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Exploring the Macroeconomic Effects of Renewable Energy in Tajikistan: An Empirical Analysis

Mirzosaid Sultonov [1,*], Behruz Hasanov [2], Pirumsho Valizoda [3] and Fumiaki Inagaki [4]

[1] Department of Global Innovation Studies, Faculty of Global and Regional Studies, Toyo University, Tokyo 1128606, Japan
[2] Electro-Energy Department, Ministry of Energy and Water Resources of the Republic of Tajikistan, Dushanbe 734064, Tajikistan; bhasanzoda@outlook.com
[3] Unit of Cooperations on Sustainable Development Issues, Ministry of Foreign Affairs of the Republic of Tajikistan, Dushanbe 734001, Tajikistan; valizoda@mfa.tj
[4] Graduate School of International Resource Sciences, Akita University, Akita 0108502, Japan; fumiaki.inagaki@gipc.akita-u.ac.jp
* Correspondence: sultonov@toyo.jp

Abstract: Tajikistan holds the eighth position globally in terms of hydropower potential, estimated at 527 terawatt-hours (TWh), with a technically exploitable capacity of 317 TWh. Only 4–6 percent of this immense potential is currently utilized. In this paper, employing a combination of the Johansen cointegration test, vector autoregression, and the Granger-causality test on annual data from 1993 to 2021, we examine the causality relationship between electricity production and key macroeconomic variables, including gross domestic product (GDP), GDP per capita, exports, imports, final consumption, capital investment, and employment, in Tajikistan. The empirical findings reveal a positive unidirectional causality from electricity production to exports and imports. A positive bidirectional or feedback causality is found between electricity production and variables such as GDP, GDP per capita, final consumption, and employment. No causality relationship between electricity production and variables such as trade openness and capital investment is observed. The exploration of complex causal relationships between electricity production and key macroeconomic variables in Tajikistan, as revealed in this study, offers a modest yet meaningful addition to academic discourse. It presents insights that may inform policymakers and stakeholders, albeit with a recognition of the limitations inherent in the findings. These insights could potentially guide the formulation of sustainable development strategies and shed light on the underutilized potential of the country's hydropower resources.

Keywords: Tajikistan; electricity; hydropower; causality; macroeconomic variables

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1. Introduction

Tajikistan ranks second globally in terms of the percentage of its area covered by mountains and third in average elevation above sea level among the world's most mountainous countries (World Population Review 2023). The high mountains in this country have endowed it with abundant glaciers, fast-flowing rivers, and enormous hydroelectricity generation potential. Tajikistan holds the eighth position globally in terms of hydropower potential, estimated at 527 terawatt-hours (TWh), with a technically exploitable capacity of 317 TWh. However, only 4–6 percent of this immense potential is currently utilized (International Energy Agency 2023; MEWRT 2023; Stat TJ 2023a).

Tajikistan possesses a relatively small and open economy, registering a gross domestic product (GDP) of USD 8.9 billion (World Bank 2023a) and a per capita income of USD 916.7 (World Bank 2023b) as of 2021. The nation's economic framework is intricately linked to regional and global landscapes, as evidenced by its export and import percentages, accounting for 24.2 percent and 47.6 percent of GDP, respectively (World Bank 2023c, 2023d). Final consumption expenditures amounted to 91.3 percent of GDP in 2021 (World Bank 2023e).

A noteworthy aspect of Tajikistan's economic dynamics in 2021 was the substantial gross capital formation, reaching 35 percent of the GDP (World Bank 2023f). The high percentage of investment indicates a significant emphasis on the country's capital investment and development initiatives. The workforce also played a crucial role, with a total employment figure of 2.5 million people (Stat TJ 2023b).

In terms of energy supply, Tajikistan exhibited a diverse mix in 2018, with 31.5 percent originating from domestically produced coal and 45.0 percent from electricity generated through hydropower (Stat TJ 2023c). Imported sources included oil products (26.5 percent) and natural gas (1.3 percent). The significant share of hydropower underscores Tajikistan's reliance on hydroelectric power, highlighting its commitment to sustainable and renewable energy sources.

Tajikistan is a predominantly hydropower-dependent nation. Hydropower accounts for over 90 percent of electricity generation (MEWRT 2023) and 45 percent of the country's total energy supply (Stat TJ 2023c). Out of the total electricity production of 20.6 TWh in the year 2021, 18.9 TWh was derived from hydropower sources, whereas only 1.7 TWh originated from thermal power generation, as reported by Stat TJ (2023a). Of the total supplied electricity, 18.9 percent was utilized by the industrial sector, 10.2 percent by the agricultural sector, 26.2 percent by households, 24.8 percent by other sectors, and 19.9 percent represented losses (Stat TJ 2023a).

Hydropower is a sustainable and reliable renewable energy source with numerous environmental, economic, and social benefits. Its ability to generate clean electricity, manage water resources, and contribute to grid stability make it crucial to transitioning to a more sustainable energy future. However, the country faces a critical energy challenge during the winter months characterized by heightened heating demand due to plummeting temperatures and irregular river water flow. Electricity losses caused by the poor quality of the country's transmission and distribution systems worsen the situation. Addressing this challenge necessitates a multifaceted energy policy, emphasizing installing new capacities and efficiency improvements to manage seasonal shortages effectively.

Electricity plays a crucial role in driving the economy of Tajikistan. The strategic and efficient harnessing of Tajikistan's abundant hydropower potential, an often overlooked and renewable energy source, could catalyze the country's development and positively impact the entire region. Significant hydropower potential is closely linked to the concept of green growth through its contributions to renewable energy generation, emission reduction, sustainable development, water resource management, creation of green jobs, and alignment with green policies and objectives. By leveraging its hydropower resources effectively, Tajikistan can achieve both economic prosperity and environmental sustainability, ultimately leading to a greener and more resilient economy.

