“Causal relationship between renewable energy consumption and manufacturing value added: Evidence from Kazakhstan”

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CAUSAL RELATIONSHIP BETWEEN RENEWABLE ENERGY CONSUMPTION AND MANUFACTURING VALUE ADDED: EVIDENCE FROM KAZAKHSTAN

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Abstract

The paper investigates the causal interaction between renewable energy consumption and manufacturing value added in Kazakhstan, a relationship of growing importance in the context of sustainable industrial development. The aim of the study is to assess the direction and nature of causality between these variables over the period from 2000 to 2021. To this end, the Toda-Yamamoto Granger causality test is applied, offering robust results regardless of the order of integration of the time series data. The empirical analysis identifies a statistically significant bidirectional causal relationship. Specifically, renewable energy consumption has a significant impact on manufacturing value added (p = 0.003), while manufacturing value added also significantly influences renewable energy consumption (p = 0.006). These findings reveal a reciprocal mechanism in which the expansion of renewable energy supports industrial growth, and industrial development, in turn, enhances renewable energy usage. The results underscore the strategic importance of integrating renewable energy policies with industrial development plans. From a policy perspective, the study provides practical insights into fostering sustainable economic growth by aligning environmental and industrial objectives in Kazakhstan.

Keywords renewable energy consumption, manufacturing value added, econometrics, Granger causality, Toda-Yamamoto test, environmental economics, sustainability, Kazakhstan

JEL Classification Q42, O14, C32, Q56

INTRODUCTION

Amid global initiatives aimed at sustainable energy transitions, analyzing the sectoral implications of renewable energy deployment is essential. Incorporating renewable energy into industrial production systems serves as a key driver for advancing sustainable manufacturing and facilitating environmentally responsible economic growth.

In recent years, Kazakhstan has demonstrated notable economic growth, with its real GDP increasing by 3.2% compared to the previous year. In 2022, the production of goods, services, and taxes on products grew by 3.5%, 2.5%, and 7.9%, respectively, indicating robust expansion across key sectors (BNS, 2023). Among these sectors, the manufacturing industry, classified under ISIC divisions 15-37, has played a crucial role in driving economic development. As a key contributor to Kazakhstan's economic performance, the manufacturing sector's value added represents the net output derived by aggregating total outputs and subtracting intermediate inputs. This metric excludes factors such as asset depreciation and natural resource depletion, offering a focused perspective on the sector's direct economic contribution (CEICDATA, 2018).

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Manufacturing value added serves as a modern economic indicator that encapsulates the net contribution of manufacturing activities to the economy. It is calculated by subtracting the value of intermediate inputs from the total output of manufactured goods, providing insight into the efficiency and productivity of the sector. Furthermore, it illustrates the sector's role as a proportion of the national GDP (Singh & Jyoti, 2023). The accelerated expansion of global manufacturing production presents considerable advantages for producers and consumers alike, yet its environmental and social implications require thorough evaluation (Hasanov et al., 2024). As Kazakhstan's economic growth accelerates and the manufacturing sector continues to expand, environmental concerns have become increasingly pressing.

The global imperative to mitigate climate change has highlighted the need for countries to transition toward green economic principles. Low-carbon development has emerged as a fundamental strategy for reducing the adverse impacts of climate change, compelling countries worldwide to set ambitious carbon neutrality targets. In alignment with this global movement, Kazakhstan has committed to achieving carbon neutrality by 2060, signaling its dedication to fostering environmentally responsible economic growth (DPRK, 2023). Despite its considerable renewable energy potential, Kazakhstan currently relies on renewable energy sources for only 1–2% of its total energy supply. Nevertheless, the country has made commendable strides in advancing its green energy agenda, meeting its 2020 target of generating 3% of electricity from renewable energy sources. Building on this progress, Kazakhstan aims to produce 15% of its electricity from renewable energy sources by 2030, excluding large hydropower (IEA, 2023). Achieving this ambitious target will require strategic investments in green technologies, enhancements to energy infrastructure, and the implementation of supportive policy frameworks to overcome existing barriers.

The incorporation of renewable energy into industrial production processes is essential for promoting sustainable manufacturing and fostering economic growth. However, there is a lack of empirical research examining the relationship between renewable energy adoption and manufacturing value added in Kazakhstan. It is necessary to investigate the causal connection between renewable energy consumption and manufacturing value added, assessing its influence on industrial productivity. The analysis can underscore the challenge of harmonizing economic growth with environmental sustainability goals within Kazakhstan's manufacturing sector. While progress has been made in renewable energy adoption, substantial challenges persist in achieving effective integration. Gaining a deeper understanding of this relationship is vital for formulating strategies that support sustainable industrial development and align with Kazakhstan's carbon neutrality targets.

