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Reduction of atmosphere pollution as basis of a regional circular economy: Evidence from Kazakhstan

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Highlights

- Atmospheric emissions in the northern industrial sector account for 95.8%, in the rest agricultural sector - 4.2% of all air pollutants.
- analyzing KPO impact on the regional development made it possible to build a matrix of the regional circular economy potential
- proposed meso-model of a circular economy based on KPO, according to forecasts can significantly (2 times) reduce the amount of air pollution in the region.

Abstract: Reducing atmospheric emissions through the introduction of circular economy principles is one of the current tasks of sustainable regional development. The research purpose is to study the impact of the actions taken by Karachaganak Petroleum Operating B.V. (KPO) in order to reduce air pollution, and basing on it, to evaluate the forming potential of the circulating economy in one of the biggest regions of Kazakhstan in which KPO is operating. Oil and gas production activities of the company is related to air pollution of the region. The study was conducted using methods of econometric modeling, statistical and comparative analyses. The study's value is determined by its interdisciplinary approach, which made it possible to combine environmental and economic criteria for sustainable regional development with the features of emissions and waste management technologies in industry. Studying the work experience and analyzing the impact of KPO on the development of the region in the period 2012-2022 made it possible to construct a matrix of the restorative potential of the circular economy of the region. A model for the formation of a circular economy is proposed, which is based on the introduction of innovations, investments in environmental protection, the use of the best available technologies for reinjecting gas into the reservoir, increasing energy efficiency, recycling of waste, which made it possible to significantly (2.2 times) reduce the amount of air pollution in region. According to the forecast model (2024-2028), it was determined that in case of maintaining independent indicators' certain dynamic of development, the level of atmospheric emissions by KPO could be reduced by 2 times. The results of the scientific work contain statements proving that further researches on the problems of reducing atmospheric pollution within the framework of the formation of a circular economy are quite perspective and promising. The results of the study might be interesting and used when implementing measures to manage air quality in the region by managers, heads of organizations, state and local authorities, and researchers interested in promoting the ESG concept of sustainable development.

Keywords: air pollution; circular economy; emissions reduction; waste recycling; ESG strategy

1. Introduction

The air pollution issue is not only becoming actively discussed, but also an issue on the daily agenda of every person and state. Climate change is accelerating the depletion of natural resources, as production and consumption amid ongoing pollution require more energy and materials. As a result, this impedes economic development, degrades the environment, has harmful effects on human health and increases regional imbalances. Air pollution is receiving special attention in the reports of the UN, the World Bank, the OECD, foreign scientists' research. According to the UN, air pollution is recognized as the most important environmental contributor to the global burden of diseases, causing millions of premature deaths and large economic losses every year. Over the past 15 years, there has been a deterioration in the air quality that more than 50% of the world's population breathes (Asrar G.R. et al,2019). The OECD estimates that global economic losses due to premature mortality caused by air pollution from fine particulate matter (PM) and ground-level ozone exceed US$1.7 trillion per year, equivalent to approximately 3.5% of global GDP (Bobylev S.N.,et al,2022). Kazakhstan is no exception. The unsustainable raw material export model of the economy that has formed in Kazakhstan leads to significant socio-ecological and economic losses, manifested in high environmental pollution and detrimental to public health (AQCA,2023).

To keep temperature growth below 1.5-2°C (Ndivhuho Tshikovhi, et al, 2023), reducing emissions of carbon dioxide and other greenhouse gases into the atmosphere by 45% by 2030 compared to 2010 levels is a key focus of international efforts to combat global warming (Friedlingstein P., et al, 2022, Safonov G.,et al, 2022, IPCC Special Report,2018). This economic transformation is becoming more and more obvious in the world in relation to climate policy. A decrease in greenhouse gas emissions correlates with a decrease in the concentration of other pollutants in the air (PM, SO2, NOx, volatile organic substances, etc.) (Jailaybekov,Y.,et al, 2022). In this context, leading countries, with a 25% share of global GDP, have established legal obligations to achieve net-zero emissions targets[1]. Kazakhstan has also committed, as part of the Paris Agreement implementation, to reduce greenhouse gas emissions by 15% (an unconditional goal) and up to 25% (under certain conditions) by 2030 compared to the level of 1990 base year. Kazakhstan intends reducing GDP energy intensity by 50% by 2050 (Adilet.zan.kz, 2023). For achieving this goal, it is essential to reduce and optimize domestically use of carbon-intensive materials.

Thus, transition to the country's sustainable development can be achieved by introducing the circular economy principles, which sets itself the task of minimizing waste and optimizing the use of resources (Adilet.zan.kz, 2013, 2021). Unlike the traditional "mining-manufacturing-disposal" industrial model, the circular economy is inherently restorative and regenerative, based on systemic innovation. It can be achieved by implementing strategies to reduce the primary materials use, improve the inventories use efficiency and reduce production waste. New economic models are used both in scientific works and in the priorities of economic management of many states and private businesses. The programs for the development of the green economy, circular economy, and bioeconomy for 2030–2050 were adopted by the European Community (EEAR,2013). Simultaneously, the situation in the global economy requires accelerating the implementation of circularity principles due to declining resources and climate change. The UN has defined sustainable development as a circular economy model (Circle Economy and Shifting Paradigms,2019). Basing on the data of Circle Economy, the global economy's circularity rate was only 8.6% in 2020 (Eurostat, 2021). At the same time, there is only limited information about this in Kazakhstan (Zlatev,V., et al,2021, Wang Qing,et al,2021) particularly:an information about practical implementation of the circular economy and its impact on the socio-economic or environmental state of the country (Report-Circular-Economy-Almaty, 2019, TleppayevA., Zeinolla, S., 2021). In shaping the economy of Kazakhstan, as well as other Central Asian countries focused on extraction of fossil resources, an important role is played by the activities of international companies in the exploration, extraction and processing of fossil, which can bring modern technologies and approaches to waste management, resources and production processes and, in general, to introduce sustainable development practices.

For the particular research, in order to introduce circular economy principles, the West Kazakhstan region (WKR) was chosen, which is of interest due to its favorable geographical location, high resource potential and status as a developed industrial-agrarian region of the country (Adambekova A., et al, 2024). The company Karachaganak Petroleum Operating B.V. (KPO) operates

[1] https://adilet.zan/kz/rusdocs/U230000123 293

in the region on the basis of Karachaganak oil and gas condensate field - the world's largest and most complex (from a technical point of view). This field accounts for 97% of the gas condensate production volume and 37% of the gas production volume in the republic. Oil refining, engineering, shipbuilding, food production and construction industries are developing in the region. The region's agriculture specializes in the production of meat and grain. Each of the developed industries in the region leaves its own ecological footprint, expressed in emissions of greenhouse gases and pollutants into the atmosphere (Brodny,J., Tutak,M., 2021), energy and natural resources consumption.

Most region's economy sectors suffer from overuse of natural resources, energy over consumption, inefficient agricultural practices, problems of food security. In addition, it has to mentioned about poor condition of the road infrastructure (only 39% of roads are in satisfactory condition), high wear and tear of power lines and substations of JSC "West Kazakhstan Regional Electric Energy Company" - 85%, heat supply networks - 50.4%, water supply networks - 60.5%, sewer networks - 61.3%, low level of waste recycling (11%). All this leads to pollution of all environment components, and first of all, atmospheric air. It should be noted that the target environmental quality indicators for the WKR for 2019-2025, established in the Comprehensive Development Plan for the region, consist of reduction of pollutants emissions (Popkova,E., Sergi,B.,2023) into the atmosphere, control of the surface water quality, the introduction of separate collection and waste disposal, as well as other measures[2]. Despite all of this, it has been established that all these indicators are determined without reference to the goal of forming circular economy, as well as not taking into account the goals of a region's balanced development, the current state of the industrial sector and its influence on the region. Reducing emissions and air pollution are key factors for minimizing the anthropogenic impact of KPO on the region. The main investments of both the companies themselves and the governments of many countries are made in this direction. The main governmental and public (civil) regulators are aimed at monitoring and supporting measures to fight air pollution. The results of implemented measures are assessed using various tools and methods.

In this study, an integral criterion is used, which can be used as a tool for assessing both the effectiveness of the implemented measures and the commitment of economic entities to reduce emissions. In particular, it is a relative indicator of the main pollutants for unit of GDP, per capita, are widely used in the world to assess the degree of anthropogenic load on the atmospheric air as a whole (https://unece.org/fileadmin/DAM/stats/documents). With this, absolute emissions values will also be collected and systematized.

The purpose of the research is to study the conditions for reducing air pollution that contribute to the circular economy formation in one of the largest industrial-agrarian regions of Kazakhstan.

2. Material and Methods

2.1. Research Methodology

The research methodology was built taking into account a comprehensive analysis of representative material characterizing the present state of the atmospheric air pollution problem knowledge, assessing the facts' significance, logical conclusions and practical recommendations. The methodology for implementing this study is based on solving the following tasks, for which the stages are defined:

- identification of the WKR's economy sectors and factors that have the greatest impact on air quality;
- data collection on the environmental state of the WKR and the impact of KPO on the region;
- study and assessment of KPO's strategies to implement measures for air pollution reduction;
- using KPO as an example propose the model for the circular economy formation;

[2] https://www.adilet.zan.kz/rus/docs/P2200000040

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- development of recommendations for the application of basic approaches to the concentration of resources, tools and methods for the circularization of economic relations based on KPO, contributing to the reduction of atmospheric pollution.

2.2. Information Database

As the information base for the study there were used atmospheric air pollution data, which were taken from annual information bulletins on the state of Kazakhstan's and West Kazakhstan Region's environment for the period 2012-2022 (https://www.kazhydromet.kz/ru, https://stat.gov.kz), as well as KPO's sustainability and tax data (https://www.kpo.kz, https://www.zoominfo.com). The peculiarity of this study methodology is that when establishing independent variables, the specifics of organizational and legal activities of KPO were identified. The literature review showed that, as a rule, for industrial companies, in addition to production volume in physical terms, the revenue value is used as a factor that accumulates various risks (currency, inflation, interest, credit, etc.). The KPO specificity is that it is legally organized as a consortium on the condition of production division between five participants: Eni (29.25%), Shell (29.25%), Chevron (18%), LUKOIL "(13.5%), NC Kazmunaigas (10%) (https://www.kpo.kz). In turn, this explains the specifics of the formation of KPO's financial results: each consortium participant reflects its results in its own consolidated statements. In addition, oil and gas condensate is a certain product from a complex of a high-boiling hydrocarbons, released from natural gases during their production. As an indicator, the volume of oil and gas condensate may include different fractions of the initial product, for example, stable and unstable liquid hydrocarbons, as well as raw gas and others. In this regard, it does not seem correct to determine the estimated cost of the extracted oil and gas condensate, since each of the components has its own price. For example, if the price for 1000 m^3 of gas varies around $300-450 (https://index.minfin.com.ua/markets/gas/ttf/), then the price of oil, depending on the type, reaches $70-85 (https://index.minfin.com.ua/markets/oil/). Taking these two conditions into account, the volume of oil and gas condensate production in natural terms is used as one of the independent variables.

The sustainable development ideas spread and decarbonization of production contributed to the environmental regulation development, which affected the transformation of not only production technologies, but also business and government management. The study identified the main factors that determine the progressive movement towards reducing harmful emissions into the atmosphere and waste using the example of the KPO case. An assessment of the correlation between pollutants emissions into the atmosphere and other independent indicators was carried out through the R program and made it possible to characterize the region's potential for sustainable development within the relations' circularization in the economy.

2.3. Literature Review

Achieving sustainable development goals (SDGs) through the implementation of a systematic approach to managing the regional resource potential is one of the urgent tasks in regional management. To achieve success in implementing this task in Kazakhstan, comprehensive interaction between government agencies, business representatives and the population is necessary. The main studies on the circular economy issues, adapted from the Kazakh experience, are devoted to arguing the circular economy theory applicability to the Kazakhstan's economy (TleppayevA., Zeinolla S., 2021), assessment of the stakeholders preparedness to create a circular economy in Kazakhstan (Zhidebekkyzy A.,et al, 2023). In this context, the mapping method, which allows the integration of multiple data sources covering different measurement scales, deserves special attention. To make decisions on improving management strategies, Paretti and co-authors proposed mapping and classifying activities along with their associated energy/resource consumption (Paretti et al,2019). Pearson, Rzotskevich and others highlight the discrepancies between resource consumption and availability, attributing them to the region's geographic features, which change over time. For long-term planning in regions expose climate and social change, they say it is critical to update integrated maps with reliable information (Pearson L., et al,2017). Bailey, Drake and others in integrated

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mapping emphasize the need to integrate different data sources at various scales, despite the challenges associated with data collection and adaptation, to identify key areas of resource use. To assess environmental impacts, the resulting maps of the spatial footprint of human activity can then be combined with remote sensing data (BaileyM.,et al,2020). Similarly, Song, Dai, and others propose an aggregated downscaling model that integrates large-scale spatial data sets such as population density, GDP, and urban development to map waste stocks in China. Its significance lies in the potential for business solutions for improving resource efficiency, management of waste and sustainability of environment at the regional or urban level (SongL.,et al, 2021).

