial urbanization.

Regarding economic urbanization, Almaty city stands out with the highest index. At the same time, Shymkent showed significantly lower results on the economic indicator, suggesting that while Shymkent's economic indicator is lower than might be expected given its geographic proximity to Almaty, other factors may be influencing its economic performance. The industrial urban data indicates North Kazakhstan and Karaganda have the most pronounced industrial production indicators. Notably, Mangystau's industrial production indicator is substantial even though it is geographically isolated, suggesting that factors such as resource availability or economic policy may play a more significant role than progress in industrial development.

The labor force urbanization index is highest in Almaty and Astana cities. This trend decreases moving away from these urban centers, with central regions like Akmola and Kostanay demonstrating average labor indicators. Their strategic geographical position supports a moderately dynamic labor market.

The social urbanization indicator for Almaty city is the highest, while Astana exhibits a marginally lower but still significant social development index. Interestingly, Turkestan and Mangystau, despite having lower urban development levels, showcased relatively high social indicators, suggesting the effectiveness of targeted social investments.

Economic indicators for Almaty city can be benchmarked at the highest value of 1.0, with Astana following at approximately 0.8 and Shymkent notably lower at around 0.3, despite geographical proximity. In the industrial domain, North Kazakhstan and Karaganda might register as 1.0 on the industrial index, with Mangystau and Turkestan performance at 0.7 and 0.6

The results showed that close locations to developed regions like Almaty and Astana do not ensure equivalent economic or labor benefits for neighboring regions, as seen with Shymkent. Additionally, regions with strategic resources or targeted policy interventions, like Mangystau, can defy geographic determinism to achieve industrial and social development.

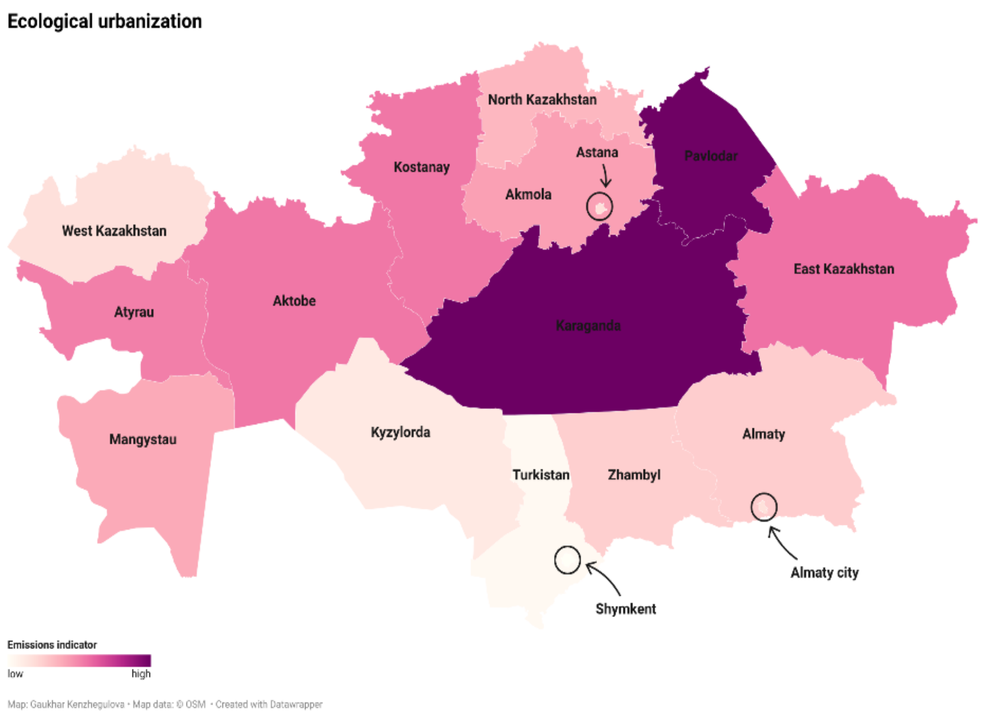
The study reveals significant causal relationships between urbanization and socio-economic indicators, such as employment and quality of life improvements. Generally, urbanization tends to increase employment opportunities by attracting businesses and industries to urban centers, subsequently improving living standards. However, our data also presents counterintuitive findings. Some regions, despite high urbanization levels, exhibit lower-than-expected improvements in socio-economic outcomes. This anomaly can be attributed to the unequal distribution of urban benefits, leading to pockets of poverty and underdevelopment even within highly urbanized regions.

