Research Article

Drivers of Sustainable Economic Growth in Turkey: The Role of Renewable Energy, Innovation, Technical Assistance, and Fisheries Production

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ABSTRACT

This study aims to investigate the relationship between sustainable economic growth (SEG) and key drivers, including renewable energy consumption (REN), innovation (INN), technical assistance grants (TEC), and total fisheries production (TFP), in Turkey over the period 1960–2023. The research seeks to understand the short- and long-term dynamics of these variables and their implications for sustainable development. The study employs an Autoregressive Distributed Lag (ARDL) model to analyze the relationships between the variables, complemented by an Error Correction Model (ECM) to capture short-term dynamics. The dataset comprises time series data for Turkey, and the econometric models are used to estimate the significance and magnitude of the variables' effects on SEG. The results reveal a significant positive relationship between renewable energy consumption and SEG, with the effect intensifying over time. Technical assistance grants also positively influence SEG in the short run. However, innovation and fisheries production exhibit negative effects on SEG, suggesting potential inefficiencies or resource management challenges. The ECM coefficient indicates weak short-term adjustments, reflecting structural rigidities in Turkey's economy. This research examines how economic, environmental, and innovation-related factors influence Turkey's sustainable growth. The findings provide valuable insights into the drivers of SEG in an emerging economy context, emphasizing the importance of renewable energy and technical assistance while addressing the challenges posed by innovation and resource management. The study contributes to the literature by offering policy-relevant recommendations for promoting sustainable development.

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1. INTRODUCTION

Sustainable economic growth (SEG) has emerged as a central priority in global policy and research, particularly against the backdrop of climate change, environmental degradation, and widening social inequalities. Unlike conventional growth models that prioritize output expansion, SEG emphasizes a development path that is environmentally sustainable, socially inclusive, and resilient over the long term (World Bank, 2020). This paradigm reflects the growing recognition that economic progress cannot be decoupled from ecological integrity and social well-being, making SEG a cornerstone of the global sustainable development agenda. International frameworks such as the United Nations Sustainable Development Goals (SDGs) underscore the urgency of aligning economic strategies with environmental stewardship and equitable resource distribution.

Within this global discourse, emerging economies occupy a particularly critical position. Their rapid industrialization and integration into global markets provide opportunities for growth, but also pose challenges related to environmental sustainability, resource depletion, and social inclusiveness (OECD, 2021a). The balance between sustaining growth and safeguarding ecological and social systems is often more precarious in such contexts, where institutional capacities and technological readiness may lag behind those of advanced economies. As a result, understanding the drivers of SEG in emerging economies is crucial for shaping policies that support both economic advancement and sustainable development.

Turkey presents a compelling case for examining these dynamics. As a strategically located emerging economy, it has experienced significant structural transformation since the 1960s, characterized by industrial expansion, rapid urbanization, and integration into global trade (World Bank, 2023). However, this trajectory has also been accompanied by persistent challenges, including inflationary pressures, external debt vulnerabilities, and regional income disparities. Turkey's environmental footprint has expanded alongside economic growth, raising concerns about the sustainability of its development model. At the same time, the country has committed to ambitious climate and sustainability goals, including its 2053 net-zero emissions target (International Energy Agency, 2022), positioning the SEG at the heart of national policy debates.

Four interrelated factors are particularly relevant to Turkey's pursuit of sustainable growth: renewable energy consumption, innovation, technical assistance grants, and fisheries production. Renewable energy constitutes a

cornerstone of Turkey's efforts to diversify its energy mix, reduce reliance on imported fossil fuels, and meet climate commitments (TÜİK, 2022). Innovation has been increasingly emphasized through initiatives such as the National Technology Initiative, which aims to strengthen research and development (R&D) and enhance technological competitiveness (OECD, 2021b). Technical assistance grants, particularly from the European Union and international organizations, have supported capacity-building, governance reforms, and infrastructure development (European Commission, 2023). Finally, fisheries production, which is an important contributor to regional economies and food security, faces mounting pressures from overfishing, pollution, and climate change, raising questions about its sustainability (FAO, 2022).

Despite the significance of these factors, their collective and individual impacts on Turkey's SEG remain underexplored. Existing studies often examine them in isolation or through cross-country comparisons, leaving a gap in country-specific analysis. The novelty of this paper lies not in reaffirming the well-documented positive role of renewable energy, but in its comprehensive approach. By jointly examining renewable energy, innovation, technical assistance, and fisheries production, it provides an integrated perspective on how multiple economic, technological, and environmental factors shape SEG in Turkey. In particular, the inclusion of technical assistance as a driver of sustainable growth represents a novel contribution, as this dimension has been largely overlooked in previous studies.

By addressing this gap, the present study investigates the short- and long-term relationships between SEG and renewable energy, innovation, technical assistance, and fisheries production over the period 1960–2023. By employing the Autoregressive Distributed Lag (ARDL) model and the Error Correction Model (ECM), the research provides nuanced insights into how these variables interact with Turkey's economic growth trajectory.

The selection of renewable energy, innovation, technical assistance, and fisheries production as the focal drivers in this study reflects their combined relevance to Turkey's sustainable growth agenda. Renewable energy represents the environmental transition underpinning Turkey's 2053 net-zero target, while innovation captures technological readiness through the National Technology Initiative. Technical assistance embodies the institutional and financial dimension of Turkey's engagement with the European Union and international organizations, and fisheries production reflects the Blue Economy's role in sustainability debates. Together, these drivers provide a multidimensional lens, environmental, technological, institutional, and sectoral, through which sustainable growth can be assessed. Other factors, such as manufacturing or trade, while important, were not included to maintain focus and avoid over-specification, but they remain important avenues for future research.

In doing so, this paper explicitly contributes to the literature by (i) introducing technical assistance into the analysis of SEG, (ii) combining economic, environmental, and institutional drivers into a single framework, and (iii) situating the empirical analysis within Turkey's unique socio-economic and environmental context. The findings aim to inform policymakers and stakeholders seeking to align Turkey's economic development strategies with its sustainability objectives.

The structure of the paper is as follows. The next section reviews the literature, highlighting the importance of the selected variables for SEG. This is followed by a description of the methodology, data sources, and econometric models used in the analysis. The results are then presented and discussed, emphasizing their implications for Turkey's economic and environmental strategies. The paper concludes with a summary of the key findings and policy recommendations.

2. LITERATURE REVIEW

Sustainable economic growth (SEG) depends on multiple factors, including renewable energy consumption (REN), innovation (INN), technical assistance grants (TEC), and total fisheries production (TFP). These factors contribute to or detract from SEG depending on their implementation, alignment with policy frameworks, and interaction with economic and environmental systems.

2.1. Renewable Energy Consumption and Sustainable Growth

Renewable energy consumption is widely recognized as a positive driver of the SEG. It fosters economic resilience, reduces dependence on fossil fuels, and mitigates environmental degradation (Sadorsky, 2009). Apergis and Payne (2010) found that increased use of renewable energy significantly enhances economic growth in the OECD countries, driven by reduced energy costs and technological spillovers. Similarly, Pao and Fu (2013) demonstrated that renewable energy consumption in BRIC countries has a direct and positive impact on GDP.

