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Article

The relationship between energy consumption, pollution, economic growth and ICT: Structural equation modeling approach

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Abstract: The following paper assesses the relationship between electricity consumption, economic growth, environmental pollution, and Information and Communications Technology (ICT) development in Kazakhstan. Using the structural equation method, the study analyzes panel data gathered across various regions of Kazakhstan between 2014 and 2022. The data were sourced from official records of the Bureau of National Statistics of Kazakhstan and include all regions of Kazakhstan. The chosen timeframe includes the period from 2014, which marked a significant drop in oil prices that impacted the overall economic situation in the country, to 2022. The main hypotheses of the study relate to the impact of electricity consumption on economic growth, ICT, and environmental sustainability, as well as ICT's role in economic development and environmental impact. The results show electricity consumption's positive effect on economic growth and ICT development while also revealing an increase in pollutant emissions (emissions of liquid and gaseous pollutants) with economic growth and electricity consumption. The development of ICT in Kazakhstan has been revealed to not have a direct effect on reducing pollutant emissions into the environment, raising important questions about how technology can be leveraged to mitigate environmental impact, whether current technological advancements are sufficient to address environmental challenges, and what specific measures are needed to enhance the environmental benefits of ICT. There is a clear necessity to integrate sustainable practices and technologies to achieve balanced development. These results offer important insights into the relationships among electricity consumption, technology, economic development, and environmental issues. They underscore the complexity and multidimensionality of these interactions and suggest directions for future research, especially in the context of finding sustainable solutions for balanced development.

Keywords: information and communication technologies; economic growth; energy consumption; environmental pollution; sustainable development; energy efficiency; environmental policy; technological innovation
JEL Classification: O14; O32; Q43

1. Introduction

Kazakhstan's economy is significantly influenced by its rich natural resources, including oil, gas, and minerals, which have historically driven economic growth. However, the reliance on fossil fuels has also led to considerable environmental challenges, including high levels of pollution. The global drop in oil prices in 2014 notably impacted Kazakhstan's economic stability, highlighting the country's vulnerability to external economic shocks. This underscores the importance of economic diversification and the adoption of sustainable practices. Additionally, Information and Communication Technologies (ICT) have become integral to modern economies, impacting various sectors and potentially contributing to sustainable development. Understanding the complex relationships between energy consumption, economic growth, environmental pollution, and ICT development is essential for formulating effective policies in Kazakhstan.

Despite extensive research on the individual impacts of energy consumption, economic growth, and ICT on environmental pollution, there is a notable gap in comprehensive studies that explore their interconnected relationships specifically in the context of Kazakhstan. This gap hinders the development of integrated strategies for sustainable development that consider these factors collectively.

The primary objective of this study is to investigate the relationships between electricity consumption, economic growth, environmental pollution, and ICT development in Kazakhstan. By analyzing these interdependencies, the study aims to provide insights into how these factors influence each other and identify potential strategies for achieving sustainable development in Kazakhstan.

- This study seeks to address the following research questions:
    - How does electricity consumption affect economic growth in Kazakhstan?
    - What is the impact of electricity consumption on environmental pollution?
    - How does ICT development influence economic growth and environmental pollution?
    - Are current technological advancements in ICT sufficient to mitigate environmental impacts in Kazakhstan?
- The hypotheses tested in this study are:
    - Increased power consumption positively affects economic growth.
    - An increase in power consumption leads to an increase in pollutant emissions.
    - Electricity consumption positively affects the development of ICT.
    - ICT positively affects economic growth.
    - ICT helps reduce pollutant emissions into the environment.
    - Economic growth leads to an increase in pollutant emissions.

This study is significant because it addresses a critical gap in understanding the multifaceted relationships between energy consumption, economic growth, environmental pollution, and ICT development in Kazakhstan. The findings can inform policymakers, businesses, and researchers about the complexities of these interactions and aid in the development of integrated strategies for sustainable economic and environmental development. Additionally, the study provides a basis for future research in similar contexts and contributes to the broader discourse on sustainable development in developing countries.

The study focuses on the period between 2014 and 2022, using panel data from various regions of Kazakhstan. While this timeframe includes significant economic events such as the 2014 oil price drop, it may not capture longer-term trends. The analysis is limited to available data from the Bureau of National Statistics of Kazakhstan, which might not include all relevant variables. Furthermore, the study's findings are specific to Kazakhstan and may not be directly applicable to other countries without considering their unique contexts.

The paper is organized as follows:

- Introduction. Provides background information, states the research problem, outlines the study's purpose, research questions, hypotheses, significance, scope, limitations, and structure.
- Literature Review and Hypotheses. Reviews relevant literature and presents the hypotheses.
- Materials and Methods. Describes the data sources, methodology, and analytical techniques used in the study.
- Results. Presents the findings of the data analysis.
- Discussion. Interprets the results, discusses their implications, and compares them with existing literature.
- Conclusions and Policy Implications. Summarizes the key findings, outlines policy recommendations, and suggests areas for future research.

2. Review of literatures

2.1. Electricity consumption and economic growth

The impact of electricity consumption on economic growth is multifaceted. Firstly, electricity is essential for many industrial processes and operations, leading to improved productivity and efficiency (Mohsin et al., 2021; Usman et al., 2021; Rahman, 2020). A reliable power supply enhances business productivity, competitiveness, and facilitates technological progress, enabling the adoption of new technologies in various sectors, which in turn contributes to economic growth (Alam and Murad, 2020; Rahman, 2020). Additionally, a stable power supply improves the quality of life by providing necessary services such as lighting, heating, cooling, and access to ICT, thereby increasing labor productivity and overall well-being (Akadiri et al., 2020; Doğan et al., 2020).

Electricity also stimulates business and entrepreneurship by being a key resource for small and medium-sized businesses, fostering job creation and economic development (Wei et al., 2023). Infrastructure development is another crucial aspect, where the expansion and modernization of power infrastructure often leads to the development of other types of infrastructure like transport and communications, further contributing to economic growth (Rahman, 2020; Usman et al., 2021). Moreover, power availability is vital for educational and medical institutions, thus improving education levels and public health, which are essential for sustainable economic growth (Banerjee et al., 2021; Hassan et al., 2022). Lastly, a reliable and efficient power system can attract more domestic and foreign investments, enhancing economic growth (Baz et al., 2021; Fan and Hao, 2020).

Given the various factors, the effect of power consumption on economic growth can vary depending on the country's context, its development level, and existing energy policies. Therefore, the study hypothesizes:

Hypothesis 1: Increased power consumption positively affects economic growth.

2.2. Power consumption and pollutant emissions

The relationship between increased power consumption and pollutant emissions is significant, especially when power generation relies on fossil fuels. Most of the world's electricity is produced from fossil fuels such as coal, oil, and natural gas, which release pollutants into the atmosphere, including carbon dioxide (CO_2), sulfur dioxide (SO_x), hydrogen sulfide (H_2S), nitrogen oxides (NO_x), and ammonia when burned (Asongu et al., 2020; Ridzuan et al., 2020). CO_2, a major greenhouse gas, is a significant contributor to climate change (Akadiri et al., 2020). The need to expand and improve energy infrastructure increases with power consumption, often leading to the construction of additional fossil fuel power plants (Destek and Aslan, 2020).

In many regions, existing energy systems are not optimized for efficient resource use, resulting in large energy losses and increased pollutant emissions per unit of electricity produced (Mohsin et al., 2021; Sharma et al., 2021). Despite the development of renewable energy technologies, their share in the overall energy mix remains relatively low, meaning increased energy consumption is often met by traditional, more polluting sources (Al-Shetwi, 2022; Strielkowski et al., 2021). Furthermore, fossil fuel power plants can harm local ecosystems through water use and thermal pollution, increasing their environmental impact (Chen et al., 2021).