1. LITERATURE REVIEW AND HYPOTHESES

The interplay between renewable energy consumption and manufacturing value added has emerged as a key area of research as countries seek to harmonize economic development with environmental sustainability. Especially in the context of renewable energy consumption and environmental sustainability, Zahoor et al. (2022) investigated the influence of natural resource abundance, manufacturing value added, urbanization, and permanent cropland on China's CO_2 emissions between 1970 and 2016. The study demonstrated that manufacturing value added had an adverse effect on environmental sustainability, whereas natural resource abundance and permanent cropland contributed to emission reductions. Similarly, Yang et al. (2021) examined the impact of economic growth on CO_2 emissions in 25 manufacturing subsectors across 38 countries between 2000 and 2014, focusing on the role of renewable energy consumption. The results indicated that although manufacturing expansion initially contributed to higher emissions, this effect weakened as renewable energy usage increased, reflecting a transition toward reduced emissions in subsectors dependent on cleaner energy sources such as natural gas and electricity.

Regarding the economic and environmental advantages of renewable energy, Krozer (2019) analyzed the shift to modern renewable energy sources, such as geothermal, wind, and solar, highlighting their role in driving economic development through increased energy service value and innovation. The findings indicated that renewable energy adoption not only contributed to CO2 emission reductions but also stimulated income growth and advancements in distributed energy systems, emphasizing the importance of supportive policies for sustainable economic progress. Heinbach et al. (2014) estimated that Germany's renewable energy sector in 2011 could generate €9.3 million in municipal value-added and create 166 jobs per model municipality, with the operation and maintenance stage contributing the most continuous effects. The study highlighted renewable energy's potential to foster economic value and employment, even in areas without manufacturing industries, thereby supporting informed local decision-making and decentralized energy generation. Bashir et al. (2024) explored the interactions between natural resource rents, industrial value added, banking sector development, renewable energy consumption, total reserves, and environmental quality in BRICS nations from 1995 to 2019. The results demonstrated that industrial growth and resource rents had adverse environmental effects. In contrast, banking development and renewable energy use significantly contributed to environmental improvements, emphasizing the necessity for sustainable resource management strategies. Singh (2022) analyzed the connections between renewable energy consumption, urban primacy, net FDI inflows, and value added in the manufacturing, construction and mining, services, and agriculture sectors across four European regions from 2000 to 2019. The study found a positive causal link between renewable energy and agriculture in Northern and Southern Europe, whereas a negative causal relationship emerged in Eastern and Western Europe. Numerous other studies have employed comparable analytical approaches and methodologies, yielding similar findings on the subject (Aderemi et al., 2022; Chandio et al., 2021; Wu et al., 2020).

In the case of Kazakhstan, this topic highlights the pressing need for further research and emphasizes the vital role of supportive policies and institutional frameworks in advancing the renewable energy transition. Addressing these obstacles could not only expand the contribution of renewables to the energy mix but also promote manufacturing value added through innovation, cost reductions, and improved environmental sustainability.

Raihan and Tuspekova (2022) investigated the influence of economic growth, renewable energy utilization, and technological innovation on CO2 emissions in Kazakhstan from 1996 to 2018, employing the Dynamic Ordinary Least Squares (DOLS) approach. The study revealed that economic expansion and fossil fuel consumption were significant drivers of CO_2 emissions, whereas renewable energy adoption and technological advancements played a crucial role in reducing emissions. The findings emphasized the importance of policy measures to foster a low-carbon economy and promote technological innovation. Issayeva et al. (2023) examined the relationship between CO2 emissions, industrial production, economic growth, and renewable energy consumption in Kazakhstan through the application of the Johansen cointegration test, VAR analysis, Granger causality, and the VECM model. The results indicated that industrial development and economic growth did not have a statistically significant effect on CO2 emissions, whereas investments in renewable energy emerged as a crucial factor in shaping emission trends. Karatayev et al. (2016) also emphasized Kazakhstan's significant renewable energy potential, with a national objective to produce 50% of its electricity from renewable sources by 2050. However, despite these ambitious goals, non-hydro renewable energy sources currently account for less than 1% of electricity demand. This limited contribution is attributed to challenges such as fossil fuel-centric regulatory policies, limited awareness of sustainable technologies, inadequate education, and market inefficiencies.

