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Analysis of the Relationship Between Green Innovation and Renewable Energy: Empirical Evidence From Brics-T Countries

Yeşil İnovasyon ile Yenilenebilir Enerji İlişkisinin Analizi: Brics-T Ülkelerinden Ampirik Kanıtlar

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ABSTRACT

Renewable energy sources precede non-renewable energy sources because their detrimental effects on environmental quality are much less. On the other hand, the transition process from fossil fuel use to renewable energy requires some infrastructure investments and innovation activities including R&D expenditures and technological innovations. In this process, in which environmental sustainability is determined as the goal, the concept of green innovation is gaining importance in terms of enabling national economies to achieve environmental problems and sustainable growth. The aim of this study is to examine the effect of green innovation on renewable energy consumption in BRICS-T countries covering Brazil, Russia, India, China, South Africa and Turkey, with annual data for the period 1990-2018. In the study, in which tests with structural breaks were applied, the existence of a long-term relationship between green innovation and renewable energy consumption was determined.

Keywords: Renewable Energy, Innovation, Economic Growth, Panel Data

ÖZET

Yenilenebilir enerji kaynakları çevresel kalite üzerindeki bozucu etkilerinin çok daha az olması sebebiyle yenilenemez enerji kaynaklarının önüne geçmektedir. Diğer taraftan, yenilenemez enerji kullanımından yenilenebilir enerjiye geçiş süreci, birtakım alt yapı yatırımları ile arge harcamaları ve teknolojik yenilikleri içeren inovasyon faaliyetlerini gerektirmektedir. Çevresel sürdürülebilirliği sağlamanın amaç olarak belirlendiği bu süreçte yeşil inovasyon kavramı, ülke ekonomilerinin çevre sorunları ve sürdürülebilir büyümeyi sağlayabilmesi açısından giderek önem kazanmaktadır. Bu çalışmanın amacı, yeşil inovasyonun yenilenebilir enerji tüketimi üzerindeki etkisinin 1990-2018 dönemi yıllık verileri ile Brezilya, Rusya, Hindistan, Çin, Güney Afrika ve Türkiye'yi kapsayan BRICS-T ülkelerinde incelenmesidir. Yapısal kırılmaları dikkate alan testlerin uygulandığı çalışmada yeşil inovasyon ile yenilenebilir enerji tüketimi arasında uzun dönemli ilişkinin varlığı tespit edilmiştir.

Anahtar Kelimeler: Yenilenebilir Enerji, İnovasyon, Ekonomik Büyüme, Panel Veri

1. INTRODUCTION

The fact that economic growth is the main target for countries causes depletion of natural resources and deterioration of living space. The mass production method adopted with mechanization after the industrial revolution and the use of fossil fuels have created serious pressure on the ecosystem, bringing along climate change and environmental pollution. Since the first half of the 20th century, this mode of production and economic growth, which poses a threat to the continuity of natural life, has begun to draw attention. The threat in question necessitated some regulations. At the beginning of these regulations is the concept of sustainable development (Wang and Wang, 2020:1; Akyol and Mete, 2022:394).

The first meeting held to acknowledge the existence of environmental problems on a global scale and to seek solutions was the Stockholm Conference held in 1972. The United Nations World Commission on Environment and Development (UNEP) was established in 1983. The Commission published a report titled Our Common Future (Bruntdland Report) in 1987, and with this report, the concept of sustainable development came to the fore for the first time. In the report, it is stated that sustainable development is a model in which economic development and environmental protection are carried out together. Sustainable development is economic development based on the use of renewable resources, taking into account the environmental effects of economic activities (Gedik, 2020: 205). Sustainable development, taking into account the protection of the environment and natural resources, foresees both the realization of economic development and the inheritance of nature in a usable form for the next generations.

Realizing economic growth without causing environmental pollution will only be possible with technological development and innovation. Schumpeter (1934) stated that economic development is driven by innovation. In the endogenous economic growth model, Romer (1986) argued that technological innovations are created through the use of research and development (R&D) activities, human capital and technical knowledge.

