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Environmental safety of power industry development in the Central Asian region

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ABSTRACT

This research has aimed to investigate the environmental aspects of the further development of energy systems in Central Asia (CA) based on traditional and renewable energy (RE). To analyze the situation at present, the article reviews the energy profiles of Central Asian states, their respective primary energy consumption and overall CO2 emissions distribution, as well as GHG (greenhouse gas) emissions, current state of the energy sectors, fuel consumption structure, energy efficiency and wear of power equipment, with the focus on Kazakhstan and Uzbekistan as the countries leading power consumption and related emissions in the region. However, the conclusions and recommendations presented in the article are equally appropriate for all Central Asian countries. As per the UN sustainable development policy document, the choice of power supply sources should be guided not only by the analysis of financial costs, but also the assessment of environmental impacts. Thus, in order to ensure such choices are environmentally safe and galvanize green projects, as well as foster sustainable development of target nations, the research team proposes a mechanism of applying a taxonomy similar to that in the European Union (EU) allowing the most expedient use of allocated financial resources. The article presents a methodology for estimating GHG and pollutant emissions into the atmosphere by thermal power plants (TPP), as well as explores the expediency of using energy storage units to support large-scale RE integration across CA with the aim of ensuring eco-safety of energy developments in the region.

KEYWORDS

environmental safety, electric power industry, thermal power plants, emissions of greenhouse gases and pollutants into the atmosphere, renewable energy sources, energy storage devices

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1. Introduction

Currently, climate change is the main issue on the planet, its effects being global in nature and unprecedented in scale. Economic development worldwide, population growth, and increased consumption of fossil fuels have contributed to increased global greenhouse gas emissions.

Greenhouse gases absorb and simultaneously emit radiant solar radiation in the thermal infrared range. These properties are responsible for the greenhouse effect, first described by the French scientist Jean-Baptiste Joseph Fourier in 1824. The primary greenhouse gases in the Earth's atmosphere are water vapor (H2O), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and ozone (O3).

One of the primary causes of global warming is related to rising levels of carbon dioxide in the atmosphere, which is released during fossil fuel combustion and general human activity. Overall, the increase in CO2 accounts for approximately 75% of the anthropogenic increase in the greenhouse effect (World Wildlife Fund). WWF. Climate and energy. Simple answers to complex climate questions).

This growth of CO2 concentration is an important driver of global warming. According to ecologists, by 2040, the planet may pass the point of no return.

The combustion of organic fuels at thermal power plants during electricity generation, which together provide more than 2/3 of the total output of all power plants in the world, is the main reason for the anthropogenic intensification of the greenhouse effect on a global scale. Fossil fuels accounted for 83.1% of the world's energy consumption in 2021 (Energy and Development in Central Asia: A Statistical Review..., 2018). Moreover, 46% of the world's electricity is coal-generated, 18% is based on gas, and about 3% is due to biomass burning.

Therefore, to protect the surrounding biosphere and human society from the effects of energy on the environment, which negatively affects climate change, it is necessary to ensure the electric power industry's development, considering environmental safety.

This article's consideration of the existing situation and the proposed solutions will not only help the general public understand the region's accumulated problems and methods of solving them, but it can also serve as the beginning of large-scale research in this area, which, of course, should be extremely important for the practical implementation of the region's principles of sustainable development.

2. The Current Environmental Situation and Energy Profiles of Central Asian Countries

Table I (EES EAEC website. World Energy, 2021) summarizes CO2 emissions in the Central Asian countries. As Table 1 shows, Kazakhstan and Uzbekistan are the leaders in the region.

Table I. CO2 Emissions in Central Asia (according to EDGAR data)

List of CA countries by CO2 emissions in megatons per year and share in % of total emissions					
Country	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
2020, mln tons	212,89	9,73	9,21	72,34	122,15
2021, mln tons	211,21	10,78	10,13	83,32	125,65
2021, %	0,56	0,03	0,03	0,22	0,33
Place in the list of the world's countries by CO2 emissions	28	107	109	41	38

Table II (Uzbekistan: ESG dossier, 2021) shows a brief energy profile for each country in 2019.