Within the framework of the goal set in the study and the stated hypotheses, in order to establish the potential for the development of a circular economy, dependent variables were identified - Y1 – atmospheric emissions of main pollutants per unit of GDP and Y2 - per living population. Data collection and dynamics analysis of these indicators will either justify the choice of one of these dependent variables, or build a model to establish the dependence level for each dependent variable.

Studying various analytical reviews, researches and annual reports on KPO’s sustainable development for 10 years revealed the following. The KPO industrial complex operation is inevitably associated with the pollutants release into the atmosphere. Pollutants are formed at all stages of the technological cycle: production, preparation, storage, transportation of gas and condensate. Each of these stages results in the oil and gas condensate production volume (https://www.kpo.kz/en/sustainability). Reducing emissions, recycling waste and using new technologies remain being the most important issues in the company's development strategy, which also depend on the production level. This allows us to determine X1, the volume of production, as an independent variable.

The European Environment Agency's Report on the review of the main directions of EU environmental policy notes the role of the best available mining technologies’ introduction in the global economy decarbonization (*Hoerber*,T.,et al,2021, EEAR, 2022). In this regard, reducing the gas flaring volume, and therefore reducing atmospheric emissions, looks like one of the key obligations for the world's oil producing companies. Gas flaring accounts for nearly half of the world's oil companies’ emissions. During 2012-2022, KPO, through the best available technologies implementation, ensured a reduction in this share from 50 to 30%. Particularly noteworthy in this regard is the technology of high-pressure gas reinjection, which can significantly reduce the gas flaring volume from the total gas produced volume (https://www.kpo.kz/en/sustainability, EEAR, 2022). The following criteria have been defined to demonstrate the best available technologies implementation: independent (inverse) variable X2 - volume of gas flared, million m^3 and X3 - volume of gas injected into the reservoir, billion m^3.

The oil and gas industry’s specifics are studied in various researches, which note that hazardous production waste, as well as places of their storage and burial, if handled unsafely, can pose a danger to the environment and be a reason of pollution of atmospheric air, ground and surface waters, soils and vegetation (D’Amato,D., et al,2022,Nyashina, G.,et al,2018). Within the framework of the “green” economy the development of municipal solid waste recycling not only helps to reduce atmospheric emissions, but also creates conditions for the transition to sustainable and resource-saving production and consumption and is crucial step in a journey that led to a circular economy creating. At KPO facilities, the discharge of wastewater into the environment is excluded, since purified wastewater is discharged into isolated storage ponds for further usage. Recycling of KPO production and consumption wastes at waste-disposal facilities of the complex, ensuring economical and environmentally friendly disposal and processing of drilling waste and liquids is considered as the best practice for drilling waste management in the West Kazakhstan. Drilling waste is processed using technologies that reduce the waste's volume and hazardousness, as well as recover components from the waste for reuse. Thus, as a result of burning non-recyclable residues in the furnace, the amount of waste is reduced by 89%. After sorting, solid household waste is transferred to third-party organizations for processing (https://www.kpo.kz/en/sustainability). The study dictated the need to select X4 as the next independent variable – the volume of processed production waste, in tons.

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A significant number of researches are devoted to studies on the environmental protection measures' effectiveness. Research is dedicated to both the explore of the role, types and impact of investments in environmental protection on the achievement of SDGs (TurbinaK., YurgensI., red.2022), as well as factors limiting this process (Browder G. et al.,2018). In addition, many analytical reviews examine aspects of ensuring environmental safety, improving environmental protection methods and technologies, rational environmental management and maintaining the level of compliance with international standards (The World Bank Group,2021). This made it possible to justify the choice of the next independent variable: X5 – environmental protection costs, million dollars.

Expanding approaches to the study of resource potential for the region's circularization economy, one can note a study devoted to the development of a resource supply map for the WKR, which combines ESG criteria. The scientific work's results contain proven arguments for the prospects of further research on the constructing integrated resource provision maps for Kazakhstan's regions (Adambekova A., et al, 2024).

Energy and environmental issues are closely interrelated because it is virtually impossible to produce, transport, or consume energy without severely impacting the environment. Many studies highlight that environmental problems squarely linked to production and consumption of energy are manifested in pollution of air, water and soil. The main cause of air pollution emissions in cities tightly connect with the combustion of fossil fuels. (https://www.eionet.europa.eu/gemet/ru/concept). Increasing energy efficiency helps reduce air emissions. This made it possible to justify the choice of the following independent variable X6 - energy consumption, in Petajoules (PJ).

The specificity and severity of the environmental situation has a distinct regional feature and is mostly measured by the natural process's characteristics. In this sense, when assessing air pollution, instead of individual meteorological elements, it is advised to use complex of specific meteorological situation and conditions specifications (Morozov,A., Starodubtseva,N., 2020). Meteorological factors, due to their diversity and complex nature of impact, require a separate study that is beyond the scope of this publication.

The literature review conducted was aimed at identifying and substantiating the dependent and independent variables necessary to establish the main factors contributing to unlocking WKR's potential being a region that complies with the circular economy principles. In sustainable development of WKR, rich with natural resources, the circular economy principles' introduction could be an effective solution for reducing atmospheric emissions, decarbonization and sustainable use of resources.

3. Results and Discussion

3.1. Identification of WKR's Economy Sectors and Factors That Impact on Air Quality

Identification of the main features and determination of approaches taking into account industry specifics allows us to clarify the potential of the WKR's regional economy to effectively create conditions for the transition to a circular type of its organization. Systematization of the findings made it possible to construct the following diagram, reflecting the main features of the circular economy's manifestation. On WKR's territory there are industrial and non-industrial economic entities (two poles), which must consider when unlocking the opportunities for the region's economy circularization (Figure 1).

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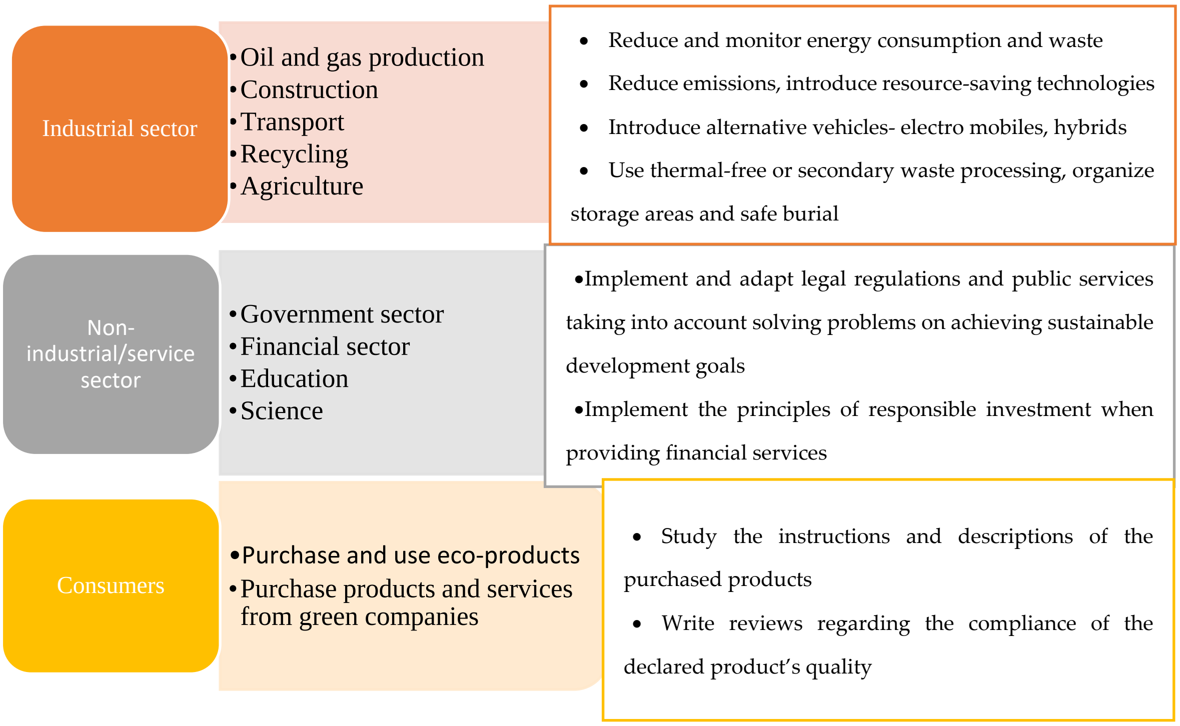
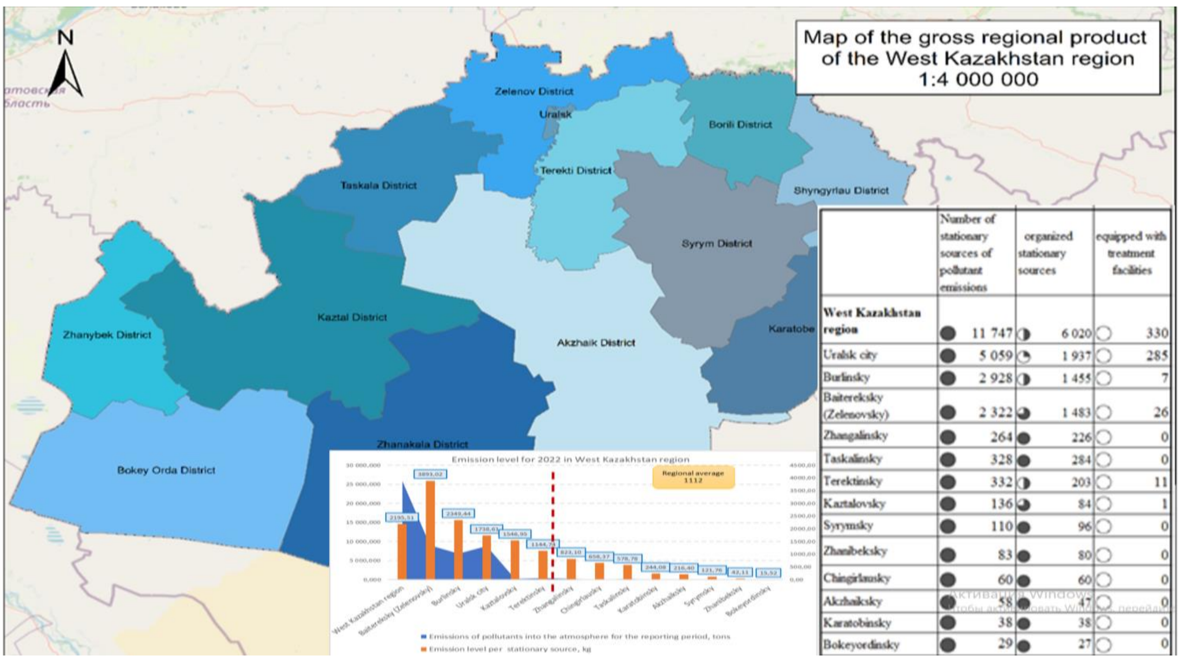


Figure 1. The main indicators of potential for the circular economy of the West Kazakhstan Region. Note: compiled by the authors based on sources (Circle Economy and Shifting Paradigms,2019, Circle Economy, 2020).

An analysis of the atmospheric emissions volumes of marker pollutants from WKR stationary sources into the atmosphere for 2012-2022 was carried out and showed that in 2022 the bulk of emissions come from industry (including energy and water supply), construction, transport and warehousing, which account for 47.9%, 16.1% and 17.0% respectively. It should be noted that in 2022 in the region there were 11747 stationary sources of atmospheric emissions, of which 6,020 were organized sources, only 330 of which were equipped with treatment facilities, which is only 5.5% of the total number of organized sources (https://www.kazhydromet.kz/ru). Moreover, there can be found an uneven distribution of emission sources, mainly in the northern industrialized areas of the region - Uralsk, Baiterek, Burli districts, which account for a total of -96.8% (Figure 2).



	Number of stationary sources of pollutant emissions	organized stationary sources	equipped with treatment facilities
West Kazakhstan region	11 747	6 020	330
Uralsk city	5 059	1 937	285
Burlinsky	2 928	1 455	7
Baitereksky (Zelenovsky)	2 322	1 483	26
Zhangalinsky	264	226	0
Taskalinsky	328	284	0
Terektinsky	332	203	11
Kaztalovsky	136	84	1
Syrymsky	110	96	0
Zhanibeksky	83	80	0
Chingirlausky	60	60	0
Akzhaiksky	58	47	0
Karatobinsky	38	38	0
Bokeyordinsky	29	27	0

Figure 2. Distribution of stationary sources of atmospheric emissions across the territory of the West Kazakhstan Region in 2022. Note: Compiled based on materials from (Adambekova,A, et al, 2024, https://www.kazhydromet.kz/ru).