The relationship between power consumption and the environment may change with the development and deployment of cleaner energy sources, energy efficiency improvements, and the application of pollutant capture and storage technologies. Thus, the study hypothesizes:

Hypothesis 2: An increase in power consumption leads to an increase in pollutant emissions.

2.3. Power consumption and ICT

Electricity consumption directly influences the development of information and communication technologies (ICT). ICT infrastructure, including data centers, communication networks, and servers, requires a reliable power supply to operate effectively (Arshad et al., 2020; Lange et al., 2020). A stable power source supports the expansion and maintenance of ICT infrastructure, improving the quality of telecommunications services (Ren et al., 2021). Furthermore, a reliable power supply stimulates innovation in the ICT sector, enabling companies and research institutions to experiment with new technologies and develop innovative products and solutions (Lange et al., 2020).

The digital economy, encompassing e-commerce, online education, telemedicine, and other digital services, depends heavily on a reliable power supply (Li et al., 2021; Usman et al., 2021). Regions with stable power supplies are more likely to adopt and use computers, smartphones, and the Internet extensively (Bilal et al., 2021). Additionally, cloud computing, which requires significant energy resources to keep servers and data centers running, is becoming a key element of modern ICT, necessitating a reliable power supply (Katal et al., 2023). The COVID-19 pandemic has further highlighted the importance of a stable power supply for supporting remote work and online education, facilitating the integration of ICT into everyday life (Jiang et al., 2021).

Thus, electricity not only supports existing ICTs but also contributes to their further development and innovation. Therefore, the study hypothesizes:

Hypothesis 3: Electricity consumption positively affects the development of information and communication technologies.

2.4. ICT and economic growth

ICTs significantly impact economic growth by increasing productivity, fostering innovation, and creating new industries. Automation of processes through ICT increases efficiency in both individual companies and entire industries, leading to lower costs, faster production, and improved product and service quality (Appiah-Otoo and Song, 2021; Vu et al., 2020). The introduction of ICTs stimulates innovation, leading to the creation of new products and services, opening new markets, and contributing to job creation in high-tech industries (Fernández-Portillo et al., 2020).

ICTs also improve access to information, which is crucial for making informed business decisions, and help companies enter new markets more easily (Cheng et al., 2021; Vu et al., 2020). Furthermore, ICTs optimize logistics and supply chain management, reducing the time and cost of delivering goods and services (Adedoyin et al., 2020; Emenike and Falcone, 2020). The growth of e-commerce, driven by ICT, expands opportunities for small and medium-sized enterprises (SMEs), allowing them to compete in wider markets (Fernández-Portillo et al., 2020; Roshchyk et al., 2022; Sarangi and Pradhan, 2020).

Additionally, ICT facilitates the development of fintech services, improving access to financial services for businesses and individuals, thereby contributing to economic growth (Cheng et al., 2021; Erlando et al., 2020). ICT also enhances educational programs and access to knowledge, improving workforce skills and promoting economic development (Appiah-Otoo and Song, 2021; Adeleye et al., 2021). Moreover, ICT enables state organizations to operate more efficiently and provide quality services to citizens, further contributing to economic development (Fernández-Portillo et al., 2020; Solomon and van Klyton, 2020).

In summary, ICT acts as a catalyst for economic growth by promoting innovation, increasing efficiency and productivity, improving access to information and markets, and fostering the development of new industries and improved quality of life. Thus, the study hypothesizes:

Hypothesis 4: Information and communication technologies positively affect economic growth.

2.5. ICTs and pollution

ICT can impact pollutant emissions by improving efficiency, optimizing processes, and facilitating the adoption of greener technologies. Organizations using the Internet often implement advanced management and automation technologies, resulting in more efficient use of resources and reduced emissions (Hao et al., 2022; Wen et al., 2021). Internet technologies can facilitate the adoption of environmentally friendly practices and technologies, such as cloud computing, which reduces the need for physical servers and data centers, traditionally large energy consumers (Caglar et al., 2021; Murshed, 2020).

Increased Internet use can also reduce the need for business travel and physical movement, thereby reducing transport emissions (De Vos, 2020; Nieuwenhuijsen, 2021; Tainio et al., 2021). The growth of e-commerce and digital services reduces dependence on physical products and packaging, decreasing waste and associated emissions (Chen and Yan, 2020; Mucowska, 2021). Furthermore, the Internet increases awareness and education about environmentally friendly practices and regulations, encouraging their implementation (Charfeddine and Umlai, 2023; Zhang et al., 2022).

It is important to note that this relationship may not be direct and may depend on various factors, such as industry type, geographic location, government environmental and technological policies, and the overall economic condition of the region or country. Therefore, the study hypothesizes:

Hypothesis 5: ICTs help reduce pollutant emissions into the environment.

2.6. Economic growth and environmental pollution

Economic growth can lead to increased pollutant emissions due to several factors. Increased industrial activity, often accompanied by expansion and intensification of industrial production, is a significant source of pollutant emissions, including CO_2, SO_x, H_2S, NO_x, and ammonia (Egbetokun et al., 2020; Rao and Yan, 2020). The growing demand for energy for industrial and domestic needs is often met by traditional energy sources such as coal, oil, and natural gas, further increasing emissions (Mughal et al., 2022; Osobajo et al., 2020).

Economic development usually involves an increase in the number of vehicles, leading to higher transport emissions (Mohmand et al., 2021; Nasreen et al., 2020). Construction and urban development, driven by economic growth, also lead to increased emissions from construction equipment and processes (Gan et al., 2021; Li et al., 2020). Furthermore, growing consumer demand and increased production of goods contribute to higher emissions, especially if production processes are not environmentally efficient (Xiong and Xu, 2021). Rapid economic growth may also occur without adequate implementation or enforcement of environmental standards, resulting in increased pollution (Heidtmann and Selck, 2021; Moroz et al., 2021).

However, the link between economic growth and increased emissions is not inevitable. The use of environmentally sustainable technologies, increased energy efficiency, transitioning to renewable energy sources, and developing and implementing environmental regulations and standards can help minimize the negative impact of economic growth on the environment. Thus, the study hypothesizes:

Hypothesis 6: Economic growth leads to an increase in pollutant emissions.

2.7. Theoretical framework

The theoretical framework of this study is based on the Structural Equation Modeling (SEM) approach, which allows for analyzing complex relationships between observed and latent variables. The framework includes constructs such as electricity consumption, economic growth, environmental pollution, and ICT development. Using SEM, the study aims to validate the proposed hypotheses and provide a comprehensive understanding of the interdependencies among these variables. The hypotheses generated are tested using panel data from Kazakhstan's Bureau of National Statistics, covering the period from 2014 to 2022.

Figure 1 shows key study measures and constructs.

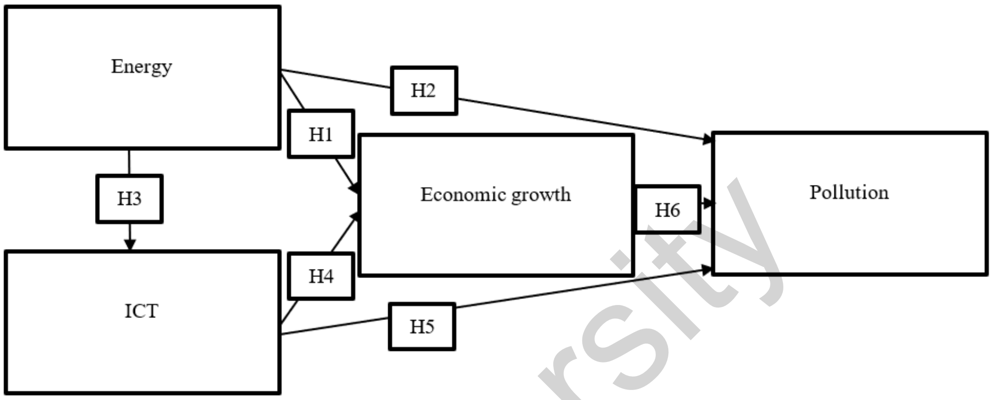

Figure 1. Research framework and hypotheses.

