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Analyzing the Relationship Between Urbanization and Greenhouse Gas Emissions: The Case of Kazakhstan

Abstract

Subject: The study analyses the relationship between urbanization and greenhouse gas (GHG) emissions in Kazakhstan, looking at the impact of urban growth on GHG emissions and suggesting pathways for their sustainable development.

Methods: The study relies on national statistics and utilizes a hybrid method that integrates the analysis data analysis with qualitative insights. In this study, we used an algorithm that includes three key steps: (1) aggregating data from various sources for the period 2015–2021; (2) using data visualization tools to construct graphs; and (3) constructing mind maps to visualize the consequences of urbanization for air quality.

Findings: Our results show that urbanization in Kazakhstan is closely linked to a growth in GHG, driven by industrial development, energy consumption, and transportation. The analysis highlights the importance of considering ecological, economic, and social aspects of balanced development urban growth and reducing environmental impacts.

Conclusions: The study also identifies opportunities to reduce emissions through strategic urban planning, green infrastructure development, and clean technology adoption. The study contributes to the current debate on sustainable urbanization by offering insights that can inform urban management policies and practices in Kazakhstan and similar contexts worldwide.

***Keywords*:** Urbanization, greenhouse gas emissions, Kazakhstan, sustainable development, economic factors, social factors, environmental factors, urban planning, energy consumption, policy implications.

Introduction

Urbanization is a transformative force on a global scale, changing the landscape of societies, economies, and the environment. As a marker of economic development and social evolution, exponential urban growth presents significant environmental challenges, and GHG emissions have notably risen. The World Bank reports that the country is undergoing significant urbanization, with the proportion of urban residents growing from 51 % in 2000 to over 58 % in 2020. This rapid expansion of urban areas is primarily driven by its growing economy, especially in the petroleum and energy industries, which contributes approximately 20 % to GDP and accounts for more than 60 % of its export revenues.

Kazakhstan is the world's ninth-largest country by area and has significant fossil fuel reserves, making it a key player in the global energy market. However, this economic growth has an environmental cost. According to the International Energy Agency (IEA), from 1990 to 2019, Kazakhstan's GHG emissions have increased by 35 %, placing the country on the list of the world's top 25 issuers. Approximately half of all GHG emissions in the country come from the industrial sector, primarily the oil and gas production sector. In contrast, emissions from the transportation sector have increased by 70 % over the last twenty years., reflecting the growing need for urban mobility.

Moreover, Kazakhstan's energy infrastructure, heavily dependent on coal, which accounts for about 70 % of its energy mix, exacerbates its environmental impact. This dependence contributes significantly to greenhouse gas emissions and poses challenges for urban air quality and public health. The capital, Astana, and the country's largest city, Almaty, have seen a marked deterioration in air quality, with levels of particulate matter often exceeding WHO recommendations.

Analysis of urbanization and GHG emissions in Kazakhstan reveals a complex interplay of economic growth, energy policies and urban development strategies. With per capita GHG emissions of about 15 metric tons of CO2 equivalent, one of the highest among Central Asian countries, Kazakhstan must shift to more

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sustainable urban and energy development models. It can be highlighted that Kazakhstan has implemented measures aimed at reducing greenhouse gas emissions and reducing the carbon footprint. In particular, the Strategic Development Plan until 2025 was adopted, establishing a 15 % reduction in emissions and an increase in the share of renewable energy sources in electricity production to 10 %.

Therefore, this paper aims to assess the economic, social, and environmental factors affecting urbanization and greenhouse gas emissions in the regional context. Thus, the main contribution of this work is to identify ways of sustainable urban development, considering the goals of environmental sustainability and climate change.

The results of this study indicate the need for an interdisciplinary approach to solving the relationship between urbanization and greenhouse gas emissions. This approach should consider the importance of the transition to low-carbon and energy-saving technologies and support innovation in the green economy. Combining various aspects of research, this paper will solve the problem of urbanized regions of Kazakhstan, reduce the negative impact on the climate, and bring the country closer to fulfilling international environmental obligations.

Literature review

The processes of urbanization and economic development have recently been critical spatial factors. Demographic trends, changing urban infrastructure, and demographic settlement pose many challenges to sustainable growth. In addition, urbanization is a complex system influenced by natural, geographical, transport, economic, and social conditions. Thus, urbanization causes an increase in the role of cities, the number of urban residents, an increase in investment and the growth of agglomeration zones.

Economic factors are vital in establishing the relationship between urbanization and greenhouse gas emissions. Studies show that energy consumption often increases as economic activity grows in cities. Urbanization is accompanied by the construction and expansion of industrial zones, which increases the use of high-carbon energy sources, such as coal and oil (Seto et al., 2016). Effective economic activity management in cities and the transition to clean energy sources become important strategic tasks for reducing greenhouse gas emissions (Kennedy et al., 2010).