Given Tajikistan's significant hydropower potential and its aim to increase utilization, this paper aims to investigate the impact of electricity production and consumption on major macroeconomic variables, including GDP, GDP per capita, exports, imports, trade openness, consumption, capital investment, and employment. Additionally, it seeks to explore the potential economic benefits of maximizing Tajikistan's hydropower potential. Lastly, the paper aims to derive policy recommendations aimed at fostering sustainable economic development and maximizing the socio-economic benefits derived from Tajikistan's hydropower potential. The empirical findings make a valuable contribution to academic literature and offer important insights for policymakers and stakeholders. These insights are significant for informing sustainable development strategies and exploring the potential of the country's hydropower resources. They pave the way for a more resilient and potentially prosperous future.

The paper is organized as follows. The next chapter provides a concise summary of the key insights derived from the reviewed literature. Section 3 elucidates the research methodology employed in this study. A detailed account of the data is presented in Section 4.

Section 5 unveils the empirical findings. The concluding sections (Sections 6 and 7) comprehensively discuss the paper's findings and offer concluding remarks.

2. Literature Review

A comprehensive review of the literature on the relationship between energy production and consumption, along with key macroeconomic variables, is presented by Azam et al. (2023), Magazzino et al. (2021), Zeren and Akkus (2020), and Faisal et al. (2017). The most discussed topics in the literature include the relationships between energy production, energy consumption, economic growth, and international trade.

Various econometric approaches, encompassing both single-country and multicountry cases, have been employed in the estimation of causality relationships between energy and GDP, energy and international trade, energy and gross capital formation, as well as energy and employment, taking into account the distinctive features of the data. Most of the literature utilizes yearly data, and a prevalent method for investigating these relationships involves applying cointegration and causality tests to annual time series.

The literature does not agree unanimously regarding the relationship between energy and key economic variables, as past studies have produced varied outcomes. The diversity in results can be attributed to differences in empirical models, national samples, and econometric approaches employed across studies.

The scholarly discourse extensively addresses the causality relationship between energy and GDP. Etokakpan et al. (2020) unveiled a causality from energy consumption to GDP for Turkey spanning the years 1970–2014, while Guo (2018) identified this causality for China in the periods 1978–1991 and 1992–2016. Dogan (2014) explored this relationship for Kenya within the temporal confines of 1971–2011, and Soytas and Sari (2003) investigated the same for Turkey, France, Germany, and Japan during the years 1950–1992. In contrast, causality from GDP to energy consumption was expounded upon by Khobai et al. (2021) for BRICS over the period of 1990–2018, and from GDP to electricity supply by Azam et al. (2020) for Pakistan in 1990–2015. Sultan and Alkhateeb (2019) elucidated bidirectional causality or a feedback relationship between energy and economic activity in India from 1971 to 2014. Furthermore, Sebri and Salha (2014) expounded upon a bidirectional causality between economic growth and renewable energy consumption within the contexts of Brazil and India, examining the years from 1971 to 2010. Additionally, Dogan (2014) reported an absence of a causality relationship between energy consumption and GDP for Benin, Congo, and Zimbabwe from 1971 to 2011.

In the realm of energy and GDP causality, scholars have delineated a phased characteristic. In the nascent stages of economic development, energy consumption has been observed to propel economic growth. However, as economies reach a stable phase of development, the nature of this relationship undergoes a transformation.

The scholarly discourse extensively examines the causal relationship between energy dynamics and international trade. Bayar et al. (2021) expounded on a unilateral causality, elucidating the influence of renewable energy on trade in Croatia and Lithuania spanning the years 1995 to 2015. Zeren and Akkus (2020) asserted that nonrenewable energy constitutes a principal determinant fostering heightened trade openness, while the augmentation of renewable energy utilization emerged as a pivotal factor in diminishing trade openness within emerging economies throughout the period of 1980–2015. Jebli and Youssef (2015) documented a unidirectional causality from renewable energy to trade, encompassing a sample of 69 countries from 1980 to 2010. Furthermore, Sadorsky (2012) reported a unidirectional causal linkage from energy consumption to imports in seven South American countries, encapsulating the timeframe from 1980 to 2007.

Bayar et al. (2021) documented a unilateral causality, indicating a directional influence from trade to renewable energy, within the contexts of Estonia, Latvia, and Slovenia spanning the years 1995 to 2015. Jebli et al. (2016) observed unidirectional causality, signifying a singular directional impact from exports to renewable energy across a dataset encompassing 25 OECD countries during the temporal interval from 1980 to 2010. In a study by Al-Mulali et al. (2015), a causative linkage was identified from trade openness to electricity production derived from wind generation, involving 23 European countries over the period from 1990 to 2013. Halicioglu (2011) asserted the existence of a unilateral causality, positing a directional influence from exports to energy, as evidenced by time series data spanning the years from 1968 to 2008, focusing on Turkey.

Jebli et al. (2016) documented a reciprocal causality between renewable energy consumption and imports, as well as a bidirectional causality involving nonrenewable energy and trade (both exports and imports) for a cohort of 25 OECD countries spanning the period from 1980 to 2010. Similarly, Jebli and Youssef (2015) observed a bidirectional causality between nonrenewable energy and trade in a dataset encompassing 69 countries over the 1980 to 2010 timeframe. In a distinct study, Sadorsky (2012) delineated a bidirectional feedback relationship between energy consumption and exports, focusing on seven South American countries throughout the period spanning from 1980 to 2007.

Azam et al. (2023) discerned a bidirectional causality between primary energy consumption and gross capital formation through the examination of panel data derived from 30 developing countries spanning the period 1990 to 2017. Topcu et al. (2020) conducted an analysis across 124 countries categorized by distinct income levels, covering the years 1980 to 2018. The research outcomes reveal a bidirectional causality relationship between gross capital formation and energy utilization in high- and middle-income countries. Conversely, in low-income countries, a unidirectional causality was noted from capital formation to energy consumption. Topcu et al. (2020) incorporated Tajikistan into a panel for vector autoregression (VAR) analysis alongside nine low-income countries, despite their limited common features with Tajikistan. The estimation results revealed a positive bidirectional causality between GDP and electricity consumption, as well as a negative unidirectional causality between gross capital formation and energy consumption.

