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Grid emission factors related to electricity generation and evaluation of attitudes towards the idea of carbon dioxide utilization. A Case of Kazakhstan

Marat Kozhikov[*1], Paata Janelidze[2a], Akbilek Seitmukhanbet[3b], Yessekina Aiman[3c] and Timoth Mkilima[4d]

[1]*Department of Environmental Engineering and Management, L.N. Gumilyov Eurasian National University, Nur-Sultan, 010000, Kazakhstan*
[2]*International Expert in the Energy Sector, PhD in Physics and Mathematics, Kazakhstan*
[3]*School of engineering and digital sciences of Nazarbayev University, Kazakhstan*
[4]*The head of the greenhouse gases inventory department, Zhasyl Damu JSC, Kazakhstan*
[5]*Department of Environmental Engineering and Management, the University of Dodoma, P.O. Box 259, Dodoma, Tanzania*

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Abstract. The first part of the study involved calculating emission factors from electricity production. The second part of the study aimed to analyze perceptions of the concept of carbon dioxide utilization and was conducted through a questionnaire survey with participants from Almaty and Astana. The results showed that there were no significant improvements in the decrease of carbon dioxide emissions between 2017 and 2020. Almost no change occurred in the rate of carbon dioxide emission throughout the course of the four years. According to the results of the survey, a number of respondents had reservations about the feasibility of using carbon dioxide utilization as a solution to tackle climate change. They felt that this technology would only offer a temporary solution to carbon emissions, without addressing the underlying causes of the problem. Despite these concerns, the participants acknowledged that carbon dioxide utilization had certain advantages in promoting sustainability.

Keywords: carbon dioxide utilization; clean development mechanism; electricity production; emission factors; environmental protection; greenhouse gases; sustainability

1. Introduction

The combustion of fossil fuels, like coal, oil, or gas, for the generation of electricity significantly contributes to the emission of greenhouse gases, which accumulate in the Earth's

∗Corresponding author, Ph.D., E-mail: new.kozhikov@gmail.com
[a]Ph.D., E-mail: paata.janelidze@gmail.com
[b]Ph.D. Student, E-mail: Akbilek.seitmukhanbet@nu.edu.kz
[c]Ph.D., E-mail: a.esekina@recycle.kz
[d]Ph.D., E-mail: tmkilima@gmail.com

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atmosphere and result in the retention of solar heat. While electricity generation and transmission are generally considered to be safe and environmentally friendly forms of energy, they still have an impact on the natural surroundings (Towoju and Oladele 2021). The environment is impacted by almost all types of electric power plants, but some have more of an impact than others (Quek *et al.* 2019). The presence of greenhouse gases has maintained the Earth's temperature at a level suitable for humans and numerous other species to inhabit, as they effectively trap solar heat. However, the current imbalance of these gases poses a considerable risk, potentially causing substantial changes to the habitats and conditions in which living organisms can thrive on our planet (Mikhaylov *et al.* 2020). It is also important to note that environmental protection is still a topic of concern on a global scale (Meiramkulova *et al*. 2020, Mkilima 2022, Mkilima *et al.* 2022).

To be more specific, the production of electricity, a cornerstone of modern society, carries the heavy environmental burden of carbon emissions, prompting global concern over the impact of greenhouse gases on climate change (Hwang *et al*. 2023). However, the intricate relationships between grid emission factors, environmental consequences, and public attitudes remain incompletely understood, leaving crucial knowledge gaps in their wake. Moreover, the relatively novel concept of carbon dioxide utilization as a potential mitigation strategy introduces further complexities, as it necessitates not only technological innovation but also shifts in societal perspectives and acceptance. These multifaceted challenges underscore the urgent need for comprehensive research that addresses these uncertainties, aligning policies, industry practices, and public perceptions in pursuit of sustainable electricity generation and climate change mitigation.

One of the striking effects of greenhouse gases is climate change (Majumdar *et al.* 2021, Manabe 2019). Unlike their ability to impede the escape of infrared (long-wave) radiation from the Earth's atmosphere, greenhouse gases allow outgoing (short-wave) sunlight to pass through without obstruction (Ramanathan and Feng 2009). The greenhouse effect, by trapping solar radiation, causes the temperature of the Earth's surface to increase (Kweku *et al.* 2018). Carbon dioxide (CO2), the most detrimental and prevalent greenhouse gas, exists in the atmosphere at unprecedented levels (Keiyinci and Aydin 2021, Liu *et al.* 2020). Rather than permitting heat to dissipate into space, these gases absorb solar energy and retain it in proximity to the Earth's surface (Xu and Cui 2021). The accumulation of heat caused by the retention of solar energy is commonly referred to as the greenhouse effect (Dunne *et al.* 2013). To address these issues, the UN created the so-called Clean Development Mechanism. The Clean Development Mechanism (CDM) is an initiative administered by the United Nations (UN) that allows countries to support emission-reducing projects in other nations. By doing so, these countries can count the reduced emissions from these projects as part of their own efforts to achieve global emission reduction goals (Chen *et al.* 2021, Fernandes and Leite 2021, Zainuddin *et al*. 2017).

In essence, the Clean Development Mechanism (CDM) offers developing countries and their private sector participants the opportunity to generate income in a stable foreign currency. This is achieved through the sale of carbon credits obtained from projects aimed at reducing greenhouse gas emissions. The main focus is on encouraging investments in environmentally sustainable endeavors within sectors such as mining, industry, power generation, district heating, and waste management (Phillips 2013). Under the Kyoto Protocol, several countries including the European Union, Japan, New Zealand, Canada, and certain developing nations have established targets for reducing their emissions. To reach these targets, they have two choices: (1) implementing measures within their own territories (domestic action), or (2) acquiring carbon credits from companies that operate in regions like the ETC zone (Grunewald and Martinez-Zarzoso 2016, Wang *et al.* 2019).

Considering that implementing policies within their own territories is often costlier compared to policies in the ETC (Emission Trading Credit) zone, the second option may be more financially advantageous. Engaging in carbon credit trading provides benefits for both parties involved, as it generates additional revenue for the ETC zone while reducing compliance costs for industrialized nations (Qi *et al.* 2020). The CDM (Certified Emission Reductions) is an approach that can be used to generate carbon credits, specifically known as Certified Emission Reductions, in this context (Ye *et al.* 2021). The project-based nature of the Clean Development Mechanism (CDM) allows project developers to enhance the financial viability of their projects by selling the resulting emission reductions. However, it is important to note that not all projects meet the requirements to be considered as CDM projects. Various procedures and clearances must be followed to ensure eligibility (Thomas *et al.* 2010). The following are examples of projects that are commonly eligible for qualification: the establishment of biomass or wind energy projects; enhancements to energy efficiency on the demand side, such as the adoption of energy-efficient lightbulbs; efforts to decrease methane emissions from landfill sites; initiatives to reduce emissions from industrial processes; and the implementation of carbon-storing forestry techniques.

The energy sector is one of the biggest contributors to greenhouse gas emissions in the Republic of Kazakhstan (Kerimray and Bakdolotov 2017, Monacrovich *et al*. 1996, Kozhikov and Kapsalyamov 2022). With 246 megatons of carbon dioxide emissions in 2018, the Republic of Kazakhstan is Central Asia's top emitter of greenhouse gases (Akhanova *et al.* 2020). The primary focus of Kazakhstan's energy sector is the utilization of hydrocarbon fuels (Koch and Tynkkynen 2021). In that matter, Kazakhstan is engaged in lowering greenhouse gas emissions, particularly in the energy sector. Calculating emission factors (EF) is one of the helpful approaches for determining the extent to which the electricity sector has contributed to the production of greenhouse gases towards proper management measures (Kim *et al.* 2020). Unfortunately, this approach still has a limited level of application in developing countries.

