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EXPLORING THE NEXUS OF COAL CONSUMPTION, ECONOMIC GROWTH, ENERGY PRICES AND TECHNOLOGICAL INNOVATION IN TURKEY

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🆔 Feride OZTURK[1]
🆔 Suat OZTURK[2+]

[1]Department of International Trade and Business, Zonguldak Bülent Ecevit University, Zonguldak, Turkey
Email: feride.ozturk@beun.edu.tr
[2]DERAC, Zonguldak Bülent Ecevit University, Zonguldak, Turkey
Email: suatozturk@beun.edu.tr

(+ Corresponding author)

ABSTRACT

This study mainly attempts to cast light into the dynamic relationships between coal consumption, economic growth, energy price and technological innovation in Turkey over the period of 1980-2015. Based on the results drawing from an autoregressive distributed lag (ARDL) model, coal consumption, economic growth, energy price and technological innovation are cointegrated. Specifically, the empirical results indicate that economic growth positively affects coal consumption, whereas technological innovation negatively affects it over a long-run. Regarding short-run dynamic relationships, economic growth and technological innovation have a positive impact on coal consumption. The results from the autoregressive integrated moving average (ARIMA) model suggest that an annual average growth rate of coal consumption will be 2.02% between 2016 and 2025. Regarding policy implications, the results of this study suggest that policy makers should allocate more resources to research and development on energy technologies to improve energy efficiency in Turkey.

Contribution/ Originality: This study is one of the few studies which have investigated coal consumption-growth nexus in a multivariate setting. Considering that technological innovation has not been incorporated by previous coal consumption-growth studies, this study contributes to the existing literature by incorporating technological innovation in the analysis.

1. INTRODUCTION

The World Energy Council reports that the world consumed over 7,800 million tons of coal in 2016 which was used by various sectors ranging from power generation to cement manufacturing. The crucial role of coal in power generation seems to continue since it is the most abundant of fossil fuels in the world. Coal is currently utilized to generate 40% of the world's electricity and it is forecasted that it will continue to supply a strategic share over the next three decades. The largest coal producing countries are China, the USA, India, Indonesia, Australia and South Africa (World Energy Council, 2016). Among other countries, Turkey is evaluated as being at medium levels in terms of the reserves and production amounts of coal and lignite in the world. Nearly, 3.2% (1.3 billion tons of coal and 17.3 billion tons of lignite) of the total world reserves of coal and lignite are in Turkey (Republic of Turkey Ministry of Energy and Natural Resources, 2018). European Association for Coal and Lignite reports that in 2015,

27.8% of Turkey's electricity production was generated from hard coal (15.2%) and lignite (12.5%). Of the remainder, 38.6% was generated by natural gas, 25.8% by hydropower, 0.8% by oil and the remaining 7.0% from waste, wind, geothermal and other renewable energy sources. Thus coal and lignite have considerable share in electricity generation in Turkey.

Turkey, through its 'National Energy and Mine Policy' which is passed on by the Ministry of Energy and Natural Resources, aims to meet increasing energy demand with domestic resources instead of using natural gas which is an imported resource to generate electricity. This policy continuous to keep the coal and lignite as vital energy sources for Turkey. Turkey's energy demand expected to increase due to the growing economy and the demographic impact of a young population. Supporting these facts, Ozturk and Ozturk (2018) forecast that in the next 25 years, total coal consumption will increase at an annual average rate of 4.87%.

Over the past three decades, numerous empirical studies have been done on the causal relationship between energy consumption and economic growth. However, relatively smaller number of empirical studies has been carried out on the causal relationship between coal consumption and economic growth. Empirical findings on the causal relationship between coal consumption and economic growth vary depending on the country or empirical methodology used. Therefore, no consensus has yet been reached. For instance, Yoo (2006) suggests bidirectional causality between coal consumption and growth in Korea; in contrast, Wolde-Rufael (2010) finds unidirectional causality from growth to coal consumption. Wolde-Rufael (2010) reports unidirectional causality from growth to coal consumption in India, while Apergis and Payne (2010a) suggest bidirectional causality, and Li and Li (2011) report a unidirectional causality from coal consumption to growth. For South Africa, Wolde-Rufael (2010) finds unidirectional causality from coal consumption to growth, while (Apergis and Payne, 2010a) suggest bidirectional causality. On the other hand, Odhiambo (2016) reports unidirectional causality from growth to coal consumption in South Africa. Kim and Yoo (2016) find bidirectional causality running from coal consumption to economic growth in Indonesia whereas (Irwandi, 2018) reports no causality. Zhang and Broadstock (2016) find bidirectional causality between coal consumption and growth in China; in contrast, Tian and Cui (2013) find co causality. In the case of Turkey, Ocal et al. (2013) and Bildirici and Bakirtas (2014) provide no causality between coal consumption and growth whereas (Apergis and Payne, 2010b) reveal bidirectional causality.