Urban systems are characterized by significant indirect carbon flows that transcend administrative and agglomeration boundaries, creating important policy challenges. This emphasizes the need for future research to take an integrated systems approach that integrates all sources, sinks, infrastructure, and technological capabilities for effective carbon management (Shobhakar, 2010).

Urban carbon emissions, which contribute significantly to global warming, depend on multiple factors, including urban form. Studying the relationship between urban form and carbon emissions, which can be optimized through architecture and urban planning, is important in supporting low-carbon urban development (Zhu, Hu, 2023).

Ding, Y., Yang, Q., and Cao, L. analyzed the connection between urbanization and carbon emissions in 182 prefecture-level cities in China during the period from 2001 to 2010, with a focus on economic growth, industrial transformation, technological advancements, public services, demographic shifts, and changes in both urban and natural environments (Ding et al., 2021). It highlights the distinct effects of social processes on carbon emissions during urbanization, including enhancements in public services reflected by advancements in education and cultural development. Khan, H., Chen, T., Bibi, R., and Khan, I. explored the influence of urbanization and institutional quality on environmental quality in Belt and Road Initiative (BRI) countries from 2002 to 2019. They discovered that urbanization initially raises carbon dioxide emissions but may result in reductions after surpassing a certain threshold. Education and government effectiveness are also discussed in relation to carbon emissions (Khan et al., 2023).

This study explores how geophysical and technical factors, including urban design and waste processing, determine greenhouse gas emissions attributable to cities. Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havránek, M., Pataki, D., Phdungsilp, A., Ramaswami, A., and Mendez, G. examine the impact of public transit and personal income on emissions, highlighting the importance of including upstream emissions from fuels (Kennedy et al., 2009).

This paper investigates the relationship between land management and GHG emissions and presents a causal framework linking settlement patterns to emissions through landscape impacts, infrastructure impacts, and buildings. Clinton, J. Andrews suggests that per-capita carbon dioxide emissions vary widely across municipalities and are influenced by population density, transit options, and the balance between residential and commercial buildings (Clinton, 2008).

Feiock, R. and Bae, J. investigate the factors that account for the local adoption of climate protection at the city level, focusing on the role of political and institutional factors and various public entrepreneurs in adopting GHG inventories. It finds that elected mayors and civic entrepreneurs promote carbon reduction in the larger community, while managers and bureaucratic entrepreneurs focus on the carbon emissions of governmental organizations (Feiock, Bae, 2011).

Urbanization influences carbon emissions through economic growth, energy efficiency, and end-use energy consumption patterns. The authors also examine the multilevel impact of urbanization on carbon emissions and analyze policy measures aimed at reducing emissions through the agglomeration effect of urbanization, which is important for government decision-makers (Wang et al., 2021).

The authors' main findings indicate an increase in greenhouse gas emissions, an intensification of the urban heat island effect, loss of green spaces, and disruption of local biodiversity. However, their study also showed that urban areas can become catalysts for sustainable solutions if policy, innovation and active community participation are combined (Bera et al., 2023).

Although many studies have examined the impact of urbanization on greenhouse gas emissions in recent years, the existing body of research on this topic remains poorly understood. For example, some studies show that social factors such as income inequality, population structure, and size can influence the relationship between urbanization and greenhouse gas emissions (Zhu, Peng, 2012).

Recent studies contribute to understanding this intricate relationship from the different vantage points. Raihan A. and Tuspekova A. analyzed the complex interactions between economic activity, including urbanization processes, and their impact on greenhouse gas emissions in Kazakhstan. They emphasize the vital role of industrial and urban growth in environmental degradation. This research underscores the necessity of considering the broader economic context in efforts to mitigate GHG emissions (Raihan, Tuspekova, 2022).

In addition, Aitkazina M.A., Nurmaganbet E., Syrlydkyzy S., Koibakova S., Zhidebaeva A.E., and Aubakirov M.Z. emphasized the contribution of the agricultural sector to reducing greenhouse gas emissions. In particular, their research focuses on approaches to improving the use of green technologies and the introduction of sustainable agriculture practices. Their work is complemented by research on the impact of urbanization on the environment, which covers agricultural practices in urban areas and on their periphery (Aitkazina et al., 2019). In turn, based on quantitative Kazakhstan data, Tleppaev and co-authors investigated the relationship between energy consumption, urban growth, and sustainable development indicators. Their article focuses on energy infrastructure and its potential to reduce greenhouse gas emissions, especially in large urban agglomerations. An important area is the development of institutional approaches and the formulation of practical recommendations for programs for the rational use of energy resources, which contributes to reducing greenhouse gas emissions (Tleppaev et al., 2023).