An emissions factor is a representative value that aims to establish a connection between the quantity of a pollutant discharged into the atmosphere and a specific activity (Spalding-Fecher 2011). These parameters are usually expressed as the ratio of pollutant weight to a unit of volume, weight, distance, or time. For example, in the electricity sector, the emission factor can be defined as the quantity of greenhouse gases emitted for each unit of electricity generated (LEE and LEE 2021). In this research, the emission factor is derived from the measurement of carbon dioxide produced per megawatt-hour (MWh) of electricity. Kazakhstan, as a participant in the Kyoto Protocol, has an obligation to comply with the guidelines for reducing carbon emissions and advancing sustainable development.

On the contrary, carbon dioxide utilization technologies, also known as Carbon Capture and Utilization technologies, are methods that harness the value of CO_2 as a valuable carbon resource. Carbon capture and storage technology has gained considerable attention from various sectors, including industry, government authorities, and the scientific community, as it offers a sustainable means of utilizing fossil fuels. However, despite its promise, the general public's awareness of this technology remains limited, and studies exploring public opinion on CCS have only emerged in the last decade (Jones *et al.* 2017). This study strategically addresses the existing gaps in the field by conducting an in-depth exploration of grid emission factors associated with electricity generation, with a specific focus on Kazakhstan. It navigates the intricate interplay between environmental consequences, technological solutions, and public attitudes, offering a holistic approach to understanding the complex challenges of sustainable energy production and carbon dioxide utilization. By bridging these knowledge gaps, this research not only contributes vital insights but also sets a clear path toward reconciling environmental concerns with the growing demand for electricity in Kazakhstan and potentially other regions, facilitating a seamless transition from grid emission factors to innovative solutions for carbon management. Furthermore, this study is structured to ensure logical and coherent transitions between key concepts, enhancing the overall clarity and comprehensibility of the research narrative. The study was conducted in two main phases. The initial phase focused on calculating the emission factors associated with electricity production. The second phase aimed to assess the perceptions of the concept of carbon dioxide utilization. For the second phase, a questionnaire survey was administered to participants residing in two cities in Kazakhstan: Almaty and Astana.

2. Materials and methods

2.1 Case study description

The layout of Kazakhstan's electricity system, which is divided into three energy zones, has been predetermined by the infrastructure of the power grid and the dynamics of power generation and consumption:

1) The North energy zone provides electricity services to approximately 41% of the country's population. It possesses a generation capacity of 13.6 GW, a surplus of 14.8 billion kWh in electricity generation, and a peak load capacity of 9.6 GW.
2) The South energy zone possesses a generation capacity of 2.8 GW, with a deficit of 11.1 billion kWh in electricity generation and a peak load capacity of 3.6 GW.
3) The West energy zone has an available generation capacity of 2.5 GW, and a slight generation deficit of 0.1 billion kWh, which is covered by the Urals Unified Power System (UPS).

The connection between the North and South energy zones is facilitated by two North-South transmission lines, along with a third line, the North-East-South 500 kV line. Additionally, a fourth line with a carrying capacity of 2 GW serves as a connection between the two zones.

They are frequently combined and referred to as the North-South energy zone. The Russian Urals Integrated Energy System (IES) maintains balance in the West Energy Zone, which is not connected to the North-South. While gas-fired generation is well-established in the West of the country, coal-fired generation predominates in the North and East of the nation. This is dependent on both the availability of coal and natural gas in various regions of the nation and the high expense of transporting coal and, more importantly, natural gas across the enormous terrain of the nation.

Generally, more than 150 power plants produce electricity in Kazakhstan in different regions, the majority of which are connected to the national power system. The power plants are separated into three categories: (1) national, (2) industrial, and (3) those of regional importance. In the wholesale market for energy, power plants in the first group—mostly big thermal power plants—sell electricity to consumers. The second category of power plants consists of combined heat and power (CHP) facilities that provide (heat and) electricity to big industrial facilities and surrounding communities. Regional utilities use regional power plants (third category) to deliver electricity to nearby customers. Since the Aktau nuclear reactor, Kazakhstan's sole nuclear power plant was shut down in June 1999, the nation now has no nuclear power generation capacity. A new nuclear power station with a 1,500 MW capacity is now being planned for Kazakhstan's southeast, next to Lake Balkash.

2.2 Estimation of grid emission factors

2.2.1 Determination of combined margin emission factor

The emission factors for the study were calculated using the combined margin emission factor (EFCM), which incorporates the Operating margin emission factor (EFOM) and the Build margin emission factor (EFBM) as components. It is important to mention that the CDM guideline provides a formula for calculating the power grid emission factor (EF). Eq. (1) was utilized to compute the combined margin emission factors.

$$EFCM = (a \times EF_{OM}) + (b \times EF_{BM}) \quad (1)$$

Whereby; a and b represent the shares of Operating margin and Build margin emission factors. In most cases a = b = 50% (CDM - Executive Board 2009).

2.2.2 Calculation of Operating margin (OM)

CDM offers four distinct approaches for determining emission factors by calculating the operating margin (OM): Simple OM, Simple Adjusted OM, Dispatch Data Analysis, and Average OM. Among these methods, the most accurate is the Dispatch Data Analysis OM, which relies on hourly data not available in Kazakhstan. On the other hand, the Average OM approach is the least precise and is not recommended. When comparing the remaining methods and deciding on the appropriate approach, it is essential to consider low-cost/must-run (LCMR) resources. These resources encompass solar, geothermal, wind, low-cost biomass, hydro, and geothermal energy plants with low marginal generation costs or those operating independently from the grid's daily or seasonal load. In Kazakhstan, the LCMR portion typically accounts for less than 50%, leading to the use of the Simple OM approach for calculations. However, certain energy zones in Kazakhstan, such as those in the south and west, may exhibit different shares of LCMR. In such cases, the Simple Adjusted OM method is employed, incorporating specific data like energy production per plant, aggregated energy production, and fuel consumption per plant.

The Simple OM emission factor is estimated by calculating a generation-weighted average of carbon dioxide emissions per unit of net electricity generation (t CO2/MWh) from all power plants serving the system, excluding LCMR power plants or units. Two options exist for calculating the Simple OM: the first option considers net electricity generation, carbon dioxide emission factor, and each power unit, while the second option takes into account the total net electricity generation, fuel breakdown, and total fuel consumption of the project's electrical system. However, in most cases, the preferred option is the first one, as it relies on average plant efficiency and electricity production.

To compute the emission factor for the power grid, the following information is necessary: a list of various power plant types (e.g., nuclear, hydro, wind, solar), exclusion of LCMR power plants from calculations, and annual data for the most recent three years, including net generation, fuel combustion categorized by fuel types, and net calorific values of each fuel.

Eq. (2) was employed to determine the basic OM emission factors based on the net electricity generated by each power unit and the corresponding emission factor for each unit.

$$EF_{OM\ simple,y} = \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}} \quad (2)$$

Whereby;

The simple operational margin ($EFOM_{simple,y}$) for the carbon dioxide emission factor in a specific year (y) is determined using Eq. (3). In the equation, $EG_{m,y}$ represents the net electricity production and delivery to the grid by power unit (m) during the year (y) in megawatt-hours (MWh), while $EF_{EL,m,y}$ represents the carbon dioxide emission factor for power unit (m) in a year (y) measured in metric tons of CO_2 per megawatt-hour (t CO_2/MWh). The equation is applied to all power plants providing grid services in the relevant year, excluding low-cost/must-run power units.

Eq. (3) is used to calculate the emission factor (EFEL,m,y) for each power unit (m) in the given year (y).

$$EF_{EL,m,y} = \frac{\sum_i FC_{i,m,y} \times NCV_{y,j} \times EF_{CO2,i,y}}{\sum_m EG_{m,y}} \quad (3)$$

Whereby;

$FE_{EL,\ my}$ is the power unit m's carbon dioxide emission factor for the year y (t CO_2/MWh); $FC_{i,m,y}$ represents the amount of fuel type (i) consumed by power unit (m) during the year (y), measured in mass or volume units. $NCV_{i,y}$ refers to the net calorific value or energy content of fuel type (i) in the year (y), measured in gigajoules per mass or volume unit. $EF_{CO2,i,}$y represents the carbon dioxide emission factor of fuel type (i) in year (y), measured in metric tons of CO_2 per gigajoule (t CO_2/GJ).