The analysis showed that for many years in WKR there has been a continuing trend of pollutants emission into the atmosphere without implementing environmental protection measures, installing appropriate treatment facilities and creating environmentally friendly production. Thus, in the region the atmospheric pollutants were disposed: in 2005 – 14.7%, 2008 – 3.1%, 2022 – 13.4% (https://stat.gov.kz/). It should be taken into account that the KPO located on the territory of the Burli district has an environmental impact both on the region itself, and on Uralsk, and the Baiterek (Zelenov) district, through which the main branches of oil and gas pipelines pass. In Burli district, only 1455 out of 2928 emission sources were recognized as organized, and out of 1455 sources, only 7 were equipped with treatment facilities. At the same time, in terms of coverage by organized emission sources, Uralsk ranks lowest - only 38% of emission sources are monitored. Obviously, the ineffectiveness of dust treatment facilities, the lack of an effective system for capturing and disinfecting pollutants in industrial emissions from enterprises, thermal power plants, as well as the impact of transport in Uralsk is one of the reasons for the high air pollution in the city. At the same time, in terms of the emissions level per 1 stationary source, the leader is the Baiterek region, where this value of 3893 kg exceeds the regional average level by almost 4 times. The established differences in the levels of sulfur dioxide, nitrogen dioxide and carbon monoxide in the atmospheric air of the Burli region in comparison with other areas of the region are primarily associated with air polluting emissions from KPO oil and gas facilities. For comparison, in 2022 at KPO the total volume of emissions into the atmosphere was 5236 tons (68,5%), while the total emissions from stationary sources throughout the Burli region were 7640.2 tons (https://www.kazhydromet.kz/ru,https://www.kpo.kz/). The analysis showed that the majority of emissions in the Burli region come from gaseous and liquid emissions, which estimate for 86% of all emissions in the region. Moreover, mainly it consists from: sulfur dioxide -35%, carbon monoxide - 22%, nitrogen dioxide -21%, as well as volatile organic compounds -21%. Solid pollution accounts for 14% (Kozhagulov S., SalnikovV.,2024).

The KPO industrial complex operation, located in the Burli area, is inevitably associated with the release of combustion products into the atmosphere. The major products of combustion are sulfur dioxide, carbon monoxide, and nitrogen oxides. At the same time, the actual emissions of these substances did not exceed the volume of established maximum allowed level of emissions within the framework of environmental permits officially obtained by KPO (https://www.kpo.kz). The map of WKR's atmospheric emissions presented in Figure 2 allows us to conclude that *zonally the region can be divided into two sectors*: the industrial north, where the main emissions into the atmosphere occur – 95.8% (Uralsk - 34.1%, Burli -26.7% and Baiterek - 35%), the other is predominantly agricultural, which accounts for the remaining emissions and this is 4.2% of all emissions of atmospheric pollutants of the region.

3.2. KPO's Contribution to the Socio-Economic Development and Environmental Condition of the WKR

KPO, being one of the largest oil production consortiums in Kazakhstan, influences both the socio-economic development and environmental sustainability of the region. Considering a significant role of KPO as a major taxpayer in the region, one cannot fail to note its importance in providing the population of the region with gas (Figure 3).

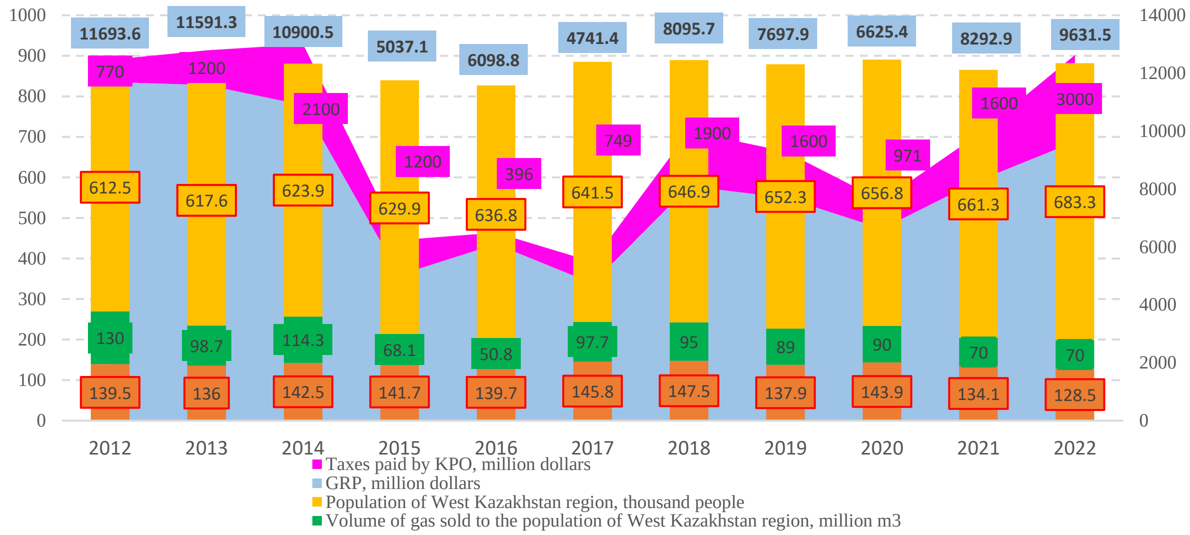


Figure 3. KPO's contribution to the development of West Kazakhstan Region: main indicators for 2012-2022 Note: compiled according to sources (https://www.kazhydromet.kz/ru, https://stat.gov.kz/,https://www.kpo.kz/,https://www.zoominfo.com/c/karachaganak-petroleum-operating-bv/369394468).

Thus, the data presented in Figure 3 indicates that taxes paid by KPO amount on average to 17% of the region's total GRP. If we compare taxes with the volume of regional budget revenues, it should be noted that on average, taxes paid by KPO could support from 3 to 7 regions of Kazakhstan, such as WKR. For example, in 2022, KPO paid $3.0 billion in taxes, while budget revenues that year amounted to $769 million (taxes contributed by KPO mainly go to the republican, not the local budget). The volume of gas sold to the population decreased by almost 2 times over the 10 years under study, but it should be emphasized that the gas supply to the population in WKR is almost 94%, and the price of gas continues to remain the most social – $0,042 (20.06 tenge) versus $0,08 (38.3 tenge) in Astana (https://stat.gov.kz/). Considering that the Karachaganak field accounts for 97% of gas condensate production's total volume and 37% of the total volume of gas production in the republic, it should be noted that KPO has significant resource potential for creating circular economy's conditions in the region.

An integral criterion characterizing production activities within the framework of a circular economy can be widely used indicators - emissions of main pollutants per unit of GDP and per population(https://unece.org/fileadmin/DAM/stats/documents/ece/ces/ge.33/2019/mtg4/5_3_RU_Ind_A1_A2_Air.pdf). These criteria can be selected as dependent indicators (Y – DV – dependent variable) and the analysis of their predictors will serve as the basis for the recommendations being developed. These indicators make it possible not only to determine the degree of anthropogenic load on the atmospheric air as a whole, but also to assess the impact on the environment by comparing data for the whole country and region and to evaluate the role of KPO in this process as a participant having a key environmental impact.

Analysis of the data presented in Figure 4a allows us to study the indicators of the harmful substances of atmospheric emissions. According to the chosen methodology, this indicator is estimated for KPO as relation of atmospheric emissions to the volume of oil and gas condensate production. Despite the differences in the indicators calculated for the country and region, this relative indicator also gives us the opportunity to objectively estimate the dynamics of reducing emissions into the atmosphere, in contrast to simply absolute values for emissions.

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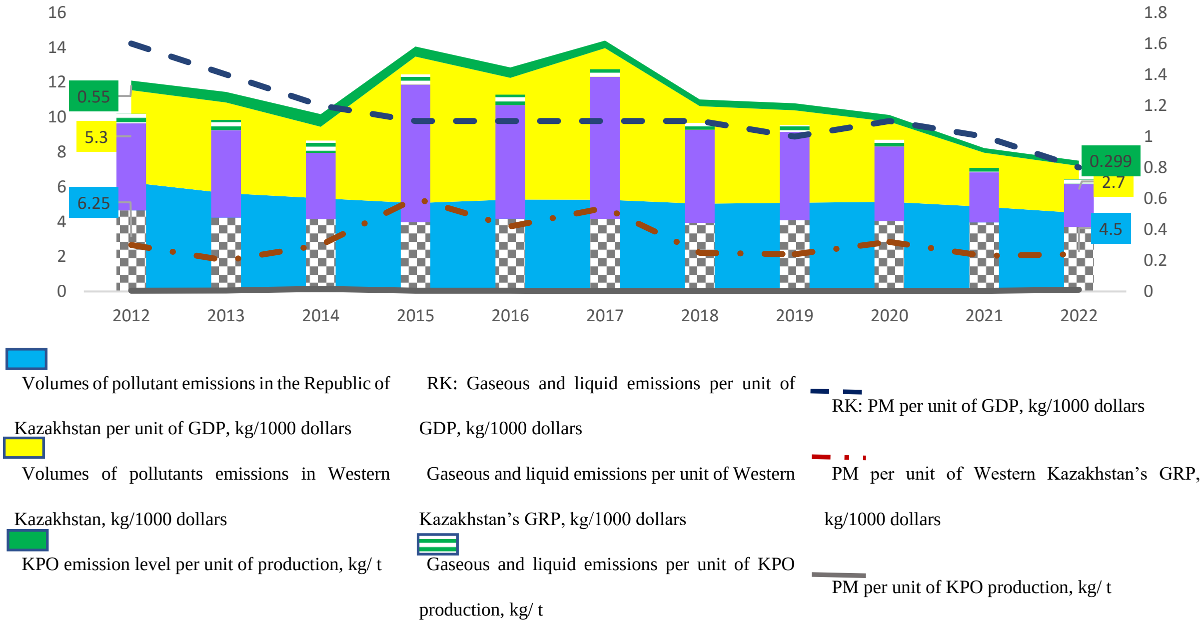
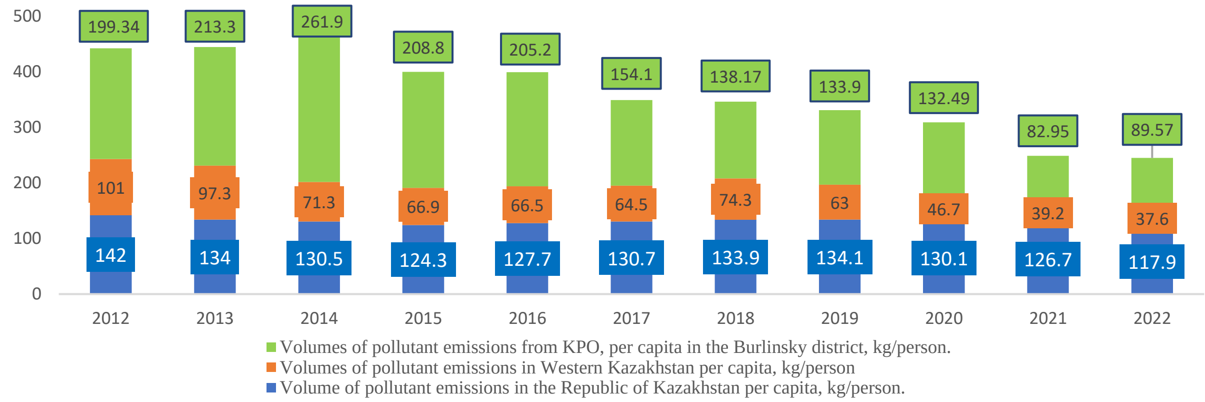


a - per unit of GDP for Kazakhstan, West Kazakhstan Region and KPO*, kg/1000 US dollars



b - per capita for Kazakhstan, West Kazakhstan Region and KPO*, kg/person

Figure 4. Atmospheric emissions of main pollutants in period 2012-2022. Note: compiled according to sources (https://www.kazhydromet.kz/ru, https://stat.gov.kz/, https://www.kpo.kz/).

A study of this indicator in terms of emission components shows a significant decrease in this indicator for the period under review, both in the republic as a whole, and in comparison, with WKR and KPO in particular. However, if in the country this figure has decreased over 10 years by almost a third (28%), then in WKR by almost half (49%) and in KPO by 46%. It should be noted that the key share of emissions is made up of gaseous and liquid pollutants. A study of another stated indicator - emissions per capita - allowed us to obtain more corrected conclusions (Figure4b).