3. Materials and methods

This study employs a quantitative research design using Structural Equation Modeling (SEM) to analyze the relationships between electricity consumption, economic growth, environmental pollution, and ICT development in Kazakhstan. The ICT variable can optionally include power consumption plus the time spent on ICT activities during a typical workday, which is 8 hours in Kazakhstan. The SEM approach integrates various components of the study in a coherent and logical manner, allowing for the examination of both direct and indirect effects among the variables.

The variables used in the SEM are detailed in **Table A1** (Appendix).

Table 1 shows main variables for building a structural model.

Table 1. Variables selected to build a structural model.

Legend	Variable	Source
Energy	Power Consumption, mil kWh	BNS
Economic growth	GRP, mil tenge	BNS
Pollution	Emissions of Liquid and Gaseous Pollutants, thous. t	BNS
ICT	No. of Companies Using the Internet, pcs.	BNS

Notes: 1) Compiled by the authors; 2) BNS is Bureau of National Statistics of Agency for Strategic Planning and Reforms of the Republic of Kazakhstan.

These include power consumption (measured in million kWh), economic growth (measured in million tenge of Gross Regional Product, GRP), pollution (measured in thousand tons of liquid and gaseous pollutants), and ICT development (measured by the number of companies using the Internet). The data were sourced from the Bureau of National Statistics of Kazakhstan.

The study covers a balanced panel data set from 14 regions of Kazakhstan over the period from 2014 to 2022. This results in a total of 126 observations for each indicator. The selection criteria for the regions and the timeframe were based on data availability and the relevance of the chosen period, which includes significant economic events such as the 2014 oil price drop.

The study utilizes official records from the Bureau of National Statistics of Kazakhstan as the primary data source. The validity and reliability of these instruments are ensured by their official and standardized nature. Data analysis was performed using SPSS Statistics 23, SPSS Amos 24, and Microsoft Excel.

Data collection involved gathering secondary data from the Bureau of National Statistics of Kazakhstan, which provided comprehensive coverage of the four indicators across all regions for the specified period. The data collection process was systematic, ensuring consistency and accuracy.

SEM was chosen for its ability to analyze complex relationships between observed and latent variables. This method combines correlation, multiple regression, factor analysis, and general linear models to study the relationships between the variables.

According to Byrne (2010) and Kline (2023), the application of Structural Equation Modeling (SEM) involves five key steps:

1) Model Building. This initial phase involves graphically depicting the researcher's a priori assumptions about the structure of both directed and undirected relationships between measured variables and latent constructs. Decisions are made about which parameters (e.g., connections, variances) will be free to estimate and which will be fixed (e.g., set to 0 or 1).

2) Model Identification. At this stage, the researcher determines the relationship between what is to be estimated (free parameters) and the initial information contained in the data (covariances, variances). The goal is to ensure there is sufficient, but not excessive, information for parameter estimation.

3) Model Evaluation. The researcher selects a method for estimating the model parameters, primarily based on the nature of the source data. This step involves employing statistical techniques to estimate the free parameters defined during model building.

4) Model Consistency Check. The model is then tested against the input data using various fit indices that measure the degree of discrepancy between the input data and the model's predictions. These indices help determine how well the model fits the data.

5) Model Correction. If the initial model does not fit the data well, adjustments are made to achieve better compliance. This can be done by adding new connections or excluding insignificant ones, refining the model iteratively.

In SEM, only the covariances (correlations) of independent variables are specified or estimated. The consistency and quality of a built model in SEM are assessed using several indicators, the most important of which include:

- Chi-Square Likelihood Criterion. A standard measure where a chi-square test is considered normal at $p < 0.05$, indicating good model fit.
- Root Mean Square Error of Approximation (RMSEA). Ideally, RMSEA should be below or equal to 0.05 to indicate good fit. Values below or equal to 0.08 are acceptable, while values between 0.08 and 1.0 indicate a weak fit, and values over 0.1 suggest a poor fit (Kline, 2023).

Comparative Fit Index (CFI). This index should be above 0.9 to indicate a good fit.

Data analysis involved descriptive statistics, correlation analysis, and the application of SEM using SPSS Amos 24. The analysis included assessing the fit of the SEM model using indicators such as chi-square likelihood criterion, root mean square error of approximation (RMSEA), and comparative fit index (CFI).

The basic model formulas for SEM used in this study are as follows:

(1) Measurement Model:

$$y = \Lambda_y \eta + \epsilon$$
$$x = \Lambda_x \xi + \delta$$

where:

y and x are the observed endogenous and exogenous variables, respectively.

Λ_y and Λ_x are the factor loadings for the endogenous and exogenous variables, respectively.

η and ξ are the latent endogenous and exogenous variables, respectively.

ϵ and δ are the measurement errors.

(2) Structural Model:

$$\eta = B\eta + \Gamma\xi + \zeta$$

where:

B is the coefficient matrix for the endogenous variables.

Γ is the coefficient matrix for the exogenous variables.

ζ is the vector of structural disturbances.

These models collectively describe the relationships among the variables and allow for the estimation of direct, indirect, and total effects.

To enhance the empirical rigor of the study, additional tests and analyses are performed, including mechanism tests, robustness tests, and heterogeneity analyses.

(1) Mechanism Test. The mechanism test aims to uncover the underlying processes through which electricity consumption affects economic growth, environmental pollution, and ICT development. This involves examining the mediating effects of ICT development on the relationship between electricity consumption and economic growth.

(2) Robustness Test. The robustness test evaluates the stability and reliability of the SEM results. This includes:
- Alternative Model Specifications. Testing the model with different specifications to check for consistency in the results.
- Subsample Analysis. Dividing the sample into different subsets (e.g., based on region or time period) and re-estimating the model to ensure the findings are not driven by specific subsamples.

(3) Heterogeneity Analysis. Heterogeneity analysis explores whether the relationships between the variables differ across different groups or contexts. This includes:
- Regional Analysis. Assessing whether the effects of electricity consumption, ICT development, and economic growth vary across different regions of Kazakhstan.
- Temporal Analysis. Investigating whether the relationships change over time, particularly before and after significant economic events such as the 2014 oil price drop.

The results of the mechanism, robustness, and heterogeneity analyses provide further empirical support for the study's findings and enhance the scientific validity of the conclusions.

The study is based on publicly available secondary data, thus ethical concerns such as informed consent and confidentiality are not applicable. However, the research adheres to ethical standards in data handling and reporting.

The study acknowledges potential limitations such as the reliance on secondary data, which may not capture all relevant variables. Additionally, the findings are specific to Kazakhstan and may not be directly generalizable to other contexts without considering regional differences.

4. Results

4.1. Data analysis

Table 2 shows descriptive statistics of analyzed variables.

Table 2 contains descriptive statistics for four variables: pollutant emissions, economic growth, power consumption, and the number of organizations using the Internet. Indicators included are the number of observations (N = 126), minimum, maximum, mean, and standard deviation. The standard deviation indicates the spread of data around the mean value, while the mean itself gives an overall idea of the central tendency of each variable.

Table 2. Descriptive statistics.

Variables	*N*	Minimum	Maximum	Mean	Std. Deviation
Pollution	126	20.6	581.3	133.384	154.5635
Economic growth	126	795,551.2	24,703,079.9	4,529,798.444	4,188,779.0920
Energy	126	1592	21,480	7263.98	5272.168
ICT	126	52.5	98.5	83.106	8.6897

Note: Compiled by the authors using SPSS Statistics 23.