The common thought in the economics literature is that innovation and technological improvement have a positive effect on environmental quality and the trend towards renewable energy, which is often referred to as the technological effect. Technological innovation is perceived as a key solution for environmental problems and sustainable development. Energy technology innovation, which refers to knowledge innovation aimed at developing energy-related science and technology, as well as product innovation with the aim of promoting the commercial application of new energy-related technologies, is an important tool in preventing climate change as a result of global warming. In summary, the transition process from fossil fuel use to renewable energy requires some infrastructure investments and innovation activities including R&D expenditures and technological innovations. The concept of green innovation, which expresses the innovations applied in products and processes that carry the industry to higher environmental sustainability levels, is gaining importance in terms of enabling the national economies to achieve environmental problems and sustainable growth.

The BRICS-T countries, including Brazil, Russia, India, China, South Africa and Turkey, which draw attention with their rapid economic growth process, are the focus of this study. Table 1 shows the share of renewable energy consumption in total energy consumption in BRICS-T countries.

Table 1. The Share of Renewable Energy Consumption in Total Energy Consumption in BRICS-T Countries (%)

Years	Brazil	China	India	Russia	South Africa	Turkey
1990	49.86	34.08	58.65	3.75	16.63	24.51
2000	42.66	29.63	46.88	3.50	16.25	17.29
2010	46.81	12.26	36.16	3.34	11.77	14.21
2018	46.95	13.71	32.82	3.18	10.19	11.83

Source: Created by the authors using data from the World Bank, www.worldbank.org

Table 1 shows that the share of renewable energy consumption in total energy consumption is gradually decreasing in every country. However, the least decrease occurred in Russia and Brazil.

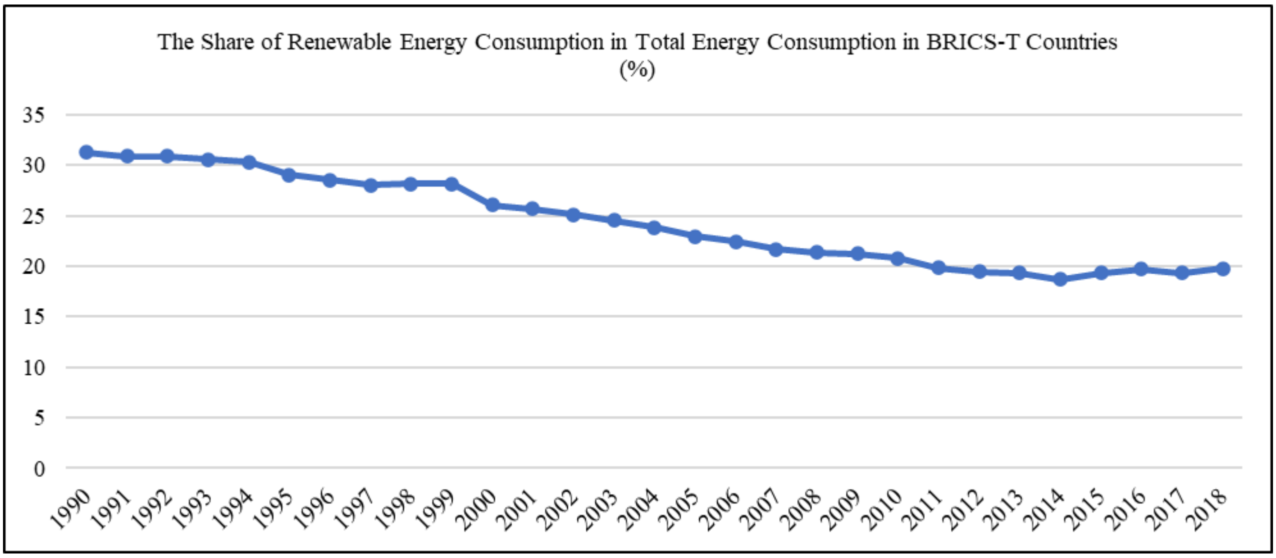

Figure 1. The Share of Renewable Energy Consumption in Total Energy Consumption in BRICS-T Countries (%)
Source: Created by the authors using data from the World Bank, www.worldbank.org

Figure 1 shows that the share of renewable energy consumption in total energy consumption is gradually decreasing in every country. The figure was created by averaging the data of the BRICS-T countries.