Narayan and Smyth (2005) ascertained the cointegration of electricity consumption, employment, and income. In the long run, they observed a unidirectional causality from employment and income to electricity consumption in the context of Australia. Cheng and Lai (1997) determined that causality exists from energy consumption to employment in the case of Taiwan, employing data encompassing the period from 1955 to 1993.

Different aspects of Tajikistan's energy sector have been covered in the existing literature. The most recent studies have focused on various topics such as solar energy (Na et al. 2023), energy transition (Mehta et al. 2023), long-term low greenhouse gas emission development strategies (Akkermans et al. 2023), and electricity consumption by household consumers (Tavarov et al. 2023). However, the number of studies specifically addressing the relationship between energy supply and major macroeconomic indicators is limited. By highlighting the causality relationship between electricity production and consumption and major macroeconomic variables, this paper contributes to the literature on macroeconomic issues in Tajikistan's energy sector.

3. Methodology

Considering the models employed in the existing literature and the characteristics of the available data for the case of Tajikistan, we employ a combination of the Johansen cointegration test (Johansen 1988), bivariate VAR models, and a Granger causality test (Granger 1969) to estimate the causality relationship between electricity production and key macroeconomic variables.

The VAR model proves particularly valuable when endogeneity is a concern. In a VAR model, all variables are treated as endogenous, indicating that they are jointly determined within the system. The endogeneity issue is of paramount importance when analyzing causality both to and from electricity production, as it is anticipated to significantly influence and be influenced by other variables in the model. Furthermore, the VAR model, as a technique for modeling bivariate and multivariate time series data, does not explicitly assume the normality of the data. VAR models are instrumental for testing Granger causality, which assesses whether past values of one variable provide information about the future values of another variable.

Pre-tests for a unit root and cointegration should be conducted before estimating the VAR model. The VAR model is applicable when the variables exhibit no unit root and lack a cointegration relation (long-run relationship). Alternatively, if cointegration exists, consideration may be given to employing a vector error correction model (VECM). The presence of a unit root for all variables' time series was examined using the augmented Dickey–Fuller (ADF) test (Dickey and Fuller 1979, 1981) and the Phillips–Perron test (Phillips and Perron 1988). Additionally, the Johansen cointegration test was employed to assess the existence of cointegration relationships among the variables.

We employed a bivariate VAR model, where the current-year values of each variable depended on both their own lagged values and the lagged values of other variables (Equation (1)). In Equation (1), p represents the number of lags, y_t is the vector of variables at time t, c is the vector of parameters, A_i is the matrix of parameters, and ε_t is the vector of residuals. The number of lags for each equation was chosen based on the Akaike (Akaike 1974) information criterion (AIC) and the Schwarz–Bayesian (Schwarz 1978) information criterion (SBIC). As a post-estimation test, the Portmanteau (Q) statistics (Box and Pierce 1970; Ljung and Box 1978) were employed to examine the null hypothesis, assessing the presence of autocorrelation in the residuals. In cases where autocorrelation was detected, adjustments to the lag numbers were made to address the autocorrelation issue.

$$y_t = c + A_1 y_{t-1} + A_2 y_{t-2} + \ldots + A_p y_{t-p} + \varepsilon_t \tag{1}$$

The VECM form of Equation (1) is

$$\Delta y_t = c + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t \tag{2}$$

where Π is a matrix of estimated coefficients and Γ_i represents coefficient matrices for lagged differences of the endogenous variables (Johansen 1988). If the variables y_t are I (1), the matrix Π has a rank $0 \leq r < K$ (Engle and Granger 1987). If the number of linearly independent cointegrating vectors (r) is $0 < r < K$, then the variables cointegrate and a VAR in the first differences is mis-specified. Using Johansen's test (Johansen 1988), we checked the cointegration between the variables and demonstrated that r = 0.

After fitting the bivariate VAR models, we examined whether one variable Granger causes another. For each equation and each endogenous variable that was not the dependent variable in that equation, we computed Wald tests and determined that the coefficients on all the lags of an endogenous variable were jointly zero. Rejection of the null hypothesis meant the independent variable in the equation Granger caused the dependent variable. This means that, given the past values of the dependent variable in the equation, past values of the independent variable were useful for predicting the dependent variable.

The combination of the Johansen cointegration test, bivariate VAR models, and the Granger causality test provided a powerful toolkit for analyzing the relationships among variables, capturing both long-term equilibrium relationships and short-term causal dynamics. The Johansen cointegration test allowed us to identify the presence of long-term relationships among variables. This was crucial because it helped to identify variables that moved together in the long run, indicating a stable equilibrium relationship. Bivariate VAR models are useful for capturing the dynamic interactions between two variables over time. By focusing on pairs of variables, bivariate VAR models provide a simplified yet powerful framework for analyzing short-term dynamics. The Granger causality test, when applied within the framework of bivariate VAR models, allowed us to assess the direction and strength of causal relationships between variables. This helped to distinguish between variables that exert a causal influence on each other and those that do not. Application of pre-tests for a unit root, information criteria for the selection of lag numbers, and post-estimation tests for autocorrelation in the residuals increased the robustness of our analysis. The logical order of the research process is described in Table A1 of the Appendix A.

4. Description and Analysis of Data

The logarithmic differences in real annual time series spanning the years 1993 to 2021, adjusted to constant prices of 2015, were systematically organized for analytical purposes. Data pertaining to GDP, GDP per capita, exports, imports, openness, final consumption, and capital investment were sourced from the World Bank, and are all reported in terms of constant 2015 prices. Employment and electricity-related statistics were obtained from Tajikistan's national statistical sources. Specifically, GDP, exports, imports, consumption, and capital investment figures are expressed in millions of USD, while GDP per capita is denominated in USD. Openness is computed as the proportion of trade relative to GDP. Employment figures are denominated in thousands of individuals, and electricity data are quantified in gigawatt-hours (GWh), as delineated in Table 1.