However, challenges exist. Shafiei and Salim (2014) highlighted that renewable energy development may impose short-term costs due to the high initial investment required for infrastructure. Furthermore, poorly managed renewable energy policies can lead to inefficiencies or resource misalloction, as shown in studies of emerging economies (Rahman et al., 2024). Similarly, Abid (2025a) highlighted that renewable energy and blue economy sectors jointly stimulated sustainable growth in New Zealand, offering insights comparable to Turkey's renewable and fisheries dimensions.

For Turkey, renewable energy represents a critical opportunity for balancing growth and sustainability. However, infrastructure gaps and reliance on imported technology may hinder long-term gains (TÜİK, 2022).

2.2. Innovation as a Driver of Economic Growth

Innovation is often associated with enhanced productivity, industrial diversification, and competitive advantage (Schumpeter, 1934; Freeman & Soete, 1997). Aghion et al. (2016) demonstrated that innovation positively correlates with economic growth in high-income economies, where technological diffusion supports balanced development. In the context of renewable energy, Zhao et al. (2024) argued that innovation in green technologies significantly boosts SEG by addressing energy and environmental challenges simultaneously.

Conversely, some studies highlight the potential negative effects of innovation on SEG in certain contexts. Fagerberg et al. (2009) found that poorly directed innovation efforts may result in inefficiencies or exacerbate income inequality. In addition, over-reliance on innovation in sectors with weak institutional support can lead to economic instability (Acs et al., 2018).

Recent evidence further emphasizes the importance of innovation. For instance, Abid (2025b) finds that green innovation, through patent–policy synergies in Korea, is a

significant driver of sustainable growth. Similarly, Abid (2025c) showed that AI-driven innovation positively influences economic performance in East Asia, underscoring the potential of technological advances for sustainability.

For Turkey, the slow commercialization of innovations and limited R&D funding are major barriers to leveraging innovation for sustainable growth (World Bank, 2020).

2.3. Technical Assistance and Development

Technical assistance grants are vital for capacity building and skill enhancement in developing economies (Burnside & Dollar, 2000). Clemens et al. (2012) showed that well-targeted technical assistance programs can accelerate SEG by improving governance, infrastructure, and human capital. For instance, African nations receiving technical assistance in renewable energy projects experienced improved economic performance and reduced energy poverty (World Bank, 2018).

On the other hand, the impact of technical assistance is not always positive. Easterly (2003) argued that ineffective allocation and dependency on foreign aid could lead to a "dead aid" phenomenon, reducing long-term growth prospects. Mismanagement or corruption often dilutes the impact of such grants, particularly in countries with weak institutional frameworks (Moyo, 2009). In addition, Abid (2025d) demonstrated that economic and environmental factors together foster green growth in Saudi Arabia, highlighting the institutional and policy dimension as a vital complement to external assistance.

For Turkey, the success of technical assistance depends on integrating foreign expertise into national strategies effectively.

2.4. Fisheries Production and Resource Sustainability

The fisheries sector acts a dual role in contributing to economic growth and maintaining ecological balance. Sustainable fisheries can provide employment, food security, and export revenues, as demonstrated in studies of Southeast Asian economies (Allison & Ellis, 2001). Cochrane et al. (2009) emphasized the importance of sustainable fisheries management in preventing resource depletion and ensuring long-term economic benefits.

Conversely, overfishing and habitat degradation have negative consequences for SEG. Pauly et al. (2002) found that excessive reliance on fisheries production reduces biodiversity and undermines marine ecosystem services.

In Turkey, the overexploitation of marine resources has led to declining fisheries production, highlighting the need for sustainable management practices (FAO, 2020).

The literature provides an understanding of the impacts of renewable energy consumption, innovation, technical assistance grants, and fisheries production on SEG. Renewable energy and technical assistance are generally associated with positive outcomes, although their success depends on effective implementation and integration into broader development strategies. Innovation shows mixed results, with its positive impact contingent on the maturity of the innovation ecosystem and institutional support. Fisheries production, while economically significant, poses challenges when poorly managed, underscoring the importance of sustainability.

This study contributes to the literature by presenting an empirical analysis of these factors in the context of Turkey, offering insights into their short- and long-term effects on SEG.

3. METHODOLOGY
3.1. Econometric methodology

The study employs an Autoregressive Distributed Lag (ARDL) model (Pesaran et al., 2001), which is particularly suitable for small sample sizes, for analyzing relationships between variables with different integration orders (I(0) and I(1)), and for capturing both short- and long-run effects. Additionally, an Error Correction Model (ECM) is used to measure the speed of adjustment toward equilibrium, providing insights into short-term deviations and long-term stability.

The ARDL and ECM approaches were selected because they provide robust estimation in situations where variables are integrated at different levels, specifically I(0) and I(1), as confirmed by unit root testing. The ARDL model is also well-suited for small to moderate sample sizes, such as the 1960–2023 dataset used in this study, making it more reliable than alternative cointegration techniques like the Johansen or Phillips–Ouliaris tests. Furthermore, the ARDL model enables simultaneous estimation of both short-run dynamics and long-run equilibrium relationships, which is essential for analyzing sustainable economic growth in Turkey. The ECM was adopted as a complementary framework to capture short-term adjustments and deviations from equilibrium, allowing the measurement of the speed at which the economy returns to its long-run growth path after shocks. The models were implemented using Stata 17 software, which provides comprehensive econometric tools for time-series and cointegration analysis.

The following systematic steps were followed in processing the data:

- **Transformation and Stationarity Testing**: All variables were transformed to natural logarithms to linearize the relationships. The stationarity of the variables was then tested using the Dickey-Fuller test (Dickey & Fuller, 1979) to ensure that none of the variables were integrated of order higher than I(1).

- **Differencing**: Non-stationary variables were differenced, and the stationarity of the differenced data was rechecked using the Dickey-Fuller test.

- **Lag Selection:** For the ARDL model, the appropriate number of lags was selected based on the Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC). The lag order for both the dependent and independent variables was determined through optimal lag selection tests that minimize the information criteria.

- **Estimation of the ARDL Model**
  The ARDL model is specified as follows:

$$Y_t = \alpha + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \gamma_j X_{t-j} + \varepsilon_t \tag{1}$$

where Y_t is the dependent variable, sustainable economic growth at time t, X_t includes the independent variables, renewable energy consumption, innovation, technical assistance grants, and total fisheries production at time t. α is the intercept and β_i and γ_j are the coefficients of the lagged dependent and independent variables. p and q are the number of lags and ϵ_{it} is the error term.

- **Diagnostic Checks for the ARDL Model:** To ensure the vigor of the ARDL model estimates, the subsequent diagnostic checks are run:
  - Autocorrelation Test: The Breusch-Godfrey LM test (Breusch, 1978; Godfrey, 1978) is conducted to detect any serial correlation in the residuals.
  - Heteroscedasticity Test: The Breusch-Pagan-Godfrey test (Breusch & Pagan, 1979) is used to check for heteroscedasticity in the residuals.

- Test of Normality: The Jarque-Bera test (Jarque & Bera, 1987) assesses whether the residuals follow a normal distribution.

