# Determinants of Green Technologies in Developing Countries

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## ABSTRACT

*One of the key factors for achieving sustainable economic growth is the creation of an economic structure that can develop patents and innovative products. Research and development (R&D) investments in green energy technologies and patents are the basis of the sustainable economic growth process. In this study, we examine the relationship between investments in green energy technologies and patents, energy prices, and environmental policies for Brazil, Russia, India, China, South Africa, and Turkey during the 1995–2018 period. To do so, we applied a long-term coefficient analysis considering cross-sectional dependency tests, second-generation unit root analyses, and a cointegration test considering structural breaks and cross-sectional dependency by creating a demand-side equation based on panel data analysis. According to the findings, the number of green patents is affected positively in the long term by the stringency of environmental policies, government support for R&D expenses, electricity prices, and total patent registrations. Conversely, government support of fossil fuel consumption and increases in environmental taxes and electricity consumption reduce the number of green technology patents.*

***Keywords:*** *Sustainable Development, Green Technologies, Patents*

**JEL Classification:** O32, O38, Q55

# Gelişmekte Olan Ülkelerde Yeşil Teknolojilerin Belirleyicileri

## ÖZ

*Sürdürülebilir ekonomik büyümenin sağlanmasındaki en önemli faktörlerden biri, patent ve yenilikçi ürünler geliştirebilecek bir ekonomik yapının oluşturulmasıdır. Yeşil enerji teknolojilerine yapılan araştırma ve geliştirme (Ar-Ge) yatırımları ve patentler, sürdürülebilir ekonomik büyüme sürecinin temelini oluşturmaktadır. Bu çalışmada, 1995-2018 yılları arasında Brezilya, Rusya, Hindistan, Çin, Güney Afrika ve Türkiye için yeşil enerji teknolojilerine yapılan yatırımlar ile patentler, enerji fiyatları ve çevre politikaları arasındaki ilişki incelenmektedir. Bu bağlamda yatay kesit bağımlılık testleri, ikinci nesil birim kök analizleri dikkate alınarak uzun dönemli katsayı analizi, panel veri analizine dayalı talep tarafı denklemi oluşturularak yapısal kırılmalar ve yatay kesit bağımlılığı dikkate alınarak eşbütünleşme testi uygulanmıştır. Elde edilen bulgulara göre, katı çevre politikalarının uygulanması, Ar-Ge harcamalarına yönelik devlet desteği, elektrik fiyatları ve toplam patent tescilleri bu ülkelerdeki yeşil patent sayısını uzun vadede olumlu yönde etkilemektedir. Buna karşılık, hükümetin fosil yakıt tüketimine verdiği destek ve çevre vergileri ile elektrik tüketimindeki artışlar yeşil teknoloji patentlerinin sayısını azaltmaktadır.*

***Anahtar Kelimeler:*** *Sürdürülebilir Kalkınma, Yeşil Teknolojiler, Patentler*

**JEL Kodları:** O32, O38, Q55

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## 1. Introduction

One of the fundamental factors of sustainable economic growth is to create an economic structure that can develop innovative products. Because of ongoing global climate change, renewable energy resources must be used increasingly in the economic production process.

As a result of rapidly increasing economic growth activities, nonrenewable natural resources are nearly depleted; soil, water, and air are polluted; the ecosystem is damaged; and species are under threat of extinction. Although the negative effects caused by economic production are increasing, populations are becoming environmentally aware, and environmentally friendly policies are starting to spread on a global scale. We evaluated these positive effects in a sustainable economic growth approach frame. With sustainable economic growth, governments should aim for sustainable economic production.

The most prominent cause of global warming and climate change is greenhouse gas emissions caused by fossil fuel use. Glacial melting, erosion, excessive precipitation, drought and desertification, decreased agricultural production, and species extinction are only a few of the threats resulting from human activities. The greenhouse gas emissions caused by economic growth can be reduced by taking measures such as using renewable resources, saving energy, actively using natural resources, and practicing carbon capture and storage. Countries have aimed to maintain the global warming that started during the Industrial Revolution and has lasted until now under $2^0$C and to encourage governments to use low carbon energy resources in economic production. Within this scope, some countries attempted to reduce the greenhouse gas emission level to what it was in the year 1990. For example, the United States has aimed to reduce $CO_2$ emissions by 26–28% until 2025, European countries by 40% until 2030, and Turkey by 21% until 2030 (IEAa, 2015: 12). If the cumulative influence of the nationally determined contributions is mitigated after 2030, then global warming will continue at a much higher rate and could rise to 3–$4^0$C by 2100. For this reason, we expect that rapidly growing developing countries will determine higher targets and take critical measures in their greenhouse gas reduction efforts (UNFCCC, 2019: 56).