Table 2 shows the following sample mean values for the research period:

- Liquid and gaseous pollutant emissions on average for the sample are 133.384 thousand tons,
- Economic growth is 4,529,798.444 million tenge,
- Power consumption is 7263.98 million kWh, and
- Number of organizations using the Internet is 83.106 units.

Total liquid and gaseous pollutant emissions in Kazakhstan over the analyzed period are increasing. Indicatively, intercountry liquid and gaseous pollutant emissions amounted to 1762.5 thousand tons in 2014 and 1868.5 thousand tons in 2022, making a 106 thousand tons increase.

Other indicators are increasing as well. Kazakhstan's GDP amounted to 102.892 billion tenge in 2022 against 39.676 billion tenge in 2014, marking a growth of 63.216 billion tenge. Power consumption in Kazakhstan amounted to 112.9 billion kWh in 2022 and 91.6 billion kWh in 2014, making an increase of 21.3 billion kWh. From 2014 to 2022, the number of organizations using the Internet increased from 52.630 units to 124.603 units, an increase of 71.973 units.

4.2. Correlation analysis

The Pearson correlation coefficient was used to assess the degree of tightness between variables. Following this, a correlation matrix was constructed with SPSS Statistics 23 (see **Table 3**).

Table 3. A correlation matrix.

Variables	Pollution	Economic growth	Energy	ICT
Pollution	1			
Economic growth	0.820**	1		
Energy	0.890**	0.353**	1	
ICT	0.054	0.355**	0.179*	1

Note: Compiled by the authors using SPSS Statistics 23.
**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Analysis of the correlation matrix has shown a very high correlation between the indicator of liquid and gaseous pollutant emissions in Kazakhstan with the indicators of economic growth (0.82) and power consumption (0.89).

In addition, a weak correlation is observed with the indicator Number of Organizations Using the Internet. At this stage of the study, preliminary conclusions are as follows:

1) Increasing power consumption in Kazakhstan has a direct positive impact on economic growth.

2) An increase in power consumption in Kazakhstan leads to an increase in pollutant emissions.

3) Power consumption in Kazakhstan has a positive impact on development of information and communication technologies.

4) Development of information and communication technologies in Kazakhstan has a positive impact on economic growth.

5) Development of information and communication technologies in Kazakhstan does not directly affect reducing the volume of pollutant emissions into environment.

6) Economic growth in Kazakhstan leads to increased pollutant emissions.

The finding that ICT development does not significantly reduce pollutant emissions is significant for several reasons and warrants a more detailed explanation. This outcome challenges the assumption that technological advancements alone can mitigate environmental impacts, suggesting that other factors need to be considered.

1) Energy Intensity of ICT. ICT infrastructure, such as data centers and communication network, consumes substantial amounts of energy. Often, this energy is sourced from non-renewable resources. The increased energy demand associated with ICT can offset potential environmental benefits, leading to a net increase in pollutant emissions.

2) Indirect Effects. While ICT can improve efficiency in various sectors, the overall increase in production and consumption driven by ICT growth can lead to higher overall emissions. For example, the manufacturing, use, and disposal of ICT equipment contribute to the environmental footprint. Furthermore, as ICT enables more business activities and consumer interactions, it may inadvertently drive higher

energy use and emissions in other sectors.

3) Policy and Implementation Gaps. The potential of ICT to contribute to environmental sustainability may not be fully realized due to inadequate policies and lack of integration of environmental considerations into ICT strategies. Without stringent environmental regulations and policies promoting green ICT practices, the environmental impact of ICT can remain significant. Effective implementation of green ICT practices and policies is crucial to harness the environmental benefits of technological advancements.

4) Lifecycle Emissions. The lifecycle emissions of ICT equipment, including manufacturing, transportation, operation, and disposal, can be substantial. If these emissions are not effectively managed or offset, the overall impact of ICT on the environment can be negative.

5) Economic Structure. In developing countries like Kazakhstan, the rapid adoption of ICT may not immediately translate to environmental benefits due to the existing economic and industrial structure. Industries that heavily rely on fossil fuels may continue to dominate, and the transition to cleaner technologies may be slow.

6) Lack of Renewable Energy Integration. The integration of renewable energy sources to power ICT infrastructure is often limited. Without a significant shift towards renewable energy, the environmental benefits of ICT will be constrained.

4.3. Analysis of the structural model

Let us apply the structural modeling method to describe the cause-and-effect relationship between power consumption, economic growth, environmental pollution, and ICT based on selected structure of indicators using calculations with SPSS Amos. As a result, a cause-and-effect relationship has been established between the variables (See **Figure 2**).

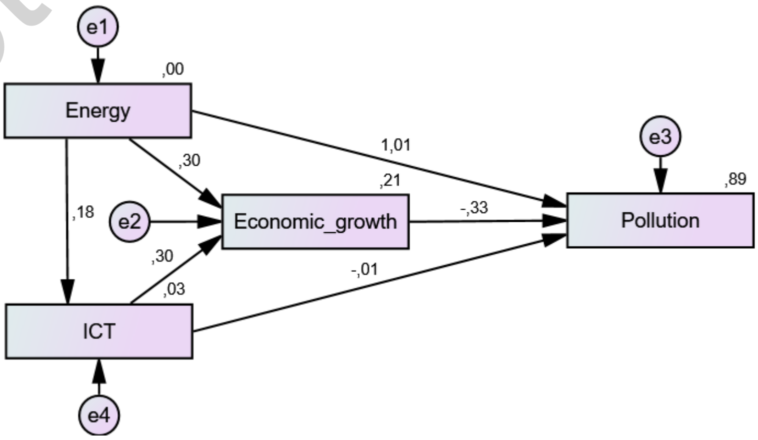

Figure 2. Structural indicator modeling.

Note: Compiled by the authors using SPSS Amos 24.

Figure 2 shows the relationship between latent variable Environmental Pollution and observed variables Power Consumption (1.01) and Economic Growth (0.33). A relationship has been established between variables Power Consumption and ICT as well. The value has been assessed using a regression coefficient (0.18). A connection was also established between variables Power Consumption and Economic Growth, the value of which has been assessed using a regression coefficient (0.30), too.

The model was tested using the following goodness-of-fit tests: The chi-squared tests the null hypothesis, i.e., whether the difference between empirical and model-reproduced covariance matrices is equal to zero. In our model, p exceeding 0.05 means good agreement. The model is considered adequate if RMSEA criterion (root mean square error of approximation) does not exceed 0.1. Analysis of the results allows us to conclude that the model has better agreement (RMSEA value does not exceed 0.1). Goodness-of-Fit Index (GFI) of at least 0.90 means good agreement (See **Table 4**).

Table 4. Model's fit indicators.

CMIN	DF	P	CMIN/DF	GFI	CFI	RMSEA
0.000	0	0.000	51.891	1.000	1.000	0.000

Note: Compiled by the authors using SPSS Statistics 23.

Table 5 shows regression coefficients and their statistical significance.

Table 5. Structural (Regression) coefficients.

			Estimate	S.E.	C.R.	*P*	Results
Economic_Growth	←	Energy	237.830	64.091	3.711	***	Supported (H1)
Pollution	←	Energy	0.030	0.001	31.958	***	Supported (H2)
ICT	←	Energy	0.000	0.000	2.037	0.042	Supported (H3)
Economic_Growth	←	ICT	145,245.222	38,885.099	3.735	***	Supported (H4)
Pollution	←	ICT	−0.142	0.562	−0.253	0.801	Refuted (H5)
Pollution	←	Economic_growth	0.000	0.000	−10.053	***	Supported (H6)

Research Hypotheses Significant at p *** ≤ 0.001, p * < 0.05.