Table 1. Descriptive statistics for the data.

Variable (Measure)	Mean	Standard Deviation	Minimum	Maximum
GDP (million USD)	5729.237	3067.245	2244.219	12,499.200
GDP per capita (USD)	732.722	273.593	371.830	1281.961
Exports (million USD)	720.608	391.733	341.786	2172.980
Imports (million USD)	2488.151	838.867	1225.926	3990.809
Openness (percentage)	61.076	11.573	40.071	76.421
Consumption (million USD)	6013.659	1971.531	2520.373	9465.139
Capital investment (million USD)	2937.182	1614.202	1124.642	8697.594
Employment (thousand people)	2114.345	265.486	1731.000	2534.000
Electricity production (GWh)	16,635.660	1822.500	13,878.000	20,691.720
Electricity consumption (GWh)	13,764.350	882.659	11,960.330	15,660.980

Source: Annual data for the period of 1993–2021 (constant 2015 prices). GDP, GDP per capita, exports, imports, openness, consumption, and capital investment data are from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l). Employment and electricity data are from Stat TJ (2023a, 2023b).

GDP is the sum of the gross value added by all resident producers in the economy, plus any product taxes and minus any subsidies not included in the value of the products (World Bank 2023g). GDP per capita is the gross domestic product divided by the midyear population (World Bank 2023h). Exports include exports of goods and services, representing the value of all goods and other market services provided to the rest of the world (World Bank 2023i). Imports include imports of goods and services, representing the value of all goods and other market services received from the rest of the world (World Bank 2023j). Consumption indicates the final consumption expenditure as the sum of the household final consumption expenditure and the general government final consumption expenditure (World Bank 2023k). Capital investment indicates gross capital formation, consisting of outlays on additions to the fixed assets of the economy, plus net changes in the level of inventories (World Bank 2023l). Employment indicates the total number of people who are employed (Stat TJ 2023b). Electricity production includes the production of electricity from renewable and nonrenewable energy sources in the country within the year (Stat TJ 2023a). Electricity consumption was calculated by extracting electricity exports and electricity loss from electricity production and adding electricity imports.

Table 1 and Figure A1 clearly demonstrate disparities in electricity production and consumption. Taking into account this distinction, we conducted separate estimations for both variables.

The logarithmic values of the time series, along with the results of the normality tests, are outlined in Table 2. Skewness and kurtosis tests for normality refuted the hypothesis that the logarithmic values of time series related to GDP, GDP per capita, imports, and employment adhered to a normal distribution. Nevertheless, these tests did not reject the hypothesis that the logarithmic values of time series associated with other variables followed a normal distribution. However, relying solely on skewness, we can reject the hypothesis that the logarithmic values of time series for openness adhere to a normal distribution.

Table 2. Description of logarithmic values.

Variables	Mean	Standard Deviation	Test for Normality			
			Pr. (Skewness)	Pr. (Kurtosis)	Statistics	*p*-Value
ln GDP	8.515	0.539	0.809	0.014	5.76	0.056
ln GDP per capita	6.528	0.383	0.862	0.029	4.79	0.091
ln Exports	6.465	0.474	0.253	0.993	1.41	0.495
ln Imports	7.756	0.376	0.241	0.002	8.94	0.011
ln Openness	4.093	0.206	0.059	0.457	4.28	0.118
ln Consumption	8.644	0.358	0.241	0.293	2.72	0.257
ln Capital investment	7.870	0.472	0.241	0.542	1.89	0.388
ln Employment	7.649	0.127	0.668	0.000	10.44	0.005
ln Electricity production	9.714	0.107	0.317	0.875	1.10	0.578
ln Electricity consumption	9.528	0.065	0.351	0.509	1.40	0.495

Source: The authors' calculations are based on data from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l) and Stat TJ (2023a, 2023b).

The logarithmic difference values of the time series, along with the results of the normality tests, are outlined in Table 3. Skewness and kurtosis tests for normality refute the hypothesis that the logarithmic difference values of time series related to GDP, GDP per capita, exports, consumption, employment, and electricity consumption adhere to a normal distribution. Nevertheless, these tests do not reject the hypothesis that the logarithmic difference values of time series associated with other variables follow a normal distribution. However, relying solely on skewness, we can reject the hypothesis that the logarithmic difference values of time series for electricity production adhere to a normal distribution. The assessment of the normality of the distribution of time series is valuable in determining the suitable econometric model.

Table 3. Description of logarithmic difference values.

Variables	Mean	Standard Deviation	Test for Normality			
			Pr. (Skewness)	Pr. (Kurtosis)	Statistics	*p*-Value
Δ ln GDP	0.042	0.084	0.000	0.001	21.07	0.000
Δ ln GDP per capita	0.023	0.083	0.000	0.001	21.19	0.000
Δ ln Exports	0.061	0.128	0.035	0.120	6.30	0.043
Δ ln Imports	0.023	0.120	0.185	0.318	3.04	0.219
Δ ln Openness	−0.009	0.088	0.744	0.210	1.82	0.402
Δ ln Consumption	0.020	0.136	0.000	0.002	17.18	0.000
Δ Ln Capital investment	−0.024	0.253	0.480	0.286	1.78	0.411
Δ ln Employment	0.011	0.027	0.227	0.001	10.86	0.004
Δ ln Electricity production	0.006	0.057	0.057	0.431	4.37	0.113
Δ ln Electricity consumption	−0.001	0.047	0.022	0.202	6.33	0.042

Source: The authors' calculations are based on data from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l) and Stat TJ (2023a, 2023b).

