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Air Pollution from CHPP-2 in Almaty and Its Health Impact

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Abstract: The development of thermal power engineering significantly affects the environmental parameters of the environment, primarily the state of atmospheric air. The active operation of thermal power plants operating on solid fuels leads in terms of pollutant emissions and the impact on public health. Almaty is a metropolis, which is characterized by a very high level of environmental pollution. The purpose of the work is to study and analyse the factors of atmospheric air pollution from heat and power enterprises using coal fuel and the consequences for public health. The research was carried out using general scientific methods of cognition, in particular, system analysis, synthesis, abstraction, deduction, generalization, and concretization. In the course of the study, the ecological state of the atmospheric air of the city of Almaty was analysed, the algorithm and results of analytical control of the state of atmospheric air were presented, the dynamics of the air pollution index in this region was presented over time, and optimal and realistic measures for implementation were developed to reduce the impact of thermal power engineering on the state of air and public health, improve the overall environmental situation. The possibilities of applying modern management and technological measures to minimize pollutant emissions based on the synergy of environmental safety and energy efficiency, with the introduction of modern innovative systems for controlling and monitoring environmental pollution, were also studied. The results of the study are of significant practical importance for the development and modernization of heat and power enterprises in Kazakhstan using coal as fuel, and can also be used as an effective tool for further analysis of the risks of diseases associated with emissions from coal combustion.

Keywords: combustion products; monitoring; environmental standards; observation post; incidence dynamics

1. Introduction

The climatic and natural conditions of the metropolis, in particular Almaty, have a number of specific features: excessive accumulation of harmful impurities in the surface area of the atmosphere, poor natural ventilation, and, accordingly, a tendency to form smog. The latter is already an integral part of the city's weather conditions, regardless of seasonality[1),2)]. For the city of Almaty, the predominant air pollutants are nitrogen dioxide, sulphur dioxide, carbon monoxide, as well as suspended solids.[3)] These pollutants determine, for the most part, the environmental risk of atmospheric pollution and negatively affect the health of the population[4),5)].

The main contribution to the quantitative indicators of emissions from stationary sources is made by large energy enterprises, in particular, the thermal power complex of CHPP-2 of AlES JSC (thermal power plants of the Almaty Electric Power Stations joint-stock company), located near the western border of Almaty. It should be noted that the northern parts of the city are the most polluted[6)]. This fact is explained by the peculiarities of climatic characteristics (wind regime, indicators of dispersion of impurities). Quantitative indicators of emissions of harmful substances into the atmospheric air from stationary sources of emissions for 2021 exceeded 46 thousand tons. Of these, 38 thousand tons were emitted from the production processes of CHPP-2, thus the indicator significantly exceeds the volume of emissions from all other stationary sources of pollution.

A separate negative factor of influence is the formation of a large amount of ash and carcinogens, which have a significant impact on the health of the population. The predominant majority of coal burned at TPPs is low-grade, with high ash content (more than 40%), originating from the Ekibastuz basin, where open-pit mining technology is

still used, without preliminary enrichment[7]. As a result of the application of classical algorithms for the extraction and preparation of fuel, focused on minimizing costs, the environment is experiencing a huge anthropogenic load. The problem of the impact of emissions into the atmosphere from the operation of coal-fired thermal power plants on the environment and public health, as well as the search for solutions that would reduce the anthropogenic load from the combustion of fossil fuels, in particular coal, has been the subject of many scientific papers and studies.

The negative effects of emissions of pollutants into the atmosphere are studied in the works of A. Askarova et al.[6], D. Kalmykov et al.[7], A. Nugymanova[8]. Scientists pay special attention to the toxic and carcinogenic properties of individual components of gas and dust flows resulting from the combustion of coal fuel. Modern scientists E. Amster[9], M. Munawer[10], J. Moon[11] come to the conclusion that many painful conditions that are difficult to treat with classical treatment and preventive medicine are provoked precisely by large-scale emissions of coal combustion products at large thermal power plants. The conclusions of scientists are supplemented by group C. Zhang et al.[12], as well as A. Cortés et al.[13], convincing of the particular relevance of the impact on children's health. H. Jo et al.[14], in search of ways to optimize the situation and mitigate the negative consequences, come to the conclusion that the modernization of existing thermal power plants with the priority of fuel environmental friendliness, in a system with effective monitoring of environmental pollution parameters, is the best method for greening the heat and power industry and preventing negative consequences for public health indicators.