In the model, the estimated regression weights of the parameters Power Consumption → Economic Growth, Power Consumption → Environmental Pollution, ICT → Economic Growth, and Economic Growth → Environmental Pollution are statistically significant (three asterisks indicate statistical significance of $p < 0.001$). The statistical significance of the parameter Power Consumption → ICT lies within $p^* < 0.05$, which does not provide grounds for its removal from the model. The statistical significance of ICT → Pollution parameters give us a reason to remove the ICT variable from the model.

- Mechanism Test.

The mechanism test reveals that ICT development partially mediates the relationship between electricity consumption and economic growth. This indicates that part of the positive effect of electricity consumption on economic growth operates through its impact on ICT development.

- Robustness Test.

The robustness test confirms the stability of the results. Alternative model specifications and subsample analyses yield consistent findings, demonstrating that the main conclusions are not sensitive to specific model assumptions or sample characteristics.

- Heterogeneity Analysis.

The heterogeneity analysis shows variation in the relationships across different regions and time periods. The positive impact of electricity consumption on economic growth and ICT development is stronger in more industrialized regions and during periods of economic stability. However, the environmental impact of electricity consumption is consistently significant across all regions and time periods, underscoring the need for sustainable energy policies.

Accordingly, we can draw the following results of testing the hypotheses put forward in this study.

Hypothesis H1 is supported. Results of the analysis have confirmed the assertion that an increase in power consumption in Kazakhstan has a direct positive impact on economic growth.

Hypothesis H2 is supported. There is a significant persistent impact of increasing power consumption in Kazakhstan on pollutant emissions.

Hypothesis H3 is supported. The assertion that power consumption in Kazakhstan has a positive impact on development of information and communication technologies has been confirmed.

Hypothesis H4 is supported. Results of the analysis confirmed the assertion that development of information and communication technologies in Kazakhstan has a positive impact on economic growth.

Hypothesis H5 is refuted. No significant relationship has been found between indicators ICT and Environmental Pollution. Development of information and communication technologies in Kazakhstan does not directly affect reducing the volume of pollutant emissions into environment.

Hypothesis H6 is confirmed. The assertion that economic growth in Kazakhstan leads to an increase in pollutant emissions has been confirmed.

5. Discussion

This study empirically explores the relationship between energy, technology, economic development and environmental issues in developing economies. Based on the literature review, six hypotheses are put forward. Based on provided results of testing our study's hypotheses, we can formulate the following discussion of the results of analysis:

Hypothesis H1: Results of the study have confirmed that an increase in power consumption in Kazakhstan has a positive effect on economic growth. This is consistent with previous studies (Mohsin et al., 2021; Rahman, 2020; Usman et al., 2021; Wei et al., 2023) showing that availability and use of energy resources are key factors in economic development. This finding highlights the importance of energy infrastructure in driving economic growth in the region.

Hypothesis H2: The study has shown a significant and persistent impact of power consumption on pollutant emission increase in Kazakhstan. This finding is consistent with previous studies (Al-Shetwi, 2022; Asongu et al., 2020; Ridzuan et al., 2020; Strielkowski et al., 2021). This reflects environmental consequences of increasing power consumption and emphasizes the need to develop and implement cleaner and more efficient energy production technologies.

Hypothesis H3: Confirmation of this hypothesis indicates the contribution of power consumption to development of ICTs in Kazakhstan. This is in line with a global trend where electricity availability is considered critical to the development of digital economy and technology.

Hypothesis H4: Results supporting this hypothesis indicate that ICT development in Kazakhstan has a positive effect on economic growth. This reflects the growing importance of digitalization in modern economies (Appiah-Otoo and Song, 2021; Vu et al., 2020) and its ability to improve efficiency, innovation, and entrepreneurial activity (Fernández-Portillo et al., 2020).

Hypothesis H5: The lack of a significant direct relationship between ICT development and reduction of environmental pollution raises important questions about the impact of technology on environment. This might indicate the need to integrate environmental considerations into ICT design and implementation (Caglar et al., 2021; Murshed, 2020).

Hypothesis H6: Confirmation of this hypothesis suggests that economic growth in Kazakhstan is accompanied by an increase in pollutant emissions. This emphasizes the issue of environmental sustainability of economic development and the need to find a balance between economic growth and environmental protection.

The findings of this study provide important insights into the complex and multidimensional relationships between energy consumption, ICT development, economic growth, and environmental pollution in Kazakhstan. They highlight the need for integrated approaches that consider multiple factors to achieve sustainable development.

1) Energy Policy: There is a need for policies that promote the use of renewable energy sources and improve energy efficiency. This can help reduce the environmental impact of increased energy consumption.

2) ICT Integration: Environmental considerations should be integrated into ICT development strategies. Promoting green ICT practices can enhance the positive impact of technology on the environment.

3) Sustainable Development: Achieving a balance between economic growth and environmental protection requires a comprehensive approach that includes regulatory measures, technological innovation, and public awareness.

Future research should explore:

- The impact of specific ICT policies and practices on environmental sustainability.
- Comparative studies across different regions and countries to identify best practices for integrating ICT development and environmental sustainability.
- Longitudinal studies to assess the long-term effects of ICT development on environmental outcomes.
- The role of renewable energy in supporting sustainable ICT infrastructure.

This study contributes to the understanding of the interactions between energy, technology, economic development, and environmental issues, providing a foundation for developing effective strategies for balanced and sustainable development in Kazakhstan and similar developing economies.

6. Conclusions and policy implications

This study confirms a direct positive relationship between increased power consumption and economic growth in Kazakhstan. This is due to the fact that power is the basis for many industrial processes and operations and its efficient and reliable supply increases productivity and competitiveness of enterprises.

It has been established that an increase in power consumption leads to an increase in pollutant emissions. This is due to the use of traditional, more polluting energy sources.

It is concluded that a reliable and affordable power supply promotes increased use and diffusion of ICTs in society and business, especially in regions where access to power was previously limited.

ICT has been found to have a positive impact on economic growth by supporting digital economy, stimulating innovation, and expanding infrastructure. This is especially important for regions with a stable power supply having a greater chance of widespread adoption and use of ICTs.

The paper has not found a direct impact of ICT development on reduction of pollutant emissions, indicating the need to integrate environmental considerations into ICT development and implementation.

It is concluded that economic growth in Kazakhstan leads to increased environmental pollution, putting emphasis on the need to integrate environmental considerations into economic policies.

The study outlines the importance of an integrated approach to studying relationships between economic growth, energy consumption, ICT, and environmental impacts. The conducted research indicates the need to create more comprehensive theoretical models that would take into account the variety of factors and their impact on sustainable economic and social development.

Our study provides important recommendations for governments and industry associations to develop policies that promote sustainable economic growth while considering environmental challenges:

- Implementation of a sustainable energy policy. Development and implementation of sustainable energy sources is required to reduce environmental damage while maintaining economic growth.
- Integration of environmental standards into ICTs. The use of environmentally friendly and energy efficient technologies must be developed and promoted.
- Educational and research initiatives. Increased investment in education and research to raise awareness of the importance of sustainable development.
- Incentives for environmentally sustainable business. Tax benefits and subsidies to companies introducing environmentally friendly technologies.

Future research could focus on several key areas to further understand the complex relationships between economic growth, energy consumption, ICT, and environmental outcomes:

1) Exploring Additional Factors. Future studies should investigate other potential factors that may influence these relationships. This could include examining the role of government policies, regulatory frameworks, technological advancements, and international trade in shaping the dynamics between energy consumption, economic growth, ICT development, and environmental impact.

2) Geographical Contexts. Comparative studies across different geographical contexts should be conducted to draw more generalizable conclusions. Understanding how these relationships vary in different regions or countries can help identify unique

factors and best practices that can be applied more broadly.

3) Long-term Impacts. Researchers should explore the long-term impacts of power consumption, ICT development, economic growth, and environmental change. Longitudinal studies can provide insights into how these variables interact over extended periods and help predict future trends and outcomes.