The results of the ADF and Phillips–Perron unit root tests for the equations, both with a constant and with a constant and trend, are presented in Tables 4 and 5. The ADF test rejected the presence of a unit root for the logarithmic values of consumption (at a 5% significance level) and electricity consumption (at a 10% significance level) in equations with a constant. The ADF test also rejected the presence of a unit root for the logarithmic values of GDP (at a 1% significance level), GDP per capita (at a 1% significance level), capital investment (at a 10% significance level), electricity production (at a 5% significance level), and electricity consumption (at a 10% significance level) in equations with both a constant and trend.

Table 4. Results of unit root test for logarithmic values.

Variables	ADF Test		Phillips-Perron Test	
	Constant	Constant and Trend	Constant	Constant and Trend
ln GDP	−1.204	−6.836 ***	0.562	−7.952 ***
ln GDP per capita	−1.447	−6.428 ***	−0.055	−7.000 ***
ln Exports	1.157	−1.659	1.361	−1.303
ln Imports	−0.579	−2.011	−0.462	−2.967
ln Openness	−1.408	−2.635	−1.085	−2.248
ln Consumption	−3.161 **	−1.636	−0.485	−5.257 ***
ln Capital investment	−2.225	−3.372 *	−2.623 *	−4.038 ***
ln Employment	−0.015	−2.695	0.003	−2.599
ln Electricity production	−0.542	−3.553 **	−0.871	−3.251 *
ln Electricity consumption	−2.829*	−3.155 *	−2.281	−2.584

Source: The authors' calculations are based on data from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l) and Stat TJ (2023a, 2023b). Notes: The maximum number of lags for the augmented Dickey–Fuller (ADF) test was determined using the Schwarz–Bayesian information criterion (SBIC). ***, **, and * denote the rejection of the null hypothesis of a unit root at the 1%, 5%, and 10% significance levels, respectively.

Table 5. Results of unit root test for logarithmic difference values.

Variables	ADF Test		Phillips–Perron Test	
	Constant	Constant and Trend	Constant	Constant and Trend
Δ ln GDP	−3.991 ***	−3.302 *	−5.783 ***	−4.546 ***
Δ ln GDP per capita	−3.887 ***	−3.292 *	−5.482 ***	−4.414 ***
Δ ln Exports	−3.016 **	−3.471 **	−3.055 **	−3.539 **
Δ ln Imports	−4.790 ***	−4.688 ***	−4.803 ***	−4.692 ***
Δ ln Openness	−3.630 ***	−3.478 **	−3.599 ***	−3.446 **
Δ ln Consumption	−7.851 ***	−7.603 ***	−8.700 ***	−8.273 ***
Δ ln Capital investment	−4.941 ***	−5.885 ***	−4.949 ***	−6.114 ***
Δ ln Employment	−5.081 ***	−5.081 ***	−5.081 ***	−5.080 ***
Δ ln Electricity production	−5.204 ***	−5.614 ***	−5.219 ***	−5.660 ***
Δ ln Electricity consumption	−3.514 ***	−3.358 *	−3.486 ***	−3.330 *

Source: The authors' calculations are based on data from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l) and Stat TJ (2023a, 2023b). Notes: The maximum number of lags for the augmented Dickey–Fuller (ADF) test was determined using the Schwarz–Bayesian information criterion (SBIC). ***, **, and * denote the rejection of the null hypothesis of a unit root at the 1%, 5%, and 10% significance levels, respectively.

The Phillips–Perron test rejected the presence of a unit root for the logarithmic values of capital investment (at a 10% significance level) in the equation with a constant. The Phillips–Perron test also rejected the presence of a unit root for the logarithmic values of GDP (at a 1% significance level), GDP per capita (at a 1% significance level), consumption (at a 1% significance level), capital investment (at a 1% significance level), and electricity production (at a 10% significance level) in equations with both a constant and trend.

The ADF and Phillips–Perron tests revealed unit roots in the logarithmic values of the time series for many variables (Table 4).

The ADF and Phillips–Perron unit root tests for the logarithmic differences of time series values for all variables are outlined in Table 5. The test results reject the existence of a unit root in the logarithmic differences of time series (at significance levels ranging from 1% to 10%) for all variables in equations with constants, as well as in equations with both a constant and trend. Given the established stationarity of the data, the estimations utilized the logarithmic differences of time series values.

5. Empirical Results

Table 6 displays the outcomes of Johansen cointegration tests. The results indicate that when the trace statistic attained its maximum rank (0), it consistently fell below the 5% critical value of 15.41 for all pairs of variables, with the exception of the pair involving electricity production and exports. In this particular case, the trace statistic surpassed the critical value, suggesting a potential cointegrating relationship. However, when applying a more stringent threshold of the 1% critical value, the estimation shifted from a maximum rank of 1 to 0 for the aforementioned pair, implying that cointegration was still plausible, but required further scrutiny. Overall, the findings led us to accept the null hypothesis that there are no cointegrating equations or long-run relationships among the variables, supporting the appropriateness of a VAR model for the analysis.

Table 6. Johansen tests for cointegration.

Pair of Variables	Number of Lags Selected by SBIC	Maximum Rank	Trace Statistics	5% Critical Value	1% Critical Value
ln Electricity production with					
ln GDP	2	0	7.083	15.41	20.04
ln GDP per capita	2	0	6.297	15.41	20.04
ln Exports	1	0; 1	16.317; 3.340	15.41	20.04
ln Imports	1	0	5.464	15.41	20.04
ln Openness	1	0	13.123	15.41	20.04
ln Consumption	1	0	13.585	15.41	20.04
ln Capital investment	1	0	13.558	15.41	20.04
ln Employment	1	0	11.393	15.41	20.04
ln Electricity consumption with					
ln GDP	2	0	10.798	15.41	20.04
ln GDP per capita	2	0	10.747	15.41	20.04
ln Exports	1	0	9.979	15.41	20.04
ln Imports	1	0	6.695	15.41	20.04
ln Openness	1	0	9.107	15.41	20.04
ln Consumption	3	0	11.707	15.41	20.04
ln Capital investment	1	0	12.088	15.41	20.04
ln Employment	1	0	6.316	15.41	20.04

Source: The authors' calculations are based on data from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l) and Stat TJ (2023a, 2023b).