- **Bounds Test for Long-Run Relationship**

The presence of a long-run association between the variables is tested using the Bounds Test for cointegration. The calculated F-statistic is compared to the critical values (Pesaran et al., 2001). If the F-statistic exceeds the upper bound, a long-run relationship is confirmed.

- **Error Correction Model (ECM) Specification**

If cointegration is verified, the Error Correction Model (ECM) is estimated to analyze short-run dynamics and the speed of adjustment to long-run equilibrium:

$$Y_t = \mu + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \gamma_j X_{t-j} + \lambda ECT_{t-1} + \epsilon_t \qquad (2)$$

where ECM_{t-1} is the error correction term, representing the deviation from long-run equilibrium in the previous period, and is calculated as:

$$ECT_{t-1} = Y_{t-1} - \emptyset X_{t-1} \qquad (3)$$

where λ is the speed of adjustment parameter (Engle & Granger, 1987). A significantly negative λ indicates convergence to equilibrium. ϕ is the long-run relationship between Y and X and ϵ_t captures any short-term disturbances.

- **Post-Estimation Diagnostic Checks for ECM**

Further diagnostic tests are conducted to validate the ECM results:
- Autocorrelation Test: To confirm the absence of serial correlation in the ECM residuals.
- Heteroscedasticity Test: To ensure that the residuals have constant variance over time.
- Stability Tests: The CUSUM and CUSUMSQ tests (Jarque & Bera, 1987) were used to assess parameter stability over time. The results indicated that the model parameters were stable.

- **Predictive Analysis: Forecasting the Impact of Renewable Energy Development on Turkey's Sustainable Economic Growth**

This section utilizes the Autoregressive Distributed Lag (ARDL) model to forecast the potential impact of renewable energy development on Turkey's sustainable economic growth (SEG), with a focus on achieving Turkey's Net-Zero Emissions (NZE) goals by 2030 and 2050. The analysis aims to assess the long-term and short-term dynamics between renewable energy consumption (REN) and sustainable economic growth (SEG), considering the projected growth in renewable energy consumption and its potential effects on economic sustainability. The forecast is conducted for the years leading up to 2030 and 2050, based on the following assumptions:
- Scenario 1: A moderate increase in renewable energy consumption, achieving 2% of the 2030 Net-Zero Emissions goal. This scenario reflects a gradual transition toward renewable energy adoption in Turkey.
- Scenario 2: A rapid adoption of renewable energy technologies, reaching 10% of the 2030 NZE goal by 2030, and 100% by 2050.

The primary objective of this predictive analysis is to evaluate how the growth in renewable energy consumption will impact Turkey's SEG by 2030 and 2050. The results of this analysis will provide insights into the implications of meeting Turkey's NZE targets and offer a foundation for policy recommendations related to the energy transition and sustainable economic growth.

3.2 Data

The dataset comprises five key variables for Turkey for the period 1960–2023: Sustainable Economic Growth (SEG), Renewable Energy Consumption (REN), Innovation (INN), Technical Assistance Grants (TEC), and Total Fisheries Production (TFP).

It is important to note that this study does not decompose Turkey's GDP into all its sectoral components. Instead, fisheries production was chosen as a representative sectoral driver because of its unique role in the Blue Economy, its contribution to regional livelihoods and food security, and its sensitivity to sustainability challenges such as overfishing and climate change. Traditional sectors such as textiles and manufacturing, while central to Turkey's economy, have been widely analyzed in prior studies, whereas fisheries remain relatively underexplored in the context of sustainable growth. This focus allows the study to highlight a sector that is both economically significant and environmentally vulnerable, providing new insights into Turkey's sustainability trajectory.

The data description and measurement are presented in Table 1.

Table 1. Data description

Variable	Description	Measurement
Sustainable indicator		
SEG	Sustainable economic growth	GDP in constant US dollars (USD)
Energy indicator		
REN	Renewable energy consumption	Gigawatt hours (GWh); equivalent to 3.6×10^{12} joules per GWh
Green economy indicators		
INN	Innovation	Total number of patent applications recorded by non-residents and residents
TEC	Technical assistance grants	Current US dollars (USD)
Blue economy indicator		
TFP	Total fisheries production	Metric tons (t); equivalent to 1,000 kg per ton

SEG represents a nation's capacity to achieve consistent and inclusive GDP growth while maintaining environmental and social sustainability, measured in constant USD. REN refers to the consumption of energy derived from renewable sources, including solar, wind, hydro, and biomass, measured in GWh, equivalent to joules. INN captures the level of technological advancement and creative activity, as indicated by the total number of patent applications filed by both residents and non-residents. TEC represents financial support aimed at enhancing technical capacities, promoting development, and facilitating skill or technology transfer, measured in current USD. TFP reflects the total volume of fish and seafood harvested for economic and subsistence purposes, indicating the health and productivity of marine resources, measured in metric tons (t).

Table 2 presents the statistical summary of key economic and environmental indicators.

Table 2. Descriptive statistics

Variable	Obs.	Mean	Stand. Dev.	Min	Max
SEG	64	26.4100	0.8200	24.9600	27.8600
REN	32	2.7800	0.2600	2.4300	3.1900
INN	42	7.5600	0.8900	6.2400	9.0500
TEC	63	17.8500	1.5800	13.6500	20.2100
TFP	63	12.8400	0.7200	11.0100	13.6500

The summary statistics provide insights into Turkey's development from 1960 to 2023. Sustainable Economic Growth (SEG) exhibits consistent progress, with a mean of 26.41 and a low standard deviation of 0.82, reflecting steady GDP growth within a range of 24.96 to 27.86. Renewable Energy Consumption (REN) shows a gradual increase, with a mean of 2.78 and moderate variability (standard deviation of 0.26), ranging from 2.43 to 3.19, indicating Turkey's shift toward renewable energy. Innovation (INN), with a mean of 7.56 and a standard deviation of 0.89, reflects moderate growth in technological advancements, as patent applications range from 6.24 to 9.05. Technical Assistance Grants (TEC) have a mean of 17.85 and moderate fluctuations (standard deviation of 1.58), with values ranging from 13.65 to 20.21, highlighting varying levels of financial support for development projects. Lastly, Total Fisheries Production (TFP) remains relatively stable, with a mean of 12.84 and a low standard deviation of 0.72, ranging from 11.01 to 13.65, suggesting balanced fisheries output. These trends underscore Turkey's progress in economic growth, renewable energy adoption, innovation, and sustainable resource management.

The correlation analysis shows the relationships between SEG and its key independent variables (Table 3).

Table 3. Correlation matrix

Variable	SEG	REN	INN	TEC	TFP
SEG	1.0000	-0.9103	0.8429	0.5381	0.6651
REN	-0.9103	1.0000	-0.6893	-0.3907	-0.6354
INN	0.8429	-0.6893	1.0000	0.3619	0.5323
TEC	0.5381	-0.3907	0.3619	1.0000	0.4416
TFP	0.6651	-0.6354	0.5323	0.4416	1.0000

The correlation matrix shows that SEG is strongly negatively correlated with REN ($r = -0.910$), indicating that higher values of REN are associated with lower levels of SEG. In contrast, SEG has strong positive correlations with INN ($r = 0.843$) and TFP ($r = 0.665$), and a moderate positive correlation with TEC ($r = 0.538$), suggesting that increases in innovation, total factor productivity, and technological development are associated with higher SEG. Among the independent variables, REN is negatively correlated with INN ($r = -0.689$), TEC ($r = -0.391$), and TFP ($r = -0.635$), while INN shows moderate positive associations with TEC ($r = 0.362$) and TFP ($r = 0.532$). TEC and TFP are also moderately positively correlated ($r = 0.442$). Overall, these results indicate potential multicollinearity between some predictors, particularly between SEG and REN, but also reveal meaningful positive associations between SEG and other development-related variables.