Payne (2010) and Ozturk (2010) conclude that the mixed empirical results might be due to omitted variable(s) and methodological drawbacks. They suggest that the use of new methodological approaches and more explanatory variables will lead to more consistent and reliable results in energy consumption-growth studies. Motivated by these suggestions, the goal of this study is to investigate coal consumption-growth nexus in a multivariate setting by including energy price and technological innovation in Turkey. Considering that technological innovation has not been incorporated by previous coal consumption-growth studies, this study contributes to the existing literature by incorporating technological innovation in the analysis.

Technological innovation could improve energy efficiency which in turn leads to a reduction in coal consumption. Wicks and Keay (2005) suggest that the introduction of clean coal-based technology leads to higher efficiency and thus reduces both costs and emissions. Energy prices are also important for coal consumption since the variations in energy prices affect coal consumption.

This present study attempts to investigate both short-run and long-run dynamic relationships between coal consumption, economic growth, energy price and technological innovation in Turkey from 1980 to 2015 applying an autoregressive distributed lag (ARDL) approach. It also forecasts coal consumption for the next decade by an autoregressive integrated moving average (ARIMA) model to provide a reference to policy makers in developing energy strategies and policies.

Rest of the study is organized as follows. Section 2 describes data sources and empirical methodology used. Section 3 provides empirical results of the research and final section presents the concluding remarks.

2. DATA SOURCES AND EMPIRICAL METHODOLOGY USED

Following the model specification from Tang and Tan (2013) the standard log linear specification of long-run relationship between the coal consumption, economic growth, energy price and technological innovation is expressed as:

$$\ln CC_t = \beta_0 + \beta_1 \ln GDP_t + \beta_2 \ln EP_t + \beta_3 \ln TI + \varepsilon_t \qquad (1)$$

where ln denotes the natural logarithm, CC_t is per capita coal and lignite consumption (kg of oil equivalent), GDP_t is per capita real gross domestic product (constant 2010 US\$), EP_t is the energy price index, and TI_t is the number of patent applications by a country. The error term ε_t is the white noise error term as usual. Two changes are made to the original model of Tang and Tan (2013). This paper uses Fuel and Materials of Energy Whole Sale Price Index instead of the indirect measure of energy prices, consumer price index (CPI) and replaces the total electricity consumption variable by the coal consumption. The expected signs for the parameters of real GDP, energy price and technological innovation are $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 < 0$, respectively.

The research time span of this study is from 1980 to 2015. This study uses secondary data of per capita real GDP, patent applications extracted from the World Bank's World Development Indicators (WDIs). Total coal and lignite consumption data is obtained from Turkish General Directorate of Energy Affairs' website and divided by population to generate per capita coal consumption. Fuel and Materials of Energy Whole Sale Price Index is from the Central Bank of Republic of Turkey. All variables are in natural logarithms to reduce heteroscedasticity and to obtain the growth rate of the relevant variables by their first-differenced logarithms.

In the literature several variables are used as the proxy of technological innovation including foreign direct investment, patent applications, trademark applications and total factor productivity. This paper uses the number of patent applications as the proxy of technological innovation following the suggestions of several empirical works that have used the number of patent applications as a measure of technological innovation (Grupp, 1996; Andersen, 1999; Hall *et al.*, 2001; Schmoch, 2007; Lee and Lee, 2013; Tang and Tan, 2013). Real GDP per capita is used as a proxy for the economic growth.

The relationship between coal consumption, economic growth, energy price and technological innovation is tested in two stages. In the first stage, the long-run relationships among the variables are tested by applying the ARDL bounds testing approach to cointegration. The second stage involves estimating short-run and long-run models to determine associated coefficients.