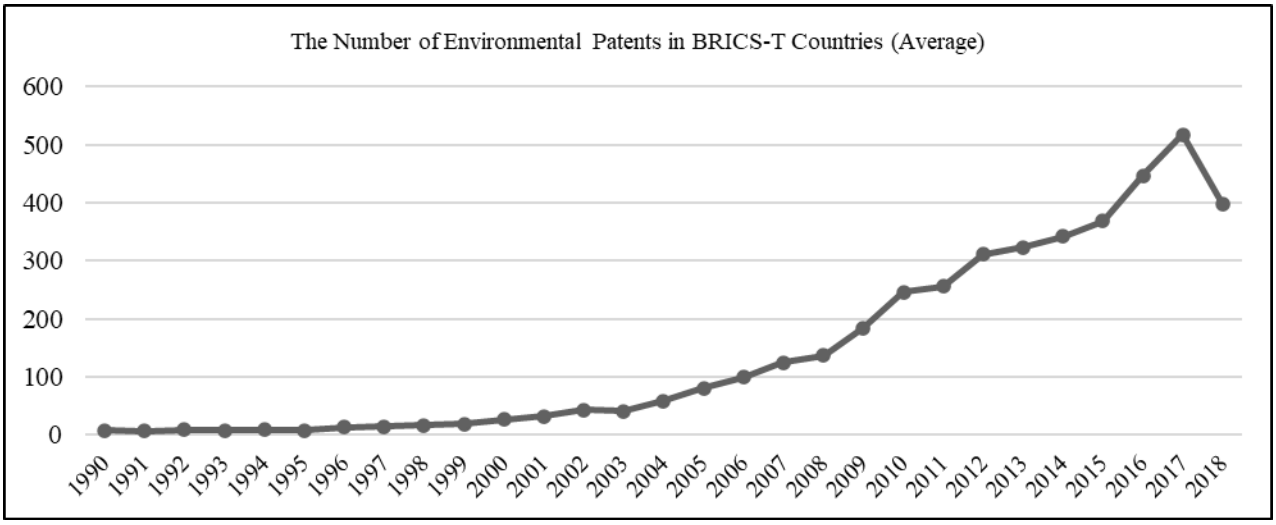

Figure 2. The Number of Environmental Patents in BRICS-T Countries (Average)
Source: Created by the authors using data from the World Bank, www.worldbank.org

Figure 2 shows the average number of patents for the environment in the BRICS-T countries. When the figure is examined, it is seen that the number of environmental patents has increased rapidly in the last ten years across the country group.

The aim of this study is to examine the effect of green innovation on renewable energy consumption in BRICS-T countries covering Brazil, Russia, India, China, South Africa and Turkey, with annual data for the period 1990-2018.

2. LITERATURE REVIEW

In the literature, some of the studies examining the relationship between technological innovation, renewable energy and environmental quality are summarized. Studies on the subject have increased in recent years.

Johnstone et al. (2010) searched the effects of environmental policies on renewable energy technologies innovation for 25 high-income countries. The results of the analysis show that public policy has a very important effect on the development of new technologies in the field of renewable energy. In addition, public spending on R&D has a positive and significant impact on innovation in terms of geothermal and ocean resources, as well as wind and solar energy in all models. Albino et al. (2014) evaluated the development of low-carbon energy technologies with the number of patents, and evaluated 131.661 patents that were formalized in the 1971-2010 period on the basis of all countries. According to the results of the study, innovative activities in the field of energy reached the highest level during the oil crisis periods and in the early 1990s with the awareness of global warming, the private sector was more effective for low carbon energy, the number of patents on alternative energy production was quite insufficient, and the patents for low carbon energy technologies were revealed that more than half of them are in the USA.

Bindi (2019) examined 47 countries in terms of the impact of green innovation on carbon emissions during the 1976-2012 period. The results of the analysis have determined that innovation reduces carbon emissions in developed countries. Hashmi and Alam (2019) examined OECD countries for the period of 1999-2014 for the relationship between technological innovation and carbon emissions. In the study, where panel regression analysis and STIRPAT model were applied and the number of patents was used as an indicator of technological innovation, it was concluded that a 1% increase in the number of patents caused a 0.017% decrease in carbon emissions. Erdoğan et al. (2019) examined the relationship between innovation and carbon emissions for 14 G20 countries in the 1971-2017 period. In the study, in which panel co-integration analysis was used, it was determined that increasing innovation in the industrial sector reduces carbon emissions.

