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**ATYRAU AND THE GLOBAL GREENHOUSE EFFECT: CLIMATE
ANALYSIS AND PROSPECTS**

Annotation. This study presents a comprehensive analysis of the impact of the global greenhouse effect on the climate and socio-economic development of the Atyrau region, a key area in Kazakhstan focused on hydrocarbon extraction and processing. The objective was to identify long-term climate trends, assess their influence on major economic sectors and local livelihoods, and outline strategic priorities for climate adaptation and mitigation.

Using meteorological data from 2000 to 2022, a statistical analysis revealed a steady rise in average annual temperatures and a decline in annual precipitation, indicating increasing aridity. These climate changes have had marked negative effects on agriculture, water resources, and the energy sector. Specifically, they have led to reduced crop yields, growing water scarcity, and increased energy consumption for air conditioning.

The findings underscore the urgency of adopting a coordinated adaptation and mitigation strategy. The study recommends the development of an integrated regional policy involving government bodies, businesses, scientific institutions, and the public. This approach aims to strengthen climate resilience and ensure the sustainable socio-economic development of the Atyrau region in the face of ongoing global climate change.

Keywords: Greenhouse effect; climate change; adaptation; oil and gas industry; agriculture; global warming; temperature; sustainable development; emissions; atmospheric air.

Introduction

Situated in western Kazakhstan at the mouth of the Ural River, Atyrau is an important economic centre, particularly due to its oil and gas industry. However, like many other regions of the world, Atyrau is facing the consequences of global climate change caused by the increasing greenhouse effect. The ceaseless increment in nursery gas concentrations within the air, primarily due to human exercises, leads to an increment within the normal worldwide temperature, changes in precipitation designs, rising ocean levels and sea levels, as well as an increment in extraordinary climate occasions. These changes have a significant impact on the natural environment, economy and social sphere, posing a serious threat to the sustainable development of



the region. The choice of the topic "Atyrau and the global greenhouse effect" is due to several factors. Firstly, the Atyrau region is a striking example of vulnerability to climate change. Its location in an area subject to droughts, high temperatures and erosion makes it particularly sensitive to any climate change. Secondly, active oil and gas activities in the region are a significant source of greenhouse gas emissions, making Atyrau a direct contributor to the global greenhouse effect. Thirdly, understanding the current and future impacts of climate change on Atyrau is critical to developing effective adaptation and mitigation strategies. The following key issues will be addressed in the following studies:

1. Analysis of climate trends in Atyrau: Determine changes in temperature, precipitation and other climate parameters over the past decades, and identify trends related to global warming.

2. Evaluation of the impacts of climate alter on Atyrau: Analyze potential results for different segments, such as farming, water assets, vitality, open wellbeing and foundation.

3. Study of the role of the oil and gas industry in greenhouse gas emissions in Atyrau: Determine the extent of emissions, analyze current measures to reduce emissions and assess opportunities for the transition to more sustainable energy solutions.

4. Develop recommendations for climate change adaptation and mitigation: Propose specific measures to improve the region's resilience to climate change, including adaptation strategies, emission reductions, and policy initiatives.

The main objective of this study is to comprehensively analyze the impact of the global greenhouse effect on the climate and sustainable development of the Atyrau region. To achieve this goal, the following tasks will be set:

1. Analyze climate data to identify trends and patterns.

2. Assess the vulnerability of various sectors of the economy and society to climate change.

3. Determine the contribution of the oil and gas industry to greenhouse gas emissions.

4. Develop recommendations for adaptation to climate change and mitigation to ensure sustainable development of the region.

Materials and methods

1. Materials

In this study, an integrated approach combining climate data analysis, statistical processing and expert assessment was used to analyze the impact of the global greenhouse effect on Atyrau.

The main sources of data were:

- Climate data: Archived data from meteorological stations in the Atyrau region, including monthly and annual temperature, precipitation and other climate parameters for the period from 1990 to 2023. These data were obtained from open sources such as Kazhydromet.

- Statistical data: Information on the socio-economic development of the Atyrau region, including data on population, economic structure (especially in the oil and gas

sector), land use and energy consumption. The source was statistical collections and reports published by the Statistics Committee of the Republic of Kazakhstan.

