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The Relationship between Renewable Energy Consumption and Economic Growth: Insights from Iceland and Azerbaijan

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ABSTRACT

Iceland leads globally in per capita green energy production, while oil-dependent Azerbaijan endeavors to transition its energy policy towards sustainable alternatives. Investigating the impacts of renewable energy consumption on the economy represents a significant contemporary scientific inquiry. The objective of this research is to empirically examine the causal relationship between GDP per capita, a key metric of economic growth, and renewable energy consumption, a fundamental aspect of the green economy. In this research, the Toda-Yamamoto causality test framework of the vector autoregressive (VAR) model was utilized to examine the causal relationship between the variables. The outcomes of this investigation reveal a significant causality between renewable energy consumption and economic growth in Iceland and Azerbaijan.

Keywords: Renewable Energy Consumption, Economic Growth, Toda-Yamamoto Causality Test, Iceland, Green Economics, Sustainability
JEL Classifications: C22; Q43; Q50; O13

1. INTRODUCTION

In considering the framework of the contemporary economy, energy emerges as an indispensable factor. It constitutes a fundamental criterion for measuring economic advancement. Within a particular synthesis, Stern (2011) provided an explanation regarding the significance of energy as a primary driver of economic growth. Ecological economists commonly highlight energy as the central driver of economic growth. The overarching goal of present-day science and technology is to transition energy production towards renewable sources. The success in achieving this transition holds the key to attaining a sustainable future for any nation.

Research on the green economy and sustainable future is fundamentally global in scope. Numerous hypotheses address the impact of green energy utilization on economic development, and its beneficial effects are extensively examined within the scientific community (Dai et al., 2016; Wang et al., 2022; Dzwigol et al., 2023). In this crucial endeavor, the careful selection of research subjects worldwide holds paramount significance. In the global pursuit of sustainable development, Iceland is distinguished by its innovative utilization of renewable energy resources, exemplifying the transformative possibilities inherent in green energy solutions. Azerbaijan, historically and traditionally an oil exporter, is also actively engaged in the transition to green energy for sustainable future.

This scientific inquiry provides an analysis of the causal relationship between renewable energy consumption and economic growth in Iceland and Azerbaijan, aiming to elucidate the prospects and hurdles associated with its transition towards sustainable energy methodologies. Employing econometric methods, this study meticulously scrutinizes the empirical connections between the utilization of renewable energy and economic advancement.

In recent years, Iceland's economy has thrived, fueled largely by tourism, with growth rates of 4.2% in 2017, 4.9% in 2018, and 2.4% in 2019. However, the pandemic caused significant setbacks, resulting in a contraction of 7.1% in 2020, but the economy is now showing signs of recovery, with GDP growth reaching 4.3% in 2021 (ITA, 2024). Within the discourse surrounding sustainable development on a global scale, Iceland is recognized as a prominent example of innovative approaches. This island nation has strategically utilized its distinct geothermal and hydropower reserves to position itself as a frontrunner in the field of renewable energy utilization. Iceland stands out as a leading model for the effective utilization of renewable energy, relying heavily on hydroelectric and geothermal sources to power its electricity grid and fulfill heating needs. Its energy strategy, which includes exporting energy-intensive goods such as aluminum and exploring direct energy exports, positions the country favorably to take advantage of the growing international importance of clean energy (Hreinsson, 2008). Given its abundant green energy resources, along with its advancements in production and consumption, Iceland emerges as a frontrunner in the pursuit of economic development within sustainable frameworks. Iceland's impressive move towards predominantly relying on renewable energy sources for its electricity production and a substantial portion of its primary energy demands has drawn worldwide notice. The accessibility of inexpensive and sustainable energy has lured investments and facilitated economic expansion. Iceland's President Ólafur Ragnar Grímsson highlighted in a speech that the clean energy economy played a crucial role in aiding Icelanders during the banking collapse due to the significantly lower costs of heating and electricity for ordinary families, homes, and businesses compared to other European nations (OECD, 2013).