To complement the correlation matrix, Figure 1 presents scatter plots illustrating the relationships between SEG and the independent variables. A clear negative association is observed between SEG and REN, whereas INN, TEC, and TFP exhibit positive relationships with SEG.
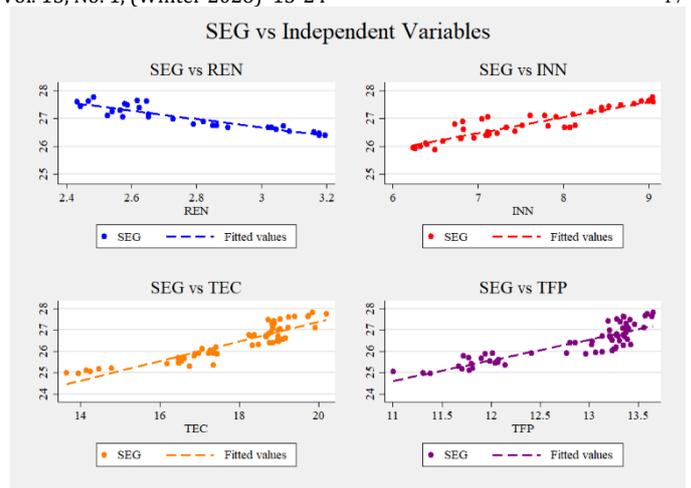

Figure 1. Scatter plots showing the relationship between sustainable economic growth (SEG) and the independent variables, with fitted regression lines included for visual interpretation.

Figure 2 shows the trends of Sustainable Economic Growth (SEG) alongside Renewable Energy Consumption (REN), Innovation (INN), Technical Assistance (TEC), and Total Fisheries Production (TFP) from 1960 to 2023.

Figure 2. Trends of Sustainable Economic Growth (SEG) alongside Renewable Energy Consumption (REN), Innovation (INN), Technical Assistance (TEC), and Total Fisheries Production (TFP) from 1960 to 2023.
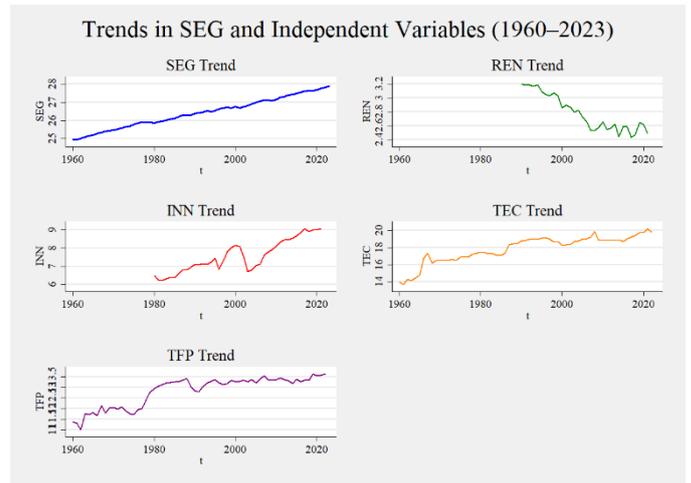
SEG exhibits a consistent upward trend, indicating steady economic growth over the years. In contrast, REN (green line) shows a downward trend from the late 1990s, suggesting challenges in expanding renewable energy consumption. Innovation displays a steady increase with some fluctuations, particularly after the 2000s, reflecting periods of growth in technological advancements, albeit with occasional slowdowns. TEC rises gradually, highlighting a steady inflow of technical assistance over the decades, contributing to development and capacity building. TFP also shows consistent growth, albeit slower, indicating that while the fisheries sector has expanded, its role in the economy remains relatively stable. Overall, the graph highlights a strong economic growth trajectory but reveals mixed trends in renewable energy and underscores the need for more consistent innovation and resource management.

To assess the stationarity of the variables, the Dickey-Fuller test was performed (Table 4).

Table 4. Dickey-Fuller test results

Variable	Statistic	p-value	Variable	Statistic	p-value
SEG	-0.2240	0.9356	dSEG	-7.8580***	0.0000
REN	-1.2830	0.6370	dREN	-6.3790***	0.0000
INN	-0.5140	0.8894	dINN	-5.0400***	0.0000
TEC	-2.2150	0.2007	dTEC	-7.7750***	0.0000
TFP	-1.7640	0.3986	dTFP	-9.3170***	0.0000
***, **, and * imply the significance at 1%, 5%, and 10% level, respectively					

The Dickey-Fuller test results indicate that the original variables are non-stationary, as the test statistics do not meet the critical values and their p-values are above the 0.05 significance threshold. However, the differenced variables have test statistics well below the critical values, and their p-values are all below 0.01, indicating that they have become stationary.

4. RESULTS

The ARDL model estimates providing insights into their dynamic effects on the dependent variable are given in Table 5.

Table 5. ARDL model estimates

Variable	Coef.	Stand. Error	Statistic	P-value	95% Confidence Interval
dSEG L1	-0.5648***	0.1622	-3.4800	0.0080	[-0.9388964, -0.1906371]
dREN					
Current	0.2282**	0.0940	2.4300	0.0410	[0.0113716, 0.4450404]
L1	0.2767**	0.0897	3.0800	0.0150	[0.0698418, 0.4835966]
L2	0.3085***	0.0733	4.2100	0.0030	[0.1396045, 0.4774521]
L3	0.3242***	0.0759	4.2700	0.0030	[0.149129, 0.4991875]
dINN					
Current	-0.0279	0.0220	-1.2700	0.2400	[-0.0787121, 0.0228123]
L1	-0.0303	0.0189	-1.6000	0.1480	[-0.0738581, 0.0132751]
L2	-0.0607**	0.0196	-3.1000	0.0150	[-0.1058909, -0.0155881]
L3	0.0084	0.0206	0.4100	0.6940	[-0.0391519, 0.0559808]
L4	-0.1372***	0.0271	-5.0600	0.0010	[-0.1997897, -0.074688]
dTEC					
Current	0.1006***	0.0246	4.1000	0.0030	[0.0439365, 0.1572034]
L1	0.0109	0.0211	0.5100	0.6210	[-0.0378104, 0.059552]
L2	-0.0960***	0.0228	-4.2000	0.0030	[-0.1486548, -0.0432912]
L3	0.0234	0.0201	1.1600	0.2790	[-0.0230172, 0.0697483]
L4	0.0465*	0.0245	1.9000	0.0950	[-0.010064, 0.103015]
dTFP					
Current	-0.2652***	0.0635	-4.1800	0.0030	[-0.4116942, -0.1187482]
L1	-0.3738***	0.0859	-4.3500	0.0020	[-0.5718141, -0.1757638]
L2	-0.1341**	0.0559	-2.4000	0.0430	[-0.263074, -0.0050326]
_cons	0.1216***	0.0128	9.4800	0.0000	[0.0920336, 0.1512085]
***, **, and * imply the significance at 1%, 5%, and 10% level, respectively					

The ARDL regression model results show a significant relationship between various independent variables and sustainable economic growth (dSEG) in Turkey. The model's overall significance is confirmed by an F-statistic of 5.27 (p-value = 0.0109), and the high R-squared value of 0.9222 indicates that the model explains over 92% of the variation in the dependent variable. Among the key variables, renewable energy consumption (dREN) has a consistently positive effect on economic growth. The current and lagged values of renewable energy consumption (dREN) are all statistically significant, with the effect becoming more pronounced over time. Technical assistance grants (dTEC) also show a positive relationship with economic growth in the short run, with the current value of technical assistance grants (dTEC) significantly influencing dSEG.