Table II. Energy Profiles of Central Asian Countries

A brief energy profile of CA countries for 2019.					
Country	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Installed capacity of power plants, MW	23 965	3 869	6 451	5 201	15 948
TPPs burning fossil fuel, %	83,8	19,0	11,1	100	88,0
Gross electricity production, mln kWh	106 879	15 100	20 676	22 534	63 021
Electricity production at TPPs, %	89,2	8,3	7,3	100	89,7
Fuel consumption at power plants and in heating installations, thousand t.c.e.t.	62 888	472	930	12 613	21 861

According to Enerdata (www.enerdata.net), Kazakhstan ranks among the world's top ten energy-intensive economies. Coal-fired generation is Kazakhstan's primary source of electricity and heat, making up approximately 70% of all energy produced. According to the Kazakhstan Electricity and Capacity Market Operator, in 2021, coal accounted for more than half of the country's domestic consumption of primary energy resources. Moreover, most of the coal burned in thermal power plants is supplied from the Ekibastuz coal basin and, therefore, has a high ash content (greater than 40%), making its enrichment unprofitable.

It is important to note that the coal and electricity production industries receive subsidies from the state, which are not taken into account when calculating the cost of electricity (in 2019 – 1831.9 million US dollars; in 2020 – 1381.2 million US dollars, according to the International Energy Agency (IEA) (EES EAEC website. World Energy, 2021). The low price of coal makes it the country's main source of electric and thermal energy, ensuring the competitiveness of the economy of Kazakhstan. The use of coal is further facilitated by energy infrastructure, which has been developing in the country for decades.

CO_2 emissions in 2021 amounted to 212.89 million tons, and in 2022 – 211.21 million tons, which is 0.56% of total global emissions (CO_2 emissions in all countries of the world, 2021).

Figure 1 (Country Report on Climate and Development: Kazakhstan, 2021) shows Kazakhstan's greenhouse gas emissions from 1990 to 2019.

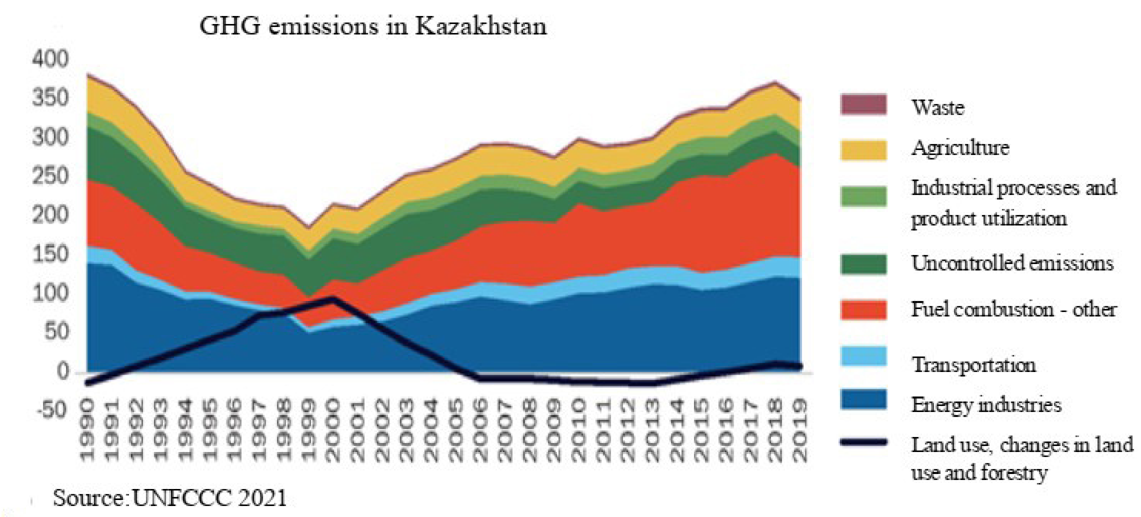

Fig.1. Greenhouse gas emissions of Kazakhstan from 1990 to 2019

In 2019, Uzbekistan's total greenhouse gas emissions amounted to 189.2 Mt CO_2eq (0.189 Gt CO_2eq).