The study aims to assess how emissions from the CHPP-2 power plant in Almaty affect local and global air quality and public health. It also seeks innovative ways to reduce the environmental impact of coal combustion and implement effective preventive measures. The study in Almaty, Kazakhstan, underscores the severe environmental and health consequences of coal-fired thermal power plants, emphasizing the need for a swift transition to cleaner energy sources and advanced technologies to reduce pollution and protect public health.

2. Materials and Methods

In the course of the study, general scientific methods of cognition were used. When studying literary sources and publications in specialized publications devoted to the problem under study, the main goal was to select relevant and progressive works on the chosen topic in order to assess the current state of research in this area. The theoretical basis of this study is a set of works and research results of modern Kazakh and foreign scientists, statistical data from official national and international sources, analytical materials, publications in scientific and metric databases. Activities in the course of the study, aimed at identifying typical features and patterns of the problem under study, the possibilities of optimizing the situation and finding the most beneficial solutions, were carried out using the generalization method. At the same time, attention was focused on the latest research on the issue under study in recent years.

The general scientific method of deduction was used to determine the essence of the process of the impact of harmful emissions on the environment and health, as a multifactorial process. In addition, in the course of the study, the method of ascent from the abstract to the concrete was used, in the form of a sequential transition from general abstract data on the vectors of the negative impact of emissions from coal combustion to specific data on the consequences of CHP-2 operation on the air and public health in Almaty, as well as to the practical innovative possibilities of preventive measures. To determine the effectiveness, features, and benefits of certain solutions in the process under study, a systematic approach was used. With its help, the study is focused on revealing the integrity of the object of study, a comprehensive search for solutions. Particular attention is paid to the variability of approaches and the need to foresee possible difficulties in practical implementation in the conditions of the economic reality of developing countries.

In the process of research, such methods as system analysis, synthesis and generalization, formalization, abstraction, concretization were also used. The synthesis method is applied to determine the feasibility of modern management decisions at the regional and national levels. The abstraction method was used to form the presentation of the process of monitoring, management and control in the field of the impact of quantitative and qualitative indicators of emissions on the state of air and public health. The concretization method was applied to determine the factors of effectiveness and economic feasibility of preventive measures, forecasting and modelling of extreme negative consequences of CHP-2 operation on the atmospheric air in Almaty and health indicators of the population of the metropolis. The determining factors for choosing optimal management and production-technological solutions to reduce the negative impact of the process of operation of pulverized-coal heat and power enterprises on the natural environment are identified. The possibility of the effective combination of innovative technological solutions with the development of a system for monitoring the parameters of environmental pollution during the operation of TPPs is considered.

In the course of the study, the formalization method was also used. The results of the work are focused on active practical application in the future, in the process of optimizing the management of risks of air pollution by hazardous and toxic substances and related morbidity, arising subsequently from the activities of heat and power enterprises, as well as for further analytical and scientific research of the phenomenon under study.

The power plant under study is the A. Zhakutov CHPP-

2 (Almaty, Republic of Kazakhstan). Construction of Almaty A. Zhakutov CHPP-2 was started in 1974 with the design capacity of the first stage of 240 thousand kW, to increase the level of seismic safety the station was buried at 12 meters. The installed capacity of the plant is: electric – 510 MW; heat – 1411 Gcal/h. The CHPP operates according to the thermal schedule with additional power generation in condensing mode. Heat supply to the Western heat complex is carried out through heat mains Dy=800 mm and 1000 mm. The hot water supply system is open.

Fig. 1: A. Zhakutov CHPP-2

3. Results

Atmospheric pollution by the products of the activity of thermal power plants using coal fuel is an influential and permanent factor influencing the environment and public health. Almaty belongs to the cities of Kazakhstan, which are characterized by a systematically high long-term level of atmospheric air pollution[4)]. At the same time, air quality indicators are formed under the influence of a complex of natural and anthropogenic factors, including meteorological conditions[12),15)].