2.2.3 Calculation of the simple adjusted OM emission factor

A modified version of the Simple OM approach called the simple adjusted OM emission factor (EFgrid, OM-adj,y) is used, which categorizes power plants/units (including imports) into two groups: low-cost/must-run (LCMR) power sources (represented by k) and other power sources (represented by m). The basic adjusted OM emission factor is calculated using Eq. (4), taking into account the net electricity generation by each power unit and the corresponding emission factor for each unit.

$$EF_{OM-adj,y} = (1 - \lambda y) \times \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}} + \lambda y \times \frac{\sum_k EG_{k,y} \times EF_{EL,k,y}}{\sum_k EG_{k,y}} \quad (4)$$

Whereby; λy is the percentage of time factor that LCMR power units are on the margin in year y.

2.2.4 Calculation of build margin emission factor

It is important to note that two methods, ex-ante and ex-post, are available for estimating the Build Margin Emission Factor (EFBM). In this case, the EFBM was determined by utilizing data from specific power plants. The following procedures were followed during the calculation process:

1) Identify the set of five power units (SET5-units), including low-cost/must-run (LCMR) units, that most recently started supplying electricity to the grid.
2) Determine the group of power plants that began supplying energy to the grid most recently, taking into account 20% of their annual generation (SET≥20%).
3) Select the set of power units from SET5-units and SET20% (SETsample) that contributes the highest annual electricity generation. If a portion of a unit's generation falls within the 20% threshold, that portion is fully considered in the calculation.
4) The same information required for calculating the Operational Margin Emission Factor

(EFOM), such as net generation, fuel consumption, and net calorific value, is also needed for the power plants chosen to compute the Build Margin Emission Factor (EFBM). Additionally, the commissioning date (year) is necessary to identify the power plants that recently started supplying electricity to the grid.

The same formula used for calculating the Operational Margin Emission Factor was also applied to determine the Build Margin Emission Factor.

2.2.5 Calculation of Combined margin emission factor (CM)

As previously noted, CM is determined by integrating the OM and BM emission components. Because the LCMR in the North Energy Zone is 50%, the operating margin emission factor was calculated using only a simple OM. Because the LCMR was not 50% in the south and west zones, both the basic OM technique and the simple adjusted OM were employed. Additionally, the proportions of OM and BM in the calculation of RES emission factors were 75% and 25%, respectively.

2.3 Carbon dioxide utilization analysis

The study used a survey questionnaire to examine how participants from two cities in Kazakhstan (Almaty and Astana) perceived the concept of carbon dioxide utilization.

2.3.1 Qualitative interview approach and participants

The primary method employed for data collection in this part of the study involved conducting individual qualitative interviews. The objective of this approach was to acquire comprehensive insights into the perspectives of both experts and lay individuals regarding emerging technologies. Qualitative interviewing was chosen over other methods like questionnaire-based surveys to avoid collecting false opinions, considering the limited awareness of carbon dioxide utilization technologies. False opinions can arise when individuals provide superficial or uninformed evaluations of unfamiliar topics. By conducting qualitative interviews, participants were provided with more information about the subject matter, and their knowledge was clarified before soliciting their opinions. This approach helps reduce the potential for false opinions. Additionally, conducting one-on-one interviews overcomes the limitations associated with group-based discussions commonly used to explore public perceptions of unfamiliar technologies like CCS and carbon dioxide utilization.

The study participants did not require prior technical or power generation knowledge. The researchers recruited a convenience sample of 18 individuals (7 females and 11 males) from Almaty through a local internet forum, university volunteers via email, and personal connections. Although there was a slight overrepresentation of university research personnel and students, individuals from various backgrounds, including lawyers and event managers, were also included in the sample. The median age of the participants from Almaty was 33.7 years.

Likewise, there were 10 participants from Astana, comprising an equal split of 5 females and 5 males. These individuals represented a range of professions, including a research governance coordinator, a retired lawyer, and two academicians, were recruited through personal connections.

The median age of this group was 44.8 years. Both the Almaty and Astana samples exhibited relatively low self-reported pre-interview knowledge of carbon dioxide utilization, with mean scores of 1.11 and 1.30 for Almaty and Astana, respectively, although a few individuals claimed to have heard of it. Despite minor and inconsistent differences, the preliminary comparative analysis

Table 1 Summary of the gender, age, and occupation of the Almaty interviewees

Code	Gender	Age (years)	Occupation
ALMATY-1	M	48	Research governance coordinator
ALMATY-2	F	53	Retired lawyer
ALMATY-3	M	38	Academician
ALMATY-4	M	35	Academician
ALMATY-5	M	36	Computer programmer
ALMATY-6	M	33	Doctor
ALMATY-7	M	21	Laboratory technician
ALMATY-8	M	27	IT expert
ALMATY-9	F	28	Research developer
ALMATY-10	F	40	Community carer
ALMATY-11	M	29	Project manager
ALMATY-12	F	29	Biotechnologist
ALMATY-13	F	36	Events manager
ALMATY-14	M	27	Library assistant
ALMATY-15	M	30	Learning support provider
ALMATY-16	M	34	University lecturer
ALMATY-17	F	29	Communications advisor
ALMATY-18	F	23	University student

Note: M = male; F = female

Table 2 A synopsis of the gender, age, and occupational profiles of the interviewees from Astana

Code	Gender	Age (years)	Occupation
ASTANA-1	M	31	University graduate
ASTANA-2	F	40	Hostel manager
ASTANA-3	F	71	Retired secretary
ASTANA-4	M	76	Retired civil servant
ASTANA-5	F	53	Accountant
ASTANA-6	F	38	Communications advisor
ASTANA-7	F	42	Occupational therapist
ASTANA-8	M	18	Student
ASTANA-9	M	42	Journalist
ASTANA-10	M	42	Architect

Note: M = male; F = female.

indicated that the Almaty and Astana samples were comparable in terms of age and pre-interview carbon dioxide utilization knowledge. Furthermore, there were no significant differences in gender distribution and self-claimed awareness levels, as confirmed by Fisher's exact tests. Table 1 and

Table 2 present an overview of the gender, age, and occupation of the interviewed participants from Almaty and Astana.

2.3.2 General introduction, expert ratings, and pre-interview questionnaire

In this section, the project objectives were restated, and the research team members and their respective roles were introduced. An overview of carbon dioxide utilization was provided, focusing on its relevance in addressing anthropogenic CO_2 emissions from significant emitters like fossil-fuel power generation. The presentation began by introducing CCS as a viable method for sequestering CO_2, followed by a discussion of its potential costs in terms of finances, energy, and waste. Subsequently, carbon dioxide utilization was presented as a promising approach to utilizing a portion of the CO_2 generated through processes like CCS for enhanced oil recovery (EOR) or the production of carbon-based products. The possible advantages of carbon dioxide utilization encompassed decreasing dependence on fresh fossil fuels in the production of goods and mitigating the release of CO_2 into the atmosphere (Jones *et al.* 2017). A visual representation illustrating the various applications of CO_2 capture was shown to the participants. Additionally, it was emphasized that for carbon dioxide utilization processes to result in net reductions in CO_2 emissions, the use of renewable or low-carbon sources of electricity would be necessary to power the capture and conversion processes. The ratings provided by the participants were based on eight evaluative criteria, including technology readiness level and profit potential. Higher scores indicated more favorable evaluations of the CCS and carbon dioxide utilization options. These ratings were derived from a group of over 10 engineers and natural scientists who possessed academic expertise in carbon dioxide utilization. Prior to the interview, a pre-interview questionnaire was distributed to gather information about the age, gender, occupation, awareness, and knowledge of carbon dioxide utilization among the interviewees. The interviews conducted in this study were approved by the Ethical Committee at Eurasian National University. Prior to the interviews, participants were provided with a consent form for their review and signature as a prerequisite.