Moreover, geographical proximity to developed and successful regions does not always guarantee similar socio-economic benefits. For instance, despite being geographically close to highly urbanized and economically robust regions like Almaty and Astana, neighboring regions such as Shymkent do not demonstrate comparable economic or labor market performance. This indicates that while geographical location can influence urbanization, it is not a determinative factor.

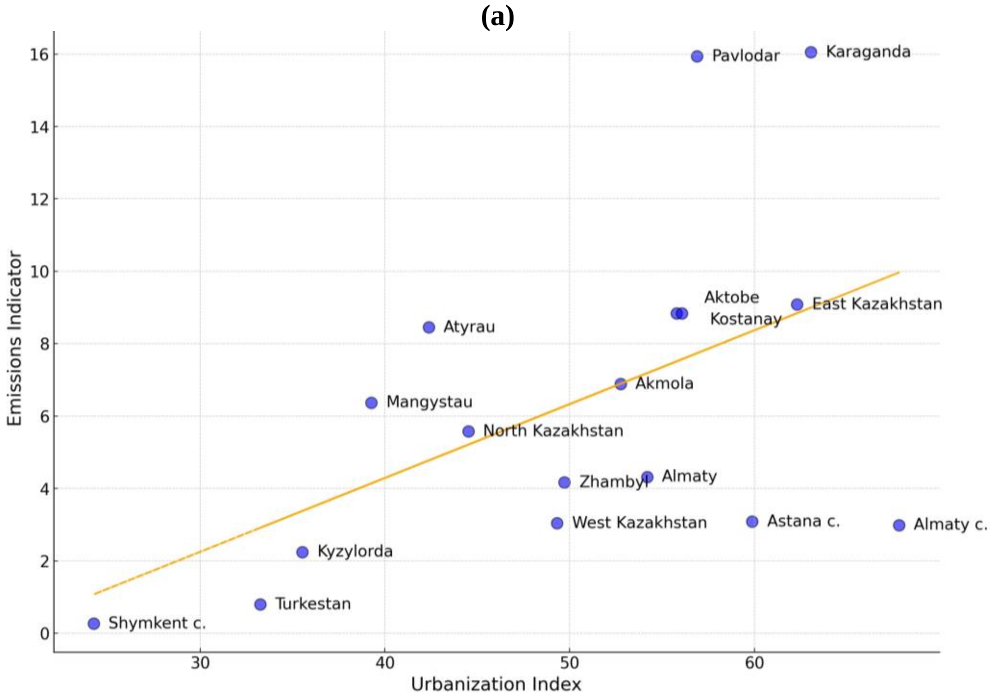
North Kazakhstan exhibits a high industrial production indicator despite moderate urbanization levels. This anomaly indicates that industrial activities are not solely dependent on urban infrastructure and can thrive in less urbanized areas, possibly due to the spread of industrial activities across rural and urban areas. Regions like Turkestan and Mangystau, despite having lower urbanization levels, showcase relatively high social indicators. This suggests that targeted social investments can yield significant social development outcomes even in less urbanized settings.

Mangystau, despite its geographic isolation, has a substantial industrial production indicator. This highlights that factor such as resource availability and economic policy can play a more significant role in industrial development than geographic proximity to urban centers.

Next, results for ecological urbanization process illustrate the emissions indicator across Kazakhstan, providing a basis for evaluating environmental impact. The results showed the regions with the highest emissions (**Figure 4**).