At the same time, despite a significant number of scientific papers on this topic, a complex analysis of the problem has not yet been carried out, and multifunctional indicators have not been developed. Issues related to disclosing the relationship between urbanization and greenhouse gas emissions remain poorly understood. Generally, for this reason, it is crucial to develop a conceptual framework in this area, especially considering interdisciplinary approaches that will be aimed at using green technologies in urban development. Moreover, the development of such a fundamental basis will not only reduce greenhouse gas emissions but also contribute to the sustainable growth of large megacities experiencing unique problems. As a result, this approach should also consider ensuring a balance between economic, environmental, and social aspects to interact with cities and the environment harmoniously.

Methods

As noted earlier, the conceptual framework for analyzing the links between urbanization and greenhouse gas emissions is based on integrated approaches. However, interdisciplinary tools that combine economic, social, and environmental aspects also occupy a special place. This paper pays great attention to a comprehensive assessment of development trends based on the processes accompanying urbanization. Quantitative indicators are used for this purpose, such as statistics on urban population growth, industrial production, data on energy consumption, and greenhouse gas emissions. The initial data were collected from various available statistical annual compilations, which included indicators of urban growth, demography, industrial production, energy consumption, and greenhouse gas emissions.

Quantitative indicators were used for the analysis covering the period from 2015 to 2021, including statistics on urban population growth, industrial production, data on energy consumption, and greenhouse gas emissions. The initial data were collected from various statistical yearbooks, including information on urban

growth, demographic changes, industrial production, energy consumption, and greenhouse gas emissions. Based on the data obtained and the study results, recommendations will be proposed to reduce greenhouse gas emissions in urbanization processes.

Thus, this paper uses a hybrid research methodology combining quantitative data analysis and a selection of recommendations for research on the relationship between urbanization and greenhouse gas emissions. This analysis provides step-by-step actions to identify possible strategies and reduce the carbon footprint. Further, the steps of the study are proposed in more detail:

(1) The first step is to aggregate the collected quantitative data. Data on urban growth, demographic trends, energy consumption, and greenhouse gas emissions (including CO_2) are aggregated for 2015–2021. Data for 2022 were not included due to the lack of up-to-date data in official statistical reports at the time of the study. Parameters such as the urban population, migration flows, and energy consumption were taken.

(2) The second step is to present the collected quantitative data. Data visualization tools were used to visualize the dynamics of urbanization processes and greenhouse gas emissions. In particular, graphs, structured tables of indicators, and systematized diagrams were constructed that display the geographical distribution of urbanization and the level of emissions in various regions of Kazakhstan.

(3) The third step is the construction of a mental circuit. Tree diagrams are widely used in research to display the relationships between various elements and components visually. In such a scheme, all essential elements are grouped around the central idea using a non-linear graphical layout, which allows for building an intuitive structure (for example, in our case, urbanization, greenhouse gas emissions, and their impact on air quality).

Thus, the proposed algorithm of step-by-step actions allows us to analyze the relationship between urbanization and greenhouse gas emissions. All these steps together form a structured basis for further conclusions and the development of practical recommendations. In addition, targeted measures to reduce greenhouse gas emissions can be proposed, including improving urban infrastructure, using green technologies, and better planning for mega-poles' growth.

Results

Today, one of the critical global environmental problems in the context of climate change is the steady increase in greenhouse gas emissions (including carbon dioxide). At the same time, these processes have a negative impact on the sustainability of the environment, an increase in the average global temperature, changes in weather, and climatic phenomena. At the same time, urbanization, which depends on economic development, changes in demographic structures, and the redistribution of natural resources, plays a significant role in accelerating this process. Industrial and megacity regions of Kazakhstan, such as Almaty, Astana, and Karaganda, are experiencing rapid urbanization rates, accompanied by increased CO2 emissions. In addition, the expansion of urban and industrial infrastructure in Atyrau and Aktau, as well as transport networks in the process of urbanization, leads to increased emissions, mainly due to the use of fossil fuels — coal, oil, and natural gas, which remain the primary sources of energy in Kazakhstan.

In general, we highlight the main aspects of the impact on CO2 emissions in Kazakhstan.

1. Economic aspects of urbanization. Urbanization in Kazakhstan is inextricably linked with GDP growth and improvement of the population's standard of living, which contributes to the active development of the industrial sector. Kazakhstan, one of the largest economies in Central Asia, is experiencing a significant increase in energy production and consumption, especially in industrialized regions such as Atyrau, Karaganda, and Pavlodar. The main sectors of the economy, such as mining, energy, and metallurgy, place high demands on energy resources, increasing CO2 emissions.

2. Social aspects of urbanization. In Kazakhstan, social changes also have an impact on greenhouse emissions. Demographic processes such as migration flows and population aging also play a significant role. Migration of the population from rural to urban agglomerations is observed in Kazakhstan, which increases the demand for infrastructure and energy. The growth of the urban population leads to higher levels of energy consumption and, therefore, to an increase in CO2 emissions. For example, the Kazakh government can actively support awareness-raising programs to improve environmental literacy, which forms sustainable energy consumption patterns in various sectors of the economy.