The city of Almaty is a metropolis of Kazakhstan, located in the southeast of the country[7)]. The natural and climatic features of the area contribute to the creation of conditions for increased atmospheric pollution. The city is located in a kind of depression, so calmness, fogs, and inversions are characteristic. The frequency of weak winds ranges from 71% in summer to 79% in winter. The average annual value does not exceed 1.7 m/s[4)]. Under conditions of temperature inversions and stable stratification, the indicators of dispersion of impurities in the surface layer of atmospheric air deteriorate significantly[10)]. The planning structure of the city is characterized by a complex landscape and geographical position. Almaty, as a representative example of a large city with a developed industry and the presence of large thermal power facilities, has poor air self-cleaning resources[8)]. Factors of self-purification of air masses by wind are at an insufficient level to maintain the required level of indicators of the state of atmospheric air.

The modern scientific approach to assessing the level of atmospheric air pollution is based on the indicator of the complex index of atmospheric pollution (API_5). It is determined by substances with maximum normalized values of maximum allowable concentrations (MAC), in accordance with RD 52.04.186 – 89 "Guidelines for the control of atmospheric pollution" [6)]. The optimality of the practical use of this approach to assessing the level of atmospheric pollution is explained by the scientific fact that the impact on human health of all pollutants is identical at the level of maximum permissible concentrations. At the same time, with an increase in the concentration of substances, the level of their negative impact increases at a different rate, which directly depends on the hazard class of the substance. The assessment of the degree of atmospheric pollution is carried out in the required time sections (Table 1).

Table 1. Assessment of the degree of air pollution in Almaty.

Air pollution level	Air pollution indicators	Estimation over time		
		in 24 hours	per month	in a year
Low	SI	0-1	0-1	0-1
	HR, %	-	0	0
	API	-	-	0-4
Increased	SI	2-4	2-4	2-4
	HR, %	-	0-19	0-19
	API	-	-	5-6
High	SI	5-10	5-10	5-10
	HR, %	-	20-49	20-49
	API	-	-	7-13
Very high	SI	More than 10	More than 10	More than 10
	HR, %		More than 50	More than 50
	API			Over 14

Note: SI – standard indicator; HR – high repetitiveness.[4]

According to the data obtained as a result of observations by RSE "Kazhydromet" over the past four years, it is possible to state a high level of air pollution in Almaty. At the same time, a progressive increase in the level of pollution is observed. For example, back in 2017, the air pollution index (API) was 6 (relatively low level), and since 2018 it has been at least 7 (high level of pollution) (Fig. 2).

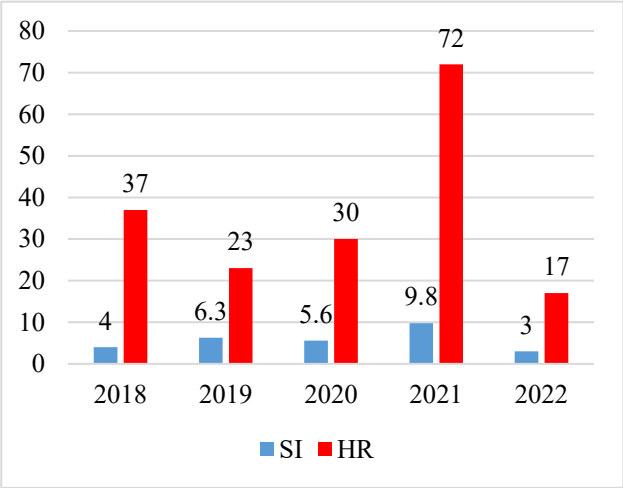

Fig. 2: Comparison of SI and HR for November 2018-2022 in Almaty[4].

Note: SI – standard indicator; HR – high repetitiveness.

Figure 1 shows the dynamics of the level of air pollution in Almaty. In November 2018, 2019, 2020, the level of pollution was high, in 2021 it was very high. Exceeding the maximum one-time MPC was observed, firstly, for suspended particles PM2.5 (686) and particulate matter RM-10 (111), as well as for carbon monoxide (300), nitrogen dioxide (707), nitrogen oxide (254), ozone (289), hydrogen sulphide (9). Exceeding the norms of average daily concentrations was observed for nitrogen dioxide and formaldehyde. The maximum excesses were noted for nitrogen dioxide[4]. Such dynamics are representative of megacities, which are affected by the consequences of the activities of heat and power enterprises, as well as the presence of specific meteorological conditions.