In 2020, CO_2 emissions from fuel combustion in Uzbekistan amounted to 90.37 Mt CO_2e, which was 0.25% of the global total. With 2.71 Mt CO_2 per capita, Uzbekistan ranked 103rd in the world (EES EAEC Website. World Energy, 2021). CO_2 emissions were 122.15

million tons in 2021 and 125.65 million tons in 2022, 0.33% of the world's total emissions (CO2 Emissions in All Countries, 2021). The energy sector is the country's leader in greenhouse gas emissions, accounting for 80% of the total emissions. Agriculture accounts for another 15%.

In (Uzhydromet, 2021), it is noted that the share of carbon dioxide CO2 in Uzbekistan accounts for 99.3% of total greenhouse gas emissions from fuel combustion. At the same time, the energy sector makes the largest contribution to greenhouse gas emissions in the production of electricity (33.6 %). Figure 2 summarizes Uzbekistan's greenhouse gas emissions from 1990-2016 (Uzhydromet, 2021).

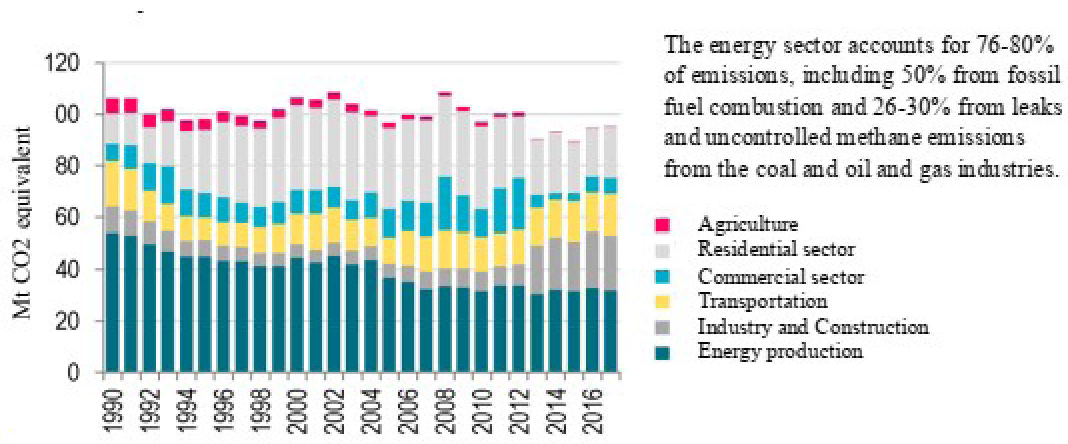

Fig. 2. Greenhouse gas emissions in Uzbekistan from 1990 to 2016.

Given that electricity production in the rest of the Central Asian countries is far lower (Fig. 3) (Energy and development in Central Asia: a statistical review..., 2018), and a number of our proposals to reduce emissions in the energy sector can be applied to all Central Asian countries, we have chosen to not include them in the scope of this paper.

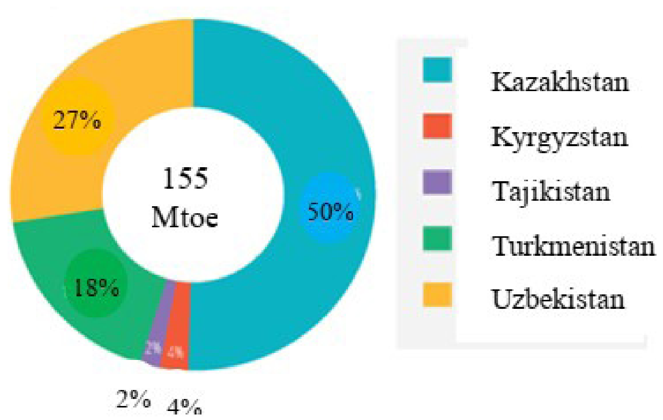

Fig. 3. Total Primary Energy Supply in Central Asian Countries

Realizing that climate change affects the entire global economy and all industries, the countries of Central Asia, alongside the rest of the world, began to take measures to reduce greenhouse gas emissions into the Earth's atmosphere.