The literature underscores the complex bidirectional relationship between renewable energy consumption and economic growth, with manufacturing value added playing a pivotal role in this dynamic. This paper aims to empirically investigate the causal relationship between renewable energy consumption and manufacturing value added in Kazakhstan, utilizing the Toda-Yamamoto Granger causality test to determine the directionality and significance of this connection. The hypotheses are stated as follows:

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H1: A causal relationship exists between renewable energy consumption and manufacturing value added in Kazakhstan.

H2: Manufacturing value added has a significant impact on renewable energy consumption in Kazakhstan.

2. METHODOLOGY

This study explores the causal dynamics between renewable energy consumption and manufacturing value added in Kazakhstan. The dependent variable, manufacturing value added, is quantified as a percentage of gross domestic product (GDP), while the independent variable, renewable energy consumption, represents the proportion of total final energy consumption. The empirical investigation is based on annual time series data from 2000 to 2021, sourced from the World Bank database. The dataset provides critical indicators for evaluating the extent to which renewable energy integration influences the industrial sector's contribution to the national economy.

It is essential to first provide a general description of the data along with a visual representation to facilitate a comprehensive understanding of its characteristics and trends. Figure 1 depicts a declining trend in manufacturing value added (% of GDP) followed by a subsequent increase from 2000 to 2021. In contrast, renewable energy consumption (% of total energy) shows little change over the same period, reflecting a slow transition toward cleaner energy sources despite increasing recognition and policy efforts.

Table 1 presents descriptive statistics that support the observed downward trend in manufacturing value added, which exhibits moderate variability and a slight positive skew, suggesting that higher values were more prominent in the earlier years. In contrast, renewable energy consumption has remained consistently low and stable throughout the period, displaying a distribution that approximates normality.

Table 1. Descriptive statistics of data variables

Statistic	MVA	REC
Mean	12.25848	1.831818
Median	11.47898	1.900000
Maximum	16.49804	2.800000
Minimum	10.27541	1.100000
Std. Dev.	1.802618	0.457099
Skewness	1.187799	0.153846
Kurtosis	3.416081	2.289409
Jarque-Bera	5.331877	0.549646
Probability	0.069534	0.759707

Note: MVA = manufacturing value added; REC = renewable energy consumption.

Source: World Bank (n.d.).

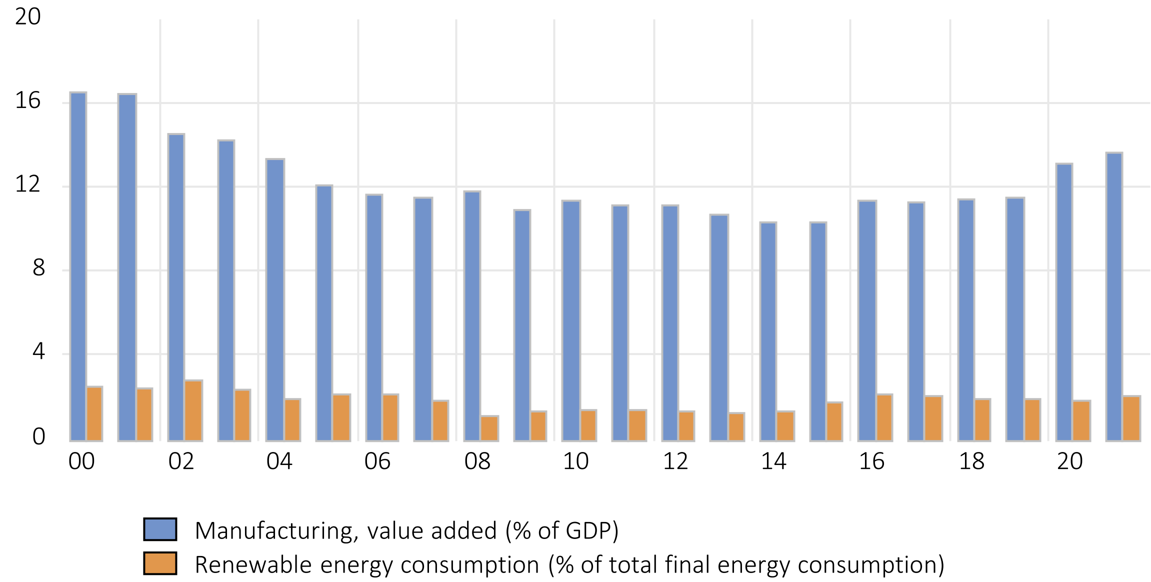

Figure 1. Trends in manufacturing value added and renewable energy consumption (2000–2021)