2.4 Statistical analysis

The data analysis in this study employed the Template Analysis approach to examine the data. The analysis focused on exploring the advantages and disadvantages of carbon dioxide utilization in three main areas: the general concept, techno-economic feasibility, and societal consequences. Additional themes, including comments about the interview process, were also identified, recorded, and coded. The coding template was modified after the initial data coding of the first interview, and the updated template was subsequently employed for the remaining interviews. Codes were adjusted or added as necessary and retroactively applied to pre-coded transcripts. Alongside Template Analysis, a range of specific statistical analysis techniques were employed in the study.

2.4.1 Parameters' correlation

The correlation indices were calculated based on the parameters of interest, including the analysis of how emission factors have been influenced by time. To assess this relationship, a column representing the years included in the study was included as input data in the correlation analysis. These indices played a crucial role in determining the strength of the relationships between the selected parameters. A high correlation, as indicated by the indices, indicated a strong association between two or more variables. Conversely, if there was minimal connection between variables, it indicated that they were not significantly associated. The correlation ratings used in this analysis included categories such as "poor," "moderate," "strong," and "extremely strong" (0-0.2, 0.3-0.49, 0.5-0.69, and 0.7-1, respectively) (Meiramkulova *et al.* 2022, Meiramkulova *et al.* 2022).

2.4.2 Data distribution analysis

The distribution of data among the selected parameters of interest was examined using box and whisker plots. These plots allowed for an assessment of data distribution based on the skewness of the numerical data. Data quartiles, which include percentiles and averages, were utilized to evaluate the distribution of the data (Mkilima et al. 2021).

2.4.3 Analysis of variance

In this research, a statistical analysis technique called single-factor Analysis of Variance (ANOVA) was employed to evaluate the statistical significance of observed variations in the parameters under investigation. This approach involves examining the extent of variation within each data group by utilizing samples from each group. To determine the significance level, a comparison was made between the p-value and a predetermined alpha value (0.05). It is important to emphasize that the alpha value represents the probability of rejecting the null hypothesis, even when it is true. If the p-value is greater than the alpha value, the null hypothesis is accepted. Conversely, a smaller p-value suggests a higher likelihood of obtaining a result that is more extreme than the one observed in the experiment.

2.4.4 Tukey's honest significance test

In the study, Tukey's Honest Significance Test, a statistical test and single-step multiple comparison method was employed to assess whether there were statistically significant deviations in the means of the parameters being investigated. This test was utilized to identify any significant differences between the means of multiple groups and determine if they deviated from each other in a statistically meaningful way.

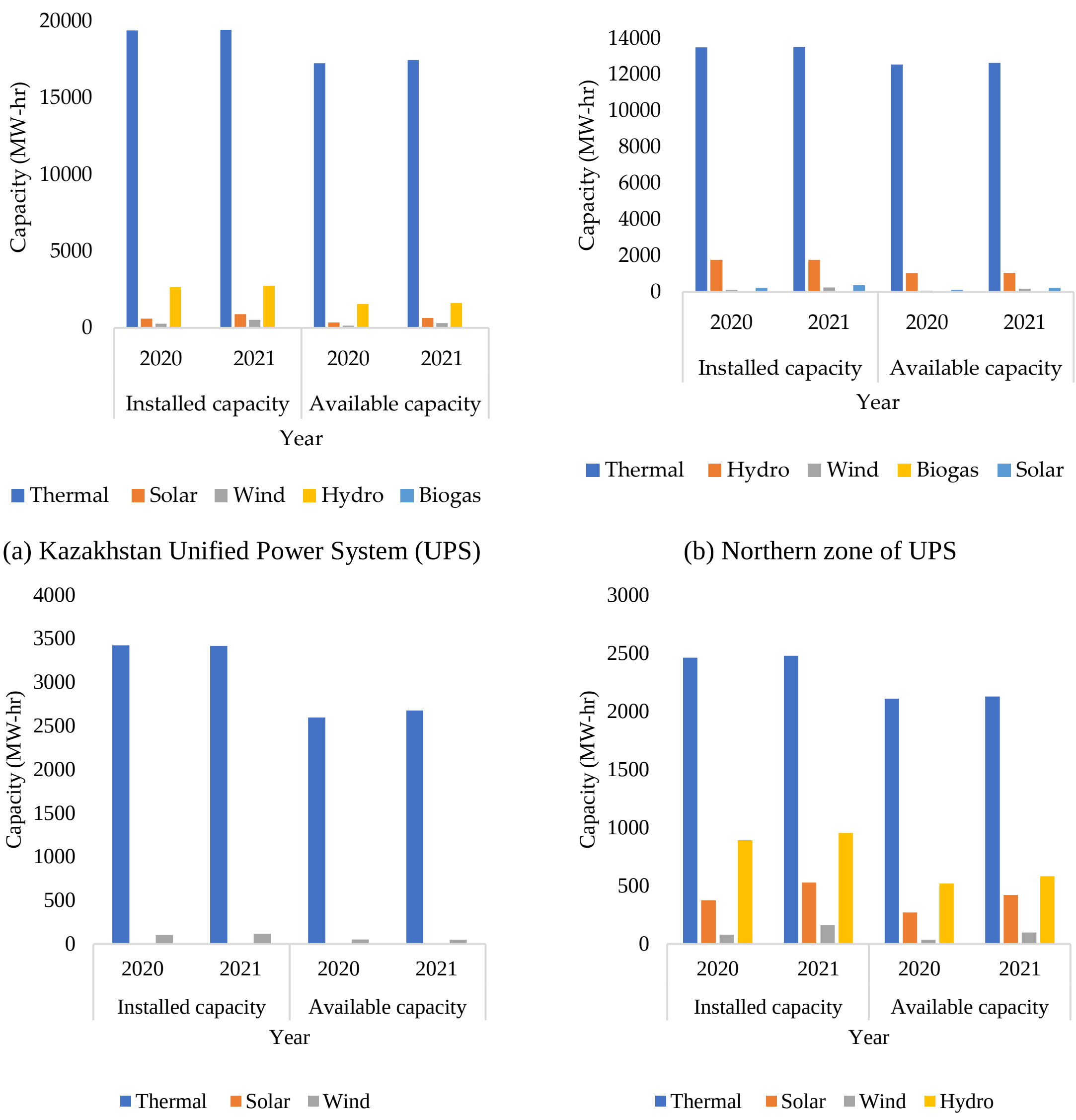
2.4.5 Scheffé multiple comparison

Like Tukey's Honest Significance Test, Scheffé multiple comparisons is another single-step multiple comparison method employed in this study. Its purpose was to assess whether there were any statistically significant deviations in the means of the parameters being investigated. This method was used to determine if there were significant differences between the means of multiple groups and to identify any statistically meaningful deviations among them.

3. Results and discussion

3.1 General analysis of the power zones

Fig. 1 presents an overview of energy production in various power zones in Kazakhstan. The data illustrates that thermal power plants hold a more prominent position in all the power zones compared to other renewable energy sources. From the Kazakhstan Unified Power System (UPS) for the years 2020 and 2021, detailing the installed and available capacity of various types of power plants. In 2021, the thermal power plants exhibited a marginal increase in both installed and available capacity, rising from



(a) Kazakhstan Unified Power System (UPS)

(b) Northern zone of UPS

(c) Western zone of UPS

(d) Southern zone of UPS

Fig. 1 Power systems in different zones

19,389 MW to 19,419.5 MW and from 17,257 MW to 17,456.1 MW, respectively. Similarly, solar power capacity experienced a notable increase from 597 MW to 885.3 MW in installed capacity and from 364 MW to 641.6 MW in available capacity from 2020 to 2021. Wind power capacity also exhibited significant growth, increasing from 282 MW to 511.6 MW in installed capacity and from 149 MW to 311.6 MW in available capacity. Hydro and biogas power plants followed a similar trend, with both installed and available capacities increasing from 2020 to 2021. These results underscore a noteworthy expansion in renewable energy sources, particularly in solar and wind power, within the

Kazakhstan UPS during the studied period.