2.1. ARDL Cointegration Analysis

The first stage involves testing for the existence of a long-run relationship between coal consumption, economic growth, energy price and technological innovation carrying out the ARDL bounds testing approach to cointegration. ARDL bounds testing approach is a cointegration method introduced by Pesaran and Shin (1999) and developed by Pesaran *et al.* (2001) to test presence of the long-run relationship between the variables. This cointegration approach has several advantages over the classical cointegration approaches such as Engle and Granger (1987), Johansen (1988) and Johansen and Juselius (1990) methods: (i) ARDL approach can be applied even if variables are integrated of different orders and thus no need for a unit root pre-testing, (ii) it is statistically more significant approach to determine the cointegration relation in small samples, (iii) and finally, it employs only a single reduced form equation and hence loss of less degree of freedom (Pesaran and Shin, 1999; Pesaran *et al.*, 2001; Narayan, 2005). Nonetheless, the underlying assumption of the ARDL bounds testing requires that if the order of any of the variables is higher than I(I), then the critical bounds provided by Pesaran *et al.* (2001) and Narayan (2005) are not valid. Therefore, before applying ARDL bounds testing approach to cointegration, stationary status of all variables are tested to determine their order of integration. In order to examine the order of integration Augmented Dickey-Fuller (ADF) and Philips-Peron (PP) unit root tests are employed both in levels and first differences of the variables. Pesaran and Shin (1999) point out, structural change and unit roots are closely related

and hence, conventional unit root tests might be biased toward a false unit root null when the data are trend stationary with a structural break. To overcome this problem, ADF unit root tests with breakpoint are also conducted.

As a first stage, the ARDL model for the log-linear functional specification of long-run is expressed as:

$$\Delta \ln CC_t = \alpha_1 + \sum_{i=1}^{a1} \phi_{1i} \Delta \ln CC_{t-i} + \sum_{p=0}^{b1} \varsigma_{1p} \Delta \ln GDP_{t-p} + \sum_{q=0}^{c1} \psi_{1q} \Delta \ln EP_{t-q} + \sum_{s=0}^{d1} \lambda_{1s} \Delta \ln TI_{t-s}$$
$$+ \sigma_1 \ln CC_{t-1} + \sigma_2 \ln GDP_{t-1} + \sigma_3 \ln EP_{t-1} + \sigma_4 \ln TI_{t-1} + u_{1t} \tag{2}$$

where the first difference operator and parameters being estimated are Δ and α, ϕ, ς, ψ, λ, σ 's; the optimal lag lengths determined by based on Akaike Information Criterion (AIC) and the white noise error terms are a, b, c, d and u_{1t}, respectively. The joint F-statistic (Wald statistic) is used for the bounds testing procedure to test the null hypothesis of no cointegration, H_0: $\sigma_1 = \sigma_2 = \sigma_3 = \sigma_4 = 0$, against the alternative hypothesis H_1: $\sigma_1 = \sigma_2 = \sigma_3 = \sigma_4 \neq 0$. Then, the lower and upper bounds critical values are generated to compare with the joint F-statistic. If the upper critical bound is smaller than the calculated F-statistics, the null is rejected, indicating cointegration. If the lower critical bound is higher than the calculated F-statistics, the hull hypothesis of no cointegration cannot be rejected. Finally, if it lies between the bounds, the result is inconclusive. The several diagnostic tests are applied to check the robustness of the ARDL model. These are the Jarque-Bera to check for normality of error terms, Breusch-Godfrey Serial Correlation LM for serial correlation, Breusch-Pagan-Godfrey for heteroskedasticity and Ramsey RESET tests for model specification.