3. Ways of solving energy-related environmental problems in Central Asian countries

Developing a global green economy is the primary task when transforming national economies. The large-scale impact of the fuel and energy companies (FEC) industries on the environment and human health is becoming a relevant issue for modern energy. The development of the energy sector should be matched by ensuring the necessary degree of energy reliability and environmental safety of power plants. Naturally, this course of action requires significant financial and intellectual resources. Today, when choosing the capacity and type of power plant to design, it is already necessary to focus on both the environmental consequences of their operation and on minimizing financial costs.

Solving environmental energy-related problems in Central Asian countries requires improving and implementing regulatory, technological, organizational, and financial structures. These aspects must be taken into account to ensure the environmental safety of fuel and energy facilities in the region. Each aspect has dozens of different implementation methods, which should be discussed in more detail in subsequent studies. Therefore, we will limit the scope of this paper to only a few of these methods.

4. Reducing Greenhouse Gas Emissions is Critical when Allocating Investments in the Energy Sector

Reducing greenhouse gas emissions is critical when allocating investments to develop the energy complex. The solution may involve using fossil energy sources, but there must be confidence that the decision will contribute to sustainable development. Taxonomy principles help select such projects.

The EU taxonomy is a classification system that establishes a list of environmentally sustainable economic activities.

The EU adopted an ambitious plan, the European Green Deal, at the end of 2019 to achieve carbon neutrality by 2050 (EU Green Deal. WECOOP, 2019). The EU Action Plan for Financing Sustainable Growth in the context of achieving carbon neutrality provides for the creation of a taxonomy. The taxonomy aims to increase the scale of sustainable development through investments in implementing the European Green Course.

During the development of this EU plan, environmental objectives were selected, and a taxonomy system was proposed that allows the assessment of economic activity's sustainability based on objective criteria. Moreover, only economic activity aimed at achieving certain climatic or environmental goals and does not cause significant damage to other goals is considered sustainable.

The EU Taxonomy Regulation sets out six environmental objectives (EU Green Course. WECOOP, 2019):

- Climate change mitigation;
- Adaptation to climate change;
- Sustainable use and protection of water and marine resources;
- transition to a circular economy;
- Pollution prevention and control;
- Protection and restoration of biodiversity and ecosystems.

The sustainability of economic activity in the EU is assessed based on objective taxonomy criteria selected and developed by technical experts. The selected taxonomy criteria are based on experience performing sectoral due diligence on development projects. The EU taxonomy provides companies, investors, and policymakers with criteria according to which economic activities can ensure a country's sustainable development.

In EU countries, a wide range of industries and the various technologies that can be categorized as "green" or adaptive, as they are efficient and necessary to reduce carbon intensity in large-scale economic transformation, have been considered. The EU taxonomy allows the financing of "sustainable" projects to be regulated in all sectors of the economy and, above all, in the energy sector, given that the main source of emissions in the EU falls in this sector.

The level of taxonomy criteria and environmental targets set in different countries can vary greatly. National taxonomies largely reflect the economies and low-carbon development pathways chosen by these countries.

The green taxonomy is the most widespread (/, 2022). It is primarily aimed at solving the problems of climate change on our planet.

At the state level, sustainability plans are made in accordance with the taxonomy's criteria. This approach to investing projects allows the government, investors, and companies to ensure the country's sustainable development.

Today, the taxonomy is both a standard and a reference point for all participants in sustainable financing of the ESG ecosystem (environmental, social, corporate governance) not only in the EU, where it originated, but also in Russia, Malaysia, China, and other countries that have already achieved certain success in the development of green taxonomy. Therefore, the taxonomy can also successfully influence companies in non-EU countries. This allows investors to assess the feasibility of investments based on the taxonomy criteria.

Both governments and private companies initiate taxonomies. Companies that operate according to the taxonomy benefit from a better reputation and gain a competitive advantage.