(a)



(b)

Figure 4. Ecological Urbanization. **(a)** ecological urbanization index; **(b)** ecological urbanization scatter plot.

The ecological conditions across Kazakhstan's regions exhibit differences between atmospheric emissions and various socio-economic factors. Examination of a complex of indicators including emission indicators, economic, labor, social, and industrial production metrics, displayed nuanced insights into the environmental impact of the urban development.

Regions with high emissions (above nine units) are Akmola and West Kazakhstan, which may be explained by high industrial production levels, indicating substantial industrial activity in these regions. Almaty and Astana cities also demonstrate high emissions levels, which could be due to their status as major urban centers with intense transportation flows and a concentration of industrial enterprises.

Regions with moderate emissions (from seven to nine units) include Almaty, Aktobe, and East Kazakhstan, which are also characterized by significant industrial activity but less than in Akmola or West Kazakhstan.

Regions that have low emissions (below seven units) are Karaganda and Pavlodar, which exhibit relatively low levels of emissions, even though the indicators of industrial production here are quite high, which may indicate cleaner production technologies or effective emission reduction measures.

Shymkent city has the lowest emissions indicator, possibly due to a low level of industrialization.

While geographical positioning impacts regions' ecological state, its role is not paramount. The nature of economic activities - industrialization and urbanization - generally exacerbates emissions, whereas agricultural orientation and adopting clean technologies can mitigate them. Socio-economic factors influence the region's capacity to implement and sustain environmentally sustainable practices.

The geographical location of the regions of Kazakhstan has a multifaceted impact on their environmental condition. High emissions observed in regions such as Akmola and Western Kazakhstan suggest that industrial activities significantly contribute to regional emissions. Likewise, high emissions in large urban centers such as Almaty and Astana may result from their dense populations, transport networks, and industrial concentration.

Conversely, regions such as Karaganda and Pavlodar, although still having significant industrial production, showed lower emissions levels. Exceptionally low emissions in Shymkent c. suggest that the region's geographic characteristics may favor less polluting agricultural practices than industrial activities.

Thus, while geographic location is undoubtedly a factor, its influence is not deterministic. It interacts with many other elements, including the type and scale of industrial activity, the level of urban development, and the adoption of technologies and practices that reduce environmental impact. To summarize, geography may predispose certain regions to increase or decrease emissions, but the interaction with human economic activity and the application of technology ultimately shapes the ecological footprint.

Next, in **Table 1**, there are provided results for regression analysis.

R (Pearson's Correlation Coefficient): Exhibits a value of 0.721, indicating a substantial positive linear correlation between the predictor variables and the response variable within the model. R^2 (Coefficient of Determination) accounts for 51.9% of the variance in the dependent variable, denoting a moderate explanatory capacity. The variance Inflation Factor (VIF) for economic indicators and industrial production is 1.00, indicating no evidence of multicollinearity. Tolerance for economic indicators and industrial production, 0.996 (close to 1), further confirms the absence of multicollinearity. The results showed that predictors retain a high degree of independence.

Table 1. Model fit, autocorrelation, collinearity.

Model	***R***	R^2	VIF (industrial production)	Tolerance (industrial production)	VIF (economic)	Tolerance (economic)
1	0.721	0.519	1.00	0.996	1.00	0.996

Results of the regression model showed that the predictors in the model—industrial production and economic indicators—are not collinear, suggesting that each provides a unique informational value to the prediction of the emissions indicator.

The hypotheses for both predictors are as follows:

- Industrial production indicator

Null hypothesis (H0): The changes in industrial production rates do not affect emissions.

Alternative hypothesis (H1): The changes in industrial production rates affect emissions.

- Economic indicator

Null hypothesis (H0): The changes in the economic indicator do not affect emissions.

Alternative hypothesis (H1): The changes in the economic indicator affect emissions.

The results for model coefficients are presented in **Table 2**.

Table 2. Model coefficients—Emissions indicator.