Also in 2021, thermal power plants in the Northern zone showed a marginal increase in both installed and available capacity, rising from 13,503 MW to 13,528.6 MW and from 12,554 MW to 12,650.6 MW, respectively. The hydro power plants exhibited consistency in both installed and available capacity, remaining relatively unchanged from 2020 to 2021. Wind power capacity displayed substantial growth, increasing from 100 MW to 232.5 MW in installed capacity and from 59 MW to 164.6 MW in available capacity. Solar power capacity also experienced significant expansion, growing from 220 MW to 356 MW in installed capacity and from 91 MW to 218.9 MW in available capacity. The results underscore a notable increase in renewable energy sources, particularly in wind and solar power, within the Northern zone of the UPS over the studied period, aligning with the broader global shift towards cleaner energy alternatives.

In 2021, thermal power plants in the Western zone showed a slight decrease in both installed and available capacity, declining from 3,424 MW to 3,414.7 MW and from 2,595.8 MW to 2,677 MW, respectively. Solar power and wind power, while maintaining a consistent installed capacity of 2 MW and 101.4 MW, respectively, saw marginal changes in their available capacities. Solar power remained at 2 MW, while wind power's available capacity slightly decreased from 52.6 MW to 49.1 MW from 2020 to 2021. These results suggest relative stability in the Western zone's power infrastructure, with minimal shifts in thermal, solar, and wind power capacities over the studied period.

Moreover, in 2021, the thermal power plants in the Southern zone experienced a modest increase in both installed and available capacity, ascending from 2,460 MW to 2,476.2 MW and from 2,107 MW to 2,128.5 MW, respectively. Solar power displayed substantial growth, escalating from 375 MW to 527.3 MW in installed capacity and from 271 MW to 420.7 MW in available capacity from 2020 to 2021. Wind power capacity exhibited a significant surge, increasing from 80 MW to 162.7 MW in installed capacity and from 37 MW to 98 MW in available capacity. Hydro power plants followed a similar trend, with both installed and available capacities increasing from 2020 to 2021. These findings underscore a noteworthy expansion in renewable energy sources, particularly in solar and wind power, within the Southern zone of the UPS during the analyzed period, aligning with the global shift toward cleaner and sustainable energy solutions.

Based on the available data, the West Energy Zone did not generate any electricity from renewable energy sources up until 2017. However, significant progress has been made since 2018, with the Energy Zone making remarkable advancements in the adoption of renewable energy. It is noteworthy to mention that Kazakhstan holds a prominent position as a producer of coal, crude oil, and natural gas, and also serves as a significant energy exporter. Although coal remains the primary component of the country's energy portfolio, Kazakhstan is now gradually increasing its electricity generation from renewable sources. To enhance accessibility and reduce reliance on coal and liquefied petroleum gas for residential consumption, it is crucial to expand the gas pipeline network. Additionally, Kazakhstan is a participant in the EU4Energy Program (Olczak *et al*. 2021), a project dedicated to the development of evidence-based energy policy. By 2020, thermal energy emerged as the primary contributor to electricity generation from renewable sources. It is noteworthy that in 2013, the Kazakhstani government introduced a feed-in-tariff (FiT) mechanism with a duration of 15 years, aiming to attract greater investments in the renewable energy sector. In 2018, the energy ministry adopted a new approach by initiating renewable auctions, marking a significant shift in their assistance strategy. These auctions facilitated transparent selection processes for projects and investors, while also encouraging the adoption of more efficient technologies and projects that minimize the impact of tariff adjustments on end users resulting from the integration of renewable energy capacities (Mouraviev 2021).

Table 3 Merged results for three energy zones of Kazakhstan

Energy zone	Operating Margin Emission Factor		Build Margin Emission Factor, EFBM t CO2/MWh	Weights				Combined Margin Emission Factor, EFCM [t CO2/MWh]	
	Method	EFOM, t CO2/MWh		For wind and solar projects		For other projects		For wind and solar projects	For other projects
				EFOM	EFBM	OM	BM		
North	Simple OM	1.0171	1.2351	75%	25%	50%	50%	1.0716	1.1261
South	Simple OM	0.5625	0.7263					0.6034	0.6444
	Simple adjusted OM	0.5482						0.5927	0.6372
West	Simple OM	1.3628	0.9102					1.2497	1.1365
	Simple adjusted OM	0.9408						0.9331	0.9255
Kazakhstan	Simple OM	0.9343	1.0246					0.9569	0.9795

Indisputably, energy plays a pivotal role in the emission of carbon dioxide, yet it remains indispensable for driving economic growth in terms of production and consumption. Consequently, the relationship between carbon dioxide emissions and economic development is a complex and interwoven one, encompassing considerations of both environmental impact and financial implications. A significant proportion of carbon dioxide emissions can be attributed to fuel consumption, which is crucial for the development of transportation infrastructure and industrial sectors that are closely intertwined with economic progress. Effectively addressing both economic and environmental objectives requires a comprehensive understanding of the inseparable link between carbon dioxide emissions and economic development. It is noteworthy that Kazakhstan holds a position among the top 30 global greenhouse gas emitters and is among the top 10 emitters on a per capita basis. Notably, energy production constitutes the primary source of carbon emissions in Kazakhstan, accounting for 82% of the country's total emissions (Aliyarov and Zhurinov 2020). As mentioned earlier, greenhouse gases, specifically carbon dioxide emissions, are widely recognized as a leading cause of climate change, making it one of the most pressing environmental concerns on a global scale (Li *et al.* 2021). Table 3 shows merged results for three energy zones of Kazakhstan. These calculations were based on data for 2017-2020.

Kazakhstan wants to replace its outdated facilities and machinery, thus there are many needs in the market for power generation. In power-generating facilities, roughly 31% of the equipment has been in operation for more than 30 years, and about 65% has been in use for more than 20 years. With an estimated 15% loss in transmission and distribution systems, electricity transmission networks are inefficient (Askarova *et al.* 2020). The Kazakhstani government has created an action plan for the development of electric power through 2030, which includes a list of power plants that might be modernized or rebuilt as well as the building of new facilities. From Table 4 it can be seen that the highest emission factors are from the Nothern Energy Zone.

Fig. 2 provides a summary of the weighted average from the selected power plants. From Fig. 3 it can be seen more than 0.5 weighted average carbon dioxide emission was retrieved from all the investigated power plants, with the highest observed from the Simple Operating Margin in the North Energy Zone. It should be noted that the average amount of carbon dioxide emitted per unit

Table 4 Operating Margin Emission Factor of the Electricity System of Kazakhstan by selected power plants in different zones

Power plants, considered in calculations	OM method	OM emission factor [t CO2/MWh]				
		2017	2018	2019	2020	Change [%]
North Energy Zone						
Gas Reciprocating Power Plant Zhanazhol TPP (GTS 56) Karaganda GRES-1 Ekibastuz GRES-2 Arcelor Mittal TPP-PVS Kazakhmys Corporation TTP Ekibastuz GRES-1 Aksu Power Plant	Simple OM	1.02	1.01	1.08	0.97	4.79
South Energy Zone						
Akshabulak GTPP Zhambyl GRES Kyzylorda TPP KOGTES	Simple OM	0.56	0.55	0.57	0.58	-4.37
Akshabulak GTPP Zhambyl GRES Kyzylorda TPP KOGTES LCMR Almaty CHP-5 Kyzylorda CHP Shymkent CHP Almaty CHP-1 Almaty CHP-3 Taraz CHP Tekeli CHP Large hydro	Simple adjusted OM	0.53	0.56	0.56	0.55	-3.38
RES						
West Energy Zone						
GTPP-200 URALSK Ural GTPP MAEC TPP	Simple OM	1.03	1.01	1.01	0.95	8.45
GTPP-200 URALSK Ural GTPP MAEC TPP LCMR Ural CHP MAEC CHP-2 MAEC CHP-1 Atyrau CHP RES Imports	Simple adjusted OM	0.95	0.95	0.92	0.63	34.06
Kazakhstan	Simple OM	0.93	0.94	0.98	0.89	4.56

of electricity produced on the grid is described by the weighted average emission factor (Colett *et al.* 2016). It is computed by dividing the region's total net generation by the absolute carbon dioxide emissions of all of its power plants. Understanding the balance between energy production and the amount of carbon dioxide produced plays a significant role in the management process. However, although we are learning more about the key processes, we still don't fully understand how much carbon dioxide the ecosystem can absorb or how precisely the long-term global carbon dioxide equilibrium is maintained (Baldocchi and Penuelas 2019). A number of significant political efforts reflect the growing worry among scientists about the steadily rising carbon dioxide levels in the atmosphere on a global scale. The world's carbon-based fossil fuels are burning and quickly converting to atmospheric carbon dioxide, which is causing carbon dioxide buildup (Qiu *et al.* 2020).