The National Taxonomy of Sustainable Development Projects was approved in Russia in September 2021 (Resolution of the Government of the Russian Federation of 21.09.2021 No. 1587..., 2021).

It pursues the following objectives:

1. Preservation, protection or improvement of the environment.

2. Reduction of pollutant emissions and prevention of their environmental impact.

3. Reduction of greenhouse gas emissions.

4. Energy conservation and increased resource efficiency.

All projects created based on taxonomy criteria aim to achieve sustainable development goals.

In the Russian Federation, based on the national taxonomy, the Center for Green Finance was created (Shulga, 2022), which forms a system of financial instruments for sustainable development.

Based on the taxonomy, the Eurasian Economic Union member countries have developed harmonized approaches to the definition of sustainable development projects, which can provide an impetus for developing cross-border green and adaptation financial instruments in the EAEU space.

In Kazakhstan, a taxonomy of green projects was approved by Government Resolution No. 996, dated December 31, 2021. This taxonomy contains the criteria to classify a project as "green" (Resolution of the Government of the Republic of Kazakhstan No. 996 ..., 2021). One of the categories of Kazakhstan's taxonomy is renewable energy.

The criteria used in this taxonomy are similar to those used in the EU taxonomy. However, they are adapted to local conditions (Criteria for Green Projects of the EAEU Member States, 2023).

In Uzbekistan, there is also interest in green finance. The government of Uzbekistan was the first in the CIS region and one of the first in the world to decide to place government bonds to finance sustainable development projects. Uzbekistan has not applied a taxonomy in selecting green projects until recently. However, the possibility of creating one in the country was discussed at the World Bank session, Mobilizing Green Finance and Innovative and Effective Green Public Investment in 2021 (ESG Directorate, 2022). The need for a taxonomy and a monitoring system for the projects being implemented was identified to assess the effectiveness of allocated green investments. However, in October 2023, the Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 561 dated 25.10.2023, "On Approval of the National Green Taxonomy", was adopted (Uzbekistan implements the National Green Taxonomy, 2023).

In the electricity sector, the following taxonomy criteria for energy efficiency investment projects can be considered, where a combined CO2-equivalent emission factor can be used in the calculation of emission reductions due to the introduction of new technologies:

- supply-side energy efficiency improvements: electricity transmission and distribution;

- supply-side energy efficiency improvements: electricity generation at RES and conventional thermal power facilities;

- energy efficiency improvement on the demand side: reduction of electricity consumption due to the introduction of energy-efficient technologies.

The environmental safety issues of electric power industry development in the CA region are primarily aimed at solving the problems of reducing CO2 emissions and, consequently, climate change in the region. At the same time, all the measures proposed per the analysis and the projects developed on their basis should comply with the provisions of the taxonomy, which will guarantee that they will ensure sustainable development.

5. Improvement of Technological Principles

Thermal power plants remain the main source of electricity generation in Uzbekistan, Kazakhstan, and Turkmenistan.

Modernization of power generating capacities. A significant number of power units of TPPs in Uzbekistan, commissioned in the middle of the last century, have exhausted their fleet life, have low energy efficiency (their fuel consumption is almost twice as high compared to modern power units) and do not meet energy efficiency requirements. Currently, 85% of the available power generation capacity in Uzbekistan is accounted for by TPPs. In accordance with the "Concept of Electricity Supply of the Republic of Uzbekistan for 2020-2030", to ensure the energy security of the country and accelerated development of RES in Uzbekistan, it is planned to introduce 15.6 GW of new and modernized generating capacities and decommission 6.4 GW of obsolete generating capacities at TPPs by 2030 (Concept of Electricity Supply of the Republic of Uzbekistan., 2020).