Predictor	Estimate	SE	*t*	*p*
Intercept	0.803	1.8623	0.431	0.672
Industrial production indicator	0.264	0.0900	2.935	0.010
Economic indicator	0.310	0.1209	2.562	0.022

The regression model presents the results of the impact of industrial and economic indicators on the emissions indicator. The intercept, estimated at 0.803 with a standard error of 1.8623, suggests the baseline level of emissions when all predictors are zero. However, its associated *p*-value of 0.672 indicates that this estimate is not statistically significant from zero. This lack of significance suggests that the intercept needs to provide meaningful information about the emissions level without the predictors.

The coefficient for the industrial production indicator is 0.264, implying that a one-unit increase in industrial production is associated with an increase of 0.264 units in the emissions indicator, holding other factors constant. The standard error of 0.0900 indicates a high level of precision in this estimate, and the *t*-statistic of 2.935, coupled with a *p*-value of 0.010, confirms that the relationship is statistically significant.

Similarly, the economic indicator has a coefficient of 0.310, indicating that each one-unit increase in the economic indicator results in a 0.310-unit increase in the emissions indicator. The standard error for this coefficient is 0.1209, which is reasonably low, and the *t*-statistic of 2.562, along with a *p*-value of 0.022, further substantiates the statistical significance of this predictor.

Overall, the regression analysis demonstrates that increases in industrial and economic activities are significantly correlated with increases in emissions. Both predictors show a positive and statistically significant relationship with the emissions indicator, underscoring the impact of economic and industrial growth on environmental outcomes. Thus, alternative hypotheses for both indicators were accepted.

Next, the overall results for Urbanization level by region is provided in **Figure 5**.