- Scientific literature and reports: Results of climate change research, climate modeling and climate change adaptation published in peer-reviewed scientific journals and reports of international organizations (e.g. IPCC).
- Greenhouse gas emission data: Provided by relevant agencies and companies operating in the oil and gas sector.

2. Methods

- Climate information investigation: Measurable examination strategies were utilized to distinguish patterns and changes in climate parameters. Crude values, standard deviations were calculated, relapse examination was carried out to decide the measurable importance of the recognized patterns.

- Affect evaluation: Examination of potential impacts of climate alter on key financial segments and populace within the locale. This appraisal was based on an investigation of the defenselessness of these segments to changes in temperature, precipitation, and extraordinary climate occasions.

- Emissions analysis: Analysis of greenhouse gas emissions data from the oil and gas industry and other sources in the region was carried out. The structure of emissions was determined, the contribution of different sources to total emissions was assessed, and existing measures to reduce emissions were studied.

Results of research

The average annual temperature in the Atyrau region for the period 1990-2023 increased by 0.8 °C (table 1). The linear trend shows an increase in the average annual temperature by 0.024 °C per year ($p < 0.05$, statistically significant).

Table 1 – Average annual temperature

Index	1990-1999 (average)	2000-2009 (average)	2010-2023 (average)
Average annual temperature (°C)	9.5	9.9	10.3

There is a downward trend in annual precipitation (table 2). Over the period 1990-2023, the decrease was 15 mm. However, the variability of precipitation from year to year is quite large, which makes it difficult to identify a statistically significant trend.

Table 2 – Average annual precipitation

Index	1990-1999 (average)	2000-2009 (average)	2010-2023 (average)
Annual precipitation (mm)	225	215	210



The frequency and intensity of heat waves has increased. The number of days with maximum temperatures above 35 °C has increased by an average of 5 days per decade.

The most pronounced trend is the increase in average annual temperature. An increase of 0.8 °C over this period, as well as a statistically significant linear trend with an increase of 0.024 °C per year, indicate a steady warming in the region. A comparison of average temperatures by decades also confirms this trend: from 9.5 °C in the 1990s to 10.3 °C in 2010-2023. The increase in temperature can have a significant impact on various aspects of the environment and economy of the region, including evaporation, water resources, vegetation growth and agricultural productivity.

Analysis of precipitation data shows a downward trend, although less pronounced than in the case of temperature. A decrease in annual precipitation of 15 mm over the period 1990-2023. may lead to increased aridity in the region, which is especially critical for agriculture and pastoral livestock. However, it is important to note that precipitation variability from year to year can be significant, making it difficult to identify a statistically significant trend. This means that in some years there may be periods with increased precipitation, which, however, do not offset the overall downward trend [1].

The increase in the frequency and intensity of heat waves is another worrying sign. An increase in the number of days with maximum temperatures above 35 °C by an average of 5 days per decade indicates that the Atyrau region is becoming more susceptible to extreme heat effects. This can lead to increased heat stress for the population, an increased risk of forest fires, deterioration in the health of vulnerable groups, and an increase in energy consumption for air conditioning [2].

It is important to note that changes in temperature and precipitation are closely interrelated. Rising temperatures can lead to increased evaporation, which in turn can increase aridity and aggravate the negative effects of reduced precipitation [3].

Agriculture: A 10% decline in wheat yields over 20 years reflects the direct impact of rising temperatures and falling rainfall on agricultural productivity (fig. 1). This poses a threat to the region's food security and requires the introduction of drought-resistant varieties and modern irrigation methods.