Physical wear of TPP equipment is also high in Kazakhstan. On average, it has reached 66% in the country; at some plants, it even exceeds the critical level of 80% (Trofimov et al., 2021). As it was stated by the President of Kazakhstan, Kasym-Jomart Tokayev, at the enlarged meeting of the government on December 12, 2022, one-third of all TPPs in the country have worked for more than half a century (Official website of the President of the Republic of Kazakhstan, 2022). It should be noted that here we are talking only about the physical wear and tear of the equipment itself, the replacement of which is necessary at least to reduce the high accident rate observed in the country in the last year, and not considering scientific and technological progress, according to which it is necessary to periodically carry out modernization in order to reduce the high specific indicators of TPPs. In the 30 years since Kazakhstan's independence, not a single TPP has been built. Almost 83% of electricity generated at these plants is generated by coal-fired TPPs. Moreover, most of the electricity in Kazakhstan is generated in the Northern Zone, whose thermal power plants produce more than 76% of the country's total electricity. By 2035, the country plans to commission new generating facilities with a total capacity of 17.5 GW (Yelyubaeva, 2022).

To reduce energy's environmental impact, it is necessary to assess the level of greenhouse gas and pollutant emissions into the atmosphere and make appropriate decisions. The solution to these problems is inevitably connected to the issues of energy security in each of the CA countries.

Reducing greenhouse gas emissions. Methodological guidelines on calculation and rationing of "Maximum permissible specific emissions of pollutants for boiler units of TPPs" developed in Uzbekistan aim to create unified regulatory requirements for determining maximum permissible specific emissions of pollutants for thermal power plants to reduce their impact on the greenhouse effect.

They were developed considering the "Methodology for calculating the greenhouse gas emission factor (CO2-equivalent)" (Self-Regulatory Organization in the field of Energy Inspection, 2015), approved by the CDM Executive Board "Guidelines for calculating the energy system emission factor" (Version 07.0), effective from August 31, 2018 (Report of the 100th meeting of the UNFCCC EB, 2018).

Let's consider the "Methodology for calculating the greenhouse gas emission factor (CO2 equivalent)" for projects in electricity generation and consumption (Self-Regulatory Organization for Energy Inspection, 2015). The CO2 emission factor is an equivalent used to calculate emissions from energy efficiency improvement projects at electricity facilities related to electricity generation to the grid and projects related to electricity consumption reduction. It is defined as the value of weighted average CO2 emissions per unit of electricity generated (tCO2/MWh) of all generating units.

As a result of any project related to the implementation of energy-efficient and/or energy-saving technologies in the electricity sector, i.e. entailing a reduction in greenhouse gas emissions, both the magnitude of greenhouse gases and the magnitude of emission reductions should be estimated in relation to a so-called baseline. A baseline is a scenario that would occur in the absence of any activity that results in emission reductions.

For projects involving electricity generation or consumption, the energy baseline is estimated as the generation (consumption) of electricity (kW·h) over a given time period (year).

Calculation methodology. According to the baseline calculation methodology approved by the CDM Executive Board, an energy system's emission factor is calculated as a weighted average of the operating and introduced range (UNFCCC EB 100th Meeting Report, 2018).

The weighting values used during the first crediting period are wOM = wBM = 0.5. Note that different weighting ratios should be used for solar and wind power projects (wOM = 0.75, wBM = 0.25) (UNFCCC IP 100th Meeting Report, 2018).

The operating and introduced ranges are specific CO2 emission factors derived from producing one kW·h of electricity from power plants connected to the grid.

The operating range can be determined using data on fuel consumption and electricity generation at each plant, using several approaches described in the above methodology. In Uzbekistan, the share of low-cost plants (HPPs and CHPs) is approximately 13.5 %, which is less than 50 % on average from 2014 to 201. Thus, a simple operating range will be used in the calculations. This approach will use data from all plants connected to a single grid, except for low-cost plants (HPP and CHP).

The introduced range is defined as CO2 emissions from generating 1 kWh of electricity at plants built in Uzbekistan not more than five years ago and combined in a single data sample. Electricity generation at five selected recently built power plants amounted to 20.8 % of the total electricity generation. Thus, in accordance with the current methodological guidance, the data sample was not expanded by adding other newer plants.

The calculation of CO2 emissions from electricity generation at JSC "TPP" thermal power plants was based on the obtained data on the lowest calorific value of fuel consumption.