4) ICTs and Renewable Energy Innovations. Future research should assess how innovations in ICT and renewable energy technologies impact economic and environmental indicators. This includes examining the effectiveness of green ICT practices and the adoption of renewable energy sources in reducing environmental pollution and promoting sustainable development.

5) Socio-economic and Cultural Aspects. Studies should investigate the influence of socio-economic and cultural aspects on the relationships between economic growth, energy consumption, ICT development, and environmental outcomes. Factors such as public awareness, cultural attitudes towards sustainability, and economic inequalities can significantly affect how these variables interact and shape policy and practice.

By addressing these areas, future research can deepen the understanding of the interactions between energy consumption, technology, economic growth, and environmental sustainability, contributing to the development of effective strategies for achieving balanced and sustainable development.

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References

Adedoyin, F. F., Bekun, F. V., Driha, O. M., & Balsalobre-Lorente, D. (2020). The effects of air transportation, energy, ICT and FDI on economic growth in the industry 4.0 era: Evidence from the United States. Technological Forecasting and Social Change, 160, 120297. https://doi.org/10.1016/j.techfore.2020.120297

Adeleye, B. N., Adedoyin, F., & Nathaniel, S. (2021). The criticality of ICT-trade nexus on economic and inclusive growth. Information Technology for Development, 27(2), 293–313. https://doi.org/10.1080/02681102.2020.1840323

Alam, M. M., & Murad, M. W. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. Renewable Energy, 145, 382–390. https://doi.org/10.1016/j.renene.2019.06.054

Al-Shetwi, A. Q. (2022). Sustainable development of renewable energy integrated power sector: Trends, environmental impacts, and recent challenges. Science of The Total Environment, 822, 153645. https://doi.org/10.1016/j.scitotenv.2022.153645

Appiah-Otoo, I., & Song, N. (2021). The impact of ICT on economic growth-Comparing rich and poor countries. Telecommunications Policy, 45(2), 102082. https://doi.org/10.1016/j.telpol.2020.102082

Arshad, Z., Robaina, M., & Botelho, A. (2020). The role of ICT in energy consumption and environment: an empirical investigation of Asian economies with cluster analysis. Environmental Science and Pollution Research, 27, 32913–32932. https://doi.org/10.1007/s11356-020-09229-7

Asongu, S. A., Agboola, M. O., Alola, A. A., & Bekun, F. V. (2020). The criticality of growth, urbanization, electricity and fossil fuel consumption to environment sustainability in Africa. Science of the Total Environment, 712, 136376. https://doi.org/10.1016/j.scitotenv.2019.136376

Banerjee, R., Mishra, V., & Maruta, A. A. (2021). Energy poverty, health and education outcomes: evidence from the developing world. Energy economics, 101, 105447. https://doi.org/10.1016/j.eneco.2021.105447

Baz, K., Cheng, J., Xu, D., et al. (2021). Asymmetric impact of fossil fuel and renewable energy consumption on economic growth: A nonlinear technique. Energy, 226, 120357. https://doi.org/10.1016/j.energy.2021.120357

Bilal, A., Li, X., Zhu, N., et al. (2021). Green technology innovation, globalization, and CO2 emissions: recent insights from the OBOR economies. Sustainability, 14(1), 236. https://doi.org/10.3390/su14010236

Caglar, A. E., Mert, M., & Boluk, G. (2021). Testing the role of information and communication technologies and renewable energy consumption in ecological footprint quality: Evidence from world top 10 pollutant footprint countries. Journal of Cleaner Production, 298, 126784. https://doi.org/10.1016/j.jclepro.2021.126784

Charfeddine, L., & Umlai, M. (2023). ICT sector, digitization and environmental sustainability: A systematic review of the literature from 2000 to 2022. Renewable and Sustainable Energy Reviews, 184, 113482. https://doi.org/10.1016/j.rser.2023.113482

Chen, W., & Yan, W. (2020). Impact of internet electronic commerce on SO 2 pollution: Evidence from China. Environmental Science and Pollution Research, 27, 25801–25812. https://doi.org/10.1007/s11356-020-09027-1

Chen, X. H., Tee, K., Elnahass, M., & Ahmed, R. (2023). Assessing the environmental impacts of renewable energy sources: A case study on air pollution and carbon emissions in China. Journal of environmental management, 345, 118525. https://doi.org/10.1016/j.jenvman.2023.118525

Cheng, C. Y., Chien, M. S., & Lee, C. C. (2021). ICT diffusion, financial development, and economic growth: An international cross-country analysis. Economic modelling, 94, 662–671. https://doi.org/10.1016/j.econmod.2020.02.008

De Vos, J. (2020). The effect of COVID-19 and subsequent social distancing on travel behavior. Transportation research interdisciplinary perspectives, 5, 100121. https://doi.org/10.1016/j.trip.2020.100121

Destek, M. A., & Aslan, A. (2020). Disaggregated renewable energy consumption and environmental pollution nexus in G-7 countries. Renewable energy, 151, 1298–1306. https://doi.org/10.1016/j.renene.2019.11.138

Doğan, B., Balsalobre-Lorente, D., & Nasir, M. A. (2020). European commitment to COP21 and the role of energy consumption, FDI, trade and economic complexity in sustaining economic growth. Journal of environmental Management, 273, 111146. https://doi.org/10.1016/j.jenvman.2020.111146

Egbetokun, S., Osabuohien, E., Akinbobola, T., et al. (2020). Environmental pollution, economic growth and institutional quality: exploring the nexus in Nigeria. Management of Environmental Quality: An International Journal, 31(1), 18–31. https://doi.org/10.1108/MEQ-02-2019-0050

Emenike, S. N., & Falcone, G. (2020). A review on energy supply chain resilience through optimization. Renewable and Sustainable Energy Reviews, 134, 110088. https://doi.org/10.1016/j.rser.2020.110088

Erlando, A., Riyanto, F. D., & Masakazu, S. (2020). Financial inclusion, economic growth, and poverty alleviation: evidence from eastern Indonesia. Heliyon, 6(10). https://doi.org/10.1016/j.heliyon.2020.e05235

Fan, W., & Hao, Y. (2020). An empirical research on the relationship amongst renewable energy consumption, economic growth and foreign direct investment in China. Renewable energy, 146, 598–609. https://doi.org/10.1016/j.renene.2019.06.170

Fernández-Portillo, A., Almodóvar-González, M., & Hernández-Mogollón, R. (2020). Impact of ICT development on economic growth. A study of OECD European union countries. Technology in Society, 63, 101420. https://doi.org/10.1016/j.techsoc.2020.101420

Gan, T., Yang, H., & Liang, W. (2021). How do urban haze pollution and economic development affect each other? Empirical evidence from 287 Chinese cities during 2000–2016. Sustainable Cities and Society, 65, 102642. https://doi.org/10.1016/j.scs.2020.102642

Hao, Y., Guo, Y., & Wu, H. (2022). The role of information and communication technology on green total factor energy efficiency: does environmental regulation work? Business Strategy and the Environment, 31(1), 403–424. https://doi.org/10.1002/bse.2901

Hassan, S. T., Batool, B., Zhu, B., & Khan, I. (2022). Environmental complexity of globalization, education, and income inequalities: New insights of energy poverty. Journal of Cleaner Production, 340, 130735. https://doi.org/10.1016/j.jclepro.2022.130735

Heidtmann, K. F., & Selck, T. J. (2021). Local level failure? Non-compliance of EU environmental policy within EU multi-level governance. Regional & Federal Studies, 1–20. https://doi.org/10.1080/13597566.2021.1998006

Jiang, P., Van Fan, Y., & Klemeš, J. J. (2021). Impacts of COVID-19 on energy demand and consumption: Challenges, lessons and emerging opportunities. Applied energy, 285, 116441. https://doi.org/10.1016/j.apenergy.2021.116441