The conclusions obtained, in our opinion, are more correct. Thus, the calculation of these indicators made it possible to obtain confirmation of the need to use uniform metrics. In this study, the use of GDP/GRP volume in monetary terms and production volume in tons as a base gives conclusion that limit their use (only dynamics can be assessed, which is what we did). When calculating the per capita emissions, in the case where the observed facility was KPO, there were used data on the population of the Burli district, which are located in close proximity.

From the point of view of the research methodology, a systematic method was used, which allows us to assess the environmental impact level proportionally to participation in this process. Thus, when studying the per capita emissions indicator, it was found that at the beginning of the

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study period, this indicator was higher for KPO - almost 2 times than for the region as a whole and almost 30% higher than the national value. Meanwhile, by 2022 the situation has changed significantly, which were caused by the measures implemented by KPO to reduce harmful emissions into the atmosphere. Besides, if the republican level of emissions (per capita) over 10 years has decreased by only 17%, then in the region every resident began to breathe 3 times less polluted air. The KPO negative impact on the environment per capita (of the Burli district) decreased by 2.2 times and became lower than the pollution level in the republic by 25% for the reporting 2022 year and by 65% over 10 years. Studying the relative dynamics of emissions per capita versus GDP for companies operating as a production-sharing consortium is more relevant and provides broader implications. Thus, the study showed that KPO has a significant economic (taxes in 2022 - $3 billion), environmental (68,5% of atmospheric emissions, 93,5% of SO_2 emissions from the Burli region) and social impact (share of local content -63.2% in KPO work) on the region’s development.

Similarly, corporations are the largest consumers of resources and polluters around the world. In 2018, in the EU, companies involved in industry, construction and mining accounted for 73.1% of all waste generated during the year, and households generated 8.2% of all waste generated during the same year (Sysoev S., Apanasovich N.,2023). In response to the growing anthropogenic impact of the corporate sector, in the developed countries the approaches of government regulation to solving environmental problems are changing: if 10 years ago they were focused on setting limits on harmful emissions, effective management of hazardous waste and the introduction of extended producer responsibility, currently, they are aimed at expanding economic levers such as emissions taxes, emission quotas through the so-called carbon price, based on circular business models (Woolven J.,2021).

Kazakhstan's pollution charge system focuses on generating revenue rather than creating incentives to reduce environmental impacts. Pollution taxes (tax payments for permitted emissions) are based on the maximum permissible emissions of each enterprise. Official bodies may impose administrative penalties for pollution in excess of those provided in project documentation and environmental permits. The judicial system ensures the payment of compensation for damage (monetary compensation) caused to the environment by emissions into the atmosphere. In most cases, the amount of "pollution damage" is determined based on the pollution tax rates for each pollutant using the monetary damages method. This system increases the costs associated with investing and doing business. The fact that effectiveness of controling and supervisory authorities are assessed by the number and volume of penalties/fines imposed creates perverse incentives. In this case, the tax system on industrial pollution could be transformed into taxes on major pollutants to encourage the use of cleaner and more efficient fuels and technologies. The development of subsequent regulations and technical references on best available technologies should ensure consistency between immediate measures to reduce air pollution and the phasing out of fossil fuels in the future In addition, carbon trading and phasing in carbon taxes can help effectively implement the polluter pays principle. (https://doi.org/10.1787/4a86e63d-ru).

The study made it possible to find out that the expansion of economic levers for regulating atmospheric emissions is due to the fact that the technological levers for reducing emissions are limited - it is impossible to make production completely free of emissions, waste and environmental involvement. In this regard, the main controversy arises: economic regulation has two effects. On the one hand, the reduction in emissions occurs due to the desire of companies to minimize fines and taxes. On the other hand, this regulation leads to the collection of funds in the form of taxes and fines to the budget of the relevant states, but for what purposes? It is logical that most likely the main item of expenditure is protecting the environment, fighting climate change and developing new technologies for decarbonization. In this context, large, export-oriented enterprises that practice green management methods and invest heavily in green technologies can organize and implement effective and mutually beneficial joint programs, as well as protect the environment and recycle waste (Tyaglov S., Sheveleva A.,2022).

3.3. Research on Opportunities for a Circular Economy in West Kazakhstan Region

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3.3.1. Analysis of the Generally Accepted Strategy and Practice of Its Implementation at KPO to Reduce Harmful Air Pollution into the Environment Within the Framework of ESG.

The potential for introducing and implementing the principles of a circular economy is manifested in those countries and regions in which operating industrial companies demonstrate their commitment to sustainable development goals and ESG principles (Yan Li,et al, 2023). To analyze the main factors determining emissions of pollutants into the atmosphere of the region, the main strategic directions for reducing emissions associated with KPO production activities were studied. The company was one of the first in Kazakhstan to formulate its vision of environmental policy as the initial stage of implementing the Environmental, Social, and Corporate Governance (ESG) system (https://www.kpo.kz/en/sustainability).An analysis of the strategy and practice of atmospheric emission reduction methods used at KPO showed that in achieving stated goals and indicators, in this industrial sphere that at the same time is ecologically impacting the environment, there are many factors and, as a result: risks in this industry(Figure 5). The construction of this matrix made it possible to identify important independent variables that influence the dependent criterion - emissions of main pollutants per unit of GDP and per living population, as an indicator affecting the circularity of the West Kazakhstan Region economy.

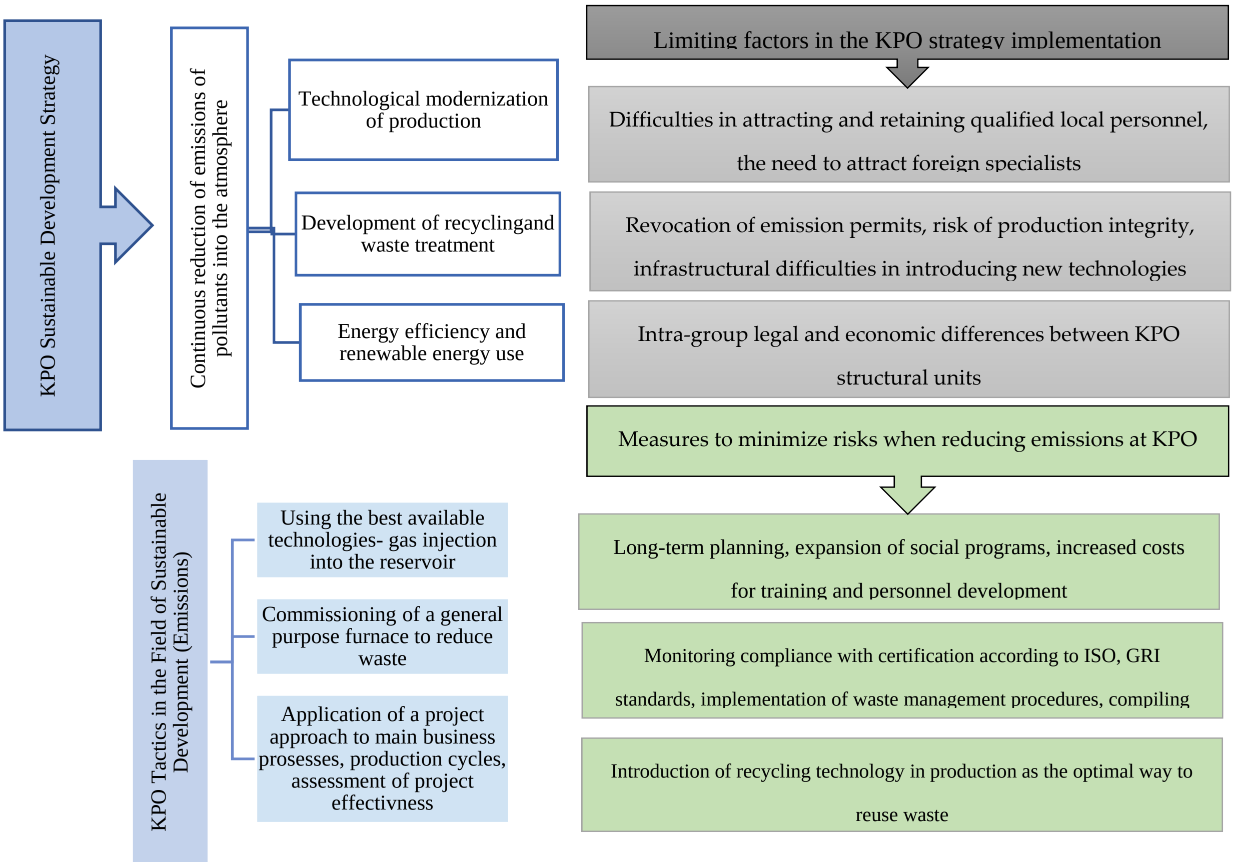

Figure 5. Compliance Matrix of the KPO's Strategy and Tactics for Reducing Air Emissions. Note: compiled by the authors based on sources (Circle Economy and Shifting Paradigms 2019, https://www.kpo.kz, Circle Economy, 2020).

Figure 6 shows information from the KPO Sustainable Development Report for 10 years, characterizing atmosphere emissions, including greenhouse gases and generation of waste, which allows us to provide an additional assessment of the KPO Sustainable Development Strategy implementation.

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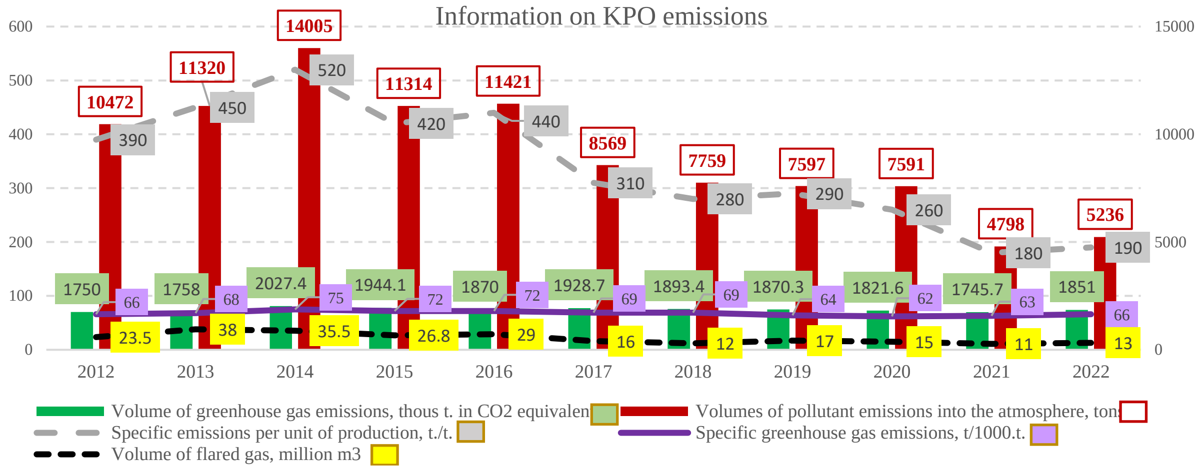
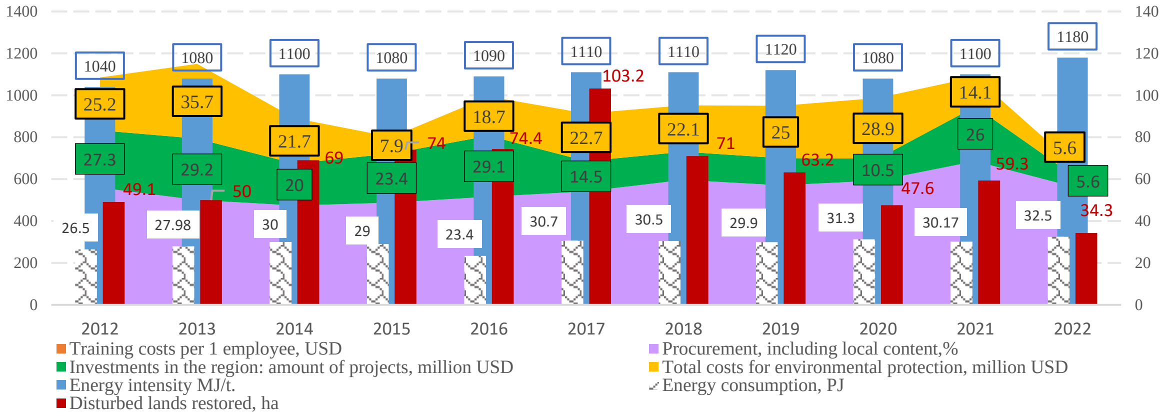


a – Indicators of atmospheric air pollution at KPO for the period 2012-2022.



b – Indicators of social impact of KPO in West Kazakhstan Region.

Figure 6. ESG indicators at KPO for the period 2012-2022. *Information on some indicators is not publicly available Note: compiled by the authors based on https://www.kpo.kz/en/sustainability.