In the absence of nationally approved CO2 emission factors for different fuel types, default factors given in the UNFCCC-specific guidance with a 95% confidence interval were used (Report of the 100th UNFCCC EB meeting, 2018). In accordance with this current methodology, the operating range emission factor for electricity generation from TPPs (excluding condensing CHP) was calculated as a weighted average of the three most recent years for which data are available. This value for 2017-2019 was 550 g CO2/kW·h.

In the Report of the 100th UNFCCC EB Meeting (2018), a weighted average calculated as the sum of the operating (average) and imposed range divided by two is proposed for determining the CO2 emission factor for grid electricity generation and consumption. This combined approach was applied to estimate the emission factor for the power system of Uzbekistan.

Different weight shares were applied for wind and solar projects: the weight share of the operating range was WOM = 0.75, and the weight share of the imposed range was WBM = 0.25.

When calculating CO2 emissions from electricity and heat generation, either the volume of fuel consumed or the amount of energy produced (kWh, Gcal) can be used. It should be noted that emissions are calculated separately for each fuel type and then summarized. Since power plants and large boiler houses have specialized laboratories, using actual data on the calorific value of the fuel used when calculating CO2 emissions is recommended.

To reduce CO2 emissions from electricity generation in Uzbekistan, it is planned to introduce RES with a total capacity of 8,000 MW by 2026 (including solar power plants (SPPs) with a total capacity of 4,000 MW and eight wind power plants (WPPs) with a total capacity of 4,000 MW), improve the management system for the use of RES (Ministry of Energy of the Republic of Uzbekistan, 2022), and increase RES capacity to 9,000 MW by 2030.

Expanding the use of green energy. In Kazakhstan, in order to reduce energy intensity, the environmental impact of the electricity generation sector and greenhouse gas emissions, the Law of the Republic of Kazakhstan dated July 4, 2009, No. 165-IV "On Supporting the Use of Renewable Energy Sources" was adopted (Law of the Republic of Kazakhstan..., 2009). Further development of RES will be done in May 2013. The Presidential Decree approved the Concept for the Transition of the Republic of Kazakhstan to a Green Economy (Decree of the President of the Republic of Kazakhstan..., 2013). In January 2021, a new Environmental Code of the RK was adopted (Environmental Code of the Republic of Kazakhstan..., 2021). All this allowed Kazakhstan to become the leading state in the Central Asian region, which created the organizational and legal basis for the transition to a "green economy".

By the end of 2022, 130 RES facilities were operating in Kazakhstan, which generated 5.1 billion kWh, or 4.5% of the country's total electricity production.

By 2035, 17.5 GW are planned to be commissioned: coal generation - about 1.5 GW; gas generation - over 5 GW; hydropower plants - over 2 GW; nuclear generation - 2.4 GW; RES - 6.5 GW (Yelyubaeva, 2022). The commissioning of new capacities will allow Kazakhstan to cover the base, regulate capacity deficit, and ensure energy independence from the energy systems of neighbouring states. In February 2021, the President of Kazakhstan instructed the government to develop a new law on alternative energy development (New Law on Alternative Energy..., 2021).

According to the Energy Sector Development Concept, up to 5 GW of SES and 3 GW of WPP were planned to be introduced in Uzbekistan by 2030; later, the timeline was revised, and the introduction of these capacities is expected as early as 2026.

Expanding the use of energy storage. However, it should be noted that electricity generation from solar and wind power plants depends only on natural conditions. Therefore, it is largely unpredictable and creates balancing difficulties in the energy system. This process is uncontrollable and cannot be dispatched, and there must be a power balance in the power system at every moment.

With the beginning of the wide integration of RES into the energy systems of all countries, a new problem of matching the electricity generated by them with the demand for electricity from consumers has appeared. Under these conditions, in accordance with the IEA recommendations, it is no longer sufficient to increase the share of flexible, manoeuvrable sources only by expanding hydropower plants and gas generation to increase RES capacity. In order to smooth the variability of generated energy from RES, damping their variability, it is advisable to store energy for its subsequent use. The solution to problems related to the variable nature of RES through the use of different types of energy storage devices in Kazakhstan was shown in the work of Trofimov (2021).