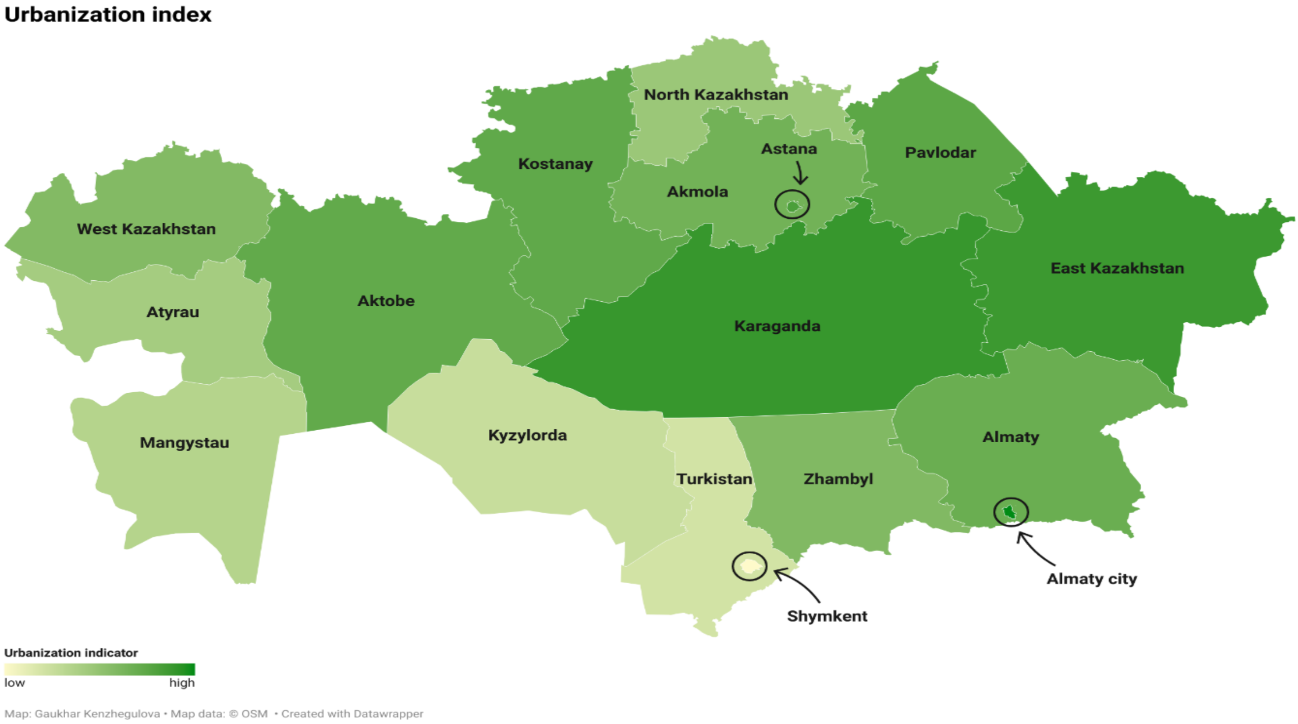


Figure 5. Urbanization index.

Almaty city (74.69) and Astana city (67.10) exhibit the highest urbanization indexes and likely have advanced infrastructure, dense populations, and a strong presence of services and industries. Higher economic and industrial production indicators suggest that urbanization accompanies diversified economic bases and potentially higher quality of life, as indicated by higher social indicators.

East Kazakhstan (61.41), Aktobe (55.33), Akmola (54.95), Zhambyl (55.27), West Kazakhstan (56.27), and Kostanay (55.63) represent regions with moderate substantial urbanization process, but not as concentrated as in Almaty and Astana cities. Karaganda (50.47), North Kazakhstan (48.58), and Pavlodar (43.71) have urbanization indexes that indicate growing urban areas that have not yet reached the density or economic diversification of more urbanized regions. Kyzylorda (43.36) also fits into this group, with the potential for urban growth and development.

Atyrau (41.17), Mangystau (40.61), and Turkestan (36.23) have lower urban development levels, indicative of a larger rural population or a transition phase towards urbanization. South Kazakhstan has the lowest urbanization index (24.23).

The degree of urban development is often a proxy for economic development, with more urbanized areas having higher economic activity and potentially better social services. However, this is not an absolute rule, as regions with natural resource wealth, like Atyrau and Mangystau, have significant economic activity without corresponding high urbanization due to industry-specific localization.

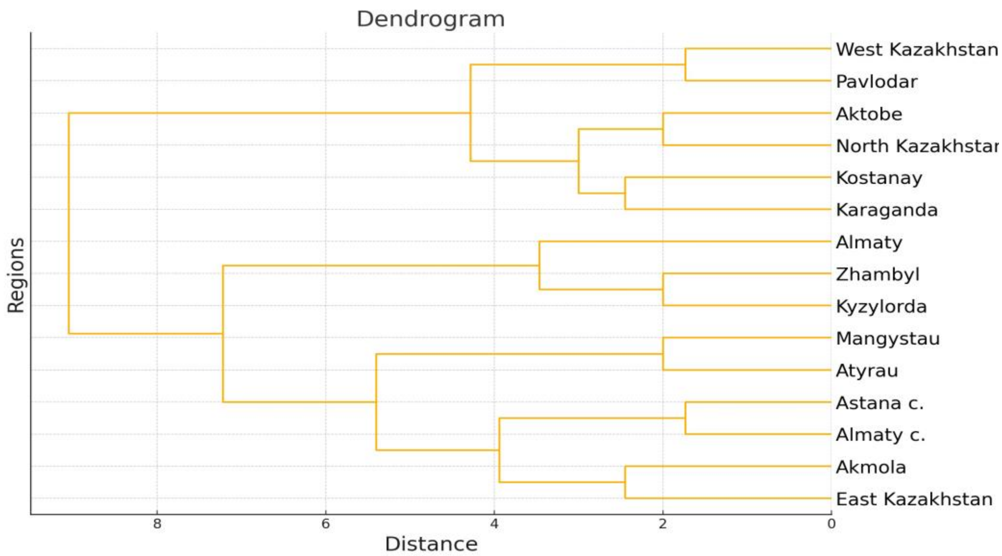
In terms of urban planning and regional development, these classifications imply that highly urbanized regions may need to focus on sustainable development and infrastructure to support their dense populations. In contrast, less urbanized areas might benefit from investments to stimulate urban growth, diversify their economies, and improve social services.