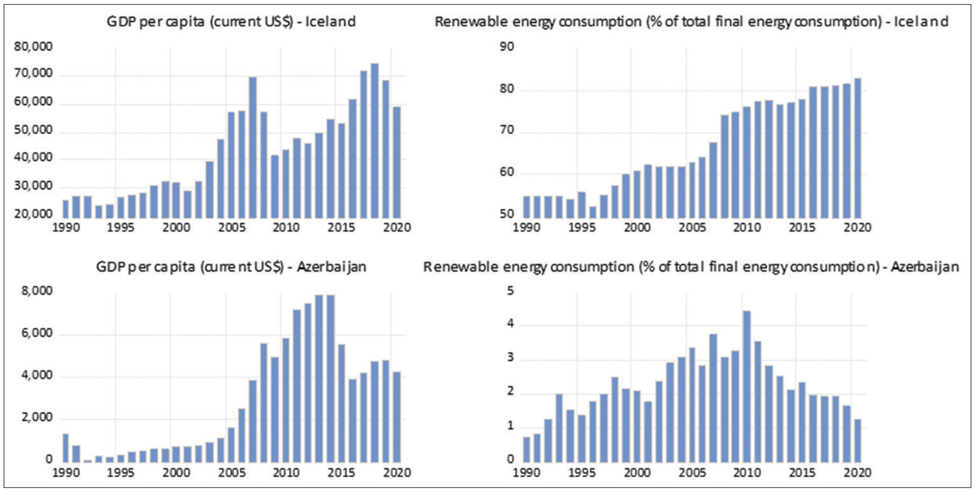
Energy serves as the backbone of Iceland's economy, with around 85% of its total primary energy supply originating from domestically produced renewable sources and this represents the largest share of renewable energy in any national energy budget globally (GOI, 2017). Nearly all of Iceland's electricity is sourced from renewable energy, with 73% generated by hydropower plants and 26.8% from geothermal energy, collectively providing over 99% of the nation's electricity consumption (VisitIceland, 2023).

Compared to Iceland, Azerbaijan is a traditional energy-producing country. Oil and natural gas contribute about 90% of Azerbaijan's export revenues and finance approximately 60% of the government budget (IEA, 2021). Azerbaijan's GDP reached $78.7 billion in 2022, marking a 4.6% rise from 2021. During this time, the country's non-oil GDP grew by 9.1%, whereas its oil GDP declined by 2.7% (ITA, 2023). Green energy production in Azerbaijan has mainly been based on hydroelectric power. Over the last 10 years, there has been a notable transition to solar and wind energy. Gulaliyev, Mustafayev, and Mehdiyeva (2020) emphasize Azerbaijan's significant solar energy potential but also point out economic challenges, such as low electricity prices, that reduce the attractiveness of investing in solar power. To achieve long-term energy security, Azerbaijan needs to increase its use of renewable energy sources (Aliyev et al., 2024). Significant state-level projects are being implemented to increase the share of renewable energy, especially after the liberation of the Karabakh region (Hasanov, 2023; AREA, 2022). With the implementation of current projects and programs, significant progress in the production and consumption of renewable energy in Azerbaijan is expected by 2030.

The graphical representations in Figure 1 illustrate the evolution of GDP per capita and renewable energy consumption from 1990 to 2020 in Iceland and Azerbaijan. The upward trajectory of GDP per capita indicates economic expansion, while the rise in renewable energy consumption reflects a shift towards more sustainable energy practices. The sharp decline in GDP per capita, primarily due to the European crisis, negatively impacted Iceland; however, this downturn did not result in a notable decrease in green energy consumption. In contrast, Azerbaijan was unaffected by this period but experienced economic challenges following a decline in oil prices after 2014. While Iceland saw a rapid increase in renewable energy consumption, Azerbaijan's renewable energy consumption decreased after 2010.