This paper utilizes the Toda-Yamamoto (1995) approach to examine the causal relationship between renewable energy consumption and manufacturing value added in Kazakhstan. The Toda-Yamamoto procedure provides a robust framework for conducting causality analysis in the presence of integrated or cointegrated variables, effectively bypassing the need for prior unit root or cointegration tests. The analysis is based on the Vector Autoregressive (VAR) model, which captures the dynamic interactions between renewable energy consumption and manufacturing value added over time. This model structure enables the identification of both short- and long-term relationships, offering a comprehensive perspective on the interdependencies between the variables. The Toda-Yamamoto model equations, tailored to the dataset employed in this paper, are formulated as follows:

$$MVA_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i MVA_{t-i} + \sum_{j=k+1}^{k+d_{\max}} \alpha_j MVA_{t-j} + \sum_{i=1}^{k} \phi_i REC_{t-i} + \sum_{j=k+1}^{k+d_{\max}} \phi_j REC_{t-j} + \nu_{1t}, \quad (1)$$

$$REC_t = \beta_0 + \sum_{i=1}^{k} \beta_i REC_{t-i} + \sum_{j=k+1}^{k+d_{\max}} \beta_j REC_{t-j} + \sum_{i=1}^{k} \delta_i MVA_{t-i} + \sum_{j=k+1}^{k+d_{\max}} \delta_j MVA_{t-j} + \nu_{2t} \quad (2)$$

The Toda-Yamamoto methodology follows the $d_{max} + k$ approach, where d_{max} is the maximum order of integration for the series, and k represents the optimal number of lags.

Unit root tests, including the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests (Dickey & Fuller, 1979; Phillips & Perron, 1988), were applied to identify the maximum order of integration for the variables. Subsequently, the optimal lag length was determined using standard selection criteria, such as the Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC). The augmented VAR model was then subjected to Wald tests to evaluate the significance of the lagged coefficients, enabling the identification of causal relationships between manufacturing value added and renewable energy consumption. This methodological framework ensures a rigorous and robust examination of the causal dynamics between renewable energy consumption and manufacturing sector performance in Kazakhstan.

3. RESULTS

Before conducting empirical econometric analysis, it is preferred to visually explore the relationship between the two variables to better understand their interaction. Figure 2 displays a scatter plot illustrating a weak positive correlation between manufacturing value added and renewable energy consumption, with significant variability in the data points, suggesting the influence of other

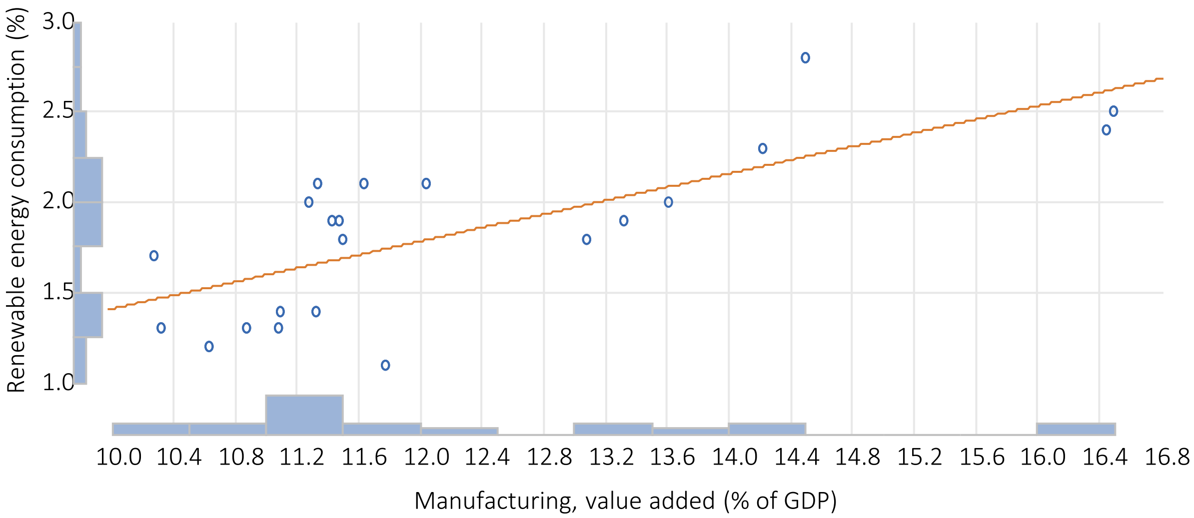

Figure 2. Scatter plot of manufacturing value added and renewable energy consumption