Although the global carbon emissions in the last 10 years of the 20th century increased by an average of 1.2% per year, they increased by 2.3% during 2000–2014. The increase in recent years is largely due to developing countries. Half the carbon emissions caused by fossil fuels globally come from three countries—the United States, China, and India; two-thirds come from 10 countries (IEAa, 2015: 27). Although the measures taken in these countries are still insufficient, the positive results of their activities are clear. For example, although the global economy has grown by 3%, energy-produced carbon emissions have remained stable. This pattern occurs approximately every 40 years (IEAa, 2015: 11). The reason for this positive development is largely the use of renewable resources and green technologies. In 2020, energy demand fell by about 4% because of the COVID-19 pandemic; as a result, carbon emissions have fallen by 5.8%, the fastest rate since World War II. When electricity demand fell because of the pandemic, the share of renewable energy in global electricity generation increased from 27% in 2019 to 29% in 2020 (IEA, 2021).

Most countries have policies supporting the use of renewable energy sources such as wind, sun, hydraulic, geothermal, and bioenergetics. At the same time, sustainable production processes are becoming widespread, and green technology investments are being transferred from developed countries to developing countries. Although renewable energy investments have appeared expensive, since 2004 these investments have increased quickly in developing countries in comparison to developed countries. Between 2004 and 2014, such investments increased 3.5 times (from \$37 billion to \$130 billion) in developed countries and increased 17 times (from \$9 billion to \$156 billion) in developing countries. China, India, and Brazil accounted for \$120 billion of the \$156 billion in investments in developing countries. The highest increase in these investments was seen in solar and wind energy (UNEP, 2016: 17). In 2018, renewable energy investments in developing countries decreased by 25% to \$152.8 billion (USD), whereas such investments increased by 11% and reached \$136.1 billion in developed countries. In 2018, the countries with the highest renewable energy generation capacity were Turkey (geothermal power), China (hydropower, solar PV, solar thermal power, wind power, and solar water heating), and the United States (biodiesel, ethanol) (UNEP, 2019: 24–25).

It is possible to achieve sustainable economic growth with the use of green technology and renewable energy sources. Research and development (R&D) investments and green technology patents are the main indicators of technological innovation. Since 1990, activities to increase energy efficiency in industrial production have accelerated in developed countries, and a significant portion of R&D investments have been transferred to studies on boosting energy efficiency and lowering greenhouse gas emissions (IEA, 2009: 21). Although 74% of the public's total energy R&D budget was transferred to fossil fuels in 1974, R&D in renewable energy increased from 3% in 1974 to 20% in 2014. Half the total public R&D budget toward energy activities and renewable energy resources is realized in the United States and Japan (IEAb, 2015). Since the beginning of the 21st century, investments in green technology have grown rapidly in developing market economies. Wong et al. (2014) studied low-carbon technological innovations in more developed Asian nations such as South Korea, Taiwan, and China by considering the scientific journal and the number of patents. According to Organisation for Economic Co-operation and Development (OECD) data covering 2000–2011, in Brazil, Russia, India, China, and South Africa (BRICS), environmental technology patent applications increased by 528%, whereas all patent applications grew by 362.7%. This ratio was similar in Turkey (275%–457.8%) and China (1040%–611.5%) (OECD, 2021).

Green technologies involve activities meant to reduce environmental impacts during a product's life cycle (from raw materials extraction to end-of-life management). These types of activities include innovations such as environmentally friendly product development, active energy use, environmental pollution avoidance, carbon capture, and storage and recycling (Chen et al., 2006: 332). Shrivastava (1995) indicated environmentally friendly technologies are used to increase competition.

Technological innovations are created primarily in developed countries and then transferred to the rest of the world. By creating information and environment exteriority, technology transfer between developed and developing countries is an important factor to encourage green innovation.