Within the Icelandic scientific context, multiple approaches are employed to investigate the current topic. Olafsson et al. (2014) critically assess the effectiveness of environmental indices in accurately measuring a nation's environmental sustainability, advocating for the development of a more comprehensive Environmental Sustainability Index. By examining Iceland as a case study, the research delves into the implications of its renewable energy expansion on sustainability. Despite Iceland's significant utilization of green energy, the study uncovers concerns about its enduring environmental and socio-economic sustainability, particularly attributed to the presence of heavy industries and a high ecological footprint. Gunnarsdottir et al. (2022) stress the importance of crafting sustainability indicators tailored to Iceland's energy system. Engaging stakeholders ensures accurate reflection of national energy priorities, with resulting indicators serving as a cornerstone of energy policy, guiding sustainable development in alignment with stakeholder backing and national goals. In the broader context, this study endeavors to clarify the hypothesis proposing a strong causal link between green energy and economic growth in Iceland, employing econometric methods for analysis. In comparison to Iceland, numerous scientific studies have been conducted that specifically address topics related to Azerbaijan. Humbatova et al. (2020) conducted a study examining the association between GDP (measured in both Manat and Dollar) and total electric energy consumption in Azerbaijan over the period from 1995 to 2017. They employed an autoregressive distributed lag model alongside several statistical tests to explore the correlations and causal relationships between these variables within various sectors of the economy. In comparison to Iceland, numerous scientific studies have been conducted that specifically address topics related to Azerbaijan. In another study, Huseynli (2022) investigated the relationship between traditional and renewable energy sources and economic growth in Turkey and Azerbaijan from 2005 to 2015. The research employed a Multiple Linear Regression Model and various assumption tests to evaluate the significance and impact of these energy variables on economic growth.

Figure 1: Gross domestic product per capita and renewable energy consumption in Iceland and Azerbaijan (1990-2020)



Data Source: World Bank

2. LITERATURE REVIEW

The Granger-causality test (1969) is the principal methodological approach used to examine the relationships between distinct economic variables. Apergis and Payne (2010) investigate the reciprocal relationship between renewable energy utilization and economic growth across twenty OECD countries spanning the years 1985-2005. It reveals a sustained correlation where both elements mutually stimulate each other's expansion over the long term. Saad and Taleb (2018) investigate the bidirectional impact of renewable energy utilization and economic growth across 12 European Union nations spanning the period from 1990 to 2014. In the short term, economic growth appears to boost renewable energy consumption, but over the long term, a more intricate relationship emerges, with both factors mutually influencing each other, illustrating a complex interplay.

Several significant studies have been conducted in academic literature on the Tado-Yamamoto Granger causality test. This test methodology was founded by Toda and Yamamoto (1995), after which it has been the subject of numerous empirical investigations. Aimer and Dilek (2021) examined the casual relationship between economic growth and long-term energy consumption across sixteen Middle Eastern and North African countries during the period of 1985-2016. Mukhtarov (2022) investigated the relationship between economic growth in Azerbaijan and the adoption of renewable energy, revealing that the period of economic prosperity spanning from 1992 to 2015 corresponded with an upsurge in renewable energy consumption. Table 1 presents additional pertinent scholarly works within this methodological framework.

The study conducted by Mukhtarov et al. (2017) in Azerbaijan from 1990 to 2015 identified bidirectional causality between energy consumption and economic growth, offering valuable insights for similar economies to guide energy-related policy decisions. The examination of the relationship between Iceland's green energy sector and its economic development was conducted through a panel analysis involving multiple countries. In the majority of studies within this domain, Iceland was not analyzed in isolation but rather compared to a multitude of other nations (Acaravci and Ozturk, 2010). Despite the presence of some research articles in this field, there are still gaps to be addressed, particularly concerning the relationship between renewable energy consumption and economic growth in Iceland. Investigating the long-term impact of this relationship on Iceland's economic and environmental dynamics, both at a global level and through regional examples, is necessary. Moreover, exploring the development of a sustainable model for future energy-intensive industries in a renewable energy-oriented context presents significant avenues for further research.