3. Environmental aspects of urbanization. Expanding agglomeration areas is accompanied by the construction of new infrastructure complexes, industrial zones, and other logistics, which require significant resources. In particular, in industrial cities such as Almaty, Astana, and Karaganda, intensive construction and the use of traditional energy sources exacerbate the environmental situation in these cities. For example, an

important initiative may be creating conservation areas and parks around large agglomerations, which will help reduce CO2 and improve air quality.

Next, we propose to consider a radial graph (cobweb), which shows the influence of various factors on urbanization and greenhouse gas emissions (see Figure 1).

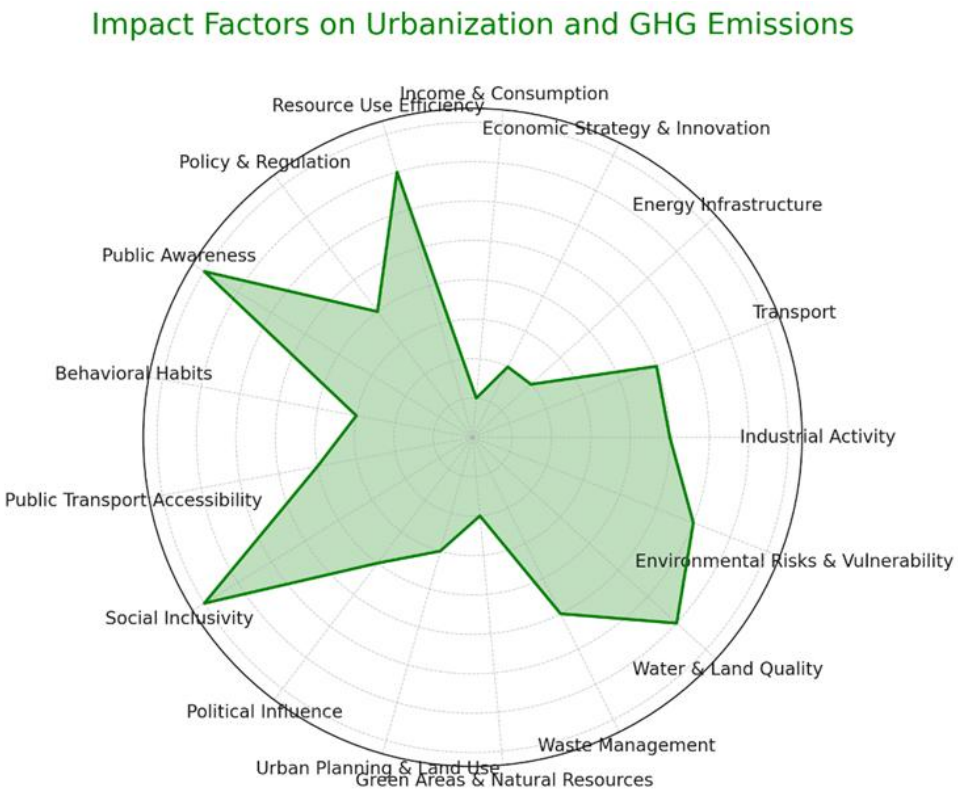

Figure 1. The radial diagram of the impact of various aspects on greenhouse gas emissions

Note — compiled with the data source of the authors

This cobweb is the cumulative impact of economic, social, and environmental aspects on urbanization processes and greenhouse gas emissions. In particular, the diagram shows that the more the area is covered along a particular axis, the stronger the impact of this indicator on urbanization and greenhouse gas emissions. According to the results, the 'public awareness' factor is of the greatest importance among other factors, which indicates that environmental awareness of society is a key element in the context of urbanization and GHG emission reduction. At the same time, the average influence is observed from such factors as 'industrial activity,' 'environmental risks and vulnerability', and 'public transport accessibility.' Finally, factors such as 'income and consumption' have the least impact and 'behavioral habits'.

The interplay between urbanization and GHG emissions is complex and influenced by many economic, social, and environmental factors. By understanding and strategically managing these factors, cities can embark on a path toward sustainable development that aligns with global climate goals. Developing integrated strategies that take these diverse influences into account is essential for lowering emissions, creating convenient and accessible infrastructure, improving environmental safety, developing public transportation, improving health care and education, and ensuring a comfortable and safe living space for all residents. This figure 1 provides a visual summary of the different impacts, offering a framework for tackling urban sustainability challenges in a holistic manner.

Discussions

Today, one of the most critical tasks is ensuring environmental safety from atmospheric pollutants. Fine particulate matter, designated as PM-2.5, is one of the most dangerous and widespread pollutants of atmospheric air. PM-2.5 particles are less than 2.5 microns in size and can contain a variety of toxic substances, which makes them especially dangerous to human health. Due to the potential threat to public health, monitoring and analysis of PM-2.5 concentrations in the atmosphere of urban agglomerations are becoming key for the development and implementation of effective strategies to improve air quality.