Dauda et al. (2021) examined the relationship between innovation and CO_2 emissions for 9 African countries over the period 1990-2016. According to the results of the analysis, in which the cointegration and generalized moments method were applied, the inverse-U relationship between innovation and CO_2 emissions was confirmed, and it was determined that the use of renewable energy reduced CO_2 emissions throughout the panel. Cheng et al. (2021) investigated how technological innovation developments reduce CO_2 emissions in OECD countries. In the study, in which the number of patents is used as an indicator of technological innovation, 35 OECD member countries were examined with the panel quantile regression model for the period 1996-2015. According to the results of the analysis, the direct effect of technological innovation, expressed in patent numbers, is that it reduces CO_2 emissions. In addition, it was determined that the effect realized in the analysis and called as moderate effect showed heterogeneity. Akyol and Mete (2021), searched the impact of environmental technological innovations on CO2 emissions in 18 OECD members. The results showed that a 1% increase in patent applications for preventing climate change reduced CO_2 emissions by 0.02%. However, a 1% increase in energy consumption caused an increase of 0.56% in CO_2 emissions. Finally, the 1% increase in the GDP growth rate caused an increase of 0.002% in CO_2 emissions. Assi et al. (2021) examined the relationship between renewable energy consumption, financial development, environmental pollution and innovations. The panel ARDL approach and causality analysis were used in the study, in which the 1998-2018 period data of ASEAN countries were used. According to the results of the analysis, the renewable energy consumption of financial development. It has been determined that there is a statistically significant and negative relationship between environmental pollution and economic freedom and renewable energy consumption, and finally, there is a statistically significant and positive relationship between innovation and economic growth and renewable energy consumption.

Akyol and Mete (2022), investigate the effects of environmental innovation, economic growth and foreign direct investments on renewable energy consumption. According to the results of the cointegration analysis, environmental innovation and economic growth affect renewable energy consumption negatively, while foreign direct investments affect renewable energy positively. According to the results of causality analysis, it has been determined that renewable energy consumption is the cause of economic growth, foreign direct investments are the cause of renewable energy consumption, and environmental innovation is the cause of renewable energy consumption.

3. MODEL AND METHODOLOGY

In this section, explanatory information about the data set, the model created to estimate the relationship between the variables in the research and the empirical methods applied are given.

3.1. Model

In this study, the number of environmental patents and per capita gross domestic product are included in the model as independent variables, and the share of renewable energy consumption in total energy consumption is included in the model as a dependent variable. Explanatory information about the data set is given in Table 2.

Table 2. Definition of Variables

Variables	Definition	Source
LRN	Share of Logarithmic Renewable Energy Consumption in Total Energy Consumption (%)	World Bank, WDI
LGIN	Logarithmic Number of Patents for Environment	OECD Statistics
LGDP	Logarithmic GDP Per Capita (Current US$)	World Bank, WDI

The full logarithmic model constructed with the variables shown in Table 2 is shown in Equation (1):

$$LRN_{it} = \alpha_i + \beta_{1i} LGIN_{it} + \beta_{2i} LGDP_{it} + \varepsilon_{it}$$

(i= 1,…,6) ve (t= 1990,…, 2018)

Six countries (Brazil, Russia, India, China, South Africa and Turkey) referred to as the BRICS-T country group were included in the empirical analysis. Dynamic panel data method was used in the analysis.

3.2. Methodology

In this study, dynamic panel data method is used to determine the effect of green innovation on renewable energy consumption by using data sets of BRICS-T countries. For this purpose, the panel cointegration test with structural breaks, developed by Westerlund & Edgerton (2008) is used. Cross-section dependency and slope homogeneity tests should be performed before panel co-integration analysis is performed.

Breusch and Pagan, 1980 in the detection of cross-sectional dependence; Pesaran, 2004; Tests suggested by Pesaran et al., 2008 are used. Another preliminary test is the delta test, which was developed by Pesaran and Yamagata (2008) and is used to test whether the slope coefficients are homogeneous (Pesaran and Yamagata, 2008: 67-69). In the homogeneity test, the hypotheses are “H_0: Slope coefficients are homogeneous” and “H_1: Slope coefficients are heterogeneous”.

As a result of the analysis, Panel Fourier LM Unit Root Test (Nazlıoğlu & Karul, 2017), which is one of the current second generation panel unit root tests and takes into account structural breaks, is used. The most important issue for the reliability of unit root tests with structural breaks is that the break dates, numbers and forms can be determined accurately beforehand. The difficulties that may arise here are tried to be overcome with Fourier unit root tests. Because these types of tests allow not only hard breaks but also gradual breaks (soft transitions), and there is no need to know the break form and date beforehand during the modeling of the test (Türkmen and Özbek, 2021:546).