Developing countries that transfer technology can succeed in doing so under three conditions.

- Information gap among countries: Countries may differ according to their success in technology transfer. For example, according to Hall and Helmers (2010), countries such as China, India, and Mexico can make a positive contribution to the economy by using their green technology power with human capital and intellectual property rights; this effect cannot be seen in underdeveloped countries.

- Scheider et al. (2008) and Popp (2012) argued that the economic and social levels and qualified environmental policies in developing countries can affect technology transfer. For example, limited opportunities in the credit market may cause difficulties in financing green technology.

- Popp (2012) stated that such policies depend on good governance. Scheider et al. (2008) noted institutional infrastructure deficiencies such as law and intellectual property rights can prevent technology transfer.

In this study, we featured the environmental dimension of sustainable economic growth and analyzed the relationship between green technologies (an important component of sustainable economic growth) and their determinants. R&D investments and green energy technology patents constitute the bases for green economic growth processes. In this context, we discussed developing countries classified as BRICS and Turkey (BRICS-T) that have too large of a share in world production and carbon emissions. Further, we analyzed the relationship between green energy technologies and green patents, energy prices, environmental policies, and economic growth. For this purpose, we used cross-sectional dependency second-generation unit root tests, cointegration tests considering the structural break, and long-term factor analysis considering the cross-sectional dependency by constituting demand-side equality based on panel data analysis.

## 2. Literature on Green Technology Determinants

In the literature, some studies have examined the relationship between green technology, economic indicators, and environmental regulations. Empirical studies have explained the relationship between government environmental regulations and green technologies with two opposite hypotheses. In some studies, researchers found that environmental regulations did not improve efficiency in production and green technologies; in others, researchers found that such regulations supported green investments. In most studies conducted in the 1970s and 1980s, researchers thought environmental regulations could negatively affect macroeconomic variables such as unemployment rate and inflation. Scholars have argued that the benefits that arise alongside reduced pollution remain limited (Denison, 1979; Gray, 1987; Portney, 1981). Conversely, Porter and Linde (1995) criticized the view that environmental regulations increase companies' costs and negatively affect competition. They stated that this view ignores the effect of green innovation, which increases resource efficiency and prevents pollution. According to this approach, which Porter and Linde (1995) described as the "compensation effect," strict environmental policies encourage firms to invest in green innovation. In recent years, researchers have conducted many applied studies supporting this approach (the Porter hypothesis).

In the literature, there are many studies arguing that environmental policies such as public R&D activity spending, environmental tax implementations, preferential tariffs, investment incentives, voluntary programs, and environment certificates help companies produce in an environmentally friendly manner. National and international environmental regulations and contracts have compulsory effects, and public R&D spending has promotional effects on companies' green technology investments. Pastaika (2002) studied public environmental policies; Frondel et al. (2007), Kammerer (2009), Hascic et al. (2009), and Horbach et al. (2012) investigated environmental legislation and conventions; Klaassen et al. (2005) studied R&D support; Popp (2010) looked at environmental policies such as carbon taxes and carbon markets; Song et al. (2020) investigated environmental regulations and R&D tax incentives; Requate (2015) examined the targets of a cap and trading system; and Fischer et al. (2017) concluded upstream subsidies have a positive impact on green technologies and renewable energy resources. Hascic et al. (2009), Klaassen et al. (2005), Gallagher et al. (2011), and Böhringer (2017) emphasized that state subsidies such as investment incentives or feed-in tariffs, R&D expenses toward low-carbon economies, and renewable energy resources ensure cost savings. Yu et al. (2016) found an inverted U-shaped relationship between the increase in government promotion and companies' R&D investments in a study conducted with 147 renewable energy sector corporations in China. In their studies on companies in different Chinese provinces, Kesidou and Wu (2020) revealed that stringent regulations not only realize pollution targets but also lead firms to green innovation studies. Desheng et al. (2021) examined the relationship between China's Environmental Protection Law and green innovation and demonstrated that companies with high political connections remained weak in green investments; they emphasized that market-oriented reform was important in creating effective policies.