Katal, A., Dahiya, S., & Choudhury, T. (2023). Energy efficiency in cloud computing data centers: a survey on software technologies. Cluster Computing, 26(3), 1845–1875. https://doi.org/10.1007/s10586-022-03713-0

Lange, S., Pohl, J., & Santarius, T. (2020). Digitalization and energy consumption. Does ICT reduce energy demand? Ecological economics, 176, 106760. https://doi.org/10.1016/j.ecolecon.2020.106760

Li, Y., Yang, X., Ran, Q., et al. (2021). Energy structure, digital economy, and carbon emissions: evidence from China. Environmental Science and Pollution Research, 28, 64606–64629. https://doi.org/10.1007/s11356-021-15304-4

Li, Z., Luan, W., Zhang, Z., & Su, M. (2020). Relationship between urban construction land expansion and population/economic growth in Liaoning Province, China. Land Use Policy, 99, 105022. https://doi.org/10.1016/j.landusepol.2020.105022

Mohmand, Y. T., Mehmood, F., Mughal, K. S., & Aslam, F. (2021). Investigating the causal relationship between transport infrastructure, economic growth and transport emissions in Pakistan. Research in Transportation Economics, 88, 100972. https://doi.org/10.1016/j.retrec.2020.100972

Mohsin, M., Hanif, I., Taghizadeh-Hesary, F., et al. (2021). Nexus between energy efficiency and electricity reforms: a DEA-based way forward for clean power development. Energy Policy, 149, 112052. https://doi.org/10.1016/j.enpol.2020.112052

Moroz, G. V., Grytsan, O. A., Vivcharenko, A., & Kobetska, N. R. (2021). Relationship between economic growth and environmental pressures (legal aspects). International Journal of Agricultural Extension, 9(4), 127–139. https://doi.org/10.33687/ijae.009.00.3728

Mucowska, M. (2021). Trends of environmentally sustainable solutions of urban last-mile deliveries on the e-commerce market—a literature review. Sustainability, 13(11), 5894. https://doi.org/10.3390/su13115894

Mughal, N., Arif, A., Jain, V., et al. (2022). The role of technological innovation in environmental pollution, energy consumption and sustainable economic growth: Evidence from South Asian economies. Energy Strategy Reviews, 39, 100745. https://doi.org/10.1016/j.esr.2021.100745

Murshed, M. (2020). An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. Environmental Science and Pollution Research, 27(29), 36254–36281. https://doi.org/10.1007/s11356-020-09497-3

Nasreen, S., Mbarek, M. B., & Atiq-ur-Rehman, M. (2020). Long-run causal relationship between economic growth, transport energy consumption and environmental quality in Asian countries: Evidence from heterogeneous panel methods. Energy, 192, 116628. https://doi.org/10.1016/j.energy.2019.116628

Nieuwenhuijsen, M. J. (2021). New urban models for more sustainable, liveable and healthier cities post covid19; reducing air pollution, noise and heat island effects and increasing green space and physical activity. Environment international, 157, 106850. https://doi.org/10.1016/j.envint.2021.106850

Osobajo, O. A., Otitoju, A., Otitoju, M. A., & Oke, A. (2020). The impact of energy consumption and economic growth on carbon dioxide emissions. Sustainability, 12(19), 7965. https://doi.org/10.3390/su12197965

Rahman, M. M. (2020). Environmental degradation: The role of electricity consumption, economic growth and globalisation. Journal of environmental management, 253, 109742. https://doi.org/10.1016/j.jenvman.2019.109742

Rao, C., & Yan, B. (2020). Study on the interactive influence between economic growth and environmental pollution. Environmental Science and Pollution Research, 27, 39442–39465. https://doi.org/10.1007/s11356-020-10017-6

Ren, S., Hao, Y., Xu, L., et al. (2021). Digitalization and energy: How does internet development affect China's energy consumption? Energy Economics, 98, 105220. https://doi.org/10.1016/j.eneco.2021.105220

Ridzuan, A. R., Albani, A., Latiff, A. R. A., et al. (2020). The impact of energy consumption based on fossil fuel and hydroelectricity generation towards pollution in Malaysia, Indonesia and Thailand. International Journal of Energy Economics and Policy, 10(1), 215–227. https://doi.org/10.32479/ijeep.8140

Roshchyk, I., Oliinyk, O., Mishchuk, H., & Bilan, Y. (2022). It products, e-commerce, and growth: analysis of links in emerging market. Transformations in Business & Economics, 21(1), 209.

Saint Akadiri, S., Alola, A. A., Olasehinde-Williams, G., & Etokakpan, M. U. (2020). The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. Science of The Total Environment, 708, 134653. https://doi.org/10.1016/j.scitotenv.2019.134653

Sarangi, A. K., & Pradhan, R. P. (2020). ICT infrastructure and economic growth: A critical assessment and some policy implications. Decision, 47, 363–383. https://doi.org/10.1007/s40622-020-00263-5

Sharma, R., Shahbaz, M., Kautish, P., & Vo, X. V. (2021). Does energy consumption reinforce environmental pollution? Evidence from emerging Asian economies. Journal of Environmental Management, 297, 113272. https://doi.org/10.1016/j.jenvman.2021.113272

Solomon, E. M., & van Klyton, A. (2020). The impact of digital technology usage on economic growth in Africa. Utilities policy, 67, 101104. https://doi.org/10.1016/j.jup.2020.101104

Strielkowski, W., Civín, L., Tarkhanova, E., et al. (2021). Renewable energy in the sustainable development of electrical power sector: A review. Energies, 14(24), 8240. https://doi.org/10.3390/en14248240

Tainio, M., Andersen, Z. J., Nieuwenhuijsen, M. J., et al. (2021). Air pollution, physical activity and health: A mapping review of the evidence. Environment international, 147, 105954. https://doi.org/10.1016/j.envint.2020.105954

Usman, A., Ozturk, I., Hassan, A., et al. (2021). The effect of ICT on energy consumption and economic growth in South Asian economies: an empirical analysis. Telematics and Informatics, 58, 101537. https://doi.org/10.1016/j.tele.2020.101537

Vu, K., Hanafizadeh, P., & Bohlin, E. (2020). ICT as a driver of economic growth: A survey of the literature and directions for future research. Telecommunications Policy, 44(2), 101922. https://doi.org/10.1016/j.telpol.2020.101922

Wei, X., Ren, H., Ullah, S., & Bozkurt, C. (2023). Does environmental entrepreneurship play a role in sustainable green development? Evidence from emerging Asian economies. Economic research-Ekonomska istraživanja, 36(1), 73–85. https://doi.org/10.1080/1331677X.2022.2067887

Wen, H., Lee, C. C., Song, Z. (2021). Digitalization and environment: how does ICT affect enterprise environmental performance? Environmental Science and Pollution Research, 28(39), 54826–54841. https://doi.org/10.1007/s11356-021-14474-5

Xiong, J., & Xu, D. (2021). Relationship between energy consumption, economic growth and environmental pollution in China. Environmental Research, 194, 110718. https://doi.org/10.1016/j.envres.2021.110718

Zhang, C., Khan, I., Dagar, V., et al. (2022). Environmental impact of information and communication technology: Unveiling the role of education in developing countries. Technological Forecasting and Social Change, 178, 121570. https://doi.org/10.1016/j.techfore.2022.121570

Appendix

Table A1. Data for analysis.