Reducing the gas flaring volume, and consequently reducing atmosphere emissions, is one of KPO's key obligations. As a number of measures result to implement the best available technologies, a significant reduction in pollutants emissions into the air was achieved. Thus, due to the ESG strategy implementation for the period 2012-2022, KPO's atmospheric emissions per capita decreased by 2.2 times. Significant changes have been observed since 2017 when emissions fell by 25% compared to 2016. Moreover, the results of this period made it possible to achieve a 40% reduction in emissions by 2022 (https://www.kpo.kz/docs/sustainability_report_2023). It was the high-pressure gas reinjection technology introduction, which makes it possible to significantly reduce the gas flaring volume from the total volume of gas produced (0.82 tons per 1 thousand tons), that created these waste reduction results. Gradually, since 2013, the volume of flare gas combustion began to decrease, which correlates with a decrease in the volume of atmospheric emissions in the WKR (Figure 6a).

Technological modernization of oil and gas condensate production has allowed KPO to significantly reduce its environmental footprint. Analysis of the dynamics of the gas injection volume into the reservoir for 2012–2022 (Application A) showed that KPO, having provided a significant reduction in gas flaring, achieved a high level (99.95%) of gas utilization, thanks to the successful use of advanced solutions and technologies to reduce emissions. Thus, in 2023, the volume of gas reinjection to maintain reservoir pressure amounted to 12.650 billion m³, which approximately corresponds to 56.5% of the total volume of gas produced (https://www.kpo.kz/docs/sustainability_report_2023). As a result, in 2023, the specific indicator of

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greenhouse gas emissions in CO_2 equivalent at KPO amounted to 65 tons of CO_2 per thousand tons of hydrocarbon production, i.e., according to the International Association of Oil and Gas Producers (IOGP), greenhouse gas emissions per unit of hydrocarbon production at KPO are 14% lower than European indicators and 44% lower than international indicators.

As part of the implementation of strategy to reduce harmful atmospheric emissions, KPO also uses a set of management decisions (Figure 5). Thus, for energy saving and increasing energy efficiency, the company conducts a mandatory energy audit according to the ISO 50001 "Energy management system" every five years (https://www.bsigroup.com/). At the same time, KPO's energy intensity indicator in 2022 was 1,18 GJ/ton of hydrocarbons, which is lower than the average energy intensity indicator of companies reporting to the International Association of Oil & Gas Producers (IOGP) -1.5 (https://www.kpo.kz/docs/sustainability_report_2023).

Analysis of reporting on KPO's sustainable development, pro-sustainable news on events reflecting the company's environmental, social and management responsibility, made it possible to collect and systematize data on KPO's social impact indicators over a ten-year period (https://www.kpo.kz/en/sustainability, https://www.kpo.kz/ru/ustoichivoe-razvitie/socialnaja-otvetstvennost/podderzhka-socialnoi-infrastruktury). It should be highlighted that KPO systematically implemented the standards of Occupational Health and Safety Management Systems (OHSAS18001-2007): 403-1, 403-7, 403-8 (applied until 2017, and since 2018 - ISO45001-2018), GRI Management: 103-1, 103-2 (3-3), ISO14001:2018 and others (https://www.globalreporting.org/, http://www.aims.org., https://www.iso.org/ru, https://www.greenwgroup.com). This undoubtedly indicates to sustainable development commitment of the company; nevertheless, an influence of external factors corrects the overall quantitative results. Thus, the presented data (Figure 6b) indicate that, in general, the ESG assessment is not entirely unambiguous.

On one hand, the company provides information on costs of environmental protection (the average amount for the period is $20.7 million) and the financing of regional development projects (similarly, $19.3 million). On the other hand, unfortunately, both indicators decreased in 2022 by almost 4 times compared to the average values for the period under review. Basing on it, we are concerned about the continued level of energy consumption and energy intensity, which are directly related to greenhouse gas emissions (Figure 7), that also continue to remain high - 1851 thousand tons in 2022, which is even 9 thousand tons higher than the average value for the period.

The company highlights the results of its activities in restoring disturbed lands, although its indicators decreased by almost 2 times in 2022. The process of reducing foreign content in the KPO value chain looks more effective. Thus, KPO is carrying out comprehensive work to involve Kazakh suppliers and commodity producers in the development of the field in terms of works, goods and services purchase. As a result of systematic work, the share of local content in the company in 2023 reached USD 756.1 million (63.2%) (Figure 6b).

An analysis of the strategy and practice of waste management methods used at KPO showed that in the implementation of the stated goals and achievement of indicators, in this sphere, as an industrial one and one that has an environmental impact, there are many factors and, as a result – risks. The construction of this matrix (Application B) made it possible to identify important independent variables that influence the dependent criterion - ESG commitment as an indicator influencing the circularity of the West Kazakhstan Region economy.

It should be noted that the KPO sustainability report, along with quantitative indicators reflecting the circularity level of companies, contains data on the specific activities of company in green and circular economy, for example, in biodiversity conservation, prospects for the use of renewable energy sources, etc. that are of interest to a large number of stakeholders. Nevertheless, during this analysis, no data were found regarding the use of renewable energy sources. It is too early to talk about the use of renewable energy sources. Only in 2022, KPO gradually began developing a "green" KPO strategy, which in the future provides for the development of renewable energy sources and projects to reduce atmospheric emissions aimed at preserving natural ecosystems and biodiversity, we are talking about the use of the region's wind potential (https://www.kpo.kz/en/sustainability).

During the research, it was found that KPO uses the subsidiary environmental responsibility principle, implementing measures to minimize the environmental footprint and impact as a business entity (from investment activities). Thus, within the framework of the terms of the contracts, the company transfers part of the waste for disposal to specialized contractors, who independently determine methods for further handling of waste received from KPO and quarterly report on their transfer to third parties. In accordance with the norms of the Environmental Code in Kazakhstan (Article 351) (Adilet.zan.kz, 2021), the company is working to organize the sorting and separate collection of industrial and household waste with the participation of contractors. This waste is then transferred to specialized enterprises for use as recyclable materials.

In addition, according to the restrictions introduced in Kazakhstan since January 2019, enterprises are prohibited from transporting to landfills anything that can be recycled: waste paper, plastic, scrap metal, glass. This limitation was reflected in reporting: business entities began to present detailed data (Application C). KPO, in turn, started transferring wastes for processing even earlier, but only since 2018 this information began to be reflected in details. In particular, according to 2017 data, the total volume of waste transferred for recycling amounted to 152 tons, while only plastic (23.18 tons) and waste paper (14.4 tons) were specified in detail.

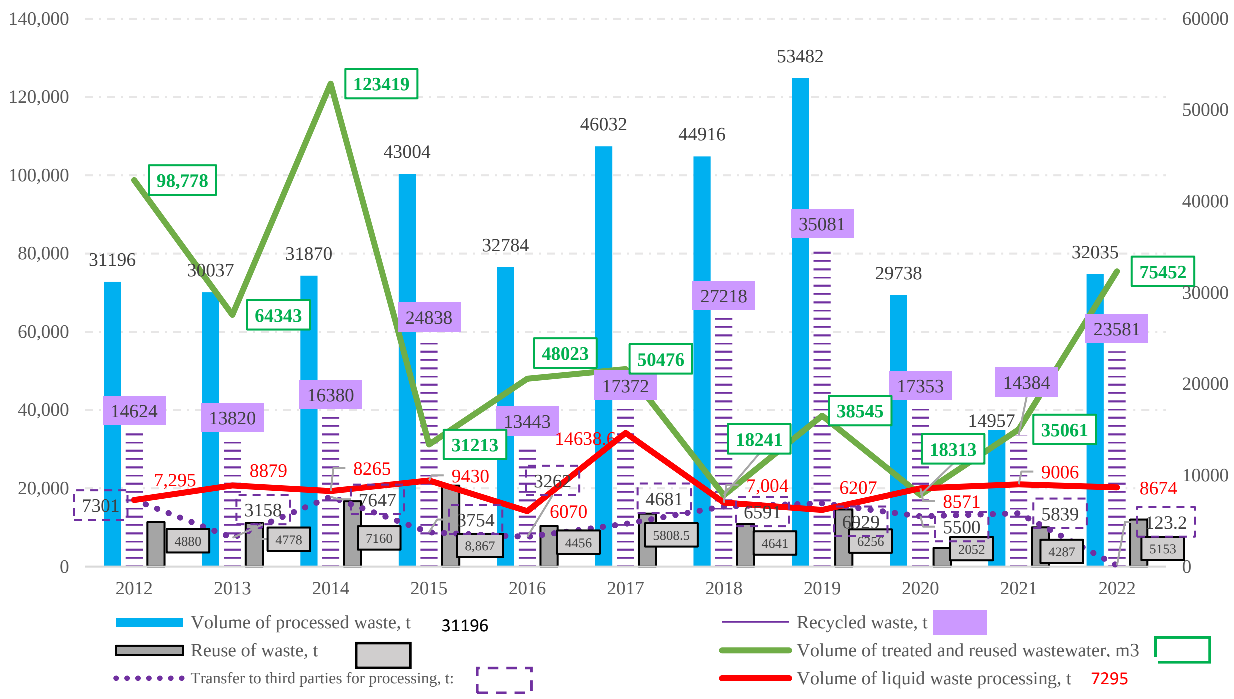

Figure 7. Waste processing data at KPO. Source: compiled by the authors based on https://www.kpo.kz/en/sustainability.

Studying data on the waste management system at KPO allows us to note the use of various technologies for the materials reuse, treatment and reuse of wastewater, processing of liquid and solid waste. Figure 7 shows data on the volume of various waste processed at KPO facilities over 10 years, which shows that the share of processed waste is growing annually, while the overall volume of waste is decreasing.

Thus, the study showed that in order to reduce atmospheric emissions, KPO uses such practices as optimization of production processes using innovations and the best available technologies, development and application of closed production cycles, introduction of energy efficient technologies and energy management systems (Popkova,E., Sergi, B.,2023), creation of an effective waste management system, including sorting, recycling and disposal of waste, promoting responsible consumption and production. In this regard, KPO, as the flagship of the oil and gas

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industry in Kazakhstan, has great opportunities to prevent the negative consequences of environmental pollution in the region.

The conducted research allowed us to draw a conclusion about the possibility of a more in-depth study of the experience of KPO in solving issues of reducing emissions of pollutants into the atmosphere, as an economic entity implementing measures and introducing technologies to reduce harmful impacts on the environment, and creating conditions for the formation of closed-loop production.

3.5. Studying the Creation of a Circular Economy Meso-Model Based on KPO

Within the framework of this research, studying the situation in reducing harmful emissions into the atmosphere and reducing waste is considered as a key basis for creating conditions for the economy circularization. This is dictated by the fact that the following approach is taken as the basis for the method of organizing such an economy. The circular economy is considered as a development model that sets itself the complex task of minimizing waste and reducing emissions based on optimizing the use of resources (Circle Economy and Shifting Paradigms,2019, Circle Economy, 2020, PottingJ,et al,2017).

3.5.1. Dependence of Atmospheric Pollutants Emissions from "Pro-Sustainable" Measures at KPO for 2012-2022.

As part of the task set to find the main reducing factors of harmful atmospheric emissions, according to the results of the literature review and analysis of the main quantitative and qualitative indicators dynamics (Figures 1,2,3,6, Application A), the following indicators were identified and systematized. These indicators will be used as the initial metadata base for correlation and regression analysis (all indicators for KPO).

Dependent Variables: $EMISSION_1$ level per unit of production (UPR), $EMISSION_2$ per capita (CAP) and $EMISSION_3$ that will be checked for sensitivity to independent variables, for multicollinearity, and as a result one dependent variable will be selected.

The following were selected as Independent Variables:

Independent Variables	Description	Independent Variables	Description
OIL GAS PROD	Oil and gas condensate production, million barrels	PRO WASTE	Volume of processed industrial waste, th.t
FLARED GAS	Volume of flared gas, million m^3	ENV PROT COST	Total costs for environmental protection, million USD
ENV TECH	Use of environmentally friendly technologies - gas injection into the reservoir, billion m^3	ENERGY_ CONS	Energy consumption, PJ

Table 1. Initial data for identifying the dependence of atmospheric emissions at KPO.

			2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
DV	**$EMISSION_1$**	KPO emission level per unit of production, kg/t.	0,55	0,61	0,721	0,585	0,599	0,431	0,386	0,404	0,387	0,262	0,299
	$EMISSION_2$	Volumes of pollutant	199,34	213,3	261,9	208,8	205,2	154,1	138,17	133,9	132,49	82,95	89,57

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		emissions from KPO, per capita in the Burli district, kg/person.											
	EMISSION3	Volumes of pollutant emissions from KPO into the atmosphere, tons	10472	11320	14005	11314	11421	8569	7759	7597	7591	4798	5236
IDV1	OIL GAS PROD	Oil and gas condensate production, million barrels	139,5	136	142,5	141,7	139,7	145,8	147,5	137,9	143,9	134,1	128,5
IDV2	FLARED GAS	Volume of flared gas, million m3	23,5	38	35,5	26,8	29	16	12	17	15	11	13

Note: compiled based on sources (https://www.kpo.kz/en/sustainability, EEAR, 2022 Nyashina, G.,2018, TurbinaK and Yurgens Yu, red.,2022., Browder G. et al.,2018).