3. DATA AND METHODOLOGY

The research study investigated the relationship between economic development and renewable energy consumption in Iceland and Azerbaijan, utilizing the Toda and Yamamoto (1995) methodology. GDP per capita (GDPPC_ICE for Iceland and GDPPC_AZE for Azerbaijan) and renewable energy consumption (REC_ICE and REC_AZE respectively), key indicators of economic development, were designated as the primary variables, with the causal relationship between them examined. Data pertaining to all variables are sourced from the World Bank (2023), recognized as one of the primary reliable data repositories for statistical information. The data variables are logarithmically transformed to enrich comprehension, interpretation, and the statistical attributes of the dataset. Figure 2 illustrates logarithmic representations of two line graphs, demonstrating upward trends in logarithmic variables, signaling a continuous rise in GDP per capita and renewable energy consumption throughout the period.

The article utilized annual data and encompassed the timeframe spanning from 1990 to 2020. In the Table 2, the statistical summary pertains to data from Iceland and Azerbaijan, with logarithm of GDP per capita and renewable energy consumption showcasing substantial average values, suggesting the country's relatively higher economic output and energy usage. Symmetric distribution, indicated by the alignment of median values with means, alongside

Figure 2: Visualizing trends: Logarithmic representation of variables

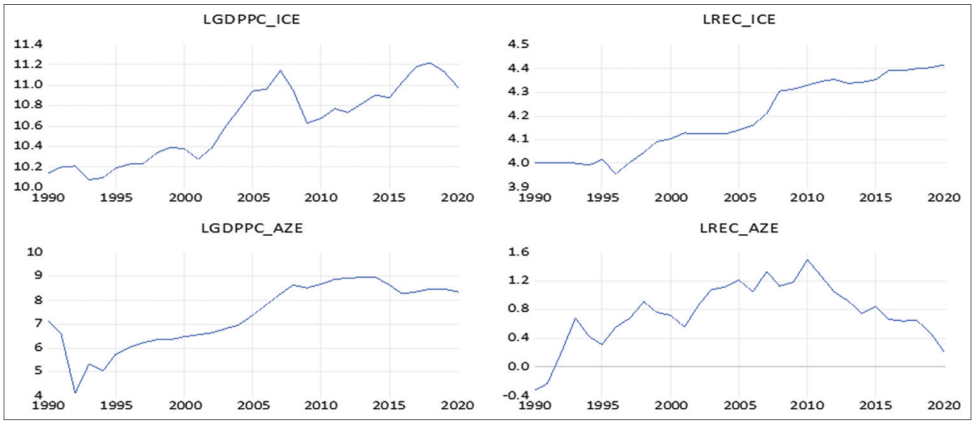


Table 1: Studies in scholarly literature

Author (s)	Countries	Toda-Yamamoto causality test result
Soytas and Sari (2009)	Turkey	A significant relationship where carbon emissions precede and influence energy consumption over the long term, suggesting that reducing emissions might not necessarily hinder economic growth.
Adom (2011)	Ghana	A unilateral causal link from economic growth to electricity consumption backs the Growth-led-Energy Hypothesis and indicates the viability of electricity conservation initiatives in the nation.
Çetin and Seker (2012)	Turkey	A positive relationship between energy consumption and economic growth but no causal link between them, implying potential negative effects of energy shortages on economic growth.
Yildirim et al. (2012)	US	Only energy derived from biomass waste exhibited a causal relationship with real GDP, implying its potential as a beneficial alternative energy resource.
Khan (2013)	Bangladesh	Bidirectional causality between energy consumption and economic growth, alongside unidirectional causality from CO_2 emissions to economic growth.
Sulaiman (2014)	Nigeria	Energy consumption impacts both CO_2 emissions and economic growth bidirectionally.
Can and Korkmaz (2020)	Bulgaria	Renewable energy consumption and renewable electricity output stimulate economic growth, economic growth and renewable electricity output drive renewable energy consumption, but economic growth and renewable energy consumption do not influence renewable electricity output.
Zou (2022)	China	A causal relationship between agricultural output growth and energy consumption, with unidirectional causality from energy consumption to the economy and agriculture.