Box and whisker graphs were employed to analyze the distribution of Operating Margin Emission Factors for the years 2017, 2018, 2019, and 2020. It is important to note that the data distribution analysis offers the advantage of determining the probability of specific observations within a sample space. This probability is calculated using a mathematical framework known as a probability distribution, which assesses the likelihood of different potential outcomes in a given test or experiment (Larsen 1985, Meiramkulova *et al.* 2020). Fig. 4 indicates that the median line is closer to the upper quartile, indicating a "negatively skewed" distribution of Operating Margin Emission Factors. This suggests that the data has a higher frequency of lower values for Operating Margin Emission Factors compared to higher values. Additionally, based on Fig. 3, it is evident that there has been minimal progress in reducing carbon dioxide emissions from power plants over

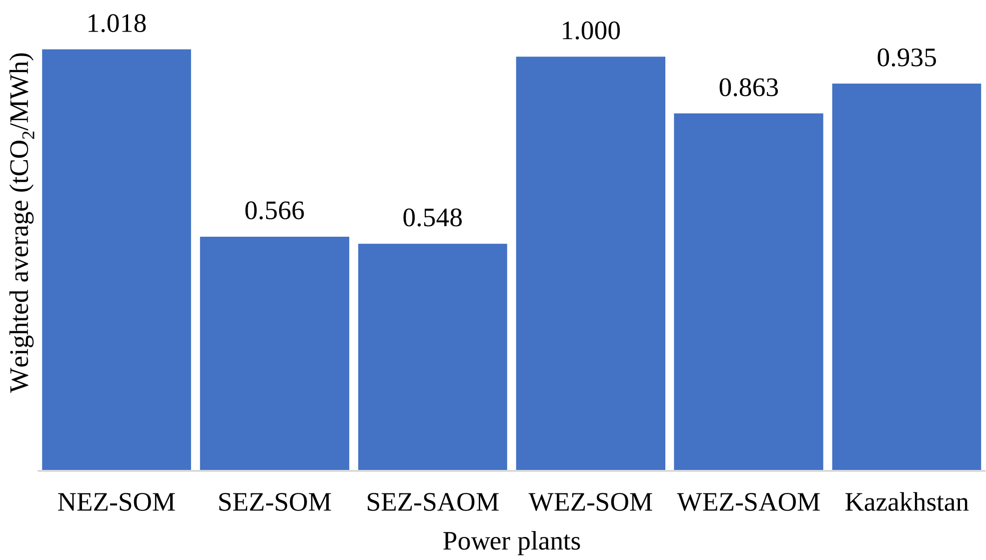


Fig. 2 Weighted average from the selected power plants. NEZ-SOM = North Energy Zone under Simple Operating Margin, SEZ-SOM = South Energy Zone under Simple Operating Margin, SEZ-SAOM = South Energy Zone under Simple Adjusted Operating Margin, WEZ-SOM = West Energy Zone under Simple Operating Margin, WEZ-SAOM = West Energy Zone under Simple Adjusted Operating Margin

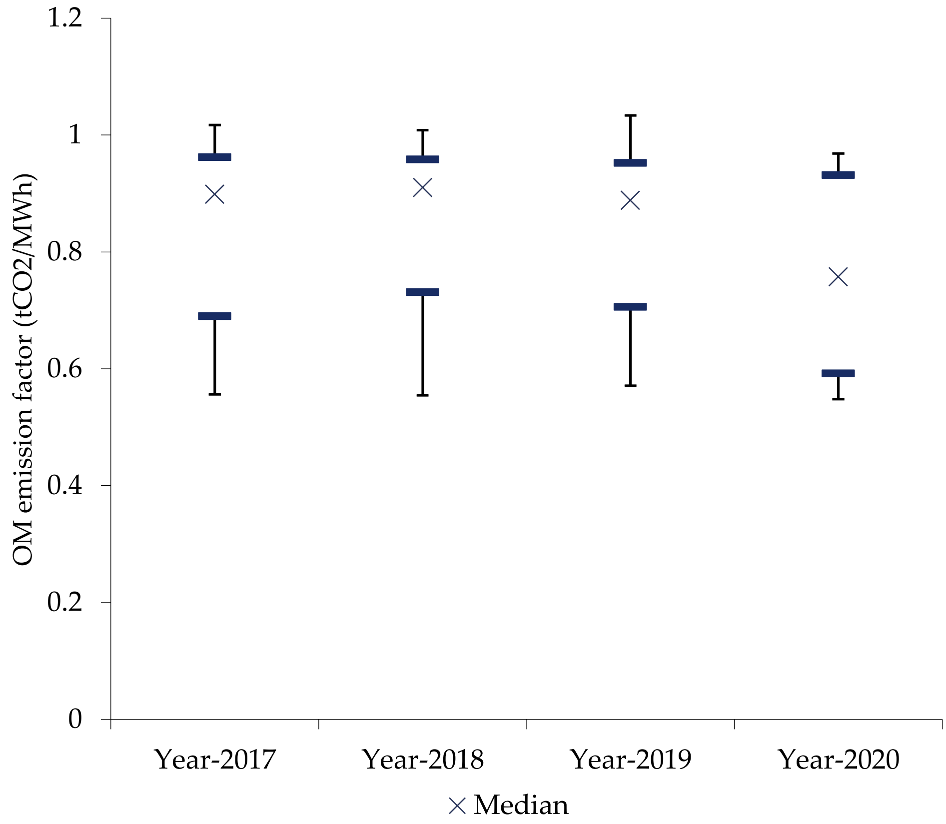


Fig. 3 Data distribution from Operating Margin Emission Factors

the four-year period studied. This highlights the need for further initiatives to improve carbon dioxide emission reduction in the country.

To mitigate carbon dioxide emissions, various technological options have been employed for many years. These options include expanding the use of renewable energy sources and nuclear energy, which have low or no net carbon dioxide emissions; transitioning to less carbon-intensive fuels like natural gas instead of coal; and utilizing carbon capture and storage techniques to absorb and sequester carbon dioxide. These measures can contribute to lowering carbon dioxide emissions from power plants and mitigating their impact on the atmosphere (Eldardiry and Habib 2018).

3.2 Analysis of variance

3.2.1 Single factor analysis of variance

Table 5 provides a summary of the outcomes obtained through the Single Factor Analysis of Variance (ANOVA). ANOVA is a statistical technique used to compare the means of multiple populations, where each population is represented by independent samples. Its purpose is to determine whether the population means are equal or not. Additionally, ANOVA is a parametric

Table 5 Results from ANOVA: Single-factor

SUMMARY						
Groups	Count	Sum	Average	Variance		
2017	6	4.9759	0.829317	0.036135466		
2018	6	5.0303	0.838383	0.032631782		
2019	6	5.0019	0.83365	0.032969899		
2020	6	4.559	0.759833	0.037887403		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.024855	3	0.008285	0.237355	0.869253	3.098391
Within Groups	0.698123	20	0.034906			
Total	0.722978	23				

Table 6 Results from Tukey honest significance difference test

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
2017 vs 2018	0.1189	0.899995	insignificant
2017 vs 2019	0.0568	0.899995	insignificant
2017 vs 2020	0.911	0.899995	insignificant
2018 vs 2019	0.0621	0.899995	insignificant
2018 vs 2020	1.0298	0.879317	insignificant
2018 vs 2020	0.9678	0.899995	insignificant

test that assumes the values being analyzed follow a normal distribution, as stated by the null hypothesis (Meiramkulova *et al.* 2022, Meiramkulova *et al.* 2022). The analysis presented in Table 8 reveals that the ANOVA conducted on the emission factors from various years resulted in a p-value of 0.869253. This p-value, associated with the F-statistic in the one-way ANOVA, exceeds the significance level of 0.05, indicating that there is no significant difference among the treatments. The ANOVA findings also indicate that there was no significant improvement in the reduction of carbon dioxide emissions from 2017 to 2020. Over the course of four years, the rate of carbon dioxide emission remained relatively stable without any significant changes.