In this context, an overview of data covering the period from 2015 to 2021 is presented, which contains detailed information on the average annual concentrations of PM-2.5 particles in various cities of Kazakhstan. The data are presented in table 1, which illustrates changes in PM-2.5 concentration levels and allows for a comprehensive analysis of spatial and temporal trends in air pollution (table 1).

Table 1. The average annual concentration of PM solid particles is 2.5 (mg/m3) in various cities

No.	City	Years						
		2015	2016	2017	2018	2019	2020	2021
1	Astana	-	0,020	0,020	0,020	0,03	0,05	0,036
2	Almaty	-	0,020	0,009	0,015	0,03	0,034	0,036
3	Shymkent	0,019	0	0,04	0,04	0,02	0,048	0,023
4	Kokshetau	-	-	-	-	0,002	0,003	0,038
5	Aktobe	0,018	0,02	0,02	0,017	0,0168	0,0136	0,1257
6	Taldykorgan					-	-	0,06
7	Atyrau	0,014	0,003	0,01	0,01	0,0129	0,035	0,088
8	Oral	-	0,02	0,01	0,023	0,01	0,003	0,004
9	Taraz	-	-	-	-	-	-	0,03
10	Karaganda	0,06	0,1	0,1	0,11	0,056	0,04	0,152
11	Balkhash	-	-	-	-	0,048	0,03	0,06
12	Zhezkazgan	-	-	-	-	0,011	-	-
13	Temirtau	-	-	-	-	0,044	0,02	0,036
14	Kostanay	-	-	-	-	0,03	0	0,1
15	Arkalyk	-	-	-	-	-	-	0,0105
16	Rudny	-	-	-	-	-	-	-
17	Kyzylorda	-	-	-	-	0,005	0,001	0,0013
18	Aktau	-	-	-	-	0,055	0,013	0,01
19	Pavlodar	0,016	0,008	0,005	0,005	0,0072	0,0072	0,01
20	Aksu	-	-	-	-	-	-	-
21	Ekibastuz	-	-	-	-	-	-	-
22	Petropavlovsk	-	-	-	-	0,012	0,004	0,002
23	Ust-Kamenogorsk	-	-	-	-	-	-	0,025
24	Ridder	-	-	-	-	-	-	-
25	Semey	0,024	0,035	0,03	0,025	0,014	0,0169	-
26	Glubokoe village	-	-	-	-	0,001	0,0149	0,019
Note — compiled with the data source stat.gov.kz								

The concentration of PM-2.5 particulate matter in micrograms per cubic meter (mcg/m3) is a key indicator of air quality in urban areas. PM-2.5 particles have a diameter of less than 2.5 micrometers, which allows them to penetrate deep into the respiratory tract and lungs of a person, as well as enter the bloodstream, which causes a significant health risk. This analysis focuses on trends in the concentration of PM-2.5 in various cities of Kazakhstan over the period from 2015 to 2021, identifying key trends and potential problems for public health.

Trend analysis: The data show different trends in the concentration of PM-2.5 in different cities. In some cities, there is a steady increase in the PM-2.5 level, which indicates a deterioration in air quality. For example, in the cities of Aktobe, Atyrau and Karaganda, there was a significant increase in the concentration of PM-2.5 during the study period. In Karaganda, the PM-2.5 level reached 0.152 micrograms/m3 in 2021, which is the highest indicator in the table under consideration and indicates a significant deterioration in air quality. Aktobe also recorded an increase in the PM-2.5 level to 0.1257 micrograms/m3 in 2021. While in other cities there is a significant variability in the PM-2.5 level, which may indicate a heterogeneity of conditions and sources of pollution. Observations on specific cities:

Karaganda: Reached a maximum concentration of PM-2.5 at 0.152 micrograms/m3 in 2021, which is the highest level among all the studied cities. This confirms the deterioration of air quality and requires urgent action.

Aktobe: The PM-2.5 level increased to 0.1257 micrograms/m3 in 2021, which indicates a deterioration in the air quality situation compared to previous years.

Atyrau and Taldykorgan: In recent years, there has been an increase in the level of PM-2.5, which indicates a tendency to deterioration in air quality.

General remarks: Data for some cities are presented only for a part of the study period, which may indicate gaps in monitoring or reporting. The lack of data for a number of cities (for example, Rudny, Aksu, Kokshetau) may be caused by insufficient monitoring infrastructure or low levels of PM-2.5 pollution in these regions.

Health effects: An increase in the concentration of PM-2.5 in cities is associated with an increase in health risks, including diseases of the respiratory and cardiovascular systems. Cities with increased PM-2.5 levels need to study the sources of pollution and develop air quality management strategies.

The analysis of PM-2.5 particulate matter concentration in the period from 2015 to 2021 demonstrates ambiguous trends in air quality in various cities of Kazakhstan. In some cases, there is an alarming increase in PM-2.5 levels, in others — stability or fluctuations. This variability highlights the need for continuous monitoring, targeted research on pollution sources and the development of effective policy measures to reduce air pollution. Improving the control of PM-2.5 sources is a key aspect for improving air quality and protecting public health.