In the second stage, if there is a cointegrating relationship between the variables of interest, then the long-run and short run coefficients are estimated by the following long-run and short-run models that are presented in Equations (3) and (4):

$$\ln CC_t = \alpha_2 + \sum_{i=1}^{a2} \phi_{2i} \ln CC_{t-i} + \sum_{p=0}^{b2} \varsigma_{2p} \ln GDP_{t-p} + \sum_{q=0}^{c2} \psi_{2q} \ln EP_{t-q} + \sum_{s=0}^{d2} \lambda_{2s} \ln TI_{t-s} + u_{2t} \tag{3}$$

$$\Delta \ln CC_t = \alpha_3 + \sum_{i=1}^{a3} \phi_{3i} \Delta \ln CC_{t-i} + \sum_{p=0}^{b3} \varsigma_{3p} \Delta \ln GDP_{t-p} + \sum_{q=0}^{c3} \psi_{3q} \Delta \ln EP_{t-q} + \sum_{s=0}^{d3} \lambda_{3s} \Delta \ln TI_{t-s} + \mu_1 ECT_{t-1} + u_{3t} \tag{4}$$

where μ is the coefficient of error correction term (ECT). ECT shows how quickly variables converge to equilibrium and it should have a statistically significant coefficient with a negative sign.

2.2. Forecasting Coal Consumption

Forecasting energy consumption has a crucial role in energy planning for both policy makers and related organizations in any country. In this study, an ARIMA model is used to predict coal consumption of Turkey for the period of 2016-2025. ARIMA models were introduced by Box and Jenkins (1970). ARIMA depends on autocorrelation patterns in the series because it uses the information in the series itself to make forecast without involving independent variables (Box and Jenkins, 1976). ARIMA (p, d, q) model has three parameters: (i) the order of autoregressive process (AR); (ii) the order of difference to make non-stationary series stationary (I); and (iii) the order of moving average process (MA), represented respectively by "p", "d" and "q".

The univariate ARIMA model is estimated in the following form:

$$Y_t - Y_{t-1} = \mu + \alpha_1 Y_{t-1} + \ldots + \alpha_p Y_{t-p} - \theta_1 e_{t-1} - \ldots - \theta_q e_{t-q} \tag{5}$$

where, $Y_t - Y_{t-1}$ is the first difference of coal consumption, α and θ are unknown parameters and e are independent identically distributed error terms with zero mean. The order of the model parameters and the best fitted ARIMA model is determined based on AIC.

3. RESULTS

3.1. Unit roots and ARDL tests

ADF and PP unit root tests are the first step to confirm the stationary and the degree of integration of each variable. These tests are used in this study to ensure that none of the variables are I(2) since the critical bounds suggested by Pesaran *et al.* (2001) are not valid if any of the variables is I(2). The results for the ADF and PP unit root tests for coal consumption (lnCC), economic growth (lnGDP), energy price (lnEP), and technological innovation (lnTI) are reported in Table 1. Both tests are conducted including constant and constant and linear trend. The results have confirmed that variables are integrated at I(0) or I(1). According to ADF test results, energy price and technological innovation series are I(1). However, coal consumption and economic growth variables with a constant and a linear trend are stationary at levels. These results are also confirmed by PP unit root test results.

Table-1. Unit root testing.

Variables		ADF		PP	
		Level	First Difference	Level	First Difference
lnCC	wc	-2.245	-8.939*	1.115	-9.098*
	wct	-3.720**	-9.032*	-3.720**	-9.744*
lnGDP	wc	-0.124	-6.412*	-0.115	-6.724*
	wct	-3.628**	-6.339*	-3.628**	-6.612*
lnEP	wc	-2.170	-7.160*	-2.026	-8.324*
	wct	-2.863	-7.044*	-2.777	-8.185*
lnTI	wc	-0.668	-4.680*	-0.668	-4.696*
	wct	-2.928	-4.634*	-2.333	-4.650*

Notes: * and ** indicate significance at 1% and 5%, respectively. wc and wct are the test statistics for a unit root with a constant and with constant and trend. The lag lengths are selected based on Schwarz Information Criterion (SIC) for ADF while the bandwith is selected using the Newey-West Bartlett kernel for PP test.

ADF unit root tests with breakpoint are also conducted. The results of breakpoint unit root tests are reported in Table 2. The results indicate that economic growth is I(0) with a constant and a linear trend, while energy price is I(0) with a constant at levels. The results of unit root tests have confirmed that variables are stationary at both levels and the first differences. Given that the none of the variables is integrated of an order higher than the I(1), the ARDL bounds testing approach to cointegration is applied in this study. The calculated F-statistic for the bounds testing approach, together with critical values for T=36 and associated diagnostic test results are reported in Table 3.

Table-2. Breakpoint unit root test.