3.2.2 Tukey honest significance difference test

Tukey's honest significance difference was employed to examine the significance of the differences in emission factors among the years investigated in the case study. Table 6 displays the results, indicating that the p-values associated with the research years were all greater than 0.01. This suggests that the observed changes in the predicted emission factors are not statistically significant.

3.2.3 Scheffé multiple comparison

Apart from the Tukey Honest Significance Difference Test, Scheffé multiple comparisons was used to investigate further the significance level of the differences in terms of emission factors from different

Table 7 Results from Scheffé's multiple comparisons

Treatments pair	Scheffé TT-statistic	Scheffé p-value	Scheffé inference
2017 vs 2018	0.0841	0.999837	insignificant
2017 vs 2019	0.0402	0.999982	insignificant
2017 vs 2020	0.6442	0.935927	insignificant
2018 vs 2019	0.0439	0.999977	insignificant
2018 vs 2020	0.7282	0.910876	insignificant
2018 vs 2020	0.6843	0.924517	insignificant

years used as a case study. Also, from Table 7 it can be seen that the p-values generated from the investigated study years were all higher than 0.01 making the differences in the estimated emission factors not statistically significant.

3.3 Correlation analysis

In statistics, the term "correlation" is used to describe any statistical association or dependency between two random variables or bivariate data, regardless of whether it is causal or not. While the term "correlation" can have a broader meaning in general usage, in statistics it primarily refers to the degree of linear relationship between a pair of variables (Mkilima *et al.* 2021). Table 8 summarizes the findings of the correlation analysis conducted on the year, Simple adjusted OM results, and datasets from EF (OM). The purpose of this analysis was to explore any potential patterns of relationship among these parameters. The results indicate that there was a relatively strong correlation between the year (time) and the emission factors from the Simple Operating Margin (0.81) and Simple Adjusted Operating Margin (0.68). However, the correlation between the two methodologies was relatively weak. Interestingly, there was no discernible pattern in the relationship between the emission components from the Simple Operating Margin and the Simple Adjusted Operating Margin. This observation aligns with the fact that the outcomes of these two methods are solely dependent on the input data.

3.4 Perception on carbon dioxide utilization

Due to the scarcity of research on public perceptions of carbon dioxide utilization, there is an increasing desire to enhance comprehension of this subject (Jones *et al.* 2017). To fill this research gap, this study aimed to explore and assess the perceptions of carbon dioxide utilization among a convenience sample of respondents in Kazakhstan. The study employed an exploratory approach and conducted 28 qualitative interviews with laypeople in Almaty (n = 18) and Astana (n = 10). Drawing upon the framework used in previous studies, the analysis focused on three main themes: ideas, technical aspects, and societal consequences related to carbon dioxide utilization. The objective was to gain insights into the evolving attitudes towards carbon dioxide utilization in different countries. Additionally, the study examined how the existing public perception of Carbon Capture and Storage (CCS) in each city influenced the interviewees' opinions regarding carbon dioxide utilization, as there may be associations between carbon dioxide utilization facilities and CCS operations.

Table 8 Correlation analysis results

	Year	EF (OM)	Simple adjusted OM
Year	1		
EF (OM)	0.809767	1	
Simple adjusted OM	0.676123	0.11519	1

The respondents generally showed a favorable attitude towards carbon dioxide utilization, albeit with some reservations and skepticism. However, this support was contingent on the understanding that carbon dioxide utilization should not be the sole focus of efforts to tackle climate change. During the interviews, three sub-themes emerged in the discussions about carbon dioxide utilization:

1) The effectiveness of carbon dioxide utilization in addressing climate change;
2) The alignment of carbon dioxide utilization with the broader sustainability goals; and
3) The comparison of carbon dioxide utilization with other technologies, especially CCS.

3.4.1 The usefulness of utilizing carbon dioxide in mitigating climate change

Some participants expressed skepticism regarding the viability of carbon dioxide utilization as a solution to climate change. They questioned whether this technology would only serve as a temporary fix, addressing carbon emissions at the end of the process without tackling the underlying causes. Instead, they argued for a stronger emphasis on reducing CO_2 production from the outset. Furthermore, interviewees raised concerns that carbon dioxide utilization would only delay the release of CO_2 into the atmosphere without providing long-term benefits for combating climate change. However, they acknowledged that not all carbon dioxide utilization products were equal in this regard, with options that offered more permanent CO_2 storage being considered more favorable. The perceived magnitude of the contribution of carbon dioxide utilization to addressing climate change played a role in shaping opinions. If the potential benefits were deemed insignificant, the value of the technology was called into question. Lastly, although carbon dioxide utilization was not considered as the ultimate remedy for addressing climate change, some participants held the belief that it could contribute to mitigating the problem or serve as a temporary solution until more effective strategies are developed.

3.4.2 The alignment of carbon dioxide utilization with broader sustainability objectives

Certain participants expressed skepticism regarding the compatibility of specific carbon dioxide utilization products, such as plastics, with the prevailing sustainability movement. In the case of Almaty, some interviewees raised concerns about the continued reliance on fossil fuels associated with carbon dioxide utilization, perceiving it as a risky technical solution to complex environmental challenges. Furthermore, there were doubts surrounding the motivations driving the promotion of carbon dioxide utilization. Some interviewees questioned whether environmental concerns genuinely drove the initiative or if economic considerations took precedence. This mistrust towards companies promoting the technology led some participants from Astana to call for stricter monitoring and regulation of industrial practices and products to ensure genuine environmental sustainability.

Notwithstanding these reservations, participants recognized several merits of carbon dioxide utilization in fostering sustainability. They perceived it as creating a new source of "recycled" carbon, which could decrease the consumption of raw materials, maximize the utilization of existing fossil fuel reserves, stimulate scientific and industrial innovation, and contribute to the transition toward a more circular economy. One interviewee from Almaty (ALMATY-16) summarized this positive perspective on carbon dioxide utilization by stating, "I love the idea of a circular economy; the waste of one process is being used as a starting product for another. Carbon dioxide utilization is brilliant and fits perfectly within it, closing the carbon loop in our society."

3.4.3 The degree to which carbon dioxide utilization is more favorable or advantageous than other technologies

Astana participants exhibited a preference for carbon dioxide utilization as a separate approach and did not support linking it with Carbon Capture and Storage (CCS). They believed that such an association limited the consideration of carbon dioxide utilization as an independent solution. Conversely, participants in Almaty favored the combination of CCS and carbon dioxide utilization. This preference stemmed from concerns and reservations surrounding underground CO_2 storage, which was perceived as wasteful, environmentally harmful, or risky, unlike utilization, which was likened to recycling. Some interviewees expressed apprehension that investment in carbon dioxide utilization might divert financial resources away from other technologies, such as renewable energy, which were considered more aligned with sustainability goals. In these cases, opinions regarding carbon dioxide utilization tended to be less positive.

3.4.4 Comments related to the feasibility and economic viability of carbon dioxide utilization

Participants frequently balanced their positive perspectives on carbon dioxide utilization with practical assessments of its technical and economic feasibility. These assessments were often rooted in a perceived lack of familiarity with the technology and the limited commercial application of many carbon dioxide utilization options. Two primary sub-themes emerged during the discussions:

1) The technical feasibility and the capability of carbon dioxide utilization to capture CO2 effectively.
2) The commercialization and market potential for carbon dioxide utilization technologies and products.