Experts believe that due to the efficiency of any type of storage device, the average annual growth rate of the energy storage market will exceed 30% in the next ten years, with a tendency to increase their total capacity and decrease the specific cost of stored energy. In recent years, there has been a real boom in energy storage in energy systems in the West and the USA, and first, to ensure wide integration of renewable energy sources. In Russia, several projects to create Energy Storage Systems (ESS) were implemented as early as 2020. Unfortunately, there are no energy storage systems in the energy systems of CA countries. It seems to us that the use of energy storage systems will contribute not only to the process of expanded use of green energy in the energy systems of the region but also, to a large extent, to solve the problem of deficit of manoeuvring capacities in the UES of Kazakhstan. For this purpose, it is advisable to hold auction tenders for the selection of RES projects together with the selection of SNE projects.

In addition, moving to the expanded placement of energy storage devices capable of providing long-term storage in the energy system is already necessary. It should be noted that the use of traditional lithium-ion energy storages at SES and WES, on the one hand, is not able to ensure the large capacity of these storages and the possibility of long-term energy storage, and on the other hand, creates certain problems related to the need for their subsequent utilization after the expiration of their service life with the resulting environmental consequences.

One new option for long-term energy storage that can alleviate many of the limitations created by other systems is cryogenic energy storage technology called LAES (cryogenic energy storage systems).

LAES can provide both very large, rated power and capacity for long-term energy storage. The system is based on proven technology. All the process equipment required to build a cryogenic energy storage system is common, readily available, and used worldwide to store liquid nitrogen, oxygen, and liquefied natural gas. The equipment is made of stainless steel and is therefore non-toxic, so it can be disposed of at the end of its service life without harming the environment. All equipment is safe, has been used for many years in many industrial processes and does not require any particularly rare elements or expensive components for production. The industry standard components used in the storage system reduce commercial risk and provide continuous cycling without degradation and a 40-year service life. Unlike many other energy storage systems, the technology does not require an energy converter. The combination of cryogenic storage in conjunction with SES and WES makes it possible to replace peaking gas-fired power plants (Trofimov & Petukhov, 2022). In addition, this technology makes it possible to obtain clean water of about 1 m3 per 1 MW*h of electricity during storage operation, which is very important for certain regions of CA.

Highview Power in the UK has developed and patented a clean cryogenic technology based on the use of liquid air for energy storage. The first pilot cryo-energy plant, Liquid Air Energy Storage (LAES), was built in 2018 near Manchester. The company then built several more such plants.

Increased utilization of the region's hydropower resources. Hydropower storage power plants (HSPPs) are important in regulating capacity in the energy system and reducing the environmental impact of operating TPPs/CHPs. However, unlike cryogenic storage, which can be located practically everywhere, appropriate hydro resources are required to use HPPPs.

At the same time, to efficiently use water in the CA region and create peak capacities to compensate for the impact of RES, it is proposed to intensify efforts in the region to jointly build hydropower plants, as well as SHPPs, using for this purpose the existing reservoirs of daily and weekly regulation, (Shamsiev et al., 2022; Khamidov, Shamsiev, 2021). Work on this plan is already being intensified. Thus, in January 2023, Uzbekistan, Kyrgyzstan and Kazakhstan signed a roadmap for the implementation of the Kambarata HPP-1 project with a capacity of 1860 MW, which will play an important role in providing electricity and water to all three countries and will have a positive impact on reducing harmful emissions into the atmosphere.

Implementing the above measures will improve environmental safety and power sector development in the CA region.

6. Conclusions

To ensure the environmental safety of electric power industry development in the CA region, it is advisable to:

To ensure the environmental safety of electric power industry development in the CA region, it is advisable to:

- to use harmonized national and international systems for the assessment of greenhouse gas and air pollutant emissions from thermal power plants;
- to select environmentally safe sources of electricity supply in the countries on the basis of taxonomy principles;
- Expand the use of renewable energy resources, including the region's hydropower resources and energy storage systems, to increase the possibility of large-scale integration of renewable energy sources.

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