Table 7 displays the outcomes derived from the Granger causality test, which systematically investigated the causality connections between the logarithmic difference values of time series related to electricity production and other variables. The initial column of the table elucidates the direction of causality between distinct pairs of variables. The upper section of the table delineates causality extending from electricity production to other variables, whereas the lower section delineates causality directed towards electricity production from other variables.

The second column of Table 7 provides the coefficients obtained from the estimation of VAR models. In the upper section, the coefficients pertain to electricity production, showcasing the influence of lagged values of electricity production on other variables. Conversely, the lower section of the second column contains the coefficients related to other variables, illustrating the impact of the lagged values of these variables on electricity production.

Table 7. Directional causality relationships between electricity production and other variables.

Causality Direction	VAR Coefficients	Portmanteau Test	Wald Test	
To		Q statistic (*p*-value)	Statistics	*p*-value
Δ ln GDP	L1: 0.284 ** (0.117)	7.501 (0.757)	5.857 **	0.016
Δ ln GDP per capita	L1: 0.289 ** (0.120)	6.996 (0.799)	5.774 **	0.016
Δ ln Exports	L1: 0.737 * (0.390); L2: −0.608 (0.489)	15.923 (0.144)	5.281 *	0.071
Δ ln Imports	L1: 0.903 *** (0.305)	6.912 (0.806)	8.752 ***	0.003
Δ ln Openness	L1: 0.452(0.281); L2: −0.253 (0.298)	4.062 (0.968)	3.307	0.191
Δ ln Consumption	L1: 0.830 *** (0.307)	10.423 (0.493)	7.316 ***	0.007
Δ ln Capital investment	L1: 0.624 (0.902); L2: 0.589 (0.933)	5.457 (0.907)	0.806	0.668
Δ ln Employment	L1: 0.148 * (0.087)	12.737 (0.311)	2.884 *	0.089
From				
Δ ln GDP	L1: 0.429 *** (0.114)	7.501 (0.757)	14.190 ***	0.000
Δ ln GDP per capita	L1: 0.425 *** (0.116)	6.996 (0.799)	13.450 ***	0.000
Δ ln Exports	L1: −0.016 (0.107); L2: 0.140 (0.090)	15.923 (0.144)	2.446	0.294
Δ ln Imports	L1: 0.148 (0.091)	6.912 (0.806)	2.643	0.104
Δ ln Openness	L1: −0.122 (0.121); L2: −0.151 (0.117)	4.062 (0.968)	3.508	0.173
Δ ln Consumption	L1: 0.258 *** (0.063)	10.423 (0.493)	16.895 ***	0.000
Δ ln Capital investment	L1: −0.019 (0.042); L2: −0.007 (0.041)	5.457 (0.907)	0.230	0.891
Δ ln Employment	L1: 0.877 ** (0.366)	12.737 (0.311)	5.739 **	0.017

Source: The authors' calculations are based on data from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l) and Stat TJ (2023a, 2023b). Notes: Logarithmic difference values were utilized in the estimation process. The determination of the number of lags for VAR equations was based on information criteria and an examination of residuals autocorrelation. The figures in parentheses for VAR coefficients represent standard errors. Significance levels are denoted by ***, **, and *, indicating significance at the 1%, 5%, and 10% levels, respectively.

The determination of the number of lags for VAR equations was based on information criteria and examination of residuals autocorrelation. The numbers presented in parentheses alongside the coefficients represent standard errors.

The estimation results revealed a positive and statistically significant influence of one-period lagged values of electricity production on GDP, GDP per capita, exports, imports, consumption, and employment. Notably, the impacts on imports and consumption achieved statistical significance at the 1% level, while the impacts on GDP and GDP per capita were statistically significant at the 5% significance level. Additionally, the impacts on exports and employment reached statistical significance at the 10% significance level.

Furthermore, the estimation results highlight a positive and statistically significant impact of one-period lagged values of GDP, GDP per capita, consumption, and employment on electricity production. In this context, the impacts of GDP, GDP per capita, and consumption were statistically significant at the 1% significance level, while the impact of employment attained statistical significance at the 5% significance level.

Portmanteau (Q) statistics show that there was no autocorrelation problem in residuals up to eleven lags, and the models were properly defined.

Wald test statistics provided evidence supporting the assertion that electricity production Granger caused changes in GDP, GDP per capita, exports, imports, consumption, and employment. This suggests that past values of electricity production contain information that significantly contributes to predicting the future values of these economic indicators. Specifically, the statistically significant Wald test statistics indicated a directional causality from electricity production to each of these variables.

Moreover, a reciprocal relationship was observed, as the Wald test statistics also revealed that GDP, GDP per capita, consumption, and employment Granger caused electricity production. This implies that past values of these economic indicators contain information valuable for predicting the future values of electricity production. The statistically significant Wald test statistics for these variables signified their impact on shaping the dynamics of electricity production.

In summary, the Granger causality tests, supported by Wald test statistics, affirmed a dynamic interplay between electricity production and key economic indicators, indicating a mutual influence in their temporal evolution.

Table 8 outlines the outcomes derived from the Granger causality test, specifically examining the causality relationships involving the logarithmic difference values of time series related to electricity consumption and other variables. In this analysis, the VAR coefficients reveal a positive and statistically significant impact of one-period lagged GDP and GDP per capita on electricity consumption. Importantly, this impact reached statistical significance at a 10% significance level.

Table 8. Directional causality relationships between electricity consumption and other variables.