Variables		ADF	Time Break		Time Break
		Level		First Difference	
lnCC	wc	-3.607	1995	-9.360*	1994
	wct	-4.164	2012	-9.903*	1994
lnGDP	wc	-1.617	2002	-6.881*	2009
	wct	-4.850**	2001	-6.826*	2009
lnEP	wc	-4.199**	2001	-7.488*	1988
	wct	-4.390	1987	-7.318*	1988
lnTI	wc	-2.238	1997	-6.444*	2003
	wct	-4.487	1999	-6.111*	2003

Notes: * and ** represent significance at 1% and 10 % level of significance. The lag lengths are selected based on SIC.

The calculated F-statistic for the bounds test (4.477) of ARDL (1, 0, 0, 4) model is greater than the 5% upper bounds critical value, (4.35). Therefore, coal consumption, economic growth, energy price and technological innovation are cointegrated in Turkey, indicating that there is a long-run relationship between these variables. In terms of diagnostic tests, ARDL (1, 0, 0, 4) model also passes all the diagnostic tests against normality of errors

(Jarque-Bera test), serial correlation (Breusch-Godfrey test), and heteroscedasticity (Breusch-Pagan-Godfrey test). The Ramsey RESET test suggests that the model is well specified.

Table-3. Bounds F-tests for cointegration and associated diagnostic tests for ARDL (1, 0, 0, 4) model.

Critical lover I(0) and upper value bounds I(I)								
			5%		2.5%		1%	
	F-Statistic	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	
								Decision
F_{lnCC}(lnCC/lnGDP, lnEP, lnTI)	4.477*	3.23	4.35	3.69	4.89	4.29	5.61	Cointegration
Diognastic tests								
Jarque-Bera	1.033 (0.596)							
Breusch-Godfrey	0.695 (0.602)							
Breusch-Pagan-Godfrey	1.798 (0.121)							
Ramsey RESET Test	2.747 (0.109)							

Notes: * indicates significance at 5% level. Diagnostic tests are presented as F-stat (p-value).

The next step of the analysis consists of estimating the long-run and short-run coefficients associated with the ARDL (1, 0, 0, 4) model by equations (3) and (4). Estimated long-run and short-run coefficients of the model and associated standard errors, T-statistics, and probabilities are presented in Table 4. Starting with the long-run coefficients, the results indicate that the economic growth has significant effect on coal consumption in the long-run with an estimated long-run elasticity of 1.436. However, technological innovation has a negative impact on coal consumption with estimated long-run elasticity of -0.349. This result indicates that an increase in technological innovation has an important role in decreasing coal consumption, and it might lead an increase in renewable energy consumption in Turkey. Regarding energy prices, associated coefficient is negative and insignificant in the long-run. The share of coal consumption in total energy consumption is about 11% during the study period and this might help to explain the unusual energy price- coal demand association in Turkey.

The results of the short-run dynamic coefficients associated with the long-run relationship are similar for the economic growth and energy price. In the short-run, however, technological innovation has positive and significant effect on coal consumption associated with estimated short-run elasticity of 0.185. The estimated coefficient of lagged ECT_{t-1} (-0.794) is negative and statically significant at 1% confidence level, confirming the established long-run relationship between the variables. Accordingly, any short-run deviations in coal consumption are corrected by 79.4% for each year towards the long-run equilibrium.

Table-4. Estimated long-run and short-run coefficients applying the ARDL (1, 0, 0, 4) model.

F_{lncc} (lnCC/ lnGDP, lnEP, lnTI)				
Long-run coefficients	**Coefficient**	**Standard Error**	**T-Statistic**	**Probability**
lnGDP	1.436	0.304	4.719*	0.000
lnEP	-0.009	0.146	-0.064	0.948
lnTI	-0.349	0.116	-2.990*	0.005
Short-run coefficients	**Coefficient**	**Standard Error**	**T-Statistic**	**Probability**
ΔlnGDP	1.141	0.280	4.0654*	0.000
ΔlnEP	-0.007	0.116	-0.064	0.948
ΔlnTI	0.185	0.093	1.967**	0.059
ECT_{t-1}	-0.794	0.151	-5.262*	0.000