In economic terms, urban centers like Almaty city and Astana city are likely to have advanced service sectors and industries, fostering higher economic indicators. Industrial production appears robust across various regions and does not correlate directly with urban development, indicating that industrial activity might be distributed across urban and less urbanized areas. Emissions tend to be higher in regions with higher urban development, which could be attributed to increased industrial activities, traffic, and energy consumption associated with urban environments. The exception of Karaganda, which has a lower urbanization index but a very low emissions indicator, could suggest efficient industrial processes or a different industrial mix that is less polluting.

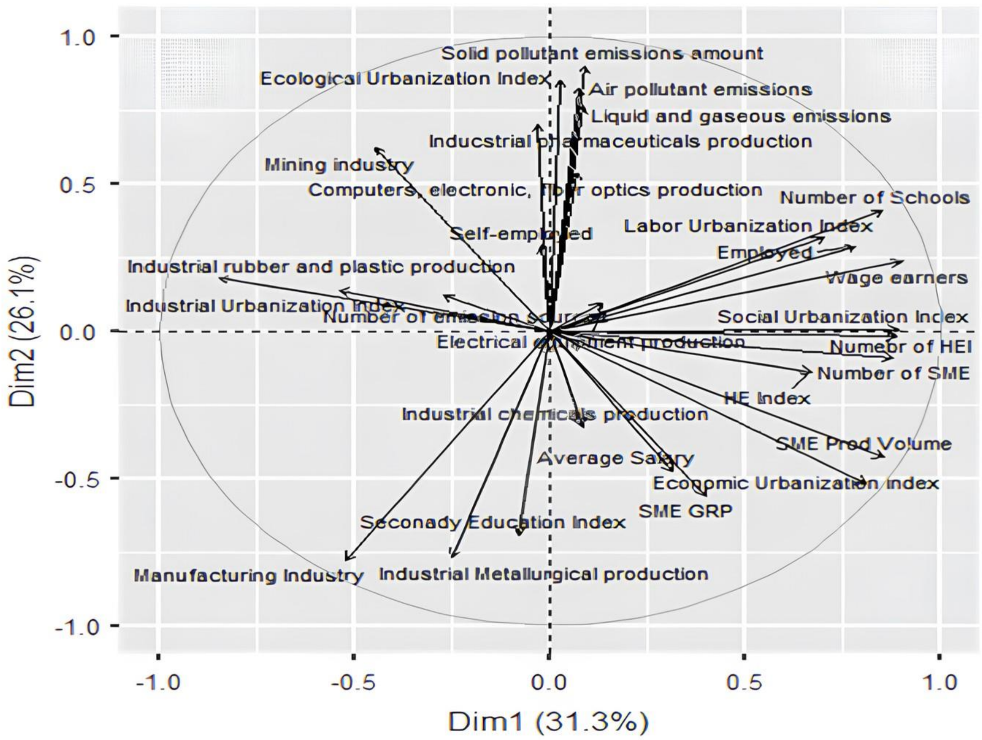
4.2. Cluster analysis

The second main stage of the analysis includes cluster analysis based on indicators used in the urbanization index for deeper analysis and identification of leader groups and regions experiencing challenges.

The results display a plot showing the optimal number of clusters. The optimal number of clusters typically corresponds to the value, after which the curve begins to flatten out, or the increase in the gap statistic becomes less significant. **Figure 6** presents data on gap statistics to determine the number of clusters in a dataset.



(a)



(b)

Figure 6. The optimal number of clusters: **(a)** hierarchical clustering of regions based on socio-economic indicators; **(b)** principal component analysis of regional socio-economic and environmental indicators.