Table 2. Concentration of Particulate Matter (PM-10) in Individual Cities (Annual Average Value), mg/m³

No.	City	Years						
		2015	2016	2017	2018	2019	2020	2021
1	Astana	0,06	0,100	0,060	0,020	0,03	0,0599	0,047
2	Almaty	0,06	0,050	0,030	0,031	0,05	0,042	0,047
3	Shymkent	0,057	0,1	0,1	0,053	0,04	0,076	0,036
4	Kokshetau	-	-	-	-	0,003	0,003	0,047
5	Aktobe	0,049	0,04	0,04	0,0288	0,039	0,0208	0,098
6	Taldykorgan	-	-	-	-	0,045	0,057	0,041
7	Atyrau	0,043	0,01	0,02	0,022	0,0236	0,056	0,0083
8	Oral	0,062	0,04	0,02	0,01	0,01	0,02	0,01
9	Taraz	0,045	0,1	0,04	0,028	0,03	0,022	0,035
10	Karaganda	0,053	0,1	0,1	0,112	0,059	0,04	0,16
11	Balkhash	-	-	-	-	0,049	0,03	0,16
12	Zhezkazgan	-	-	-	-	0,018	-	0,09
13	Temirtau	-	-	-	-	0,044	0,02	0,063
14	Kostanay	-	-	-	-	0,02	0,03	0,05
15	Arkalyk	-	-	-	-	-	-	0,0146
16	Rudny	-	-	-	-	0	0	0
17	Kyzylorda	-	-	-	-	0,001	0,001	0,0142
18	Aktau	-	-	-	-	0,11	0,105	0,1
19	Pavlodar	0,039	0,016	0,006	0,0066	0,0411	0,0171	0,04
20	Aksu	-	-	-	-	-	-	0,02
21	Ekibastuz	-	-	-	-	0,0782	0	0,02
22	Petropavlovsk	-	-	-	-	0,009	0,007	0,006
23	Ust-Kamenogorsk	0	0	0,5	0,04	0,05	0,0476	0,028
24	Ridder	-	-	-	-	0,04	0,0498	0,019
25	Semey	0,021	0,024	0,02	0,033	0,016	0,0214	0,016
26	Glubokoe village	-	-	-	-	0,001	0,0183	0,028
Note — compiled with the data source stat.gov.kz								

This table 2 analyses of annual average PM-10 particulate matter concentrations, expressed in micrograms per cubic metre (μg/m³) of air, in cities from 2015 to 2021. PM-10 particles are a critical indicator of air quality, as they have a significant impact on environmental conditions and human health. These particles, being smaller than 10 micrometres, can penetrate the respiratory tract and lungs, making them an important monitoring target for assessing air pollution and its impact on public health.

A key aspect of the analysis is that cities such as Astana, Almaty, and Shymkent provide comprehensive data on PM-10 concentrations, allowing for a comprehensive study of the dynamics of air quality changes in these regions. At the same time, cities such as Kokshetau and Taldykorgan only provide data for 2019. This limitation may indicate deficiencies in monitoring or reporting systems for earlier periods, making it difficult to cinduct a comprehensive analysis of air quality changes in these locations.

Variability of PM-10 concentrations: The study found significant variability in PM-10 concentrations both within and between cities. In particular, Karaganda and Balkhash showed notable increases in PM-10

levels in 2021. Increasing PM-10 emissions are a serious environmental concern that have significant implications for both environment and human health.

Data gaps: The lack of data for a number of cities in the initial years of observation indicates that the air quality monitoring system was underdeveloped or that there was no relevant judicial practice in the country at that time. This situation highlights the need to improve the mechanisms for collecting and analyzing environmental data, which is an important condition for an objective assessment of the environmental situation and the development of effective measures to improve it.

Future direction: National cities such as Astana and Almaty show differences in PM-10 concentrations, indicating differences in air pollution control efforts and natural resource management strategies. These changes in trends underscore the need for continuous monitoring of the situation and effective measures to improve air quality.

In this regard, PM-10 concentrations are key indicators of air pollution and environmental conditions. The observed variability and trends identified in the analysis highlight the need for ongoing monitoring and development of effective air quality management strategies. The lack of early data for some cities underscores the need for consistent and comprehensive air quality monitoring systems. Addressing these issues is critical to improving air quality and protecting future public health.

The smart map (Figure 2) visually illustrates the complex relationship between urbanization and greenhouse gas emissions, showing how the two interact through different drivers and their impacts.