In recent years, researchers increasingly have used the number of green patents in their studies. The number of patents is used as one of the indicators of green technology because of some of its advantages. Patents are a tangible indicator of R&D expenses and can reflect industry developments. Innovation activities can indicate the quality as well as the number. Public environmental policies play a major role in spreading green patent practices. For example, Lanjouw and Mody (1996), Jaffe and Palmer (1997), Newel et al. (1999), Hamamoto (2006), Hascic et al. (2009), and Kesidou and Wu (2020) stated that public environmental policies have a positive impact on companies' R&D expenses on sustainable production and efficient energy use. Based on the Environmental Protection Law implemented in China in 2015, Fang et al. (2021) concluded the number of green patent applications from companies operating in industries that create heavy pollution has increased. Johnstone et al. (2008) and Li and Lin (2016) noted that environmental policy tools such as environmental taxes, public R&D expenses, and foreign trade certificates positively influence the number of green patents. By contrast, Jaffe and Palmer (1997) and Brunnermeier and Cohen (2003) argued environmental compliance costs barely influence the patent number. Kim and Kim (2015) stated that renewable energy technology companies that are supported by environmental policies and R&D activities are more competitive. Fabrizi et al. (2018) stated that countries that internalize new technologies are successful in a system that encourages research networks with firms, universities, and research centers, which can create positive externalities. Companies that can export in green product markets are mostly experienced and can produce goods with advanced technologies. Joelle and Roger (2015) analyzed technical changes from fossil fuels to renewable energy innovations using firm-level patent data. Weina et al. (2016) noted green patents do not have a significant effect on carbon emissions, but they are positively correlated with environmental productivity in Italy. Laurens et al. (2016) found the post-Kyoto period is an era of developing green technology in all sectors in Japan, the United States, and Europe. Bel and Joseph (2018) examined the impact of low-carbon economies and emissions trading systems on green technologies in the European Union; they reached conclusions supporting the Porter hypothesis in their studies and revealed that well-designed and strictly implemented environmental policies positively affect green patents.

Changing energy prices are another variable that affects the number of green patents. The increased price of fossil fuels has a particularly widespread impact on the use of renewable energy. After looking at analyses from Newell et al. (1999) and Popp (2002), Barbieri (2016) showed that energy prices positively affected green patents, whereas Li and Lin's (2016) analysis demonstrated energy prices negatively affected green patents. Guillouzouic-Le Corff (2018) stated that increased oil prices had a strong and positive effect on biofuel innovation, especially in the 2000s.

In applied studies carried out since the 1970s, researchers have emphasized the determinants of sustainable development and green growth. In these studies, scholars stated that sustainable development and green growth can be achieved primarily via decarbonization. Green technologies play an important role in reducing carbon emissions. The Porter hypothesis shows that these technologies are connected with public policies for environmental protection. In the literature, some studies have been carried out to address this topic. The studies summarized in this section are those that tested the relationship between green technologies and environmental policies using different variables. In these studies, researchers generally analyzed developed countries and China, one of the largest economies in the world. According to these studies' findings, there is a long-term relationship particularly between environmental policies supporting renewable energy investments and green technology investments. In this study, we used Johnstone et al.'s (2008) model to test the relationship between the number of green patents and different macroeconomic variables. By doing so, we could analyze the indicators discussed in various studies in the literature in a single model; thus, we could interpret long-term positive and negative effects among variables in a single model. In this study, we examined the relatively homogeneous BRICS-T countries, which have a critical place in the world economy and carbon emissions. As a result, we expected our results would be indicative of other developing countries. Considering the current and potential carbon emissions of BRICS-T countries, we believe our study's results show the effectiveness of environmental policies in developing countries.

**3. Econometric Model**

We studied the relationship between investments in and patents created for green energy technologies, which are two of the most important factors in accomplishing renewable growth and energy prices, environmental policies, and economic growth. Within this scope, we also evaluated the effects of environmental policies and economic factors on renewable technologies. For this purpose, we estimated the equation below, as Johnstone et al. (2008) asserted:

$$(PATENTS_{i,t}) = \alpha_i + \beta_1(POLICY_{i,t}) + \beta_2(R\&D_{i,t}) + \beta_3(CONS_{i,t}) + \beta_4(PRICE_{i,t}) + \beta_5(EPO_{i,t}) + \varepsilon_{i,t} \quad (1)$$