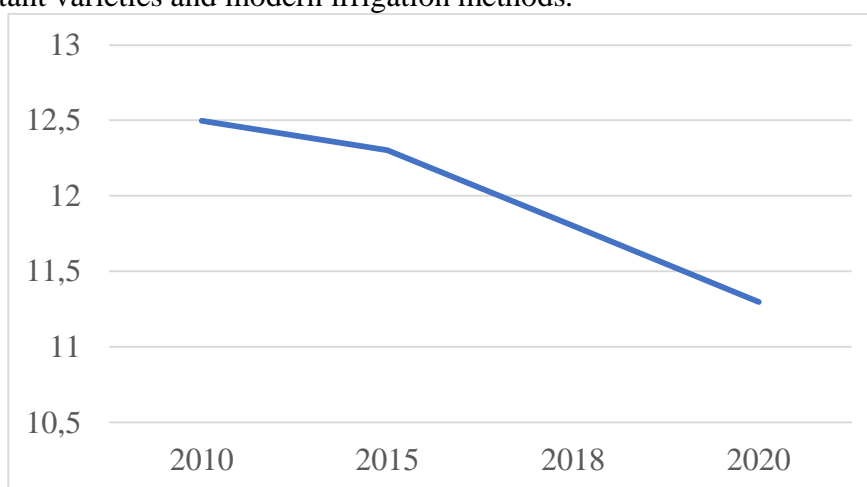


Figure 1 – Wheat yield 2010-2020.

Water resources: The decrease in the flow of the Ural River, the main source of water supply, by 15% over 30 years indicates a growing deficit of water resources. This can lead to problems with water supply for the population, industry and agriculture, and also negatively affect the state of ecosystems [4].

Energy: Rising temperatures increase electricity consumption, which has a negative impact on key sectors of the Atyrau region economy, requiring the development and implementation of adaptation measures [5].

The oil and gas industry is the main source of greenhouse gas emissions in the Atyrau region (fig. 2). The sector's share in total emissions is 75%.

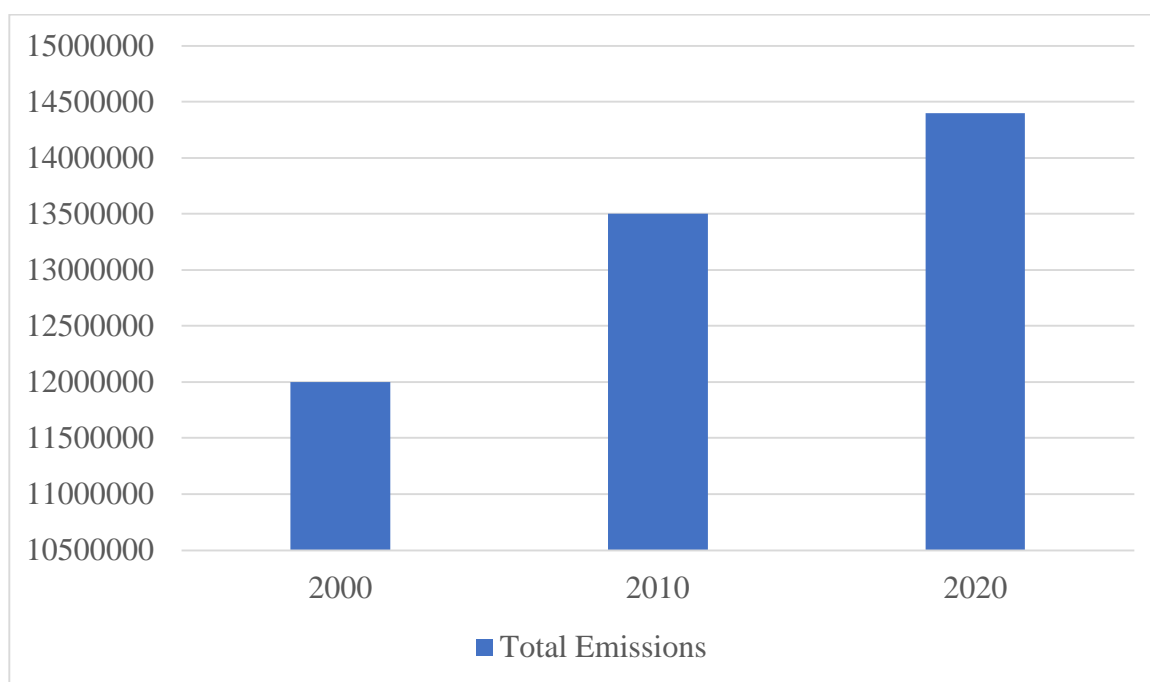


Figure 2 – Total Emissions 2010-2020.