In the panel Fourier LM (Nazlıoğlu & Karul, 2017) unit root test, the distribution of the individual statistic depends only on the Fourier frequency and the panel statistic has a standard normal distribution. The small sample characteristics of the test were examined with Monte Carlo simulations for different data generation processes (Nazlıoglu & Karul, 2017). The null hypothesis of the test in question is based on the assumption that there is a unit root.

Consideration of structural breaks is very important in order not to obtain biased results in the cointegration tests to be applied. For this reason, considering that the series in the panel contain unit roots at the level, Westerlund and Edgerton (2008)'s cointegration test with structural break is applied. This test is Lagrange Multiplier (LM) based, developed from (Schmidt and Phillips (1992), Ahn (1993) and Amsler and Lee (1995)) unit root tests and also allows for varying variance, serial correlation. On the other hand, this test, which was developed by Westerlund and Edgerton, also allows for breaks in constant term and slope (trend) on different dates for each country (Ornek and Türkmen 2019: 123).

The cointegration coefficients were estimated using the Augmented Mean Group Estimator (AMG) method developed by Eberhardt and Bond (2009), which takes into account the cross-sectional dependence and can also be used in cases where heterogeneity is detected in the coefficients.

4. EMPIRICAL FINDINGS

In this section, the results of econometric tests are given. The pre-test findings that should be done before the cointegration analysis are given in Table 3.

Table 3. Pre-Tests.

	Cross-Section Dependency of Variables					
	LRN		LGIN		LGDP	
Tests	Stat. Value	P-value	Stat. Value	P-value	Stat. Value	P-value
CD_{lm1} (BP,1980)	22.408*	0.098	46.241***	0.000	29.487**	0.014
CD_{lm2} (Pesaran, 2004)	1.352*	0.088	5.704***	0.000	2.645***	0.004
CD_{lm3} (Pesaran, 2004)	-2.637***	0.004	-2.725***	0.003	-2.948***	0.002
LM_{adj} (PUY, 2008)	38.224***	0.000	14.790***	0.000	24.035***	0.000
	Cross-Section Dependency of the Cointegration Equation					
	Stat. Value			P-value		
CD_{lm1} (BP,1980)	49.462***			0.000		
CD_{lm2} (Pesaran, 2004)	6.292***			0.000		
CD_{lm3} (Pesaran, 2004)	-0.118			0.453		
LM_{adj} (PUY, 2008)	16.492***			0.000		
	Slope Homogeneity					
Tests	Stat. Value			P-value		
$\tilde{\Delta}$	7.217			0.000		
$\tilde{\Delta}_{adj}$	7.622			0.000		

Note: *, **, *** indicate statistical significance at 10%, 5% and 1% levels, respectively.

According to the findings in Table 3, it was found that there is a cross-section dependency in the variables and the cointegration equation and the slope coefficient of the established model is heterogeneous. The findings allow to apply the Fourier LM unit root test developed by Nazlıoğlu & Karul (2017), one of the second generation panel unit root tests. Table 4 shows the unit root test results of renewable energy consumption, green innovation and economic growth variables.

Table 4.Results for Panel Fourier LM Unit Root Test.

	LRN			LGIN			LGDP		
Countries	Fourier tau LM_1 k=1	Fourier tau LM_2 k=2	Fourier tau LM_3 k=3	Fourier tau LM_1 k=1	Fourier tau LM_2 k=2	Fourier tau LM_3 k=3	Fourier tau LM_1 k=1	Fourier tau LM_2 k=2	Fourier tau LM_3 k=3
Brazil	-0.254	0.184	-0.562	-1.254	-0.064	-0.044	-2.379	-0.354	-2.633
China	0.714	-0.458	0.356	-1.333	-1.784	0.246	-0.965	-0.201	-1.842
India	1.302	2.125	1.457	-1.760	-0.369	-1.254	-0.511	0.284	0.721
Russia	-1.760	0.864	1.985	0.257	-0.874	-0.471	-0.777	-0.478	0.786
S. Africa	1.127	0.365	0.457	-0.744	-2.685	-1.444	-2.784	-0.666	0.541
Turkey	-2.526	-3.457	-4.311	-1.846	-2.125	-1.782	-0.208	-1.588	-0.965
Panel Results									
Z_{LM}	8.905	6.700	6.362	7.884	4.425	4.688	7.154	4.578	5.462
p- value	1.000	1.000	1.000	0.999	0.999	0.990	1.000	1.000	1.000

In the panel Fourier LM unit root test results, it was found that the dependent and independent variables in the BRICS-T country group contain unit root at level. Therefore, this allows the cointegration test to be performed.