The equation below is characterized in regard to the panel data put into practice:

$$ERP_{i,t} = \alpha_i + \beta_1(SUPP_{i,t}) + \beta_2(TAX_{i,t}) + \beta_3(EPS_{i,t}) + \beta_4(RD_{i,t}) + \beta_5(CONS_{i,t}) + \beta_6(PRICE_{i,t}) + \beta_7(EPO_{i,t}) + \varepsilon_{i,t} \quad (2)$$

In the equation above, *ERP* is total patents in environment-related technologies at the European Patent Office (EPO), *SUPP* is the government support for fossil fuel consumption (percentage of total taxes), *TAX* is peripheral taxes (GDP percentage), *EPS* is the Environmental Policy Stringency index, *R&D* is expenses made by the government for environmental technologies, *CONS* is electricity consumption, *PRICE* is electricity prices, and *EPO* is the total patent registration number made in the EPO.

In the study, we used the panel data set of six developing countries (BRICS-T) in the 1995–2018 period. Data included in the panel data set are compiled yearly from the OECD Stat database.

**4. Methodology**

In our econometric analyses, we applied cross-section dependence tests, first- and second-generation unit root tests, a cointegration test considering the structural breaks and dynamic panel threshold, and factor tests as panel data estimators.

### 4.1. Cross-Section Dependence

To test the cross-section dependence in the panel data set, we used Pesaran's (2004) $CD_{LM}$ test, Breusch-Pagan's (1980) $CD_{LM1}$ test, Pesaran's (2004) $CD_{LM2}$ test, and Pesaran et al.'s (2008) $CD_{LMADJ}$ test methods. The $CD_{LM1}$ and $CD_{LM2}$ tests are estimators of whether there is cross-section dependence in case of T > N. The $CD_{LM}$ test is an estimator that tests whether there is cross-section dependence in case of N > T, and the $CD_{LMADJ}$ test is an estimator that tests in both conditions. With the $CD_{LM1}$ and $CD_{LM2}$ tests, we tested the prospect that every country in an individual time effect would be influenced discretely. The tests were estimated based on Lagrange multiplier testing. The $CD_{LM1}$ test was calculated as follows:

$$CD_{LM1} = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \tag{3}$$

In the equation $\hat{\rho}_{ij}^2$ above, each equation is the simple correlation factor between the inclusions acquired from least squares and its predictions, and if there is no correlation between the inclusions the $CD_{LM1}$ under the null hypothesis, when $N$ is stable and for $T \rightarrow \alpha\ X2$ range is pointed (Pesaran, 2004: 4). The $CD_{LM2}$ test was calculated as follows:

$$CD_{LM2} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{\rho}_{ij}^2 - 1) \tag{4}$$

In the $CD_{LM2}$ test, $T \rightarrow \alpha$ and $N \rightarrow \alpha$ were estimated considering asymptotic distribution, and it was estimated under the null hypothesis between the cross-section when there was no dependence. The $CD_{LMADJ}$ test, which is the bias-adjusted LM test, provided consistent and strong results when the $CD_{LM}$ test could not provide consistent and strong results also by $T \rightarrow \alpha$ and $N \rightarrow \alpha$ asymptotic normal distributions.

However, the test produced significant results with small samples. The $CD_{LMADJ}$ test statistics were defined as follows:

$$LM_{adj} = \sqrt{\frac{N}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{T-k(\rho_{ij-}^2 \mu_{Tij}}{u_{Tij}} \tag{5}$$

### 4.2. Second-Generation Unit Root Tests

In this analysis, we used the estimators called second-generation unit root tests, the Hadri and Kurozumi (HK) (2012) unit root test and Pesaran (2007) cross-sectional Im, Pesaran and Shin (CIPS) test.

### 4.3. Cointegration Test

In this analysis, we tested the cointegration as a null hypothesis based on the Westerlund (2006) study; as an alternative hypothesis, we implemented the Westerlund cointegration test if there was a cointegration relationship for each individual country. The test was a Lagrange multiplier test considering the structural break and the cross-section dependence test. To implement the Westerlund test, we estimated the following model:

$$y_{it} = z_{it}\gamma_{ij} + x_{it}\beta_i + \varepsilon_{it} \tag{6}$$

$$\varepsilon_{it} = r_{it} + v_{it} \tag{7}$$

$$r_{it} = r_{it-1} + \emptyset_i v_{it} \tag{8}$$

In the model above, $y_{it}$ is the time sequence variable. The time period $t=1,\ldots,T$ shows the $i=i,\ldots,N$ panel cross-section. In the test practice, the case = 4 hypothesis was estimated (i.e., the structural breaks were considered when there was an individual constant and trend). The maximum lag length was 3, and the replication was taken as 1.000.