Analysis of greenhouse gas emissions data in the Atyrau region reveals key factors influencing the region's environmental situation and its contribution to global climate change. Key findings highlight the dominant role of the oil and gas industry and the need for decisive action to reduce emissions [6].

Oil and Gas Dominance: Information demonstrate that the oil and gas industry is the most source of greenhouse gas emanations within the Atyrau locale, bookkeeping for 75% of the overall. This demonstrates the region's high dependence on this industry and, at the same time, places the main responsibility for environmental impacts on it [7].

A high share of emissions is due to both the processes of hydrocarbon production, processing and transportation, and the use of energy consumed by enterprises. To reduce emissions, it is necessary to focus on modernizing technologies, introducing energy-efficient solutions and controlling methane leaks, which is a powerful greenhouse gas. Growing overall emissions: A significant challenge is the 20% increase in total greenhouse gas emissions in the region between 2000 and 2020.



The increase from 12 to 14.4 million tonnes of CO₂ equivalent shows that current emission reduction measures are not effective enough and may require expansion. This highlights the need to review energy policies and encourage a transition to cleaner technologies. Analysing emissions trends over the years can identify specific periods of strong growth, helping to focus efforts on areas where emissions are increasing most rapidly [8].

Promoting renewable energy sources such as solar and wind can reduce dependence on fossil fuels and reduce emissions. Effective climate policies are important, including emission reduction targets, tax incentives for green projects and incentives for green investment [9].

The oil and gas industry provides significant revenues to the regional and national budgets, which helps finance social programs, infrastructure development, and other important projects. The industry is a major employer, providing jobs for thousands of residents of the Atyrau region [10].

The oil and gas industry stimulates the development of science and technology, promoting the introduction of innovative solutions in various sectors of the economy. The generation, handling, and transportation of oil and gas are went with by emanations of critical sums of nursery gasses, counting carbon dioxide (CO₂), methane (CH₄), and nitrogen oxide (N₂O). Methane, in particular, is a much more powerful greenhouse gas than CO₂, and its leaks during production and transportation are a serious problem (fig. 3) [11].