Table 2: Descriptive data analysis of variables

Statistical measures	LGDPPC_ ICE	LREC_ ICE	LGDPPC_ AZE	LREC_ AZE
Mean	10.627	4.190	7.348	0.748
Median	10.674	4.138	7.364	0.751
Max	11.217	4.416	8.973	1.492
Min	10.068	3.956	4.098	−0.328
Std. Dev	0.370	0.157	1.331	0.423
Skewness	0.0005	0.047	−0.516	−0.670
Kurtosis	1.586	1.431	2.326	3.326

small standard deviations, implies clustered data around the mean, reflecting low variability specific to both countries.

The Toda-Yamamoto test provides a remedy for certain obstacles faced in the Granger causality test through its capability to handle integrated series of varying orders, thus facilitating the evaluation of causal relationships among these series. An important feature of the Toda-Yamamoto test is its disregard for cointegration information, permitting testing in situations where series lack co-integration (Tekin and Yener, 2019, p.83). This methodology follows a specific methodological trajectory. To evaluate the significance of parameters in a vector autoregressive (VAR(k)) model, the Modified Wald statistic provides a valuable approach, encompassing several sequential steps. Initially, the maximum order of integration (referred to as d_{max}) for the time series is established, followed by the determination of the optimal lag length (k) for the VAR model. Subsequently, upon identifying these values, the estimation of a VAR model of order ($k + d_{max}$) is undertaken, ensuring the asymptotic Chi-square distribution of the Wald statistic. Ultimately, the hypothesis evaluation is conducted using a standard Wald statistic test, which conforms to a chi-square distribution with m degrees of freedom. The Toda and Yamamoto (1995) causality test formulas can be described in the following manner:

$$LY_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i LY_{t-i} + \sum_{j=k+1}^{dmax} \alpha_j LY_{t-j} + \sum_{i=1}^{k} \phi_i LE_{t-i} + \sum_{j=k+1}^{dmax} \phi_j LE_{t-j} + v_{1t} \quad (1)$$

$$LE_t = \beta_0 + \sum_{i=1}^{k} \beta_i LE_{t-i} + \sum_{j=k+1}^{dmax} \beta_j LE_{t-j} + \sum_{i=1}^{k} \delta_i LY_{t-i} + \sum_{j=k+1}^{dmax} \delta_j LY_{t-j} + v_{2t} \quad (2)$$

In this study, LY and LE denote the logarithmically transformed variables representing LGDPPC_ICE, LGDPPC_AZE and LREC_ICE, LREC_AZE, properly. The parameter k signifies the optimal lag order, while d indicates the maximum order of integration within the series. Furthermore, v_1t and v_2t denote the error terms incorporated in the equations.

4. EMPIRICAL RESULTS

The evaluation of causal relationships among variables holds significant prominence within econometric analyses, necessitating the utilization of various methodologies to mitigate the risk of spurious findings. Identifying the order of integration of the series (d_{max}) and determining the suitable lag length ($k+d_{max}$) are essential prerequisites for conducting the causality test.

The initial phase entails assessing stationarity, typically achieved through the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1981). The results presented in Table 3 elucidate the outcomes of the ADF Unit Root test, indicating non-stationarity in both the intercept and trend and intercept variants at the level. Nonetheless, both variables demonstrate stationarity in the first difference variant. This current state of stationarity indicates that the results are integrated to the first order, denoted by I (1). Consequently, the variables within the system exhibit a maximum order of integration of one, denoted as d_{max}=1.

The second phase is the lag order selection, where it is aimed to find the optimal lag length (p) as determined by the LR, FPE, AIC, SC, and HQ criteria. In the research, a VAR model incorporating all endogenous variables was estimated, employing a randomly selected lag interval. Following this, a determination test for lag intervals was conducted on the residuals to identify the optimal lag interval.