In contrast, innovation (dINN) and total fisheries production (dTFP) have a negative impact on economic growth. Innovation, particularly in the second and fourth lags, appears to hinder growth, while fisheries production (dTFP) consistently shows a negative effect, especially in the current and first lag periods. The model's constant term is also significant, suggesting that other unobserved factors influence economic growth in addition to the included variables. Overall, these findings highlight the complex dynamics between renewable energy, technical assistance, innovation, and fisheries production, and their varying impacts on sustainable economic growth in Turkey. To validate the reliability of the ARDL model estimates, diagnostic tests for autocorrelation, heteroscedasticity, and normality were conducted. The results are presented in Table 6.

Table 6. Results of Diagnostic tests for the ARDL model

Check for autocorrelation	Coefficient	P-value
Residuals L1	0.1779	0.3250
Check for heteroscedasticity	**Statistic**	**P-value**
White's Test	1.2300	0.5411
Cameron & Trivedi's IM-test	1.2300	0.5411
Skewness Test	2.1900	0.1393
Kurtosis Test	0.8400	0.3593
Breusch-Pagan / Cook-Weisberg Test	0.0500	0.8252
Test of normality	**Statistic**	**P-value**
Shapiro-Wilk test	0.9695	0.56822

The diagnostic results indicate that the estimated model meets the key assumptions of regression analysis. The autocorrelation test shows no evidence of serial correlation in the residuals, as the coefficient of 0.1779 has a non-significant p-value (0.3250). Heteroskedasticity checks, including White's test, Cameron & Trivedi's IM-test, and the Breusch-Pagan/Cook-Weisberg test, all produce high p-values (greater than 0.05), confirming that the residuals exhibit constant variance. Similarly, normality of residuals is supported by the Shapiro-Wilk test (p = 0.5682), alongside non-significant results for skewness and kurtosis tests, which together suggest that the distribution of residuals does not deviate significantly from normality. Overall, these findings imply that the model satisfies the assumptions of no autocorrelation, homoskedasticity, and normality, supporting the reliability of its estimates. We conduct the Bounds Test to examine the long-run relationship between the variables. The results of this test (Table 7) help determine whether a cointegration relationship exists among the variables in the model.

Table 7. Bounds Test for Long-Run Relationship

Hypothesis	F-statistic	P-value
H₀: Long-run relationship	6.4900***	0.0035
*** , ** , and * imply the significance at 1%, 5%, and 10% levels, respectively		

Since the p-value (0.0035) is less than 0.05, we reject the null hypothesis and decide that there is a significant long-run relationship between the variables in the ARDL model.

We estimate the Error Correction Model (ECM) to analyze the short-term dynamics and long-term relationships between the variables. The results of the ECM model estimates are presented in Table 8.

Table 8. ECM model estimates

Variable	Coefficient	Standard Error	t-statistic	P-value	95% Confidence Interval
dREN	-0.1925**	0.0969	-1.9900	0.0600	[-0.3941, 0.0090]
dINN	-0.0056	0.0288	-0.1900	0.8490	[-0.0655, 0.0544]
dTEC	0.0283	0.0266	1.0600	0.3000	[-0.0271, 0.0837]
dTFP	0.0747	0.0798	0.9400	0.3600	[-0.0914, 0.2407]
ecm	1.0863	0.7341	1.4800	0.1540	[-0.4404, 2.6130]
_cons	0.0409***	0.0087	4.6900	0.0000	[0.0228, 0.0590]
*** , ** , and * imply the significance at 1%, 5%, and 10% levels, respectively					

The ECM regression results suggest that, among the individual variables, dREN (a lagged variable) has a coefficient of -0.1925, with a p-value of 0.060, indicating a negative relationship with dSEG. In contrast, the variables dINN, dTEC, and dTFP do not exhibit significant effects, suggesting that they do not have a strong statistical relationship with dSEG. The ECM (Error Correction Model) coefficient is 1.0863, but it is not statistically significant (p-value = 0.154), implying that the short-term dynamics represented by the error correction term do not significantly influence dSEG in this model.

For the ECM model, diagnostic tests were performed to ensure the consistency of the results. Additionally, the CUSUM and CUSUMSQ tests were used to check for the stability of the model over time (Table 9).

Table 9. Diagnostic tests results for ECM model

Test for autocorrelation	Chi-squared	P-value
Durbin's test	0.7670	0.3810
Test for heteroscedasticity	**Chi-squared**	**P-value**
Breusch-Pagan / Cook-Weisberg	0.6200	0.4325

The diagnostic results for the ECM model indicate that the model satisfies key regression assumptions. The Durbin test for autocorrelation yields a Chi-squared value of 0.7670 with a p-value of 0.3810, suggesting no significant autocorrelation in the residuals. The Breusch-Pagan/Cook-Weisberg test for heteroskedasticity produces a Chi-squared value of 0.6200 with a p-value of 0.4325, indicating that the residuals exhibit constant variance. Overall, these results suggest that the ECM model is free from issues of autocorrelation and heteroskedasticity, supporting the validity and reliability of its estimates.

The CUSUM and CUSUMSQ tests were used to check for parameter instability over time, focusing on squared residuals (Figure 3).
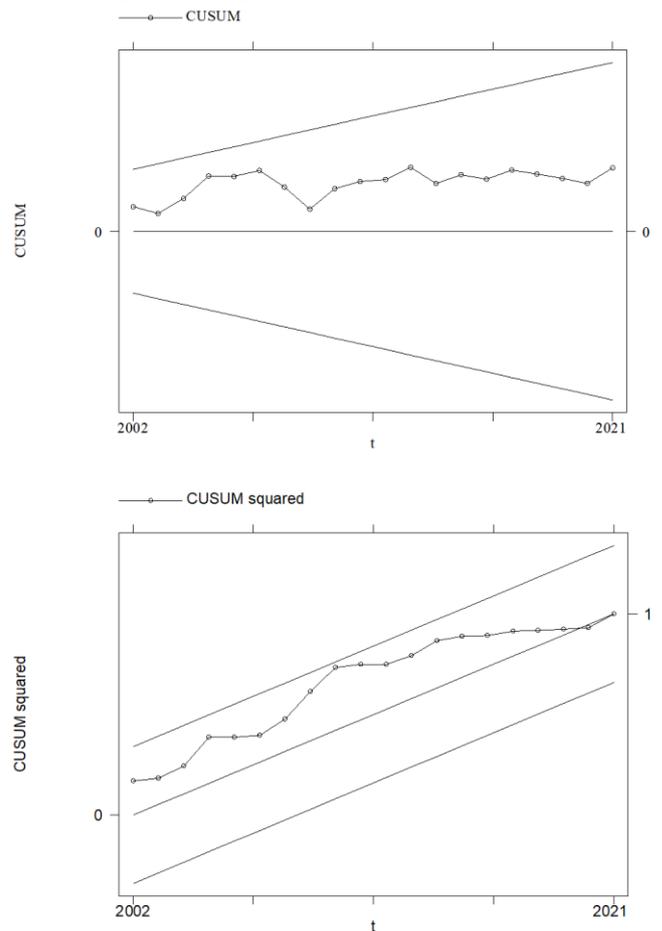