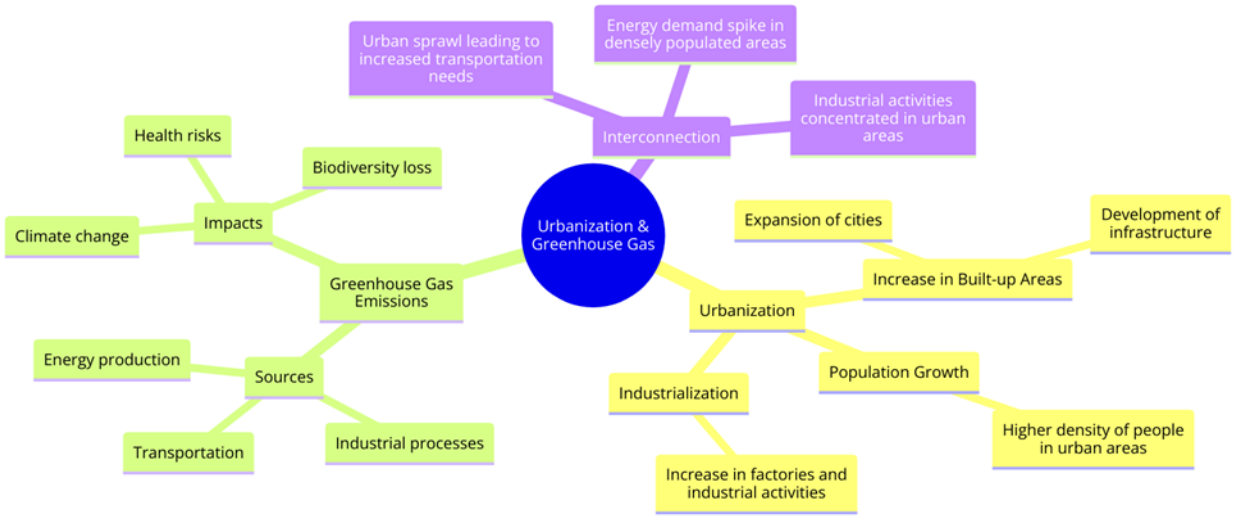

Figure 2. Mind Map of the relationship between urbanization and greenhouse gas emissions
Note —compiled with the data source of the authors

The urbanization branch marks the growth of cities provided with increase in built-up areas and subsequent development of infrastructure. Mentioned improvements cause have strong impact on emissions increase. In particular, there could be highlighted Karaganda, where inhalable particulate matter concentrations exceeded the threshold by more than 30 times in 2021. Moreover, across considered cities in the analysis there was recorded the highest level of particulate pollution observed across the studied cities. In Aktobe, there was observed a similar urban growth, and was recorded increase in inhalable particulate matter concentrations the threshold by more than 25 times. In other words, there is a significant correlation between urbanization and the increase in emissions. Therefore, without implementing and following sustainable development steps infrastructure and careful urban planning, constant growth in emissions will continue to increase along with urban expansion.

The accelerated industrialization process in Kazakhstan in 2010–2022 was accompanied by a significant increase in the number of industrial enterprises, the development of finished product production, and the intensive development of the construction sector. All these conditions for diversifying the economy and reducing dependence on raw materials significantly impacted the environment, which resulted in a sharp increase in CO2 emissions into the atmosphere. The problem is especially acute in industrial centers such as Atyrau and Karaganda, which has led to a significant excess of the maximum permissible concentrations of harmful substances and an increase in transport emissions. The increase in the content of pollutants in regions dominated by energy production and manufacturing industry leads to a deterioration in air quality, an increase in morbidity among the population, and a negative impact on the environment. In particular, there is

a big problem in some industrial regions, such as Karaganda, Temirtau, and Ust-Kamenogorsk, where the largest volume of emissions falls on industry and concentrations of pollutants exceed permissible norms.

The treemap showed that the increase in emissions in large cities, where large industrial enterprises are located, significantly affects pollution, especially in conditions of urbanized processes. In general, it can be seen that the largest volume of emissions is noticeable in megacities with a high concentration of production, transport networks, and outdated infrastructure. Generally, it is necessary to develop effective measures to reduce air pollution in large urbanized areas.

Urbanization significantly impacts greenhouse gas emissions through its links to population growth, infrastructure development, industrial activity, and transportation. The findings from Karaganda, Aktobe, Atyrau, and Almaty demonstrate that as cities grow, emissions increase due to rising energy use and industrial expansion. Without the implementation of sustainable practices, this upward trajectory in emissions is expected to persist, potentially leading to further environmental and economic consequences. The mind map provides a focused and insightful view of how these elements interact, reinforcing the need for comprehensive strategies that prioritize greener urban planning, efficient energy use, and improved transportation systems to effectively reduce emissions.