Table 3: ADF unit root tests

Statistical measures	LGDPPC_ICE		LGDPPC_AZE	
	Level	1st difference	Level	1st difference
Intercept				
P-value	0.558	0.008*	0.771	0.000*
t-statistics	−1.420	−3.742	−0.908	−6.107
Trend and Intercept				
P-value	0.144	0.040*	0.157	0.000*
t- statistics	−3.018	−3.670	−2.970	−5.988
	LREC_ICE		LREC_AZE	
Intercept				
P-value	0.939	0.000*	0.122	0.001*
t-statistics	−0.107	−4.793	−2.511	−-4.600
Trend and Intercept				
P-value	0.285	0.003*	0.849	0.000*
t-statistics	−2.594	−4.716	−1.370	−5.722

*The maximum and optimal lag order (k) are determined using the Schwarz criterion within the Augmented Dickey-Fuller (ADF) test. Critical values from MacKinnon (1996) are employed for the ADF tests. The findings indicate rejection of the null hypothesis when examining first differences

Table 4: VAR lag order selection

Lag	LogL	LR	FPE	AIC	SC	HQ
Panel 1. Iceland						
0	19.467	NA	0.00098	−1.247	−1.152	−1.218
1	85.194	117.369*	0.00001*	−5.656	−5.371*	−5.569*
2	89.247	6.658	0.00001	−5.660*	−5.184	−5.515
3	92.444	4.795	0.00001	−5.603	−4.937	−5.399
Panel 2. Azerbaijan						
0	−49.904	NA	0.13970	3.707	3.802	3.736
1	7.363	102.263	0.00311	−0.097	0.188	−0.010
2	16.528	15.057*	0.00216*	−0.466*	0.009*	−0.320*
3	19.444	4.373	0.00237	−0.388	0.277	−0.185

*indicates lag order selection by the criterion

Table 4 presents the findings of a statistical analysis aimed at determining the optimal number of lags for a Vector Autoregression (VAR) model, highlighting a preference for a lag length of 1 for Iceland and 2 for Azerbaijan across various criteria. These criteria encompass LogL (Log-Likelihood), LR (Likelihood Ratio), FPE (Final Prediction Error), AIC (Akaike Information Criterion), SC (Schwarz Criterion), and HQ (Hannan-Quinn Criterion). Each criterion possesses distinct strengths and limitations, shaping the selected lag order. An asterisk (*) denotes the statistic with the smallest value in each category, indicating the optimal lag according to that particular criterion.

Figure 3 provides a visual representation of the stability condition for an autoregressive (AR) model, a critical aspect in time series analysis to ensure model stability. Confirming the model's stability, all inverse roots of the AR characteristic polynomial lie within or on the unit circle, emphasizing the importance of this condition for valid analysis based on the model's outputs.

No root lies outside the unit circle. VAR satisfies the stability condition. The analysis was conducted employing the Eviews software platform.

Assessing the integrity of the VAR model, Serial correlation LM tests and VAR residual diagnostics, involving evaluations of normality and White heteroskedasticity, meticulously scrutinize the existence of autocorrelation, adherence to normality, and uniformity of variance in the residuals, guaranteeing efficiency of estimators and validity of inferences, while upholding precise model specification and validity of hypothesis testing assumptions, ultimately facilitating dependable forecasts and accurate policy analyses. Tables 5 and 6 collectively highlight key findings regarding the VAR model. Table 5 demonstrates the stability and temporal independence of residuals, indicated by the absence of serial correlation. Meanwhile, Table 6 confirms the reliability of the model through the absence of significant deviations from normality or heteroskedasticity, affirming its suitability for robust statistical inference.

In the final stage of analysis, based on the Toda and Yamamoto causality test, Table 7 indicates that the null hypotheses stating "Renewable Energy Consumption (REC) does not Granger cause Gross Domestic Product Per Capita (GDP_PC)" and "Gross