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factors. The trend line highlights a general pattern where higher manufacturing value added is linked to a slight increase in renewable energy consumption.

Table 2 displays the results of the unit root tests, indicating that both manufacturing value added and renewable energy consumption are non-stationary at their levels but achieve stationarity after first differencing, signifying they are integrated of order one (I(1)). While traditional Granger (1969) causality testing typically requires cointegration analysis to examine causal relationships, the Toda-Yamamoto approach facilitates direct testing of causality in levels, even when the variables are non-stationary. The application of the Toda-Yamamoto Granger causality test requires determining the maximum order of integration, D_{max}, and adding the lag length, K, from the VAR model. In this case, D_{max} is found to be 1, which is consistent with the order of integration of the variables, thereby enhancing the validity of the causal relationships identified in the test.

Table 3 identifies the optimal lag length for the VAR model as 1, based on the results of the likelihood ratio test and the minimization of the FPE, AIC, SC, and HQ criteria. Incorporating a single lag notably enhances the model's fit relative to the zero-lag model, while reducing the complexity penalties observed at lag 2. This selection effectively balances the need to capture the dynamic relationships between variables and the goal of maintaining model simplicity for accurate forecasting.

In the context of the Toda-Yamamoto Granger causality test, with a lag length (K) of 1, the total maximum order of integration, $D_{max} + K$, equals 2, thereby strengthening the reliability of the causal inferences drawn from the analysis.

Table 4 shows that no root lies outside the unit circle, meaning that all roots have moduli less than one. This confirms that the VAR model satisfies the stability condition, ensuring stability. As a result, the underlying time series are likely stationary or can be transformed into stationarity, making the model suitable for further analysis such as impulse response functions, forecast error variance decomposition, and Granger causality tests.

Table 4. Roots of the characteristics polynomial

Root	Modulus
0.616253 – 0.266184i	0.671283
0.616253 + 0.266184i	0.671283
0.201065 – 0.357481i	0.410146
0.201065 + 0.357481i	0.410146

Table 5 presents the results of three diagnostic tests: serial correlation, normality, and heteroskedasticity, applied to the VAR model. The Serial Correlation LM Test shows no significant autocorrelation in the residuals, as all p-values for the tested lags (1, 2, and 3) are greater than 0.05, indicating no serial correlation. The Normality Test provides no strong evidence against normality, with p-values for individual components and the joint test exceeding 0.05, suggesting the residuals are normally distributed. Additionally, the Heteroskedasticity Test indicates no significant heteroskedasticity, as the p-value for the joint test is 0.4011, greater than 0.05. These findings collectively support the validity of the VAR model, suggesting that the residuals do not violate

Table 2. Unit root test

Variables	ADF Level	ADF 1st Difference	PP Level	PP 1st Difference
REC	–1.845 (0.349)	–3.914 (0.008)*	–1.795 (0.372)	–3.870 (0.008)*
MVA	–2.613 (0.106)	–3.358 (0.025)**	–2.600 (0.108)	–3.410 (0.022)**

Note: * Significant at 1% level, ** Significant at 5% level.

Table 3. Optimal lag selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	–36.65099	NA	0.163574	3.865099	3.964672	3.884536
1	–16.13564	34.87609*	0.031504*	2.213564*	2.512284*	2.271877*
2	–12.16467	5.956450	0.032141	2.216467	2.714334	2.313656

Note: * indicates lag order selected by the criterion.