Causality Direction	VAR Coefficients	Portmanteau Test	Wald Test	
To		Q statistic (*p*-value)	Statistics	*p*-value
Δ ln GDP	L1: −0.095 (0.179)	6.580 (0.832)	0.283	0.595
Δ ln GDP per capita	L1: −0.106 (0.184)	5.554 (0.901)	0.331	0.565
Δ ln Exports	L1: 0.426 (0.577)	10.497 (0.486)	0.545	0.460
Δ ln Imports	L1: 0.709 (0.462)	10.262 (0.507)	2.354	0.125
Δ ln Openness	L1: 0.282 (0.386)	3.857 (0.974)	0.533	0.465
Δ ln Consumption	L1: 0.520 (0.465)	5.626 (0.897)	1.250	0.264
Δ ln Capital investment	L1: −0.287 (1.144)	12.325 (0.340)	0.063	0.802
Δ ln Employment	L1: −0.024 (0.131)	5.080 (0.927)	0.035	0.852
From				
Δ ln GDP	L1: 0.206 * (0.114)	6.580 (0.832)	3.275 *	0.070
Δ ln GDP per capita	L1: 0.216 * (0.116)	5.554 (0.901)	3.473 *	0.062
Δ ln Exports	L1: 0.008 (0.088)	10.497 (0.486)	0.009	0.926
Δ ln Imports	L1: 0.055 (0.080)	10.262 (0.507)	0.465	0.495
Δ ln Openness	L1: −0.098 (0.109)	3.857 (0.974)	0.798	0.372
Δ ln Consumption	L1: 0.073 (0.067)	5.626 (0.897)	1.207	0.272
Δ ln Capital investment	L1: 0.011 (0.037)	12.325 (0.340)	0.096	0.756
Δ ln Employment	L1: 0.091 (0.356)	5.080 (0.927)	0.065	0.799

Source: The authors' calculations are based on data from the World Bank (2023g, 2023h, 2023i, 2023j, 2023k, 2023l) and Stat TJ (2023a, 2023b). Notes: Logarithmic difference values were utilized in the estimation process. The determination of the number of lags for VAR equations was based on information criteria and an examination of residuals autocorrelation. The figures in parentheses for VAR coefficients represent standard errors. Significance level is denoted by *, indicating significance at the 10% level.

The Portmanteau (Q) statistics indicate that there were no autocorrelation issues in the residuals up to eleven lags. This suggests that the models were appropriately specified.

Moreover, the Wald test results presented in Table 8 provide additional insights into the causality dynamics. These results indicate a unidirectional causality, specifically from GDP and GDP per capita to electricity consumption. This suggests that past values of GDP and GDP per capita had a significant influence on shaping the current patterns of electricity consumption. The statistical significance at the 10% level underscores the reliability of this observed causality relationship. This finding has implications for understanding the economic factors contributing to electricity consumption patterns, highlighting the role of GDP and GDP per capita in shaping energy demand.

6. Discussion

The empirical results demonstrated positive bidirectional causality between electricity production and GDP, as well as between electricity production and GDP per capita. This implies a mutually reinforcing relationship between electricity production and overall economic growth in Tajikistan. Similar feedback causality was reported by Sultan and Alkhateeb (2019) between energy and economic activity for India during the period of 1971–2014. The majority of the literature reported unidirectional causality between energy and GDP. Given the bidirectional causality between electricity production and GDP/GDP per capita, policies supporting electricity production can be considered as a means to stimulate economic growth and improve the standard of living in Tajikistan.

Additionally, positive unidirectional causality was found from GDP and GDP per capita on electricity consumption. This indicates that economic growth and higher income levels contribute positively to electricity consumption. Policymakers should be mindful that GDP and GDP per capita have a positive unidirectional causality on electricity consumption. Policies aimed at economic growth and increasing income levels can be expected to drive higher electricity consumption.

Positive unidirectional causality exists from electricity production to the export and import of goods and services in Tajikistan. This suggests that an increase in electricity production in Tajikistan positively impacts the country's trade activities. Similar findings were reported by Bayar et al. (2021), Zeren and Akkus (2020), Jebli and Youssef (2015), and Sadorsky (2012). In Tajikistan, policies should focus on promoting electricity production to boost exports and imports of goods and services, potentially leading to increased economic activity.

Positive bidirectional causality was found between electricity production and total consumption expenditure, as well as between electricity production and employment. These findings suggest that increased electricity production is associated with higher consumer spending and increased employment in Tajikistan. Unidirectional causality running from employment and income to electricity consumption was reported by Narayan and Smyth (2005) in the case of Australia, and causality running from energy consumption to employment in the case of Taiwan was reported by Cheng and Lai (1997). Policymakers may explore ways to enhance electricity production, as it appears to have positive bidirectional causality with total consumption expenditure and employment. This could involve initiatives to support industries that are electricity-intensive.

No causality was revealed between electricity production and gross capital formation. However, Azam et al. (2023) and Topcu et al. (2020) reported the existence of a causal relationship between these variables in developing countries. The absence of causality between electricity production and gross capital formation suggests that these variables may need separate attention in policy formulations. Policies to enhance electricity production may not directly impact capital formation.

The impact of electricity consumption on key macroeconomic variables is deemed insignificant. It implies that changes in electricity consumption do not significantly influence or contribute to fluctuations in broader economic indicators. This interpretation suggests that factors other than electricity consumption play a more dominant role in shaping the macroeconomic landscape in Tajikistan. It is essential to consider that the overall impact of electricity consumption on macroeconomic variables can be influenced by the efficiency of the electricity supply chain, the resilience of the economy to changes in energy consumption, and the presence of alternative energy sources. Additionally, the significance of electricity consumption may vary over time. Another interpretation could be framed from a policy or sustainability perspective. If electricity consumption across sectors has an insignificant impact on key macroeconomic variables, it may imply that there is potential for optimizing energy usage without adversely affecting the broader economy. Policymakers might focus on the potential for optimizing energy use, fostering sustainability, and enhancing resilience to external energy-related challenges.