The results of the indicators dynamics' analysis and the conclusions interpretation made it possible to establish that the use of a relative indicator - KPO emission level per unit of production, kg/t ($EMISSION_1$) as a dependent variable will not be entirely correct, since the calculation base for it was the volume of oil and gas condensate production in natural volumes. While other indicators by level of pollutant emissions in the country and WKR were calculated based on GDP in monetary terms.

The results of assessing the correlation dependence of $EMISSION_1$ on independent variables showed that there is practically no connection with three indicators - OIL GAS PROD, PRO WASTE, ENV PROT COST, which indicates the need to check the next dependent variable $EMISSION_2$. At this stage, we have obtained a low dependence and interrelation between $EMISSION_2$ and the PRO WASTE indicator, however, in general, this dependence can be considered for further research. Considering that the $EMISSION_2$ indicator is a qualitative criterion obtained by calculation, the process of econometric calculations for the $EMISSION_3$ indicator was continued (Table 2).

Table 2. Correlation dependence (basic result for $EMISSION_3$).

	EMISSION3	**OIL GAS PROD**	**FLARED GAS**	**ENV TECH**	**PRO WASTE**	**ENV PROT COST**	**ENERGY_ CONS**
EMISSION3	1						
OIL GAS PROD	0,381727	1					
FLARED GAS	0,904194	0,029387	1				
ENV TECH	-0,7176	-0,45938	-0,5966	1			
PRO WASTE	0,131856	0,450074	-0,07479	-0,38974	1		
ENV PROT COST	0,303915	0,365131	0,340601	-0,34042	0,060849	1	
ENERGY_ CONS	-0,55713	-0,06261	-0,55508	0,731779	0,100638	-0,20968	1

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An assessment of the correlation dependence for the dependent variable $EMISSION_3$ (volume of pollutant emissions into the atmosphere at KPO) showed that, just like for the $EMISSION_2$ indicator, here we observe a weak relation with the PRO WASTE indicator. Obviously, this is explained by small values of PRO WASTE, i.e. those wastes that are processed at KPO itself, and the impact of non-recyclable waste incinerated in the furnace, which can significantly reduce their volume (by 89%), is obviously reflected in an increase in ENV PROT COST energy consumption, which requires further study. At this stage of the study, we excluded the independent variable PRO WASTE - the volume of processed KPO industrial waste, as a weakly influencing indicator. At the same time, the interrelation with other indicators turned out to be higher. In this regard, under the influence of identified factors, it was decided to continue econometric calculations for the dependent variable $EMISSION_3$ and select it as the main performance indicator for modeling forecast elections.

Table 3. Correlation dependence (accepted result for $EMISSION_3$).

	$EMISSION_3$	**OIL GAS PROD**	**FLARED GAS**	**ENV TECH**	**ENV PROT COST**	**ENERGY_ CONS**
$EMISSION_3$	1					
OIL GAS PROD	0,381727	1				
FLARED GAS	0,904194	0,029387	1			
ENV PROT COST	-0,7176	-0,45938	-0,5966	1		
ENERGY_ CONS	0,303915	0,365131	0,340601	-0,34042	1	
ENV PROT COST	-0,55713	-0,06261	-0,55508	0,731779	-0,20968	1

Output of regression analysis results using the R program

Before building a model, we will form a correlation matrix to determine multicolinearity

It clearly shows the correlation between each pair of variables. Analyzing the heat map, we can see that multicolinearity between the regressors is not observed. Based on this, we include all parameters in the model and build an equation.

Residual standard error: 714.8 on 5 degrees of freedom

Multiple R-squared: 0.9685, Adjusted R-squared: 0.9371

F-statistic: 30.79 on 5 and 5 DF, p-value: 0.0009212

By removing the remaining predictors from the equation, except for the first two, we improved the model. We also checked the significance of the regressors using the Student criterion, which showed that the calculated t-statistics are greater than the critical one and confirmed the significance of the factors. Since the regression showed no significant relationship between $EMISSION_3$ and ENV TECH, PRO WASTE, ENV PROT COST and ENERGY CONS we removed them from the model and conducted further research on the relationship between $EMISSION_3$ ~ OIL GAS PROD + FLARED GAS.

Based on this, the forecast will be more accurate.

Let's build a 3D visualization of the relationship model <- lm($EMISSION_3$ ~ OIL GAS PROD + FLARED GAS, data = data)

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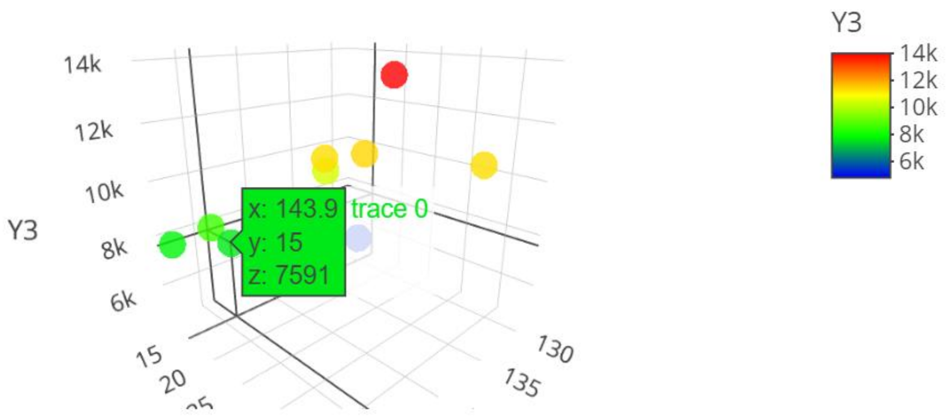

Figure 8. 3D visualization of the relationship model.

By removing non-significant predictors from the model, we found that even (Intercept) became significant at the p value of 0.00626 **

The significance of the model increased F-statistic: **from 30.79 up to 67.19**

model <- lm($EMISSION_3$ ~ OIL GAS PROD + FLARED GAS **, data = data)**

Residuals:

Min	1Q	Median	3Q	Max
-1458.07	-356.51	38.36	463.90	894.01

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-22400.09	6094.87	-3.675	0.00626	**
OIL GAS PROD	184.55	43.53	4.240	0.00284	**
FLARED GAS	265.24	24.88	10.660	5.26e-06	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 755.3 on 8 degrees of freedom

Multiple R-squared: 0.9438, Adjusted R-squared: 0.9298

F-statistic: 67.19 on 2 and 8 DF, p-value: 9.968e-06

By removing the remaining predictors from the equation, except for the first two, we improved the model. We also checked the significance of the regressors using the Student criterion, which showed that the calculated t-statistics are greater than the critical one and confirmed the significance of the factors.

print(future_predictions (Figure 9))

Year	Forecast_Value
1	**4592.582**
2	**3841.618**
3	**3090.655**
4	**2339.691**
5	**1588.727**

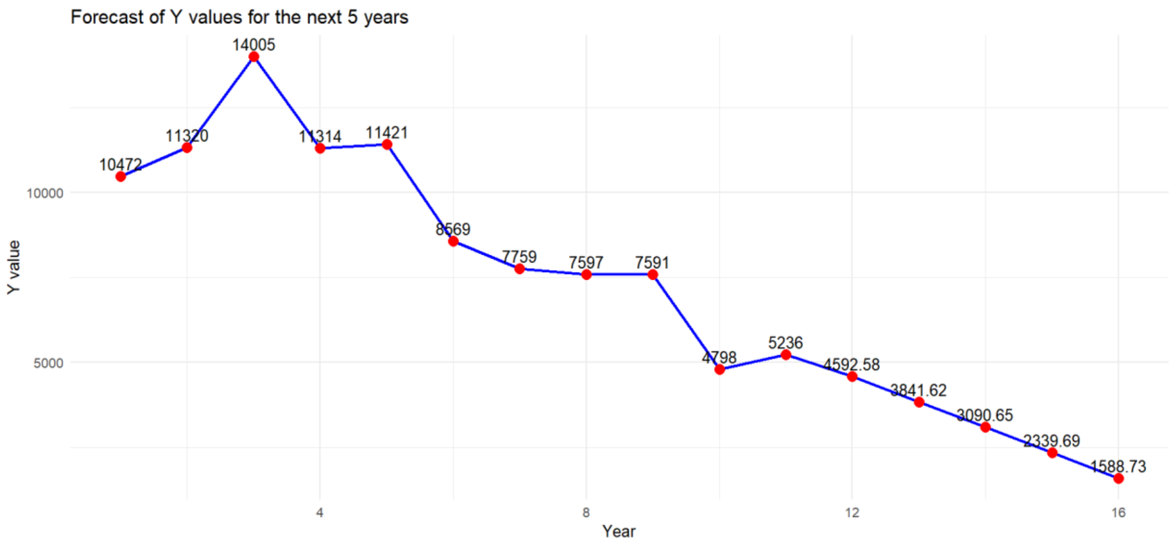

Figure 9. Forecasting the dependence of KPO emissions on sustainable emission management measures through the R program.

Based on the provided results of the linear regression model metrics, we will conduct a deep testing of the model for its accuracy from the standpoint of errors.

The result of calculations of forecast reliability metrics is made in the R program:

Mean absolute error (MAE): 526.8903

```
> cat("Mean square error (MSE):", mse, "\n")
Mean square error (MSE): 414844.4
> cat("Root of the root mean square error (RMSE):", rmse, "\n")
Root of the root mean square error (RMSE): 644.0842
> cat("Determination coefficient (R²):", r_squared, "\n")
Determination coefficient (R²): 0.9438106
> mape <- mean(abs((data$Y3 - predictions) / data$Y3)) * 100
> cat("Mean absolute percentage error (MAPE):", mape, "%\n")
```

Interpreting the output of the model error check in R

Mean Absolute Percentage Error (MAPE): 5.923575 %

(MAE): the error of 526.89 can be considered small, since Y3 varies in thousands (which we can see from the data), so the model shows a good level of accuracy.

(MSE): 414,844.4 (MSE measures the average squared deviation between forecasts and actual values, the metric is especially sensitive to large deviations. MSE is more sensitive to outliers than MAE). In this case, it does not exceed MAE (526.89), which indicates the absence of large outliers.

(RMSE): 644.08 The difference between MAE and RMSE indicates the absence of significant outliers, the absence of outliers means there are no anomalies in the original data itself.

(R^2): 0.9438 - R^2 indicates that the model explains 94.38% of the variations in the dependent variable ($EMISSION_3$), indicating that the model explains the relationship between the independent variables (OIL GAS PROD, FLARED GAS) and the dependent variable ($EMISSION_3$) well. This means that most of the variations in $EMISSION_3$ are explained by the model.

(MAPE): 5.92% indicates that on average, the model's forecasts deviate from the actual values by 5.92%, indicating high forecast accuracy.

Metrics Inference: All metrics including MAE, RMSE, R^2, and MAPE indicate that the model is highly accurate and does a good job of forecasting. Small deviations revealed by RMSE may be insignificant and indicate the absence of significant outliers.

The construction of this regression model made it possible to confirm the positive relationship between emissions and production volume and the volume of flared gas, which proves the

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correctness of our chosen independent variables and the presence of mathematically proven connections between these indicators. At the same time, testing the model showed the absence of a statistically significant relationship between emissions and environmental protection costs, the volume of gas injected into the reservoir and the volume of energy consumed. Thus, a forecast was built based on the relationship $EMISSION_3$ ~ OIL GAS PROD + FLARED GAS, also guided by the results of error checking

The data obtained as a result of the multiple regression analysis on the forecasted indicators of emissions of pollutants into the atmosphere, both through modeling in the R program and in the Excel program, made it possible to establish that while maintaining certain dynamics of independent indicators development, the level of emissions at KPO may be reduced 2 times by 2028. However, forecasting a high probability of events, as well as predicting a low probability of events, determined the possibility of establishing a possible corridor for the probability of deviations, along which the level of emissions by 2028 could rise to the level of 2019 in case of a deterioration in the indicators selected as factor predictors of atmospheric emissions.

Thus, based on studying the atmospheric pollution reduction based on a circular economy model formation in the WKR, we can conclude that two poles can be distinguished in the region: one is the industrial north, where the main emissions into the atmosphere occur; the other is predominantly agricultural, which accounts for the remaining emissions. The analysis showed that the introduction of the circular economy principles is possible at the mezo level - of an individual company, in this case KPO, to create an effective air quality management system.