Figure 3. CUSUM and CUSUMSQ tests

Since the plots for the CUSUM and CUSUMSQ tests do not deviate from the threshold lines, it suggests that the model does not exhibit any signs of instability over time. This indicates that the parameters of the model remain stable, and there is no evidence of structural breaks or instability in the relationship between the variables. Therefore, we can conclude that the model is stable and reliable for further analysis.

4.1. Empirical Findings and Policy Implications

The results of the ARDL model and ECM analysis provide clear evidence of how renewable energy consumption, innovation, technical assistance, and fisheries production affect sustainable economic growth (SEG) in Turkey. The main findings can be summarized as follows: (i) renewable energy consistently exerts a strong and positive effect on SEG in both the short and long term, (ii) technical assistance contributes positively in the short run, though its long-term effects are limited, (iii) innovation has an unexpected negative effect, reflecting inefficiencies in Turkey's innovation system, and (iv) fisheries production shows a persistently negative impact, highlighting resource management challenges. These results underscore the importance of renewable energy and external support while also revealing structural weaknesses that hinder sustainable growth.

Renewable energy consumption (REN) exhibits a consistently positive and statistically significant relationship with sustainable economic growth (SEG), with both current and lagged effects indicating that the benefits of renewable energy investments accumulate over time. This suggests that policies fostering renewable energy development, particularly in the solar and wind sectors, can generate immediate as well as long-term economic advantages. Consequently, expanding

renewable energy infrastructure should be a core component of Turkey's sustainability strategy, reducing reliance on fossil fuel imports while supporting cleaner, more resilient, and inclusive economic growth.

Innovation (INN) unexpectedly shows a negative impact on sustainable economic growth (SEG), particularly in the medium term, as seen in the second and fourth lags. This indicates that inefficiencies in R&D investment, limited commercialization of research outcomes, and institutional constraints are hindering innovation's contribution to growth. To harness the full potential of innovation, Turkey should reform its innovation ecosystem by increasing R&D funding, enhancing institutional support, and implementing effective commercialization strategies that transform research into tangible economic value.

Technical assistance grants (TEC) have a positive and statistically significant impact on sustainable economic growth (SEG) in the short term, though their long-term effect appears limited, as reflected in the ECM results. This suggests that while external aid provides immediate economic benefits, it does not automatically translate into sustained growth. Therefore, technical assistance should be embedded within broader development strategies focused on long-term capacity building, ensuring that short-term support evolves into enduring structural and institutional improvements.

Fisheries production (TFP) consistently exerts a negative impact on sustainable economic growth (SEG), both in current and lagged periods, highlighting the adverse effects of overfishing, pollution, and climate-related stress on marine resources. These factors diminish the sector's economic contribution and threaten long-term sustainability. To mitigate these risks, Turkey should strengthen fisheries management by enforcing catch limits, combating illegal fishing, and investing in sustainable aquaculture practices, ensuring that ecological preservation supports rather than undermines broader economic growth.

In summary, the findings reveal a dual narrative: while renewable energy and technical assistance act as enablers of SEG, innovation inefficiencies and unsustainable fisheries practices act as constraints. The results demonstrate that achieving long-term sustainable growth in Turkey requires not only expanding clean energy but also addressing institutional weaknesses and ecological challenges

4.2. Predictive Analysis: Forecasting the Impact of Renewable Energy on Turkey's Sustainable Economic Growth

In this section, we use the ARDL model to forecast the potential impact of renewable energy development on Turkey's Sustainable Economic Growth (SEG), considering the country's Net-Zero Emissions (NZE) targets for 2030 and 2050.

Figure 4 illustrates the projected growth of Sustainable Economic Growth (SEG) in Turkey from 2025 to 2050 under three different scenarios: the actual SEG, the Scenario 1 forecast (assuming moderate adoption of renewable energy), and the Scenario 2 forecast (assuming rapid adoption of renewable energy).
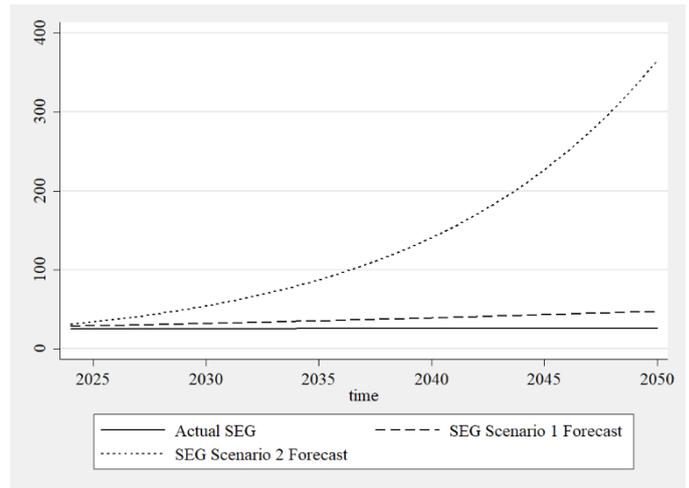

Figure 4. Forecasting the Impact of Renewable Energy on Turkey's Sustainable Economic Growth

The actual SEG shows a gradual and relatively moderate increase in Turkey's economic growth. This trajectory reflects the current pace of economic growth, assuming that renewable energy consumption continues to grow steadily without significant acceleration in adoption or major policy changes. The growth in SEG under this scenario remains stable but does not experience the sharp increases seen in the forecasted scenarios, suggesting that the current path may not be sufficient to meet future energy or economic sustainability goals.

Scenario 1 represents a more moderate increase in renewable energy consumption. Under this scenario, renewable energy adoption progresses gradually, with a slow but consistent rise in SEG over time. The growth rate accelerates after 2030, reflecting the expected impacts of incremental renewable energy policies and technologies. However, despite this acceleration, the growth in SEG under Scenario 1 remains considerably below that of Scenario 2, indicating a more conservative approach to energy transition and economic growth.

Scenario 2 assumes the rapid adoption of renewable energy technologies. This scenario projects a steep increase in SEG, particularly after 2030, as Turkey adopts renewable energy at a much faster rate. With a goal of achieving 10% of the 2030 Net-Zero Emissions (NZE) target by 2030 and 100% by 2050, this scenario reflects the most optimistic forecast for economic growth driven by renewable energy. It suggests that aggressive policy measures, rapid technological advancements, and substantial investments in renewable energy could lead to a significant boost in Turkey's economic growth.