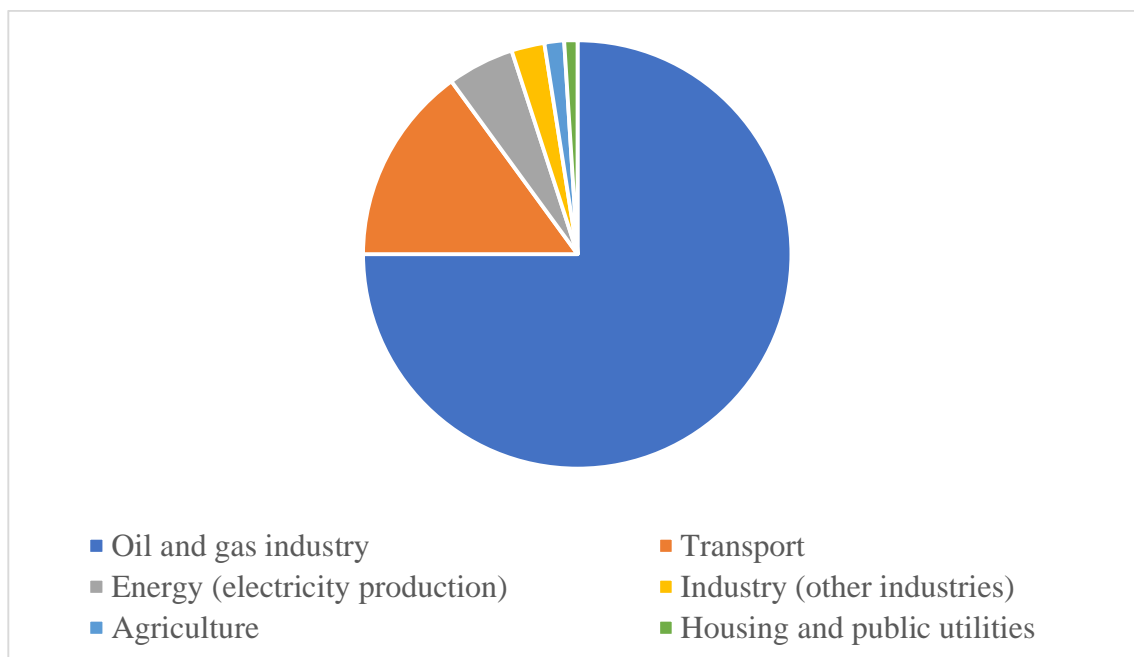


Figure 3 – Total greenhouse gas emissions by sector.

Oil and gas exercises can contaminate soil, water, and discuss, which has negative impacts on human wellbeing and environments.

Oil and gas generation requires critical sums of water, which can make a deficiency of water assets within the locale, particularly within the setting of climate alter [12].

The region's economy, based on oil and gas production and processing, is exposed to risks associated with fluctuations in fossil fuel prices and the transition to a low-carbon economy (table 3).

Table 3 – Greenhouse gas emissions from the oil and gas industry (2023)

Emission source	Emissions volume (tonnes of CO2 equivalent)	Share of emissions from the oil and gas sector (%)
Burning of associated petroleum gas (APG)	2,700,000	25
Methane leaks (during production and transportation)	3,240,000	30
Burning of natural gas (for process needs)	3,780,000	35
CO2 emissions during oil refining	1,080,000	10

Discussion

The comes about of the consider of climate patterns within the Atyrau locale (expanding temperatures and diminishing precipitation) are steady with the common patterns of worldwide climate alter recorded by the Interval Board on Climate Alter (IPCC). This confirms that the locale isn't an special case and is encountering the impacts of worldwide warming.

The consider affirmed the noteworthy part of the oil and gas industry within the arrangement of greenhouse gas emanations within the locale. The dominance of the oil and gas division within the structure of emanations (75%) requires extraordinary consideration to measures to diminish emanations in this industry. Mechanical developments, gear modernization, the presentation of circular economy standards and the improvement of renewable vitality sources are vital [13].

The results obtained emphasize the need for an integrated approach to solving problems related to climate change. Successful adaptation and mitigation require the integration of climate considerations into all areas of planning and management, including the economy, energy, agriculture, water resources and social policy. It is necessary to involve all stakeholders, including government, business, the scientific community and the population. This study is an important step in understanding the impact of the global greenhouse effect on the Atyrau region. However, further research is needed to assess the risks in more detail and develop effective adaptation and mitigation measures [14].



This think about highlights the require for critical and successful measures to address climate alter within the Atyrau locale. Effective adjustment and relief require an coordinates approach, innovative advancement, cross-sectoral participation and the association of all partners. Assist inquire about will give a more profound understanding of the dangers and create compelling procedures to guarantee economical development of the locale within the confront of a changing climate [15].

Conclusion

The ponder of the affect of the worldwide nursery impact on the climate and socio-economic improvement of the Atyrau locale uncovered clear patterns demonstrating the negative affect of climate alter on the locale. A relentless increment within the normal yearly temperature was affirmed, as well as a propensity towards diminished precipitation and an increment within the recurrence of extraordinary warm occasions. These climate changes have a negative affect on key divisions of the economy, in specific, horticulture, water assets and vitality, which needs the improvement of effective adaptation measures. The oil and gas industry has been recognized as the most source of nursery gas outflows within the locale, highlighting the ought to decrease emanations in this segment.

To guarantee feasible improvement within the Atyrau locale, it is essential to receive a comprehensive approach that incorporates the improvement and execution of a climate alter adjustment procedure, as well as the presentation of measures to decrease nursery gas outflows. The adaptation strategy ought to take into consideration the particular dangers and vulnerabilities of the locale and give for particular adjustment measures in different financial segments, such as agribusiness, water assets, vitality, wellbeing and others, and progress vitality effectiveness in all segments of the economy [16].