Conclusions

In this in-depth analysis of the complex relationship between urbanization and GHG emissions in Kazakhstan, we have explored the intersection of economic, social, and environmental aspects. that intricately weave the fabric of this national phenomenon. Kazakhstan's urbanization, propelled by its robust economic expansion, especially in the oil and gas sector, has contributed significantly to the increase in GHG emissions, highlighting the global problem of the intersection of urbanization processes with the challenges of environmental sustainability. The economic underpinnings of urbanization in Kazakhstan underscore a pivotal source of GHG emissions, predominantly through industrial expansion, escalated energy consumption, and transportation. While instrumental in advancing the country's development agenda, this economic dynamism paradoxically amplifies its environmental footprint. It brings to the fore the critical imperative for balancing economic growth with environmental stewardship, necessitating a strategic pivot towards sustainable development practices that are less carbon-intensive and more environmentally benign.

Social insights gleaned from the study accentuate the influential role of societal behaviors, public awareness, and policy engagement in shaping urban environmental outcomes. The burgeoning urban centers in Kazakhstan, characterized by increased mobility demands and energy consumption, mirror the societal transition towards urban living. However, they also highlight the potential of community engagement and inclusive policy-making in driving the transition towards sustainable urban ecosystems. This underscores the importance of fostering a societal ethos that is attuned to sustainable practices, from energy conservation to

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Урбанизация мен парниктік газдар шығарындылары арасындағы байланысты талдау: Қазақстан мысалы

Аңдатпа

Мақсаты: Зерттеу Қазақстандағы урбанизация мен парниктік газдар (ПГ) шығарындылары арасындағы байланысты талдайды, қала өсімінің парниктік газдар шығарындыларына әсерін зерттейді және олардың тұрақты дамуының жолдарын ұсынады.

Әдісі: Зерттеу ұлттық статистикаға негізделген және сандық деректерді талдау мен сапалы нәтижелерді біріктіретін гибридті әдісті пайдаланады. Бұл зерттеуде біз үш негізгі қадамды қамтитын алгоритмді қолдандық: (1) 2015–2021 жылдар аралығындағы әртүрлі көздерден алынған деректерді біріктіру; (2) графиктерді құру үшін деректерді визуализациялау құралдарын пайдалану; және (3) урбанизацияның ауа сапасына әсерін визуализациялау үшін ақыл-ой карталарын құру.

Нәтижелер: Біздің нәтижелеріміз көрсеткендей, Қазақстандағы урбанизация өнеркәсіптік даму, энергия тұтыну және көлік әсерінен парниктік газдар шығарындыларының ұлғаюымен тығыз байланысты. Талдау қаланың теңгерімді дамуының экологиялық, экономикалық және әлеуметтік аспектілерін есепке алудың және қоршаған ортаға әсерді азайтудың маңыздылығын көрсетеді.

Қорытынды: Зерттеу сонымен қатар стратегиялық қала құрылысын жоспарлау, жасыл инфрақұрылымды дамыту және экологиялық таза технологияларды қабылдау арқылы шығарындыларды азайту мүмкіндіктерін анықтайды. Зерттеу Қазақстандағы қала саясаты мен тәжірибесіне және дүние жүзіндегі ұқсас контексттерге ақпарат бере алатын түсініктерді ұсына отырып, тұрақты урбанизация бойынша ағымдағы пікірталасқа үлес қосады.

Кілт сөздер: Урбанизация, парниктік газдар шығарындылары, қазақстан, тұрақты даму, экономикалық факторлар, әлеуметтік факторлар, экологиялық факторлар, қала құрылысы, энергияны тұтыну, саясаттың салдары.

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Анализ взаимосвязи между урбанизацией и выбросами парниковых газов: пример Казахстана

Аннотация

Объект: В исследовании анализируется взаимосвязь между урбанизацией и выбросами парниковых газов (ПГ) в Казахстане, рассматривается влияние роста городов на выбросы ПГ и предлагаются пути их устойчивого развития.

Методы: Исследование опирается на национальную статистику и использует гибридный метод, объединяющий анализ количественных данных и качественных выводов. В данном исследовании мы использовали алгоритм, включающий три ключевых этапа: (1) агрегирование данных из различных источников за период 2015–2021 годов; (2) использование инструментов визуализации данных для построения графиков; и (3) построение mind maps для визуализации последствий урбанизации для качества воздуха.

Результаты: Наши результаты показывают, что урбанизация в Казахстане тесно связана с ростом выбросов парниковых газов, обусловленным развитием промышленности, энергопотребления и транспорта. Анализ подчеркивает важность учета экологических, экономических и социальных аспектов сбалансированного развития городов и снижения воздействия на окружающую среду.

Выводы: В исследовании также определены возможности сокращения выбросов за счет стратегического городского планирования, развития «зеленой» инфраструктуры и внедрения экологически чистых технологий. Исследование вносит вклад в текущую дискуссию об устойчивой урбанизации, предлагая идеи, которые могут быть использованы в политике и практике управления городами в Казахстане и аналогичных контекстах по всему миру.

Ключевые слова: Урбанизация, выбросы парниковых газов, Казахстан, устойчивое развитие, экономические факторы, социальные факторы, экологические факторы, городское планирование, энергопотребление, политические последствия.

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