In conclusion, the figure highlights a significant gap between the actual SEG and the forecasted scenarios, with Scenario 2 offering the highest potential for economic growth. While Scenario 1 provides a more conservative forecast, it still shows that a proactive approach to renewable energy adoption could drive steady economic improvements. Ultimately, the figure underscores the need for substantial investments and strong policies to increase renewable energy adoption in order to realize the full economic potential of a transition to Net-Zero Emissions by 2050.

5. DISCUSSION

This research delves into the dynamic relationships between sustainable economic growth (SEG) and key determinants, renewable energy consumption (REN), innovation (INN), technical assistance grants (TEC), and total fisheries production (TFP) in Turkey. Using an ARDL model, the

findings shed light on the varied effects of these factors on SEG, offering important implications for policy formulation.

5.1. Eenewable Energy Consumption and Sustainable Growth

The study finds that renewable energy consumption (REN) has a consistently positive and significant influence on SEG in Turkey, both in the short and long term. For example, the ARDL results show that the REN has a coefficient of 0.228 (p < 0.05) in the current period and increases to 0.324 (p < 0.01) at lag 3, confirming that the benefits of renewable energy investments accumulate over time. This outcome aligns with existing literature, which highlights the role of renewable energy in fostering sustainable development by reducing environmental degradation and energy dependency (Sadorsky, 2009; Apergis & Payne, 2010). Recent studies further support this positive relationship, emphasizing that renewable energy contributes directly to economic growth through job creation and indirectly by reducing the ecological footprint (IRENA, 2021; Pao & Fu, 2013). However, the significant initial investment required to develop renewable energy infrastructure remains a challenge (Shafiei & Salim, 2014). In Turkey's context, the findings suggest progress in leveraging its renewable energy potential, particularly in solar and wind power, but underline the need for stronger policy incentives and improved grid infrastructure to sustain this momentum (TÜİK, 2022).

Importantly, the positive role of renewable energy is not an isolated finding but must be understood in combination with the other variables examined in this study. The ARDL framework reveals that the strength and persistence of renewable energy's contribution are shaped by parallel dynamics in innovation, technical assistance, and resource management. This highlights the novelty of our approach: rather than reaffirming a single expected relationship, we demonstrate how renewable energy interacts with other drivers in ways that are often unexpected.

5.2. Innovation: A Complex Relationship with Growth

Contrary to the expectations, innovation (INN) demonstrates a negative impact on SEG in Turkey. The ARDL model reveals a coefficient of –0.061 (p < 0.05) at lag 2 and –0.137 (p < 0.01) at lag 4, indicating that innovation reduces SEG in the medium term. This finding deviates from the conventional view of innovation as a growth engine (Schumpeter, 1934; Freeman & Soete, 1997). One possible explanation is the inefficiency of Turkey's innovation ecosystem, where limited R&D funding, weak institutional frameworks, and inadequate commercialization of research outputs hinder the transformative potential of innovation (Acs et al., 2018; Fagerberg et al., 2009). Moreover, studies have highlighted that the benefits of innovation may be delayed or constrained in economies where industrial structures are not fully prepared to absorb advanced technologies (Zhao et al., 2024). In our model, this means that while renewable energy has strong potential to drive SEG, innovation-related inefficiencies may dilute or delay its benefits, creating a more complex picture than expected. This underscores the need for targeted policies to enhance institutional support, increase R&D investments, and promote innovation aligned with sustainability goals.

5.3. The Role of Technical Assistance Grants

Technical assistance grants (TEC) exhibit a positive influence on SEG in the short term, underscoring their role in enhancing technical capacity and facilitating technology transfer (Burnside & Dollar, 2000; Clemens et al., 2012). The ARDL estimates show that TEC has a coefficient of 0.101 (p < 0.01) in the current period, underscoring its immediate effect. However, the long-run effect weakens, as reflected in the ECM, where the coefficient of 0.028 (p = 0.30) is not statistically significant. In Turkey, such grants likely contribute to immediate economic benefits by funding critical development projects and skill-building initiatives. However, the lack of long-term significance, as evidenced by the ECM results, suggests that technical assistance alone is insufficient for sustained growth. Crucially, our results indicate that technical assistance may amplify the benefits of renewable energy by providing the knowledge, institutional support, and financial resources necessary to translate clean energy investments into measurable economic gains. This interaction reveals that external support mechanisms can act as short-run accelerators for energy-driven sustainability transitions. This aligns with Easterly's (2003) critique of aid dependency, highlighting the need for integrating external assistance into broader, well-coordinated development strategies to maximize its impact over time.

5.4. Fisheries Production and Its Negative Implications

Fisheries Production (TFP) demonstrates a consistently negative relationship with SEG in Turkey. The ARDL results show strong negative coefficients of –0.265 (p < 0.01) in the current period and –0.374 (p < 0.01) at lag 1, confirming that overexploitation of marine resources reduces economic growth. This align with concerns in the literature regarding resource overexploitation and environmental degradation (Pauly et al., 2002; Cochrane et al., 2009). Overfishing and inadequate management of marine resources are likely contributing to declining productivity in the fisheries sector, reducing its positive economic contribution. This finding echo global trends, where unsustainable fishing practices harm biodiversity and the economic stability of coastal communities (FAO, 2020). In the broader framework of this study, the negative contribution of fisheries production further underscores the importance of complementing renewable energy policies with sustainable resource management. Without such measures, the benefits of clean energy expansion risk being offset by ecological degradation in other sectors. To mitigate these effects, Turkey must adopt stricter fisheries management policies, such as implementing catch limits, reducing illegal fishing, and investing in sustainable aquaculture development (Allison & Ellis, 2001).

5.5. Predictive analysis

The predictive analysis compares Turkey's actual Sustainable Economic Growth (SEG) with two forecast scenarios based on different rates of renewable energy adoption. The actual SEG shows a moderate increase, reflecting current energy consumption trends, which may not be sufficient to meet Net-Zero Emissions (NZE) targets by 2030 and 2050.

Scenario 1, which assumes a moderate increase in renewable energy consumption, shows a gradual but steady rise in SEG, particularly after 2030. This scenario suggests that incremental renewable energy adoption can support long-term economic growth but may not meet the 2030 and 2050 NZE goals unless accompanied by stronger policies.

Scenario 2, assuming rapid adoption of renewable energy technologies, leads to a sharp increase in SEG, reflecting the transformative potential of aggressive renewable energy policies. This scenario aligns with global trends, where countries investing in renewable energy experience significant

economic growth alongside improved sustainability, as noted in studies by the IEA (2020) and Li and Shen (2019).

The stark contrast between Scenario 1 and Scenario 2 highlights the importance of aggressive policy measures, technological innovation, and investments in renewable energy to achieve Turkey's Net-Zero Emissions goals. Scenario 2's forecast suggests that a rapid energy transition is essential for aligning economic growth with sustainability objectives. Policy recommendations include subsidies, tax incentives, and international collaborations to accelerate renewable energy adoption.