Notes: * and ** indicate significance at 1% and 5% levels, respectively.
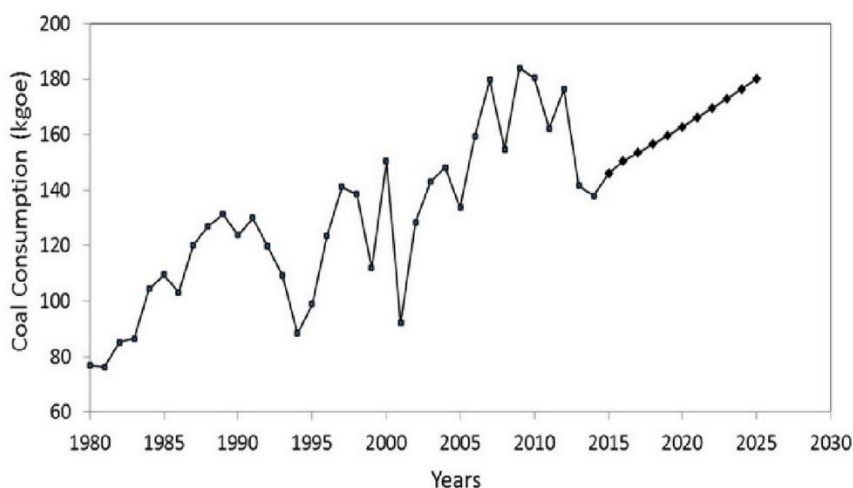
3.2. Forecasting Coal Consumption

The Box-Jenkins ARIMA model is used to forecast per capita coal consumption for Turkey for the next decade. Table 5 shows that the ARIMA (0, 1, 0) model gives the smallest AIC for coal consumption. Regarding forecasted coal consumption values, Figure 1 and Table 6 indicate that the coal consumption will continue to increase in the next decade. An annual average growth rate of coal consumption is expected to be 2.02% between 2016 and 2025.

The forecast results also indicate that in 2025, coal consumption will be 19.79% (180.13 kgoe) higher than its value in 2015 (146 kgoe).

Table-5. The smallest AIC for coal consumption.

Dependent Variable	ARIMA (p, d, q)	AIC
CC	ARIMA (0, 1, 0)	-0.849

Fig-1. Forecasted and actual values of coal consumption (kgoe)

Table-6. Forecasted coal consumption (kgoe).

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CC	150.36	153.41	156.52	159.69	162.93	166.23	169.60	173.04	176.55	180.13
Average Growth Rate of CC (%)	2.02									

4. CONCLUDING REMARKS

This study attempts to examine the coal consumption-growth nexus in Turkey using annual data from 1980 to 2015. Apart from the previous studies on this matter, this study contributes to the existing literature by including technological innovation in coal consumption-growth relationship in order to enhance the reliability of empirical estimates. In this study, the ARDL approach is employed to assess the long-run and short-run relationships between coal consumption, economic growth, energy price and technological innovation. Moreover, the Box-Jenkins ARIMA model is utilized to predict per capita coal consumption of Turkey for the next decade.

The ARDL cointegration test results have confirmed the cointegration between coal consumption, energy price, economic growth and technological innovation in Turkey. The estimated results reveal that economic growth has a positive impact on coal consumption while technological innovation has a negative impact on it in the long-run. In the short-run, both economic growth and technological innovation positively influence coal consumption. On the other hand, energy price has negative but insignificant effect on coal consumption both in the long and sort runs. The results from coal consumption forecast indicate that in 2025 per capita coal consumption will be 19.79% higher than its value in 2015. Moreover, the average growth rate of the coal consumption is expected to be 2.02% for the 2016-2025 period.

Turkey's energy demand is expected to increase in the near future due to both its growing economy and population. Foreseeing these facts, Turkey, through its Vision 2023 strategy, plans to increase its energy production by constructing new lignite-fired power plants and increasing the shares of wind and geothermal power. Based on the above empirical results, two important policies might be followed in Turkey. First, an increase in economic growth leads more coal consumption and hence, conversation policies should be applied to reduce inefficiencies in coal consumption. Considering adverse effects of coal consumption on environment, increasing the

share of renewable energy in total energy consumption is suggested. Second, the negative impact of technological innovation on coal consumption indicates that technological advancements might enhance efficiency in utilization of coal in the long-run as the traditional theory of sustainable development suggests. Therefore, policy makers should allocate more resources to research and development on energy technologies to improve energy efficiency.

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