Table 5 shows Westerlund & Edgerton (2008) panel cointegration test results. The table also presents the break date determined for each country by the panel cointegration test applied for level shift and regime shift situations.

Table 5. Results for Cointegration Test with Structural Breaks.

	$Z_\tau(N)$		$Z_\varphi(N)$	
Model	Stat. Value	p- value	Stat. Value	p- value
No Break	-0.977	0.164	-0.263	0.396
Level Shift	-2.371***	0.008	-2.533***	0.005
Regime Shift	-1.451*	0.073	-1.295*	0.097
Countries	Break Dates			
	Level Shift		Regime Shift	
Brazil	2008		1996	
China	2005		1996	
India	2010		2010	
Russia	2010		2010	
S. Africa	2009		2011	
Turkey	2000		2000	

Note: *, *** indicate statistical significance at 10% and 1% levels, respectively.

According to the results of both statistics obtained for the BRICS-T country group, the null hypothesis of no cointegration is rejected at the 1% significance level. As a result, it was found that there is a long-term relationship between green innovation and renewable energy consumption.

Long-term cointegration parameters for the panel as a whole and on a country basis are calculated by the AMG method developed by Eberhardt and Bond (2009). Findings including long-term coefficient estimates are given in Table 6.

Table 6. Results for Panel Cointegration Coefficient Estimation.

	β_1			β_2		
	Katsayı	**Std. Hata**	**p-değeri**	**Katsayı**	**Std. Hata**	**p-değeri**
AMG	0.047	0.048	0.305	0.066	0.058	0.311
Country Results						
Brazil	0.231***	0.049	0.000	-0.067***	0.024	0.000
China	0.312*	0.181	0.072	0.235***	0.035	0.000
India	0.019	0.062	0.812	0.186***	0.012	0.000
Russia	-0.047	0.132	0.774	-0.147	0.105	0.496
S. Africa	-0.222**	0.106	0.037	-0.221***	0.071	0.001
Turkey	0.184*	0.098	0.067	0.179***	0.042	0.000
*, **, *** indicate statistical significance at 10%, 5% and 1% levels, respectively.						

When the cointegration parameters applied for the 1990-2018 period in the BRICS-T country group were examined, it was determined that the long-term coefficients of both green innovation and economic growth variables were not statistically significant throughout the panel. It is seen that the individual results of many of the countries that are not found to act together in the context of green innovation - renewable energy consumption relationship are statistically significant. According to teh results; in the long term, a 1% increase in the number of patents for the environment increases renewable energy consumption by 0.23% in Brazil; 0.31% in China and 0.18% in Turkey; but in South Africa, it decreases by 0.22%. On the other hand, a 1% increase in per capita income reduces renewable energy consumption by 0.06% in Brazil and 0.22% in South Africa, but it increases by 0.23% in China; 0.18% in India and 0.17% in Turkey. It has been determined that the long-term coefficient of the number of patents for the environment is statistically insignificant for India and Russia.

5. CONCLUSION

In the study, which examines the effect of green innovation on renewable energy consumption, BRICS-T countries including Brazil, Russia, India, China, South Africa and Turkey were examined with annual data for the period 1990-2018. In the study, in which tests with structural breaks were applied, it was determined that there is a long-term relationship between the number of environmental patents and renewable energy consumption as an indicator of green innovation. According to the findings, the results differ on a country basis.

Environmental patent applications have increased significantly in the last 20 years across BRICS-T countries. This increase reveals that the BRICS-T countries attach importance to policies to prevent environmental problems. In addition, the acceleration of globalization, the increase in the world population and the increase in total demand increase the production and energy demand. Although the efforts to reduce energy consumption due to fossil resources and the interest in renewable energy have increased recently, the share of renewable energy consumption in total energy consumption has not reached the desired levels yet.

With the development of environmental innovations, the return to the use of renewable energy will be faster. This will bring about both the reduction of negative environmental externalities and the reduction of the dependency on fossil fuel energy demand and the crisis environments that occur in the face of price changes.

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