The CHPP-2 enterprise, with a capacity of 510 MW, uses fossil coal as the main fuel and is the largest thermal power plant in the region, providing Almaty with heat (by 60%) and electricity (by 40%)[7]. The exhaust combustion products of organic coal fuel burned at CHPP-2 contain fly ash and bottom ash, sulphuric and sulphurous anhydrides, nitrogen oxides, sodium salts, vanadium compounds, aldehydes, ketones, soot solid particles, coke, gaseous products of incomplete combustion of organic fuel. All of them, when certain concentrations are reached, have a detrimental effect on the environment and public health. Combustion products contribute to acid precipitation and the greenhouse effect[10]. The consequences for the human body, according to the results of modern research and statistical observations, are not limited to frequent respiratory diseases caused by elevated concentrations of sulphur dioxide and nitrogen dioxide in the atmospheric air. Solid particles provoke lung diseases, and heavy metals provoke the development of neurological disorders, delay in the development of children, and also have carcinogenic properties[13),14)].

Particular attention should be paid to PM2.5 particles resulting from coal combustion. They are air pollutants consisting of microparticles of a mixed state of aggregation up to 2.5 μm in size[16]. Small doses of these substances do not cause an immediate reaction of the human body, but they are able to accumulate, having a cumulative effect, and over time lead to serious diseases of the cardiovascular and respiratory systems, inflammatory processes, diseases of the circulatory system, and oncology (Fig. 3).

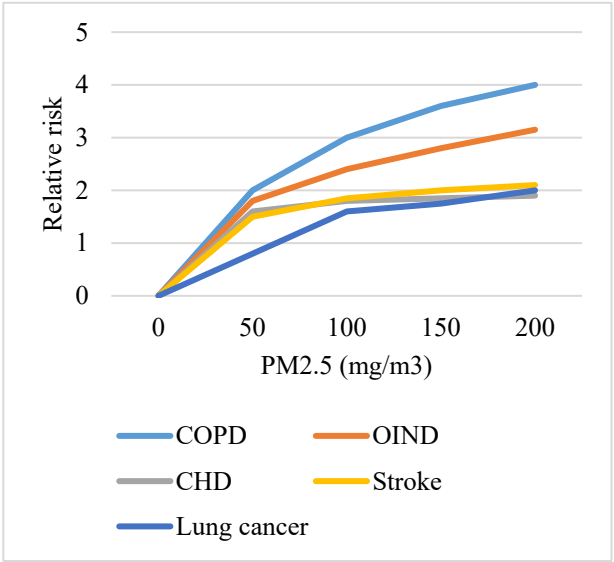

Fig. 3: PM2.5 concentration and the risk of serious diseases.[19]

Note: COPD - chronic obstructive pulmonary disease, CHD - coronary heart disease, OIND - other inflammatory neurological diseases

Based on the results of studies, it is worth noting that with an increase in PM2.5 in the composition of atmospheric air to 200 μg/m^3, the relative risk of deaths caused by lung cancer increases by 100%, and the relative risk of deaths from chronic obstructive pulmonary disease (COPD) is increased by 300%. It should be noted that in the city of Almaty, the values of air pollution with PM2.5 particles often reach 526 μg/m^3. Statistics on premature mortality in Kazakhstan testify to the fact that diabetes is the leading cause of death caused by dirty air (15%). In addition, 6% of neonatal deaths are a direct consequence of elevated PM2.5 concentrations in the air (Fig. 4).