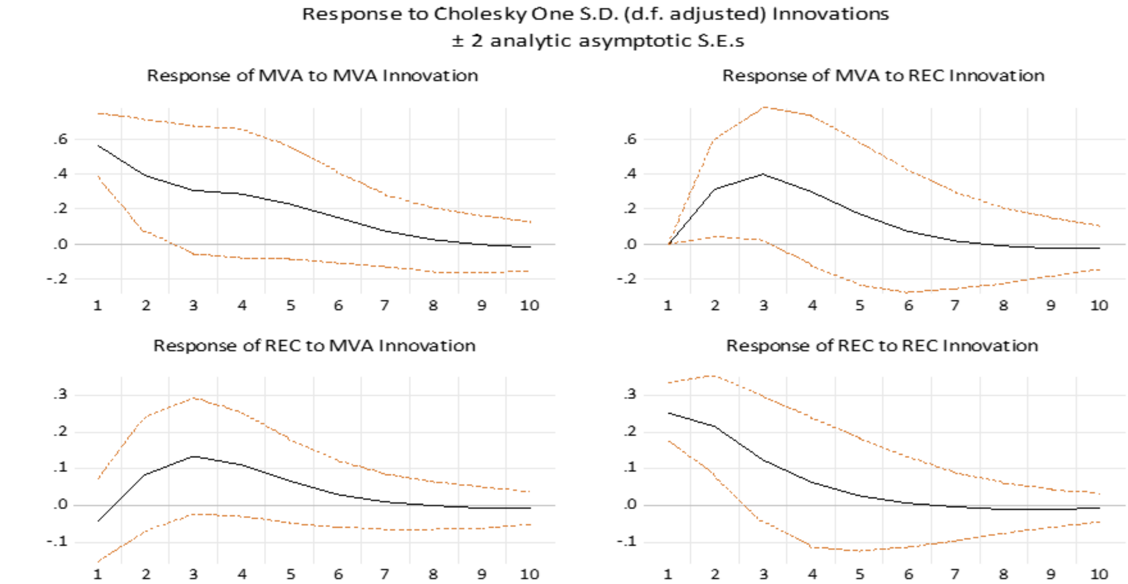
key assumptions. The absence of serial correlation, heteroskedasticity, and strong non-normality increases confidence in the reliability of the model's results and its statistical inferences. With these diagnostic tests passing, the model is deemed suitable for further analysis, including impulse response functions, variance decomposition, and Granger causality tests.

Table 5. VAR diagnostic test results

Serial Correlation LM Test			
Lag	**LRE stat**	**df**	**p-value**
1	3.961099	4	0.4113
2	1.885699	4	0.7568
3	6.763513	4	0.1489
Normality Test			
Component	**Jarque-Bera**	**df**	**p-value**
1	4.739155	2	0.0935
2	0.598396	2	0.7414
Joint	5.337551	4	0.2544
Heteroskedasticity Test			
	Chi-sq	**df**	**p-value**
Joint	25.08683	24	0.4011

Impulse Response Functions (IRFs) in Figure 3 illustrate how one variable reacts to shocks in another, offering insights into the dynamic interactions between variables over time. The analysis reveals that manufacturing value added responds positively to its own shocks, with the effect tapering off over time, while renewable energy consumption demonstrates a more sustained response to both its own shocks and those of manufacturing value added. This suggests a bidirectional relationship between manufacturing value added and renewable energy consumption, implying the existence of feedback loops where growth in manufacturing may drive renewable energy consumption and vice versa. These findings have significant policy implications, indicating that promoting renewable energy could stimulate manufacturing growth, while manufacturing expansion may increase renewable energy demand.

The Toda-Yamamoto Granger causality test results in Table 6 reveal a bidirectional relationship between renewable energy consumption and manufacturing value added. Both null hypotheses are rejected with *p*-values of 0.003 and 0.006, indicating that past values of renewable energy consumption contribute to predicting manufacturing value added, and past values of manufacturing value added aid in forecasting renewable energy consumption. These results suggest that policies encouraging renewable energy could positively impact the manufacturing sector, while growth in manufacturing may lead to an increase in renewable energy consumption.



Note: MVA = manufacturing value added; REC = renewable energy consumption.

Figure 3. Dynamic responses of manufacturing value added and renewable energy consumption: Impulse response functions

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Table 6. Toda-Yamamoto Granger causality test results

Null Hypothesis	Chi-Square	p-value	Lag (k)	$K+D_{max}$
REC → MVA	8.798	0.003*	1	2
MVA → REC	7.339	0.006*	1	2

Note: * Significant at 1% level. MVA = manufacturing value added; REC = renewable energy consumption.

The findings validate both hypotheses, demonstrating a bidirectional causal relationship between renewable energy consumption and manufacturing value added in Kazakhstan, with manufacturing value added exerting a significant impact on renewable energy consumption, and the reverse also being true.