It is important to note that these implications were derived based on observed statistical relationships, and policy decisions should also consider other contextual factors and potential unintended consequences.

Theoretical mechanisms referring to the underlying principles or frameworks that explain how electricity production and consumption influence the macroeconomy can include various channels through which changes in electricity production and consumption impact economic variables. One mechanism is the input–output relationship, where electricity serves as a critical input in the production process across various sectors of the economy. An increase in electricity production can lead to higher output levels in industries reliant on electricity, thereby stimulating overall economic activity and contributing to GDP growth. Similarly, changes in electricity consumption patterns can affect production costs and efficiency, influencing firms' profitability and investment decisions. Another mechanism involves the impact of electricity availability on productivity and technological advancement. Adequate electricity supply facilitates the adoption of modern technologies and innovations, enhancing productivity levels in sectors ranging from manufacturing to services. This productivity boost can drive economic growth by increasing output per worker and fostering competitiveness. Furthermore, electricity consumption patterns can reflect shifts in consumer behavior and preferences, thereby influencing aggregate demand and consumption expenditure. Changes in electricity prices or availability may alter households' disposable income, affecting their purchasing power and consumption patterns. This, in turn, can impact overall economic growth through its effect on aggregate demand.

The scope of this study is limited to annual data for Tajikistan. The exclusive utilization of annual data for the singular case of Tajikistan inherently possesses both advantages and disadvantages. The limitation arises from the relatively constrained number of observations, although it was deemed acceptable for the selected model. Conversely, the merits are discernible in the enhanced precision of information pertaining to the country. The reliability of annual data surpasses that of their more frequent counterparts, namely, quarterly or monthly data, particularly in the context of macroeconomic variables. This preference for annual data acquisition underscores its intrinsic propensity to provide a more robust and dependable foundation for analytical endeavors, thereby contributing to the methodological refinement of research within the specified singular-country framework.

We envision future research endeavors incorporating quarterly data for Tajikistan and utilizing panel data from countries within the region. Additionally, addressing the diversification and energy sources and in the mid and long term is essential for our future investigations, offering a more comprehensive perspective on the dynamics between electricity production and key macroeconomic variables.

7. Conclusions

We investigated the causality relationship between electricity production and key macroeconomic variables in the context of Tajikistan. The empirical findings indicate a positive unidirectional causality, with electricity production influencing both the export and import of goods and services during the specified period. Additionally, a positive bidirectional causality was observed between electricity production and GDP, electricity production and GDP per capita, electricity production and final consumption expenditure, as well as electricity production and employment. However, no significant causality was detected between electricity production and trade openness, nor between electricity production and gross capital formation.

Furthermore, a positive unidirectional causality was identified from both GDP and GDP per capita to electricity consumption. Conversely, no causal relationship was found from electricity consumption to GDP or GDP per capita, and no significant causality was established between electricity consumption and other variables.

The study uncovers the complex causal relationships between electricity production and major macroeconomic indicators in Tajikistan. These findings offer a valuable addition to the academic discourse, offering insights that can inform policymakers and stakeholders. This understanding aids in the formulation of sustainable development strategies and the effective utilization of the country's hydropower resources, albeit within realistic bounds.

Hydropower is a renewable energy source that generates electricity by harnessing the energy of flowing or falling water. As a clean and sustainable energy option, electricity from hydropower plays a crucial role in reducing reliance on fossil fuels, thereby contributing to mitigating climate change and promoting sustainable development goals.

While hydropower is considered a clean energy source, the construction of dams and reservoirs for hydropower projects can have significant environmental impacts. Therefore, the relationship between hydropower and sustainable development must carefully consider environmental sustainability and the conservation of natural resources.

By carefully managing the trade-offs and maximizing the benefits of hydropower development, Tajikistan can harness the potential of this renewable energy source to promote green growth and achieve sustainable development objectives.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Methodological approach.

Step 1. Test the stationarity of data using the ADF and Phillips–Perron unit root tests.
Step 2. Determine the optimum lag order based on AIC and SBIC information criteria.
Step 3. Perform the Johansen cointegration test to examine the cointegration between variables.
Step 4. Estimate the VAR model if there are no cointegrating equations.
Step 5. Assess the presence of autocorrelation in the residuals.
Step 6. Perform the Granger causality test to estimate the causality relationship between variables.

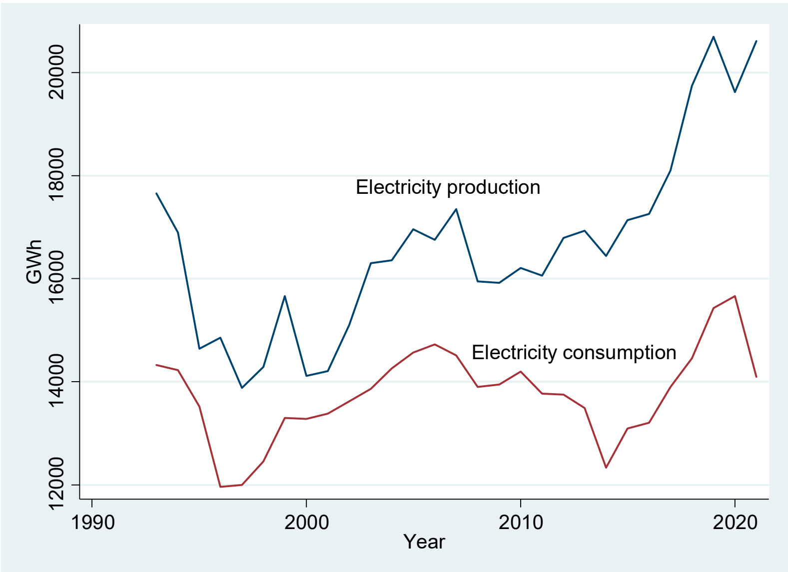

Figure A1. Electricity production and consumption. Source: The figure was created by the authors based on data from Stat TJ (2023a).

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