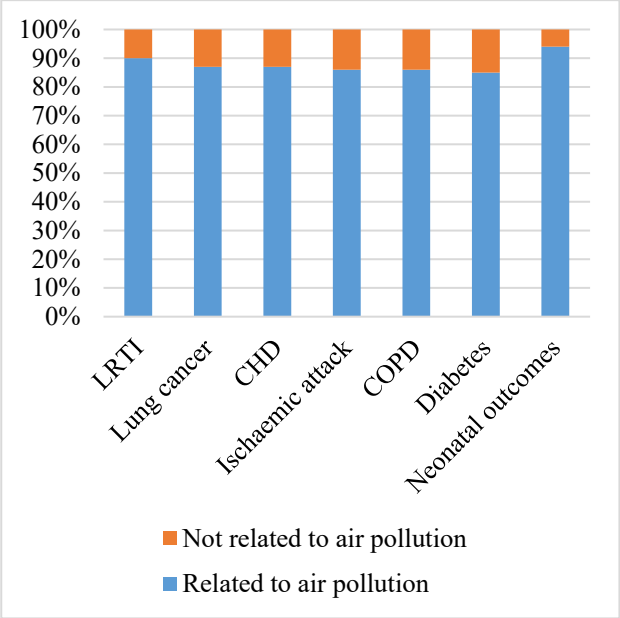

Fig. 4: Dependence of mortality rate on diseases provoked by air pollution in Kazakhstan.[20)]

Note: LRTI - Lower respiratory tract infection, CHD - coronary heart disease, COPD - chronic obstructive pulmonary disease.

Monitoring of environmental parameters of atmospheric air in the city of Almaty is carried out by the enterprise "Kazgidromet". For this purpose, 16 observation posts are used (5 stationary posts, 5 automatic ground posts and 6 high-altitude automatic posts)[4)]. Analysing the observational data on the state of the air obtained with the help of ground stations No. 30 (6 km east of CHPP-2) and No. 1 (13 km southeast of CHPP-2), it is possible to identify a certain regularity in the distribution of harmful impurities in the surface layer of the atmosphere with distance from the source of emissions from CHPP-2. Post no. 30, located 6 km from the thermal power plant, is more polluted. This trend can be tracked both by the concentration of sulphur dioxide and by the concentration of nitrogen dioxide. Thus, the level of atmospheric air pollution with sulphur dioxide per year exceeds the maximum allowable concentration by 6.7 times and is 0.337 mg/m^3 for the post located closer to CHPP-2, while for the post that is further away, the average concentration of sulphur dioxide is 0.027 mg/m^3, which exceeds the maximum allowable concentration by 0.5 times. The same regularity is typical for nitrogen dioxide (the average concentration per year is 0.208 mg/m^3 for the station located closer to CHPP-2, and 0.139 mg/m^3 for a more remote station). As for the maximum one-time concentrations of nitrogen dioxide, the difference is even more noticeable. So, at post no. 30 their excess of MPC can reach 15.8 times while at post No. 1, the excess value is no more than 4.4[4)].

There are several viable options for further reducing pollution from heat production in Almaty, which include the adoption of renewable energy sources, implementing efficiency improvements, and embracing cleaner technologies. Almaty can accelerate its shift towards renewable energy sources such as solar, wind, and geothermal energy for heat production. Solar thermal systems, in particular, can be used to generate heat directly from sunlight, reducing reliance on fossil fuels.

Implementing combined heat and power systems that simultaneously generate electricity and useful heat can significantly improve energy efficiency, reduce emissions, and lower overall operating costs. Utilizing biomass and biogas as renewable fuel sources for heat production can be a sustainable option. Biomass boilers and biogas digesters can convert organic waste into useful heat energy. Modernizing and expanding district heating systems can enhance their efficiency and reduce heat loss during heat distribution. Well-designed district heating networks can efficiently deliver heat to homes and businesses.

Implementing energy-efficient technologies and practices, such as upgrading insulation, using high-efficiency heating equipment, and optimizing building designs, can reduce the overall demand for heat. Implementing carbon capture and storage technologies in heat production facilities can capture carbon dioxide emissions before they are released into the atmosphere, helping to mitigate pollution. Utilizing waste heat from industrial processes or power generation for district heating can increase energy efficiency and reduce emissions. The government can introduce and enforce stricter emissions standards and incentives to encourage the adoption of cleaner technologies and practices in the heat production sector. Raising awareness among the public and industries about the environmental impact of heat production and the benefits of cleaner alternatives can promote voluntary reductions in pollution. Investing in research and development of innovative technologies and solutions for cleaner and more efficient heat production can drive long-term sustainability. By combining these measures and tailoring them to Almaty's specific needs and resources, the city can significantly reduce pollution from heat production while simultaneously improving energy efficiency and promoting sustainability.

Specific Pollutants Emitted from CHPP-2:

1. Particulate Matter (PM): CHPP-2 emits fine particulate matter, including PM2.5 (particles with a diameter of 2.5 micrometers or less) and PM10. These particles can carry various toxic compounds and have adverse health effects.