Region	Year	GRP, mil tenge	Number of Companies Using the Internet, pcs.	Liquid and Gaseous Pollutant Emissions, thous. t	Power Consumption, mil kWh
Akmola,Astana City	2014	5,070,660.6	7680	102.3	7996
	2015	5,930,661.5	8637	96.3	8061
	2016	6,209,650.0	11,906	101.7	8285
	2017	7,328,324.9	13,233	98.8	8645
	2018	8,405,877.2	24,610.0	96.5	9141
	2019	9,768,408.7	25,493.0	100.7	9209
	2020	10,259,222.9	24,149.0	100.8	9196
	2021	11,601,834.9	25,031.0	99.7	10,310
	2022	13,798,918.7	31,620.0	92.2	10,690
Aktobe	2014	1,926,239.6	3165	101.7	4232
	2015	1,769,175.2	3721	113.3	4798
	2016	2,071,115.8	3484	136.1	5272
	2017	2,341,889.2	3714	149.3	5900
	2018	2,708,455.4	3981	136.1	6301
	2019	2,974,420.9	4101	114.7	6437
	2020	2,956,872.2	4049	114.5	6647
	2021	3,586,222.6	4351	115.4	6890
	2022	4,312,580.9	4406	117.6	6940
Almaty/Zhetysu, Almaty City	2014	10,053,936.4	13,261.0	76.3	10,168
	2015	11,076,053.7	20,599.0	77.2	9917
	2016	12,791,352.9	25,505	71.9	9960
	2017	14,365,267.7	24,872	67.3	10,446
	2018	14,927,766.7	28,181.0	75.5	10,977
	2019	16,793,038.8	30,649.0	74.6	11,351
	2020	17,190,842.1	34,024.0	72.2	11,367
	2021	19,606,853.2	31,294.0	70.1	12,450
	2022	24,703,079.9	38,948.0	68.1	12,850
Atyrau	2014	4,340,623.0	1741	106.8	4251
	2015	4,216,773.5	2455	107.6	4272
	2016	5,200,673.2	2303	163.8	4711
	2017	5,947,653.8	2346	172.8	5537
	2018	7,818,812.1	2656	169.1	6185
	2019	9,327,263.3	3127	160.9	6350
	2020	7,738,259.2	2727	147.6	6255
	2021	10,627,583.4	2678	157.5	6670
	2022	14,114,693.4	3438	129.9	6690

Table A1. (*Continued*).

Region	Year	GRP, mil tenge	Number of Companies Using the Internet, pcs.	Liquid and Gaseous Pollutant Emissions, thous. t	Power Consumption, mil kWh
West Kazakhstan	2014	1,987,705.7	1743	41.4	1791
	2015	1,709,952.7	1769	39.6	1804
	2016	2,032,669.9	2418	39.8	1808
	2017	2,337,505.7	2352	38.7	1931
	2018	2,790,661.6	2120	45.8	2009
	2019	2,946,389.1	2410	39.0	1998
	2020	2,735,953.1	2326	28.4	2256
	2021	3,533,014.4	2641	23.8	2610
	2022	4,402,500.4	2520	23.7	2550
Zhambyl	2014	979,666.1	1543	25.8	3898
	2015	1,014,504.6	1947	28.3	3782
	2016	1,182,798.9	1838	41.0	3191
	2017	1,350,661.6	1930	38.4	3802
	2018	1,532,118.6	1925	39.1	4321
	2019	1,712,883.6	2012	42.5	4473
	2020	1,901,385.0	2198	39.1	4948
	2021	2,262,750.6	2255	41.9	5320
	2022	2,749,013.2	2751	40.5	4980
Karaganda/Ulytau	2014	2,899,976.8	4639	470.8	15,433
	2015	3,107,085.6	5732	475.5	15,712
	2016	3,712,055.9	6321	477.4	15,786
	2017	4,284,362.6	6896	479.0	16,695
	2018	4,734,402.0	7673.0	466.8	17,319
	2019	5,388,260.6	8175.0	519.3	17,991
	2020	6,099,856.2	8089.0	512.2	18,460
	2021	7,446,273.2	7778.0	454.2	19,000
	2022	9,070,350.7	8444.0	463.8	19,080
Kostanay	2014	1,394,867.8	3339	56.6	5473
	2015	1,378,258.4	3238	42.3	4688
	2016	1,522,282.1	3601	53.4	4599
	2017	1,850,281.0	3939	62.8	4689
	2018	2,069,286.2	4162	72.0	4782
	2019	2,451,736.4	4309	75.0	4786
	2020	2,872,209.6	4845	67.4	4615
	2021	3,516,221.0	4204	84.2	4810
	2022	4,167,726.2	4381	83.4	4590

Table A1. (*Continued*).

Region	Year	GRP, mil tenge	Number of Companies Using the Internet, pcs.	Liquid and Gaseous Pollutant Emissions, thous. t	Power Consumption, mil kWh
Kyzylorda	2014	1,380,132.3	1385	25.1	1642
	2015	1,164,800.0	1719	25.9	1605
	2016	1,308,295.3	1695	25.6	1592
	2017	1,430,980.1	1635	23.0	1658
	2018	1,647,016.4	1894	21.8	1689
	2019	1,828,864.7	1909	20.6	1760
	2020	1,645,067.2	1999	25.1	1760
	2021	1,926,000.2	1819	26.0	1950
	2022	2,339,345.6	1731	21.8	1940
Mangistau	2014	2,418,214.6	1979	83.9	4898
	2015	2,123,785.5	2079	67.0	4978
	2016	2,463,408.1	1744	62.4	5011
	2017	3,296,136.8	2667	59.4	4956
	2018	3,803,063.3	2956	62.4	5237
	2019	3,685,383.5	2780	61.4	5111
	2020	3,074,392.9	2840	70.1	5023
	2021	3,627,008.1	2927	73.2	5270
	2022	4,052,851.1	3402	76.3	5300
Turkestan, Shymkent City	2014	2,398,774.6	2949	48.9	4148
	2015	2,508,380.9	3869	58.5	4090
	2016	2,789,228.0	4321	61.4	4270
	2017	3,187,724.4	4512	57.0	4646
	2018	3,834,084.2	8066.0	52.3	4953
	2019	4,219,077.4	7906.0	51.8	5097
	2020	4,877,400.2	9084.0	46.7	5211
	2021	5,479,567.4	8595.0	51.2	5760
	2022	6,671,570.5	9217.0	51.4	6010
Pavlodar	2014	1,746,774.4	2805	474.4	17,363
	2015	1,736,155.9	2979	431.4	16,975
	2016	1,975,487.3	3691	424.3	17,611
	2017	2,369,297.8	3770	484.0	18,654
	2018	2,746,652.1	4104	551.0	19,433
	2019	3,029,608.9	4370	564.4	19,527
	2020	3,120,136.9	4653	566.4	20,731
	2021	3,883,826.6	5017	581.3	21,480
	2022	4,178,243.9	5434	572.6	19,400

Table A1. (*Continued*).

Region	Year	GRP, mil tenge	Number of Companies Using the Internet, pcs.	Liquid and Gaseous Pollutant Emissions, thous. t	Power Consumption, mil kWh
North Kazakhstan	2014	795,551.2	2266	47.2	1704
	2015	837,179.9	2294	49.1	1643
	2016	918,236.9	2500	51.7	1685
	2017	1,113,959.4	2852	50.6	1731
	2018	1,212,007.8	2999	49.8	1800
	2019	1,382,322.2	2939	51.6	1764
	2020	1,571,903.6	3494	52.2	1665
	2021	1,790,770.4	3204	39.4	1730
	2022	2,122,838.2	3090	33.2	1610
East Kazakhstan/Abai	2014	2,282,709.8	4135	101.2	8664
	2015	2,311,366.2	4148	100.0	8523
	2016	2,793,895.7	4452	100.5	8530
	2017	3,174,812.8	4940	100.9	8563
	2018	3,589,332.8	5375.0	100.5	9080
	2019	4,024,968.4	5351.0	98.9	9339
	2020	4,605,532.1	5769.0	97.9	9204
	2021	5,063,661.9	5327.0	97.9	9640
	2022	6,208,132.9	5221.0	93.9	10,310