Figure 3: Inverse roots of AR characteristic polynomial

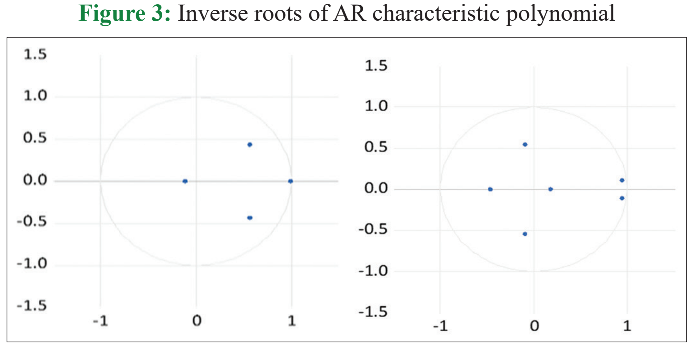


Table 5: Serial correlation LM tests

Panel 1. Iceland				Panel 2. Azerbaijan			
Lag	LRE* statistic	df**	P-value	Lag	LRE statistic	df	P-value
1	5.283	4	0.259	1	13.468	4	0.009
2	6.030	4	0.197	2	1.362	4	0.850
3	2.556	4	0.634	3	3.473	4	0.482
				4	3.408	4	0.492

*Edgeworth expansion corrected likelihood ratio statistic. **df signifies the degree of freedom. The null hypothesis states that there is no serial correlation

Table 6: VAR residual diagnostics

Panel 1. Iceland				Panel 2. Azerbaijan.			
Normality test				Normality test			
Component	Jarque-Bera	df	P-value	Component	Jarque-Bera	df	P-value
Joint	2.730	4	0.603	Joint	2.237	4	0.692
Heteroskedasticity test				Heteroskedasticity test			
White	χ^2*	df	P-value	White	χ^2	df	P-value
Statistic	37.53	36	0.398	Statistic	30.77	36	0.715

*χ^2 represents the Chi-squared value

Table 7: Toda-Yamamoto Granger causality test results

Null hypothesis	Lag (k)	K+dmax	Chi-squared test	Conclusion
Panel 1. Iceland				
Renewable energy consumption (REC) does not Granger cause gross domestic product per capita (GDPPC)	1	2	4.59586 (0.032*)	Reject
gross domestic product per capita (GDPPC) does not granger cause renewable energy consumption (REC)	1	2	11.12693 (0.001*)	Reject
Panel 2. Azerbaijan				
Renewable energy consumption (REC) does not Granger cause Gross domestic product per capita (GDP_PC)	2	3	8.821 (0.012*)	Reject
Gross domestic product per capita (GDPPC) does not Granger cause renewable energy consumption (REC)	2	3	9.833 (0.007*)	Reject

*Statistical significance at the 5% level

Domestic Product Per Capita (GDP_PC) does not Granger cause Renewable Energy Consumption (REC)" are both rejected at the 5% significance level for Iceland and Azerbaijan. This finding confirms the existence of a causal relationship between economic growth and renewable energy consumption in Iceland, suggesting that positive changes in one variable can lead to corresponding effects on the other.

Renewable energy consumption and economic growth are pivotal factors in achieving a sustainable future, with their interplay significantly influencing long-term prosperity. Using Iceland and Azerbaijan as case studies, the article underscores the importance of implementing green economic strategies and policies to foster sustainable development, emphasizing their potential to shape a nation's economic trajectory over the long term. By prioritizing investments in renewable energy and aligning economic policies with sustainability goals, countries can enhance their environmental resilience and promote economic growth and prosperity for future generations.

5. CONCLUSION

This academic investigation undertakes an empirical analysis of the economic progress within the green energy sectors of Iceland and Azerbaijan, spotlighting these countries as distinct case studies. The article utilized yearly data spanning from 1990 to 2020 and employed a VAR framework to examine the causal relationship between renewable energy consumption and economic growth in both Iceland and Azerbaijan. By utilizing a modified version of the Granger causality test developed by Toda and Yamamoto, the study identified a bilateral causal link from GDP per capita to renewable energy consumption in both countries.

The findings highlight Iceland and Azerbaijan as important cases with a strong relationship between the consumption of renewable energy and economic development. Consequently, the article suggests the adoption of policies to encourage an increase in the proportion of renewable energy use within the global energy consumption framework, with both countries serving as potential models for sustainable economic development through green energy initiatives.

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