2. Sulfur Dioxide (SO2): CHPP-2 releases sulfur dioxide into the atmosphere, a major contributor to acid rain. SO2 can irritate the respiratory system and exacerbate respiratory conditions.

3. Nitrogen Oxides (NOx): Nitrogen oxides, including nitrogen dioxide (NO2) and nitrogen monoxide (NO), are produced during combustion at CHPP-2. They contribute to the formation of ground-level ozone and can lead to respiratory problems.

4. Carbon Monoxide (CO): CO is a colorless, odorless gas emitted from CHPP-2. High levels of CO can reduce oxygen delivery to the body's organs and tissues, potentially causing health issues.

5. Volatile Organic Compounds (VOCs): CHPP-2 may release VOCs, which can react with other pollutants in the atmosphere to form ground-level ozone and contribute to smog formation.

6. Heavy Metals: Coal combustion can release heavy metals like mercury, lead, and cadmium. These metals can accumulate in the environment and have toxic effects on human health.

The quantities of pollutants emitted from CHPP-2 can vary depending on factors such as fuel type, combustion technology, and emission control measures. It is crucial to obtain emissions data directly from the plant's regulatory records or environmental impact assessments to provide precise quantities.

PM, NOx, and SO2 are associated with respiratory problems such as asthma, bronchitis, and reduced lung function. They can also worsen existing respiratory conditions. Air pollutants, including CO, PM, and VOCs, can increase the risk of cardiovascular diseases, including heart attacks and strokes. Some pollutants, like lead and mercury, can have neurotoxic effects, particularly in children, leading to developmental issues and cognitive impairments. Long-term exposure to certain pollutants, such as benzene and formaldehyde (VOCs), can increase the risk of cancer. Emissions from CHPP-2 can contribute to smog formation, acid rain, and damage to ecosystems, impacting biodiversity and water quality.

The specific health effects can vary depending on the concentration of pollutants, duration of exposure, and individual susceptibility. Monitoring and regulating these emissions are crucial for minimizing their impact on public health and the environment. Public health authorities and environmental agencies typically conduct air quality assessments and health impact studies to evaluate the effects of emissions from facilities like CHPP-2 on local populations[17)-19)].

Many scientists accept standardized emissions of pollutants into the atmosphere as basic information for further analytics and the development of solutions[21)]. In accordance with generally recognized world standards in the field of atmospheric air protection, emissions from pulverized coal thermal power plants are currently limited by four main indicators: oxides of sulphur, nitrogen, carbon and fly ash (Table 2).

Table 2. Current standards for emissions of harmful substances into the atmospheric air, mg/m^3 [10)]

Pollutant	Kazakhstan standards	Intermediate standards	European Union standards
Solid particles (ash)	1200-1600	300-600	50-100
Sulphur dioxide	2000-3000	1000-1500	400
Nitrogen oxides	600	650	500

Analysing Table 2, it is worth noting that the adoption of lower standards for coal-fired thermal power plants in Kazakhstan was a forced measure, primarily related to the technological backwardness of the main equipment[3)]. The difference in standards for quantitative measures of emissions in different countries today is significant, but it ensures the adaptability of the transition process to the requirements of a green economy. As part of the Green Deal implemented by the European Union in the field of environmental protection and energy, actions in the energy sector should be aimed primarily at reducing the share of solid fuels in the energy mix. The requirements for its quality are also becoming stricter. This situation requires the coal mining industry to reorient its approach to the evaluation of deposits, which must be analysed in terms of technical, and economic parameters, as well as the quality of coal and its potential environmental impact during its combustion. At the same time, it is clear that significant reducing the environmental stress of the heat and power complex, in this case, the city of Almaty, can only be achieved by using fuel that is cleaner in terms of environmental parameters, for example, natural gas[7)]. The current “green” course of development of industry and economy, which the world community is striving for, must certainly be reflected in the process of modernization of the heat and power industry in Kazakhstan.

The discussion of the health impacts on Almaty residents may be more relevant if local health statistics are taken into account. To obtain relevant information on the impact of CHPP-2 on the health of Almaty residents, aspects such as morbidity surveillance can be taken into account. Analyzing statistics on the incidence of respiratory diseases (such as asthma, bronchitis), cardiovascular diseases (heart attacks, strokes), and other diseases that may be related to air pollution from CHPP-2[20)].