4. DISCUSSION

The result that "renewable energy consumption Granger-causes manufacturing value added" suggests that policies aimed at fostering renewable energy adoption, such as subsidies or mandates, could positively affect the manufacturing sector by encouraging the use of cleaner energy, reducing costs, and enhancing the sector's environmental reputation. This finding is significant as it underscores the interdependence between the adoption of renewable energy sources and the growth of the manufacturing sector. In contrast, the finding that "manufacturing value added Granger-causes renewable energy consumption" indicates that manufacturing sector growth leads to higher energy demand, which may be satisfied by renewable sources due to factors like government incentives, stricter regulations, or lower renewable energy costs, thereby creating a feedback loop where growth in one sector supports the expansion of the other. Emirmahmutoglu et al. (2021) and Zou (2022) arrived at similar findings on renewable energy consumption by applying the Toda-Yamamoto Granger causality test. Their analysis demonstrated that renewable energy positively contributes to economic development, consistent with theoretical frameworks in green economics.

The evidence of bilateral causality indicates that renewable energy consumption not only promotes manufacturing value added but also that the growth of the manufacturing sector, in turn, fosters increased renewable energy usage. This reciprocal relationship can be attributed to several factors, particularly the enhanced feasibility and economic viability of renewable energy integration as manufacturing processes become more technologically advanced and energy-efficient (Jie & Rabnawaz, 2024). The reinforcing relationship between renewable energy consumption and manufacturing value added carries significant policy implications. In Kazakhstan, policymakers should prioritize measures to encourage the adoption of renewable energy technologies within the manufacturing sector. Potential policy instruments could include tax incentives, subsidies, and financial grants to support renewable energy projects and foster a more sustainable industrial landscape (Boute, 2020; Lan et al., 2023). In Kazakhstan, the expansion of the manufacturing sector supported by renewable energy consumption could play a pivotal role in promoting economic diversification and enhancing resilience, thereby mitigating the country's dependence on oil and gas exports (Azretbergenova & Syzdykova, 2020; Shakeyev et al., 2023).

The results suggest that incorporating renewable energy policies within industrial strategies could promote complementary growth in both sectors, with manufacturing driving greater renewable energy consumption and renewable energy adoption improving manufacturing performance. However, the study points to the need for further research to investigate the underlying mechanisms through which these variables influence each other, as well as the impact of government policies, technological advancements, and other macroeconomic factors. Employing advanced econometric methods, such as structural vector autoregressions or panel data models, may provide deeper insights into these complex relationships. Ultimately, understanding the interaction between manufacturing value added and renewable energy consumption is essential for policymakers and business leaders to develop effective strategies that foster sustainable industrial growth and broader economic development.

CONCLUSION

This study aimed to explore the bidirectional relationship between renewable energy consumption and manufacturing value added in Kazakhstan. The findings from the Toda-Yamamoto Granger causality test demonstrated a significant reciprocal causal link, with past values of each variable aiding in the prediction of the other. These results suggest that the adoption of renewable energy can spur growth in the manufacturing sector, while industrial expansion drives an increased demand for renewable energy. The study highlights the importance of incorporating renewable energy initiatives into industrial policy to promote sustainable development and economic diversification in Kazakhstan. Future research could investigate the mechanisms underlying this relationship, focusing on the role of policy interventions, technological progress, and other macroeconomic influences.

AUTHOR CONTRIBUTIONS

Conceptualization: Ramil Hasanov, Asli Kazimova, Aytakin Mammadova.
Data curation: Ramil Hasanov, Rashad Salahov.
Formal analysis: Asli Kazimova, Aytakin Mammadova, Rashad Salahov, László Vasa.
Investigation: Ramil Hasanov, Aytakin Mammadova.
Methodology: Ramil Hasanov, László Vasa.
Project administration: László Vasa.
Resources: Ramil Hasanov, Asli Kazimova, Aytakin Mammadova, Rashad Salahov.
Software: Ramil Hasanov.
Supervision: Ramil Hasanov, László Vasa.
Validation: Asli Kazimova, Aytakin Mammadova, Rashad Salahov, László Vasa.
Visualization: Ramil Hasanov, Rashad Salahov.
Writing – original draft: Ramil Hasanov, Aytakin Mammadova.
Writing – review & editing: Asli Kazimova, Rashad Salahov, László Vasa.

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