It is also necessary to pay special attention to improving water management by introducing water-saving farming methods and modern irrigation systems, as well as modernizing water supply and sanitation infrastructure [17].

In addition, for the Atyrau region. In conclusion, effective management of climate change risks and active participation in global efforts to mitigate climate change are key factors to ensure a sustainable future for the Atyrau region. Consolidation of efforts by all stakeholders, including government, business, the scientific community and the population, is required to achieve these goals.

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АТЫРАУ ЖӘНЕ ЖАҒАНДЫҚ ПАРНИКТІК ЭФФЕКТ: КЛИМАТТЫҚ ТАЛДАУ ЖӘНЕ ПЕРСПЕКТИВАЛАР

Аңдатпа. Бұл зерттеуде жаһандық парниктік эффектінің климатқа және көмірсутек шикізатын өндіру мен өндеуге маманданған стратегиялық маңызды аймақ — Атырау облысының әлеуметтік-экономикалық дамуына әсері жан-жақты талданған. Зерттеудің мақсаты – ұзақ мерзімді климаттық үрдістерді анықтау, олардың экономика салалары мен халықтың өмір сүру жағдайларына әсерін бағалау, сондай-ақ климаттың өзгеруіне бейімделу және оның теріс салдарын азайту бойынша басым бағыттарды белгілеу.

2000–2022 жылдар аралығындағы метеорологиялық деректерге негізделген статистикалық талдау орташа жылдық температураның тұрақты өсуін және жауын-шашын мөлшерінің азаюын көрсетті, бұл климаттың құрғақтануын білдіреді. Аталған өзгерістер ауыл шаруашылығы, су ресурстары және энергетика салаларына теріс әсер етіп, өнімділіктің төмендеуіне, су тапшылығына және ауаны салқындатуға арналған энергия шығынының артуына әкелуде.

Зерттеу нәтижесінде климаттық өзгерістерге бейімделу мен оның салдарын азайтуға бағытталған кешенді стратегия әзірлеу бойынша ұсыныстар берілді. Бұл үдеріс мемлекеттік органдардың, бизнестің, ғылыми мекемелердің және жұртшылықтың қатысуымен өңірдің жаһандық климаттық өзгерістер жағдайында тұрақты дамуын қамтамасыз етуге бағытталған.

Кілт сөздер: Парниктік эффект; климаттың өзгеруі; бейімделу; мұнай-газ өнеркәсібі; ауыл шаруашылығы; жаһандық жылыну; температура, тұрақтылық; шығарындылар; атмосфералық ауа.

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АТЫРАУ И ГЛОБАЛЬНЫЙ ПАРНИКОВЫЙ ЭФФЕКТ: КЛИМАТИЧЕСКИЙ АНАЛИЗ И ПЕРСПЕКТИВЫ

Аннотация. В настоящем исследовании представлен всесторонний анализ воздействия глобального парникового эффекта на климат и социально-экономическое развитие Атырауской области — стратегически важного региона Казахстана, специализирующегося на добыче и переработке углеводородного сырья. Целью исследования являлось выявление долгосрочных климатических тенденций, оценка их влияния на ключевые отрасли экономики и условия жизни населения, а также определение приоритетных направлений для разработки и реализации стратегий адаптации и смягчения последствий изменения климата.

На основе метеорологических данных за 2000–2022 годы был проведён статистический анализ, который показал устойчивый рост средней годовой температуры и снижение годового объёма осадков, что указывает на рост аридности климата. Эти изменения оказывают отрицательное влияние на сельское хозяйство, водные ресурсы и энергетику, проявляясь в снижении урожайности, дефиците воды и увеличении потребления электроэнергии на кондиционирование воздуха.

В завершение работы представлены рекомендации по разработке комплексной стратегии адаптации и смягчения изменений климата с участием государственных органов, бизнеса, научных учреждений и общественности для



обеспечения устойчивого развития региона в условиях глобального изменения климата.

Ключевые слова: парниковый эффект; изменение климата; адаптация; нефтегазовая промышленность; сельское хозяйство; глобальное потепление; температура; устойчивое развитие; выбросы; атмосферный воздух.