3.4.5 The ability of carbon dioxide utilization to be implemented from a technical standpoint, and the potential for capturing CO_2

The interviewees showed hesitation regarding the effectiveness of carbon dioxide utilization in capturing CO_2. Their level of support for the technology was influenced by their belief in its ability to capture substantial amounts of CO_2 and mitigate carbon emissions. However, some participants expressed a need for more comprehensive information about the actual benefits and capture potential of the technology before fully endorsing it. Moreover, concerns were raised about the immediate advantages of carbon dioxide utilization, as the technology is still in its early stages and has limited market penetration. They argued that it would take a long time for carbon dioxide utilization to have a meaningful impact on global issues like climate change, and significant international investment would be necessary for it to make a difference. In both urban areas, certain participants expressed skepticism regarding the substantial energy requirements of carbon dioxide utilization conversion processes and their potential to result in overall increases in CO_2 emissions. Nevertheless, there were individuals who believed that investing in existing carbon dioxide utilization technologies could enhance the feasibility of future technological advancements.

3.4.6 The potential for commercialization and marketability of carbon dioxide utilization

There was a level of uncertainty regarding the financial aspects of commercializing carbon dioxide utilization, as well as the potential market for related technologies and products. Participants acknowledged that for carbon dioxide utilization to be successful, it must be financially viable for investors. This led to discussions speculating on how carbon dioxide utilization facilities would be funded and whether this would have an impact on consumers. However, many participants expressed the belief that utilizing CO_2 could be a profitable venture for investors, either through direct means or by reducing emissions taxes. They also believed that the appeal of carbon dioxide utilization to industries would be significant if it could provide a low-cost carbon feedstock for various products.

In both cities, interviewees identified multiple economic advantages for investors in carbon dioxide utilization. They acknowledged that integrating carbon dioxide utilization and its products with existing industrial infrastructures would be seamless, allowing access to diverse markets. Moreover, they believed that investing in the research and development of carbon dioxide utilization technology could pave the way for future domestic and international retail markets. In Almaty, a few participants also perceived investing in carbon dioxide utilization as a means to enhance the business credibility of investors and promote further investment in the renewable energy sector.

3.4.7 The potential impact of carbon dioxide utilization on society and its implications

The study identified four main themes related to carbon dioxide utilization:

1) Its potential impact on society;
2) How it might affect consumers;
3) The potential risks to public health and the environment;
4) Its implications for businesses and industries.

The interviewees had differing views on whether investing in carbon dioxide utilization would have positive or negative impacts on promoting sustainable lifestyles in society. Some participants expressed concern that people might use the environmental benefits of carbon dioxide utilization as a justification for not adopting more sustainable practices in their daily lives. However, others believed that carbon dioxide utilization could serve as a catalyst for change in both the public and business sectors, encouraging them to adopt more sustainable practices. Furthermore, some participants expressed the belief that investing in carbon dioxide utilization in cities like Almaty and Astana could set a positive example for other countries and inspire similar initiatives in other cities undergoing industrial development. They saw the potential for these cities to become pioneers in carbon dioxide utilization, showcasing the benefits and inspiring others to follow suit.

There was a perception among the interviewees that carbon dioxide utilization could be an expensive process, and the question of who would bear the costs was raised. There were suggestions that consumers might experience higher prices for products in order to cover these costs. However, others argued that this potential price increase might not be a significant issue if it was small and if the environmental benefits of carbon dioxide utilization were clearly communicated. Some interviewees believed that individuals, driven by ecological awareness, would be willing to pay more for eco-friendly products.

However, not all participants expressed concerns about consumer price inflation. Some believed that carbon dioxide utilization had the potential to provide a cost-effective source of carbon, which could help reduce or mitigate the expenses associated with consumer products like transportation fuel.

Interviewees raised concerns about the transportation and storage of unused carbon dioxide (CO_2), primarily due to the potential risks of leakage, explosions, and harm to local populations, as well as to the surrounding flora and fauna. However, when it came to the use of CO_2 in the conversion process, the perceived level of risk was not as high. Although some participants mentioned the possibility of hazardous emissions resulting from the chemicals used in the process.

Furthermore, there were discussions regarding the potential existence of unknown risks associated with products derived from carbon dioxide utilization. In Astana, some participants expressed confidence that regulatory systems could safeguard consumer welfare and enhance the safety of CO_2-derived products. It is worth noting that a few interviewees in Astana also expressed enthusiasm for the utilization of CO_2-derived products as a symbol of honor.

Interviewees in both cities primarily emphasized the practicality of carbon dioxide utilization in the creation of various products, including fuels and plastics, and its potential to support businesses and industries. In Almaty, the technology was perceived as non-disruptive, allowing industries to reduce emissions without causing significant societal changes. Additionally, interviewees in both cities believed that captured CO_2 could serve as a substitute for carbon-based products, reducing the reliance on crude-oil imports and promoting energy independence. This substitution potential was particularly highlighted by participants from Astana. They also recognized the existing industries in the country as a solid foundation for investing in carbon dioxide utilization, provided a viable business case was established. Some interviewees in Almaty also mentioned the potential for job creation within the carbon dioxide utilization industry, although the specific number and duration of such opportunities remained uncertain.

3.4.8 Discussion of general issues

Throughout the discussion, various crucial themes emerged, including the essential requirement for effective communication and proactive engagement with the general public, the critical significance of thorough consideration when determining optimal facility construction and deployment locations, and valuable input and commentary specifically addressing the interview process.

Participants from both cities emphasized the significance of early engagement and effective communication with the public for advocates of carbon dioxide utilization. They expressed concerns about the potential hindrance of poor public engagement to the success of the technology. One interviewee from Almaty specifically raised concerns about the media amplifying perceived technological risks and stressed the importance of proponents of the technology taking control of the narrative. Furthermore, some participants cautioned against drawing premature conclusions about public acceptance of carbon dioxide utilization based solely on opinion polls or surveys. They argued that the current low level of public awareness about the technology might result in a superficial endorsement that could change as people gain more knowledge about the technology and its implications.

4. Conclusions

Different aspects of carbon dioxide emission from electricity production in the case of Kazakhstan have been investigated. The research was split into two main sections. The initial phase focused on establishing the emission factors related to electricity generation. The second section was designed to gauge people's perceptions of the concept of carbon dioxide utilization. This was done by conducting a survey in two cities in Kazakhstan, namely Almaty and Astana. All of the power plants under investigation produced greater than 0.5 weighted average carbon dioxide emissions, with the Simple Operating Margin in the North area producing the highest levels. Similarly, the highest weighted average emission factor (1.0198) was observed from the North Energy Zone under the Simple Operating Margin method. A p-value of 0.869253 was obtained from the Analysis of the Variance of the emission factors across different years. Similar results were seen when the estimated emission factors were subjected to the Scheffé multiple comparisons and Tukey's honest significant test. The findings indicated that between 2017 and 2020, the reduction in carbon dioxide emissions did not significantly improve. Over the course of four years, the rate of carbon dioxide emission hardly changed at all. These findings indicate that more initiatives are required to achieve a significant reduction in carbon dioxide emissions in the electricity production sector. Based on the survey findings, some participants expressed doubts regarding the practicality of employing carbon dioxide utilization as a means of addressing climate change. Their opinion was that this approach would merely provide a short-term resolution to carbon emissions, without tackling the root causes of the issue. Nevertheless, despite these apprehensions, the respondents acknowledged that carbon dioxide utilization had some benefits in terms of promoting sustainability. Moreover, participants emphasized the crucial need for effective communication and proactive public engagement for advocates of this technology, highlighting concerns about potential hindrances caused by poor public engagement. They cautioned against drawing premature conclusions based solely on opinion polls, given the current low level of public awareness, which could change as people gain more knowledge about the technology and its implications. Furthermore, some participants cautioned against drawing premature conclusions about public acceptance of carbon dioxide utilization based solely on opinion polls or surveys. They argued that the current low level of public awareness about the technology might result in a superficial endorsement that could change as people gain more knowledge about the technology and its implications. These findings offer valuable insights for managing carbon dioxide emissions, not only in Kazakhstan but also globally, underscoring the essential requirements of efficient communication, careful consideration of facility locations, and public engagement in shaping a sustainable future.

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