5.6. Policy Implications

Taken together, the results reveal that the positive contribution of renewable energy to SEG is best understood as part of a broader system of interactions. Innovation inefficiencies weaken the absorptive capacity of the economy, technical assistance provides short-term boosts that can magnify energy-related gains, and unsustainable fisheries practices impose environmental costs that counteract growth. This comprehensive perspective demonstrates that Turkey's sustainable growth trajectory depends not only on expanding renewable energy but also on simultaneously addressing institutional, technological, and ecological challenges.

The findings of this research paper have significant policy suggestions for fostering sustainable economic growth (SEG) in Turkey. First, expanding investments in renewable energy is critical. Policies should prioritize enhancing incentives for renewable energy adoption, addressing grid infrastructure gaps, and encouraging private sector involvement to ensure long-term economic and environmental advances. Renewable energy sources like solar, wind, and hydropower have the dual advantage of reducing environmental degradation while fostering job creation and technological advancement, as highlighted by IRENA (2021). Second, strengthening Turkey's innovation ecosystem is imperative. Policymakers must focus on increasing R&D funding, building robust institutional frameworks, and promoting the commercialization of innovations to ensure that technological advancements translate into economic growth (Acs et al., 2018). The negative short-term impact of innovation observed in this study underscores the need for targeted reforms to improve the efficiency of the innovation system. Third, optimizing the utilization of technical assistance grants can further enhance SEG. Efforts should be directed toward integrating external assistance into comprehensive development strategies to avoid dependency and ensure sustainable impacts (Burnside & Dollar, 2000). Lastly, the consistently negative impact of fisheries production on SEG calls for the implementation of sustainable fisheries management policies. Stricter regulations, such as catch limits, combating illegal fishing, and promoting sustainable aquaculture practices, are essential to conserve marine resources and enhance their economic contribution (FAO, 2020). Together, these measures provide a roadmap for aligning Turkey's economic growth trajectory with its long-term sustainability objectives.

The findings of this study hold direct relevance for Turkey's ongoing policy initiatives. The positive long-term impact of renewable energy on sustainable economic growth (SEG) strongly supports Turkey's commitment to the 2053 Net-Zero Emissions Target and the Paris Agreement, reinforcing the importance of scaling up solar and wind investments under the National Energy and Climate Plan. Similarly, the short-term benefits of technical assistance highlight the role of external

funding and expertise—particularly from the European Union and international organizations—in strengthening Turkey's alignment with SDG 7 (Affordable and Clean Energy) and SDG 9 (Industry, Innovation, and Infrastructure). The negative contribution of innovation suggests that the National Technology Initiative should be restructured to focus not only on R&D spending but also on commercialization pathways, institutional reforms, and knowledge transfer mechanisms. Finally, the adverse effect of fisheries production underscores the urgency of integrating sustainable fisheries management into Turkey's Blue Growth Strategy and its commitments under SDG 14 (Life Below Water). Taken together, these results highlight that Turkey's path toward sustainable growth requires a balanced policy mix that links domestic strategies with international obligations, ensuring coherence between national development goals and global sustainability commitments.

Overall, the discussion underscores that the model used in this study provides a deeper and more nuanced understanding of sustainable growth in Turkey than previous research. By examining the joint and interactive effects of renewable energy, innovation, technical assistance, and fisheries production, the analysis moves beyond single-variable explanations and highlights the complexity of achieving sustainable economic development in an emerging economy context.

6. CONCLUSION

This study examines the dynamic relationships between sustainable economic growth (SEG) and key drivers, namely renewable energy consumption (REN), innovation (INN), technical assistance grants (TEC), and total fisheries production (TFP), in Turkey over the period from 1960 to 3023. By employing an ARDL model and an Error Correction Model (ECM), the analysis provides important insights into both the short- and long-term determinants of SEG.

The findings reveal that renewable energy consumption positively and significantly contributes to sustainable economic growth, underscoring the vital role of clean energy in fostering long-term economic sustainability. The positive effects of renewable energy intensify over time, likely driven by advancements in technology and increasing resource efficiency. This highlights the importance of continued investment and policy support for renewable energy development to achieve sustainable economic outcomes.

Technical assistance grants also demonstrate a positive and significant impact on SEG in the short run, indicating that financial and capacity-building programs can catalyze economic growth. However, the limited significance in the long term suggests that these grants must be accompanied by complementary measures to ensure lasting development benefits. This finding points to the need for well-designed, outcome-oriented technical assistance programs that align with broader economic goals.

Conversely, innovation exhibits a negative relationship with SEG in the medium term, with significant lags observed in its impact. This counterintuitive result may stem from inefficiencies in translating technological advancements into tangible economic value or from the disruptive nature of innovation during periods of adjustment. Similarly, total fisheries production consistently shows a negative effect on SEG, likely reflecting challenges related to overfishing, resource depletion, and unsustainable marine practices. These findings underscore the need for improved resource management and policies to mitigate negative environmental and economic consequences.

The Error Correction Model results indicate weak short-term dynamics, as reflected by the non-significant ECM coefficient. This suggests structural rigidities in the economy, where short-term adjustments do not strongly influence SEG. The findings emphasize the need for long-term strategies to address these challenges and foster sustainable growth.

Turkey should prioritize efficient innovation policies and sustainable fisheries management to mitigate negative effects. First, promoting renewable energy should remain a top priority for policymakers, as it has a consistently positive and growing impact on sustainable economic growth. Investments in renewable energy infrastructure, coupled with supportive policies, are essential to maximize its benefits. Second, enhancing the effectiveness of technical assistance programs is crucial. Policymakers should focus on designing grants that facilitate skill and technology transfer, ensuring that short-term gains translate into long-term sustainable development.

Moreover, addressing the challenges in innovation is critical. Governments and stakeholders must focus on improving the efficiency of innovation systems and aligning technological advancements with broader economic and societal objectives. Finally, the negative impact of fisheries production on SEG underscores the urgency of implementing sustainable fisheries management practices. Policymakers must adopt measures to combat overfishing, promote ecosystem conservation, and support sustainable resource use to mitigate adverse effects.

This study highlights the complex relationship between environmental, technological, and economic factors in shaping sustainable economic growth in Turkey. While renewable energy and technical assistance emerge as critical enablers, challenges in innovation and resource management must be addressed to unlock their full potential.

Predictive analysis conducted as part of this study demonstrates that Turkey's future economic growth is highly dependent on the acceleration of renewable energy adoption. Scenario 2, which assumes a rapid adoption of renewable energy, indicates that aggressive policies in renewable energy can lead to a sharp rise in SEG, potentially aligning economic growth with Net-Zero Emissions targets. This predictive analysis suggests that Turkey must focus on scaling up renewable energy rapidly and proactively to ensure that long-term economic sustainability and climate goals are met.

Future research should expand the scope of analysis by incorporating additional variables, sectoral perspectives, and nonlinear dynamics to better understand these relationships and support evidence-based policymaking. This study contributes to the growing empirical research exploring the interplay between environmental, economic, and institutional factors in shaping sustainable development. However, the findings are specific to Turkey, and their generalizability to other countries may require further investigation. Future studies could explore nonlinear relationships or examine the effects of additional variables, such as trade openness and population growth, to gain deeper insights into the drivers of SEG.

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