Conducting specialized medical studies to assess the impact of specific pollutants, such as heavy metals, nitrogen oxides, and sulfur dioxide, on the health of residents. Conducting continuous air quality monitoring in Almaty, including measuring pollutant levels and the spread of polluted air along the wind. Studying the dynamics of air pollution and morbidity over the years to identify links and trends. Taking into account the geographical features of the area and the location of residents in relation to the CHPP-2 to more accurately determine the possible impact on specific areas. The results of such a study can provide more specific

information on the health impacts of the CHPP-2 on Almaty residents, and this information can be used to develop specific measures to minimize negative health impacts and improve air quality in the city[21].

To date, the "Program for the Development of Almaty until 2025"[6] has been developed, according to which large energy companies will switch to natural gas. To minimize the impact of CHPP-2 on the environment, appropriate documentation is being developed for conversion to natural gas. Until 2024, one coal-fired boiler at CHPP-2 should be decommissioned, which will reduce emissions by 4.5 thousand tons per year. At the same time, it is planned to put into operation a gas block with emissions of about 830 tons/year. The expected level of emissions from CHPP-2 in 2025 will be about 3.7 thousand tons/year, and after the subsequent commissioning of three gas units, by 2030 it should decrease to 2.5 thousand tons/year. Thus, the conversion of CHPP-2 to natural gas will reduce the volume of pollutant emissions by 33.5 thousand tons per year. Such cardinal measures can not only optimize the ecological parameters of the environment, but also significantly reduce the risk of serious diseases in the population caused by the toxic effect of coal combustion products in the atmospheric air of Almaty. In addition, the introduction of strict requirements for improving the quality of coal and the installation of multi-stage cleaning systems at CHPPs can serve as a kind of "safety cushion" in case of difficulties on the way to the complete abandonment of coal in the long term, and in the case of a peremptory introduction into operation today can significantly reduce the anthropogenic pressure from coal combustion on the environment.

4. Discussion

Numerous scientific studies confirm the negative cumulative effect of air pollution on the emergence of various negative health conditions and increasing the risk of deaths. Modern scholars S. Wang[22] propose to be guided by the "concentration-response" relationship, which links the impact of air pollution with the increase and risk of morbidity. Using this approach, it is possible to effectively assess how the current decline in population health is related to the level of atmospheric pollution. This approach to studying the relationship between the state of air in large cities where coal-fired thermal power plants operate and the level of health of their population is supported by the group of Z. Asif et al.[23] Their recent research demonstrates the results of the synergy of the concentration-response relationship with modern atmospheric models that track the deposition, dispersion, and chemical transformation of atmospheric pollutants. With this approach to the analytical process, it is possible to make an adequate estimate of the number of deaths that could have been avoided using alternative scenarios for emissions from coal-fired thermal power plants.

Differences in the existing standards for quantitative measures of emissions in different countries today are significant, but it ensures the adaptability of the transition process to the requirements of a green economy. Many scientists convince of this in their works[21] and it is difficult to disagree with them. Ecologization of heat and power processes in the process of adaptation to the requirements of a green economy involves the use of highly efficient dust and gas cleaning equipment as part of the modernization of existing coal-fired power plants[24)-26]. Such measures minimize the harmful impact of CHPP operation on the atmospheric air, bringing quantitative indicators closer to international environmental standards. A. Rossiter and B. Jones[27] are convinced that effective management can become an effective tool for improving the energy efficiency of enterprises and reducing the burden on the environment. Such a theory requires the implementation of the real economic conditions of Kazakhstan, taking into account the national characteristics of the development of the fuel sector, but it deserves attention at the transitional stage of modernization of the energy industry. There is positive international experience in phasing out coal from the energy market, and both experience and discovered hidden obstacles to the process should be used to the maximum[28),29].