3.5.2. Matrix of Industrial-Agrarian Potential of West Kazakhstan Region

The following directions, consolidated into a matrix of regional capabilities, have been chosen as the key approaches for systematizing accumulated experience and technological innovations as the basis for the circularization of the region. The construction of a matrix for the industrial sector in "oil and gas production" category made it possible to identify the main conditions, factors, expected results from the circularization measures implementation and identify the risks accompanying this process at the beginning of the period under study (2012). A similar approach was applied to other categories of the industrial sector, but in this case for the current moment - the construction industry, energy, transport and logistics, waste processing and the agro-industrial sector and its categories (crop production and livestock farming). According to the calculations of foreign experts in Kazakhstan, 46% of the used arable land (11.5 million hectares) and 70% of pastures in terms of ecological condition are suitable for organic crop and livestock production (https://www.fao.org/agroecology/database/detail/ru). It should be noted that the use of this approach was dictated by different resource capabilities and technological features of these industries. In other words, what KPO has done over the period from 2012 to 2022 in the field of reducing pollutants emissions into the atmosphere, introducing the best available technologies to reduce emissions and recycle waste, other enterprises in other industries are just starting to implement, or their experience is negligible. For this reason, the remaining sectors were assessed according to their current state of development in the area. For each of them, only those aspects that are directly related to the terms for the circular economy formation were specified.

The matrix, built basing on the materials, reflecting main conditions and factors determining the need to organize a circular economy in the WKR, as well as taking into account all previously obtained results, allows us to make the following conclusions (Figure 10).

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Industrial Sector Management

Sector	Factors/Conditions	Expected results	Risks
Oil and Gas Production, 2012	Lack of automatic environmental monitoring stations along the perimeter of the sanitary protection zone	Improving monitoring and control of air quality	Increased maintenance costs
	Outdated wastewater treatment systems at the field	Elimination of waste water discharge	Increasing energy intensity of production
	Increase in industrial waste and the need to study waste reuse	Waste processing and disposal	Increased emissions due to combustion in general incinerators
	Conducting independent reviews of the effectiveness of stakeholder audits, contracts	Improvement of methods and procedures for monitoring and analysis in production management.	Lagging of implemented technologies from regulatory changes
Construction industry, 2024	Increased energy consumption	Increasing energy efficiency	Risks associated with fluctuations in energy prices
	Increase in CO_2 equivalent emissions	Implementation of green building principles	The gap between current and desired decarbonization levels is significant
	Rising cost of building materials	Development of production of low-carbon building, modular designs materials	Rising construction costs and rising prices for end consumers
	Low rate of adoption of digital technologies	Development of R&D, financing of startups in innovative technologies	Lack of strict building codes and regulations
Energy sector, 2024	Moral and physical wear and tear of thermal power plant equipment	Reconstruction of the thermal power plant	Increase in energy tariffs
	Deterioration of engineering, electrical, water, heat and sewer networks in the region	Reconstruction of engineering, electrical, water, heat and sewer networks in the region	Lack of investment
	Outdated energy saving technologies	Replacing coal and liquid fuels with gas and biofuels	High cost of technical re-equipment of reconstruction
	Increased energy consumption	Development of bioenergy, launch of	Transport and logistics risks
Transport and logistics, 2024	Depreciation of vehicles by 70.5%	Technical re-equipment, transfer of transport to eco-fuel	Lack of investment
	Freight traffic growth, 85%	Creation of a transport and logistics center of Eurasia	Increase in atmospheric emissions
	Road wear, 39%	Improving the quality of road surfaces	Increased cost of transport services

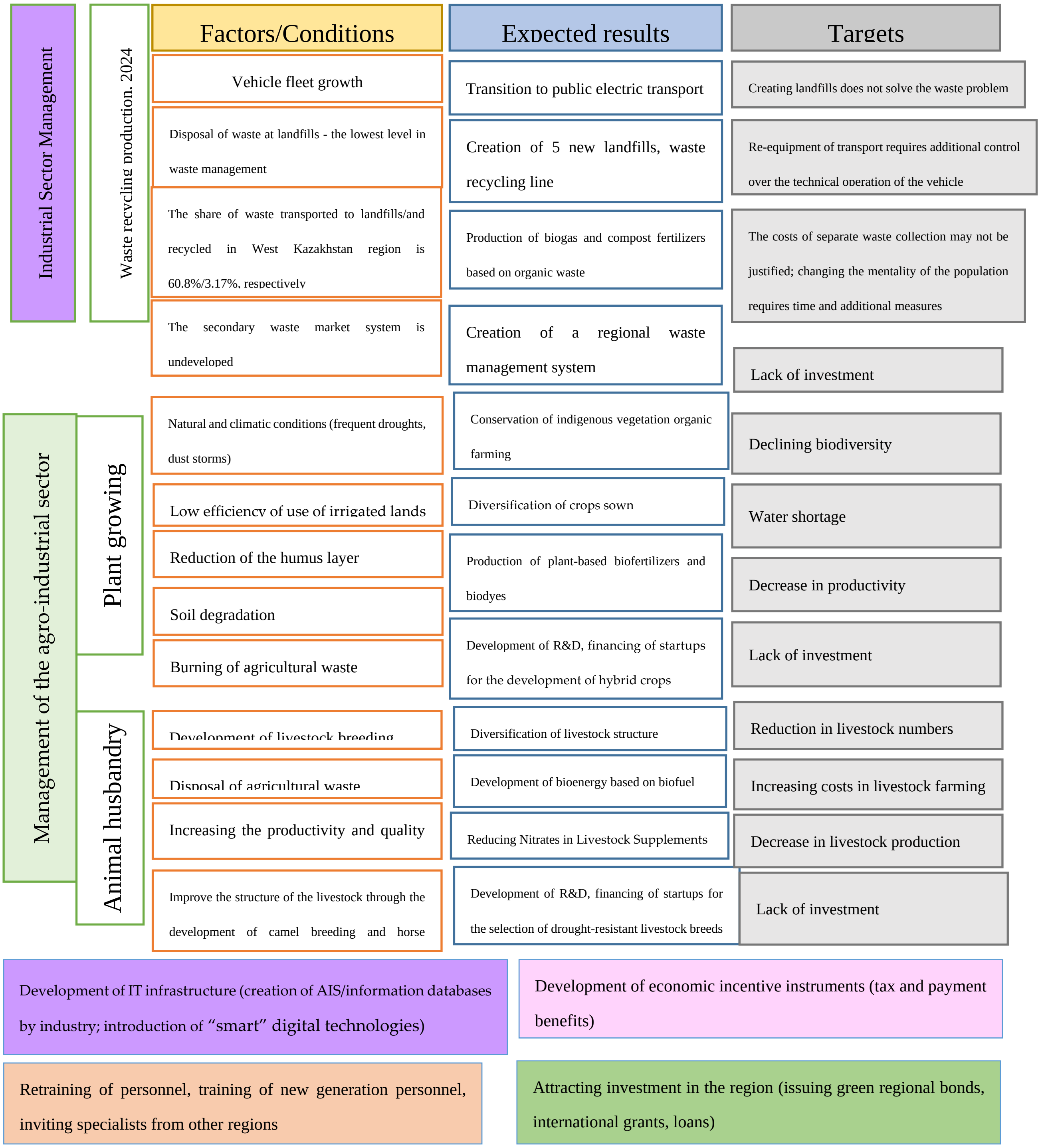

Figure 10. Matrix of industrial-agrarian potential of the West Kazakhstan Region for creating conditions for the circularization of the regional economy. Note: compiled by the authors based on the analysis of (Circle Economy and Shifting Paradigms,2019, Circle Economy, 2020, Kazhiakhmetov,S., Khazhiakhmetov, R. 2023).

Regional zoning has shown that the significant concentration of emissions in the northern part of the region determines the need to concentrate circularization efforts, first of all, among those companies operating in this part of the region. In addition, this requires concentrated efforts to create the necessary infrastructure for monitoring and control of atmospheric emissions and wastes in this part of the region and surrounding areas. At the same time, the study shows that companies in other industries also demonstrate a desire to implement circular management principles. Thus, by

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determining the conditions/factors that exist or which ensure the implementation of the circularity of technological, production and labor relations – regional authorities can direct efforts to these components when developing Roadmaps, strategies or programs for the development of the region.

The correlation and regression analysis, revealing close relationship between the volume of atmospheric emissions and indicators reflecting the results of KPO's measures to implement the best available technologies, spending funds on environmental protection, the volume of gas burned and others, showed the effectiveness of KPO's emission reduction activities. From other side, this analysis made it possible to argue for the correctness of the approaches and their applicability in constructing a matrix of the industrial-agrarian potential of the WKR to create conditions for the circularization of the region's economy. By connecting the matrix of "Oil refining, 2012" category with the results of econometric modeling, we were able to assess the measures efficiency and argue conclusions regarding the standard selection of KPO as an example for building managerial, technological and economic decisions to form conditions for the WKR's economy circularization. This, in turn, made it possible to model a matrix for KPO, reflecting the consequences of the "circularity" of production at the enterprise, achieved as a result of the implementation of measures to reduce emissions and recycle wastes (Application D).

An assessment of the matrix of other industries in the region, which are just launching technologies that will form conditions for the regional economy circularization, showed the effectiveness of the systematic approach used in the study and emphasized the achievability of the goal set in the study. Thus, the matrix allows us to see the potential for circularity between industries in the agro-industrial sector and the energy sector, transport industry, logistics, waste management and construction. This matrix allows us to identify the region's potential to implement the integration of all production, technological, and logistics processes using the key principle - a focus on reducing polluting emissions into the atmosphere and recycling waste.

Along with it, this matrix was supplemented with other conditions ensuring the circularization process. First of all, the development of IT infrastructure through the creation of an automated information system (AIS) that will form an information database for industries that helps ensure uninterrupted supply chains, organizes an effective sales system for finished products (high need in the agro-industrial sector), and maintains up-to-date data on pollution, emissions and waste (environmental sustainability of the region). In addition, a major contribution to the circularity of the region's economy can be made through the development of IT technologies in crop production (introduction of "smart" greenhouses, "smart" irrigation), in livestock farming ("smart" pasture), in construction (introduction of digital technologies as in construction of residential buildings, as well as industrial and office premises) and others (Popkova,E., Sergi,B.,Eds.,2021).

An important condition for stimulating the conditions creation for the circularity of the economy is intended to be a system of preferential taxation and a targeted system of payments, the sale of quotas, which can be implemented within a given region, and initiated generally throughout the country. Launching a circulation system within even one region will require a qualitative update of the region's labor resources. In this case, the support of regional authorities is key factor. This can be expressed in the organization of programs/platforms for retraining personnel, training a new generation of personnel, and even attracting specialists from other regions. The main risks in the matrix of regional potential are increased costs, rising prices for products and services for the end consumer, and lack of investment.

Thus, the set goal was achieved and the hypothesis put forward was confirmed during the research. The results of the analysis made it possible to identify a high level of scientific attractiveness of reducing atmospheric emissions based on the formation of a circular economy in the WKR. The study of various scientific works on the research problem made it possible to substantiate the argumentation of the factors determining the reduction of atmospheric emissions of pollutants. As a result of the study, using the example of KPO, a circular economy model was developed, a close connection was revealed between the volume of atmospheric emissions and indicators reflecting the results of KPO's activities to implement the best available technologies, energy saving, and spending funds on environmental protection. It has been established that while maintaining independent indicators' certain dynamic of development according to the forecast model for the period 2024-2028, the level of atmospheric emissions at KPO can be reduced by 2 times.

The established and proven potential of KPO as a company that successfully implements measures to reduce atmospheric emissions and implement an ESG sustainable development strategy allows regional authorities to take into account their experience when creating conditions for the formation of a circular economy in the region, when developing Roadmaps, strategies or programs for the development of the region. The developed matrix of industrial and agricultural potential of the West Kazakhstan region made it possible to identify the region's potential for the implementation of the integration of all production, technological, and logistics processes, using the key principle - focus on reducing polluting emissions into the atmosphere and recycling waste. Thus, we can recommend key measures to reduce atmospheric emissions: technological modernization of production based on the best available technologies and innovations; forming an reliable waste management system, including sorting, recycling and disposal of waste, promoting responsible consumption and production; energy efficiency stimulation and renewable energy sources use; development of IT infrastructure (creation of AIS/information databases by industry; introduction of "smart" digital technologies); development of economic incentive instruments (tax and payment benefits). The system of taxes on industrial pollution could be transformed into taxes on major pollutants to encourage the use of cleaner and more efficient fuels and technologies. In this regard, attracting investments in the form of issuing green regional bonds, international grants and loans is a necessary resource for circularization in the region.