The optimal number of clusters was based on results from the gap statistics. The peak of the gap statistic was at $k = 2$, followed by minor fluctuations. At $k = 3$ or higher, there was an indication that additional clusters do not provide statistically significant improvement in data separation without a significant increase in clustering informativeness. Thus, two clusters were identified as the optimal number for this analysis. Next, the hierarchical agglomerative cluster analysis results suggested division for micro, intermediate and macro clusters.

Microclusters include two groups at the primary level, one of which provides for "Astana city" and "Almaty city", and the second—included "Karaganda" and "East Kazakhstan". The proximity of these microclusters in dendrogram space indicates a high degree of similarity of characteristics within these subgroups.

Intermediate clusters indicated the presence of standard features between regions, but this similarity is less pronounced compared to microclusters of the primary level.

Macroclusters, the highest level of dissimilarity was observed during the formation of a cluster that includes "Northern Kazakhstan", "Akmola", "Kostanay" and "Aktobe", which is illustrated by their unification at the level of approximately 12–13. This indicates a significant difference between these regions and other clusters, which might reflect specific features. Therefore, the results supported the idea that two clusters are optimal.

The principal component analysis (PCA) biplot simultaneously displays projections of the original variables and individual observations. The first principal component (Dim1) is significantly correlated with variables related to urbanization, industrial production, and economic indicators such as Ecological Urbanization Index, Average Salary and Economic Urbanization Index.

The second principal component (Dim2) appears to be related to pollution level variables such as "Solid pollutant emissions amount", "Air pollutant emissions" and "Liquid and gaseous emissions". Thus, regions with high industrial development tend to have higher pollution levels.

Economic significance can be seen in the correlation between economic and environmental indicators. Regions with high values for the first component may have a high standard of living but also face problems associated with managing environmental risks. Regions with high scores on the second component may need stronger ecological regulations and investments in clean technologies. By comparing the biplot and the plot of individual observations, one can conclude the heterogeneity of economic and environmental conditions among the regions of Kazakhstan.

The distribution of different regions of Kazakhstan represents the projection of multidimensional data into a two-dimensional space for visualization.

Group 1 (Almaty and Astana cities, Karaganda, and East Kazakhstan) includes regions grouped together and indicated at the top left of the graph. These regions have similar economic characteristics or socio-demographic indicators.

Group 2 (the rest of the regions) also represents regions with similar features but different from the first group, located at the bottom right of the graph.

In the context of multidimensional scaling via principal component analysis (PCA), the 17 Kazakhstani regions can be stratified into several clusters.

Cluster A—Socially and Educationally Advanced Regions. Almaty and Almaty cities are characterized by a high Social Urbanization Index and a dense concentration of 'Higher Education Institutions (HEI).

Cluster B—Economically Focused Regions. Astana city is characterized by SME GRP and Average Salary, developed small and medium enterprise (SME) sector, and higher economic output per capita. Pavlodar indicates a region with strong economic production (which showed a positive trend in the Economic Urbanization index, SME Product Volume).

Cluster C—Balanced Socio-Economic Profile. Akmola, Aktobe, East Kazakhstan, Kostanay, and North Kazakhstan are centrally located in the PCA plot, implying a balanced distribution of industrial and social variables, suggesting a diverse economic and social landscape.

Cluster D—Industrially Oriented Regions. Karaganda showed a higher concentration in the Industrial Metallurgical production vector and an overall pronounced industrial base, especially in metallurgy. Kyzylorda and Atyrau showed industrial orientation, drawing attention to the low Average Salaries and Secondary Education Index, which suggests that in these regions, the industry plays a crucial role in the economy, the level of wages and the level of second-level education may be lower compared to the other regions.

Cluster E—Low Urbanization and Industrial Activity. Mangystau and West Kazakhstan showed lower values on Ecological Urbanization Index and Industrial Urbanization Index, and showed less urban and industrial development rates relative to other regions.