The negative impact of coal combustion on the health of the population stimulates the creation of new priorities in the process of "coal revolution" [30]. After all, the well-being of the population in terms of health indicators is one of the main indicators of the degree of development of the country as a whole[11),31]. Of particular concern are the studies of modern scientists regarding the indicators of children's health, and even prenatal development[13)-15]. Today, health indicators against the background of global climate change and the global strategy for phasing out coal fuel should become a priority litmus test for determining the vectors of managerial and technological decisions in the energy sector[32)-34]. Thus, it can be argued that only in close interaction of the technological, economic and environmental components of the process of modernization and optimization of the operation of pulverized coal-fired power plants, it is possible to achieve a real reduction in the negative impact on the environment. The studies of many modern scientists are based on this approach[35]. Z. Asif et al.[23] are convinced that the key to a significant reduction in air emissions from coal combustion is the optimization of existing air pollution control technologies based on the basic principles of a circular economy. There is a need to create a management system that can take into account the relationship between environmental requirements and economic goals, as well as minimize the likelihood of pollution risk. B. Wibawa et al.[35] conclude in the studies that in parallel with data monitoring, it is necessary to predict the concentration of pollutants under various meteorological conditions in order to develop a mitigation strategy and develop preventive measures.

Some scientists focus on the effect of dispersion on the level of air pollution[36]. In their view, dispersion enhances the transport of pollutants over long distances, thus threatening the health of the population located far from the source of emissions. Among the directions for minimizing the anthropogenic load from pulverized coal-fired CHPPs (for example, CHPP-2 for the city of Almaty), it is worth highlighting those that deserve priority attention[37),38]. First, the prerogative should remain with the technological modernization of existing equipment and fuel combustion processes, taking into account current environmental standards. Radical measures can carry an unbearable burden from the point of view of the economic aspect. Although, the desire for partial or complete replacement of coal fuel with natural gas should be the main long-term goal of modernizing the energy sector[39]. Secondly, among the technological solutions, special attention should be paid to those that combine energy efficiency, productivity increase and minimization of pollutant emissions from coal fuel combustion into the atmospheric air[40),41]. Certainly, we cannot disregard the influence of efficient management measures, including stricter supervision of air pollutant emissions, the establishment of an environmental monitoring system, and the incorporation of innovative prediction and monitoring capabilities[42].

The evolution of Kazakhstan's energy sector is closely intertwined with the worldwide movement towards emphasizing environmental considerations in energy operations and mitigating adverse effects on public health. A gradual and economically sound adoption of green economy and energy principles can foster a harmonious equilibrium, preventing the emergence of distressing adverse outcomes.

5. Conclusions

For Kazakhstan's advancement toward a "green" economy and the transformation of production processes, a crucial step involves redirecting the energy sector toward eco-friendly fuels. Additionally, it necessitates a comprehensive overhaul of existing thermal power facilities, integrating energy-efficient, environmentally conscious innovative technologies. These technologies play a pivotal role in controlling the formation of harmful substances and curbing emissions into the atmosphere. The primary objective in this context is the transition to natural gas as a fuel source, which can significantly diminish adverse effects on the environment.

Within the study, a thorough examination was conducted to scrutinize the key aspects of the detrimental impact of emissions from pulverized coal-fired thermal power plants, using CHPP-2 of AlES JSC as a case study, on air quality parameters and the health indicators of the Almaty population, serving as a representative region. The research encompassed an analysis of morbidity trends based on the concentration of specific harmful substances and the overall level of air pollution. Furthermore, the study delved into the relationship between air pollution indicators in Almaty and the proximity to CHPP-2.

Possible consequences for the health of the population of a metropolis in the case of a long-term cumulative effect of pollutant exposure are considered. The study proved that coal-fired thermal power plants reproduce the maximum burden on the environment, primarily on the quality of atmospheric air, the secondary consequences of which are serious negative changes in the health of the population. It has been determined that only the joint application of technological, and managerial measures and the introduction of innovative control methods can have a significant impact on minimizing the consequences of the operation of existing Kazakhstani TPPs. The information obtained as a result of the study can be effectively used for practical application.

Strict observance of the requirements in terms of maximum permissible concentrations of harmful substances in emissions of combustion products into the air, reduction of existing regulations to the standards of developed countries, the use of modern innovative technological solutions in the coal-fired power industry, the gradual abandonment of coal in favour of gas fuel and alternative energy sources will help optimize the operation of coal-fired thermal power plants, along with effective management measures and the introduction of an environmental monitoring system. Further research requires the possibility of modelling and predicting the impact of emissions, as well as determining the optimal preventive solutions.

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