Limitations and prospects for further research. When developing the model, only those variables were chosen that showed a close and moderate relationship with the aggregate indicator: in particular, we observed a weak connection with the X4 indicator - the volume of recycled industrial waste, due to their small values. At the same time, as part of further research, it will be possible to consider all types of companies formed both at KPO and in the region as a whole. The meteorological factors of the region, due to their diversity and complex nature of impact, were not considered in this study and require further research, the results of which will make it possible to create a modern information database of pollutants using GIS technologies to predict atmospheric air quality.

4. Conclusion

The conducted research allowed us to draw the following conclusions.

1. This study is the first presentation of the possibility of reducing air pollution based on the circular economy formation in Kazakhstan's industrial-agrarian region. Despite the fact that efforts are being made in Kazakhstan to build a circular economy, in comparison with world developed countries, the field of circular economy is still at the beginning of its journey.
2. In this work, based on an analysis of pollutant emissions from each sector of the West Kazakhstan region economy, based on international experience, the task was to consider possible approaches to a circular economy formation that would ensure an atmospheric emissions reduction. The construction of the industrial-agrarian potential matrix of the West Kazakhstan region made it possible to obtain results aimed at updating approaches in managing regional development in order to circularize all processes.
3. The study of atmospheric emissions in the West Kazakhstan region made it possible to zonally identify two sectors: the industrial north - 95.8%, (Uralsk - 34.1%, Burli -26.7% and Baiterek - 35%), and – agricultural south, 4.2% from all atmospheric pollutants emissions in the West Kazakhstan region. Taking this factor into account allows you to adjust the strategy for developing decisions. In the north of the region, in the industrial center, it is necessary to install a coordinated system of automated monitoring and control of atmospheric air quality to promptly respond to changes, allowing adjustment of measures taken on the basis of the geoportal created in the region.
4. It is shown that the international company KPO has the greatest economic (taxes in 2022 - $3 billion), environmental (68,5% of atmospheric emissions from the Burli region) and social impact (share of local content -63.2% in KPO work) on the regional sustainable development. Within the framework of the KPO strategy, implemented in the period 2012-2022 measures to reduce

emissions and waste made it possible to note the effectiveness of these measures and the achievement of a reduction in KPO atmospheric emissions per capita by 2.2 times, the gas utilization rate was 99.95%.

5. The analysis showed that at the moment, the introduction of the circular economy principles is possible only at the mezo level - of an individual international company, in particular KPO. The possibility of using circularity indicators in the company's work was assessed and a circular economy model was proposed. Correlation and regression analysis revealed a close relationship between the volume of atmospheric emissions and indicators reflecting the results of KPO's activities to implement the best available technologies, energy saving, and spending funds on environmental protection. According to the forecast model for the period 2024-2028, it was determined that while maintaining independent indicators' certain dynamics of development, the atmospheric emissions level at KPO can be reduced by 2 times.
6. The scientific work results contain proven arguments for the prospects of further research into the circular economy models formation in the regions of Kazakhstan, aimed at protecting the environment in general, and in particular reducing air pollution.
7. Experience of KPO company which was studied in the work on the formation of a circular economy in the region is relevant and can be applied in other Central Asian countries with the same commodity economy with significant influence of international companies. The governments of Central Asia countries during regulation of the operation of international companies need to form close cooperation with those companies within the framework of corporate social responsibility of business in order to implement sustainable development practices.

Author Contributions: Saken Kozhagulov (correcponding author): Conceptualization, Methodology, Investigation, Writing – original draft, Formal analysis, **Ainagul Adambekova:** Methodology, Validation, Software, Investigation, Writing – original draft, Visualization, **Jose Carlos Quadrado**: Coordination, Conceptualization, Methodology, Formal analysis., **Vitaliy Salnikov:** Coordination, Methodology, Conceptualization, **Svetlana Polyakova**: Methodology, Formal analysis, **Tamara Tazhibayeva**: Formal analysis, Visualization, **Alexander Ulman:** Formal analysis, Visualization.

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Conflicts of Interest: The authors declare no competing interests.

Application A. Environmental Friendliness of Gas Production at KPO for 2012-2022

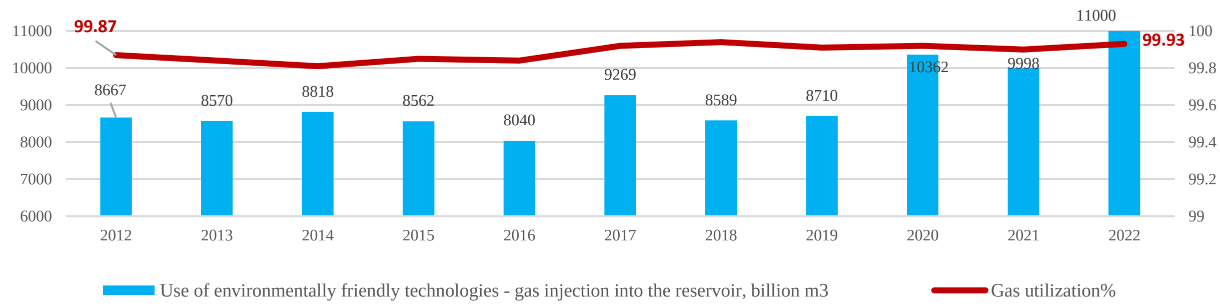

Figure A1. Environmental friendliness of gas production at KPO for 2012-2022. Note: compiled by the authors based on https://www.kpo.kz/.

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Application B. Compliance Matrix for Waste Management Strategy and Tactics at KPO

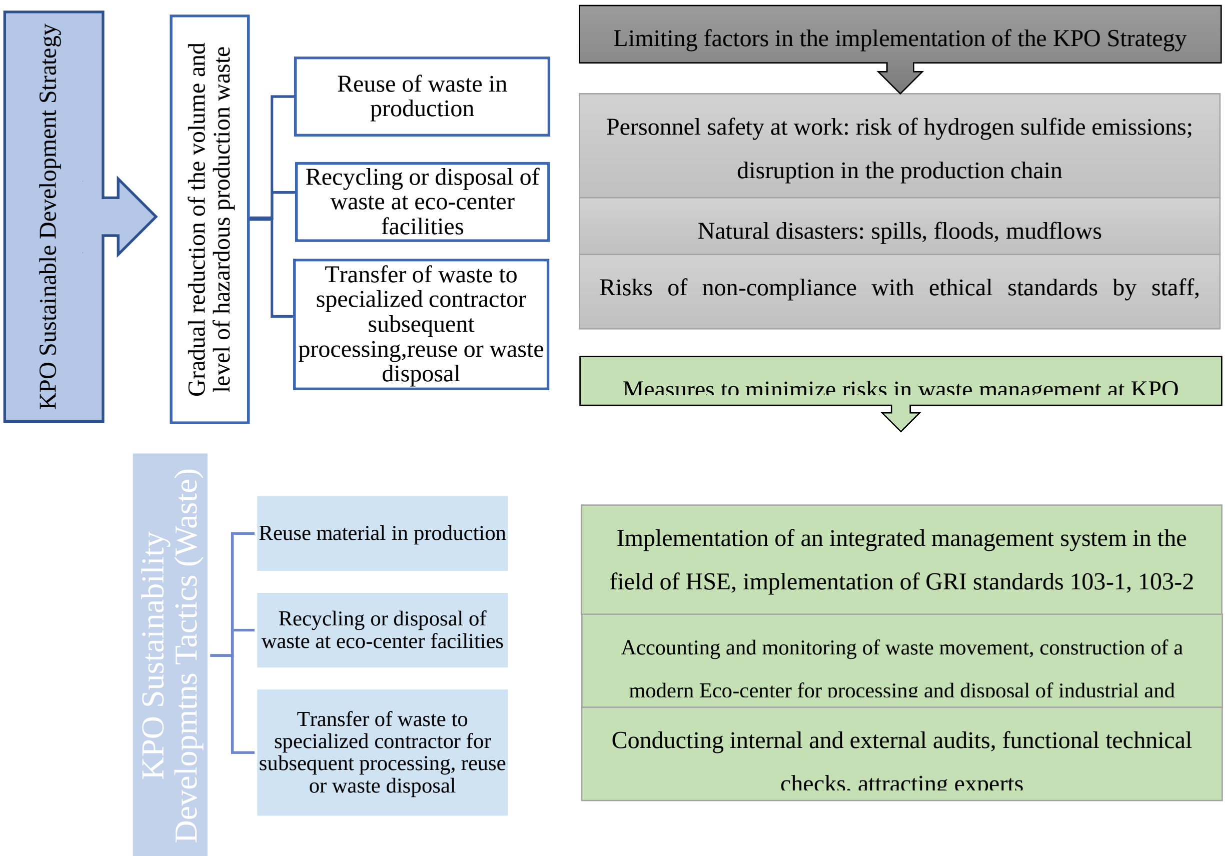

Figure A2. Compliance Matrix for Waste Management Strategy and Tactics at KPO. Note: compiled by the authors based on sources (Circle Economy and Shifting Paradigms,2019, https://www.kpo.kz/en/sustainability, http://waste-nn.ru/sistema-upravleniya-othodami-v-stranah-es).

Application C. Transfer of KPO Waste for Processing to Third Parties for 2012-2022

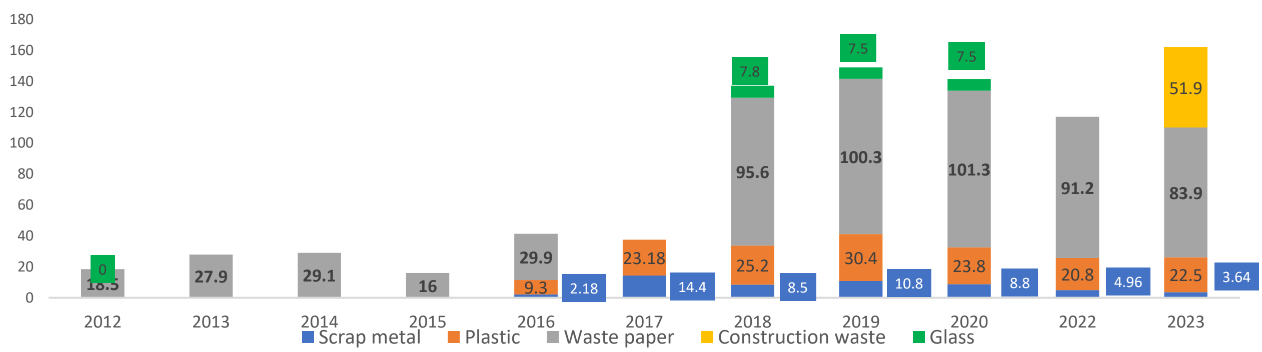

Figure A3. Transfer of KPO waste for processing to third parties for 2012-2022. Source: compiled by the authors based on https://www.kpo.kz/en/sustainability.

Application D. KPO Matrix for the Forecast Period of the Study (2024-2028)

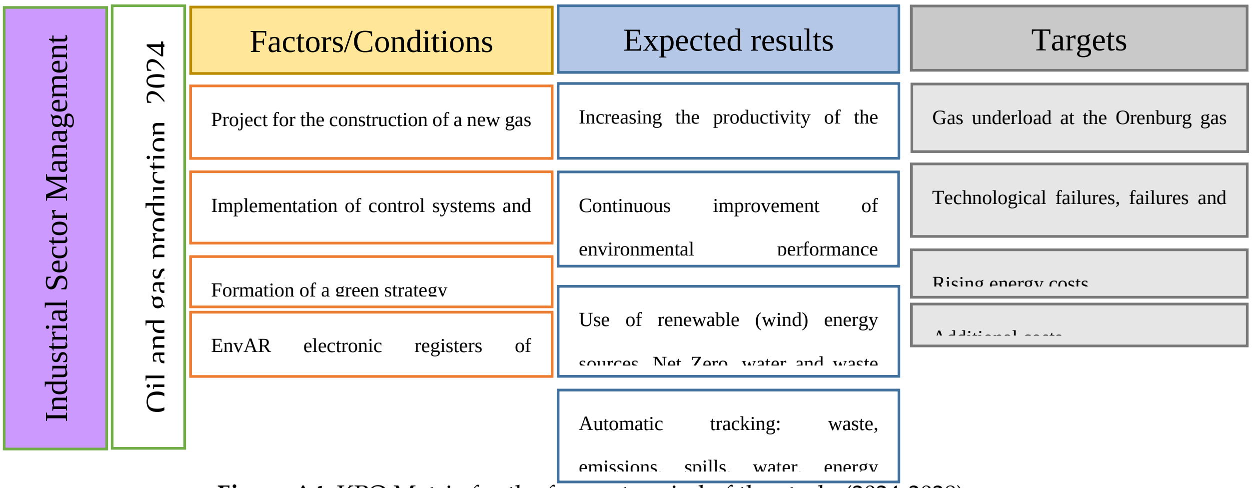

Figure A4. KPO Matrix for the forecast period of the study (2024-2028).

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