Cluster F—Social Infrastructure Development Potential. Zhambyl is situated lower on PC2 and could be characterized by a lesser emphasis on social infrastructure, such as ‘Number of Schools’ and ‘Labor Urbanization Index.’

Cluster G—Diversified Socio-Economic Regions. Pavlodar demonstrates a moderate socio-economic profile, indicating no extreme development in any specific industrial or social domain.

This stratification permits a nuanced understanding of regional characteristics, guiding targeted policy interventions. Notably, the discerned clusters are contingent on the relative expression of the regions across the constructed principal components and warrant a thorough examination through advanced statistical modeling and analysis of the original metric data.

5. Discussion

The difference in the results for regional clustering showed various options for the division of regions. It is important to admit that context for analysis has a crucial impact on the overall results. The cluster analysis showed that regions one and the same region could be included in several clusters based on various indicators and combinations of indicators. Therefore, an optimal number of clusters suggested initially gives a more vivid conclusion. Thus, Almaty and Astana cities stand out as the strongest regions showcasing high results for each indicator. The rest of the regions exhibited strong performance in single indicators or moderate development with low results in a few indicators.

Urbanization Index revealed key differences and factors specific to countries with regional policy development. The results showed that countries with a regional approach are less prepared for expanding urban areas. First, there are other factors besides geographical location that influence neighboring regions’ development. At the same time, high emission rates do not appear in neighboring regions as in the case of Karaganda and Turkestan. Second, significant factors such as industrial production are developed through rural areas, as North Kazakhstan, showcasing that industrial production is developed regardless of social and economic factors. Economic indicators such as SME development showed a positive trend in most regions, except for Turkestan, showing that economic indicators (SME) are developed regardless of the other indicators, such as industrial and social. Interestingly, both indicators have a significant impact on ecology, while the labor force and society have an insignificant relation to air pollution.

Regional policy usually considers the weak sides of the region and directs all efforts to improve it. However, in the case of Kazakhstan, state management is is focused on general approach tackling arising issue in all regions simultaneously. Such an approach distracts the attention of local government from specific issues. Therefore, region clustering suggested two clusters of two cities of Republican Status and the rest part of the country. Although Almaty and Astana are regarded as separate regions, the approach for their management is more of a city. Conversely, the rest of the country consists of rural and urban areas and requires different approaches to management.

6. Conclusion

Regional policy does not consider the specifics and operates in each region. The current strategy, which focuses on a one-size-fits-all solution to problems, may need to be more effective due to significant factors in development patterns, infrastructural features, and logistics needs between different regions.

While noting the high level of urbanization in Astana and Almaty, it is necessary to recognize that other regions have unique challenges and opportunities. The development of these cities places particular emphasis on strengthening urban employment and services. A differentiated approach allows for more efficient use of resources and accelerates regional development.

Moreover, the vast territories of many urbanized regions offer industrial development and manufacturing opportunities. This can lead to economic diversification and job creation, which in turn can stimulate urbanization and improve quality of life. Instead of applying one-size-fits-all traditional models, such regions could use policies focused on developing specific industrial sectors or creating an economic zone.

In the context of Kazakhstan, for the successful implementation of targeted urban policies and development programs, it is advisable to pay attention to successful political initiatives from other countries. For example, strategies for improving urban infrastructure and developing public transportation, successfully implemented in developed countries, can be adapted to the specifics of Kazakhstani cities.

For further research in the field of urbanization in Kazakhstan, it is proposed to conduct a deeper analysis of the impact of urbanization processes on the social and economic development of the country's regions. This includes studying the relationship between the level of urbanization, the availability of public services such as healthcare and education, and their impact on the population's quality of life. Additionally, further research may include analyzing factors that determine the attractiveness of cities for migration and the mechanisms for regulating migration flows in the context of urbanization. Unexplored aspects of urbanization in Kazakhstan may include analyzing the impact of urbanization on the environmental condition of regions, including air, water, and soil pollution levels, as well as the effectiveness of environmental programs and policies in urban areas.

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