### 4.4. Long-Term Coefficients

To estimate the long-term coefficients, we tested the mean group (MG) and pooled mean group (PMG) estimators developed by Pesaran et al. (1999) and the common correlated effects (CCE) estimators developed by Peseran (2006).

To estimate the long-term equality, we first used the ARDL:

$$y_{it} = \alpha_i + \emptyset_i y_{i,t-1} + \gamma_i X_{it} + \delta_i z_t + u_{it} \quad (9)$$

For each, in equation $X_{it}$, it is the $k\ x\ 1$ vectors' proxy variable. The $z^t$ is a common effects vector; panel cross-section $i = 1,2,\dots,N$ and time period $t = 1,2,\dots,T$ are shown in the model (Pesaran, 1997: 187).

Pesaran et al. (1999) developed two estimators to estimate the panel ARDL: mean group estimation (MGE) and pooled mean group estimation (PMGE). The MG estimator does not make any restriction on the long-term ARDL specification factor, and it reaches the long-term derivatives with the long-term mean factors in the individual ARDL estimators. Moreover, the MG estimators are used to estimate a country's individual ARDL model. In this model, the homogeneity in long-term variables and the heterogeneity in short-term variables were denied. This estimator did not allow the panel member factors to be the same. The PMG estimator could be used instead of the MG estimator. The PMG restricted the long-term factors, but it allowed the stables, variances of disturbance terms, and long-term factors to change. For this reason, in the panel ARDL model hypothesis, variables' long-term homogeneity and short-term heterogeneity were ensured.

However, the model also gave us the opportunity to choose between the alternative model specifications. Therefore, to test the PMG or MG estimator's consistency and effectiveness by estimating the model in practice, we implemented the Hausman (1978) test.

We implemented another method to estimate the long-term factors, the CCE mean group (CCEMG) and CCE pooled (CCEP) estimators from the CCE model test considering the cross-section dependence developed by Peseran (2006). We tested the multifactor error-correcting model below to reach coefficients in the CCE estimators based on the least-squares method, which can be used in mixed series.

$$y_{it} = \infty_i + d_t + \acute{\beta}_i x_{it} + \acute{g}_i \bar{z}_t + \varepsilon_{it} \quad (10)$$

$$\varepsilon_{it} = \gamma_i f_t + \epsilon_{it} \quad (11)$$

The equation above shows $\bar{zt}$ = ($\bar{yt}$, $\bar{xt}'$), the cross-section means of the dependent and independent variables. The $\gamma i$ shows the cross-section dependence, and the $ft$ shows the unobservable common effects. In the model, the cross-section dependence, autocorrelation, and heteroscedastic were considered; in the CCEMG model, the slope heterogeneity was allowed. For this reason, we used this test, which is a normalized version of the Swamy's slope homogeneity test developed by Pesaran and Yamagata (2008), as supplementary statistics.

## 5. Econometric Findings

In the study, we investigated the relationship between the number of green patents and environmental policies and selected economic variable in the long term. To do so, first we estimated the existence of the cross-section dependence in the panel data set. We used the Breusch-Pagan (1980) $CD_{LM1}$ test, the Pesaran (2004) $CD_{LM2}$ test, and the Pesaran et al. (2008) $CD_{LMADJ}$ test to test the cross-section dependence in the T > N condition in the panel data set. We provided the 24 years (T), including the 1995–2018 period, and six developing countries (N) to actualize the T > N condition. In the $CD_{LM1}$, $CD_{LM2}$, and $CD_{LMADJ}$ tests, we estimated using the hypothesis that every country could be affected discretely from individual time effects. The test results related to the cross-section dependence are listed below.

**Table 1:** Cross-Section Dependence Test Results

| | $CD_{LM1}$ | $CD_{LM2}$ | $CD_{LMADJ}$ |
|---|---|---|---|
| ***ERP*** | 28.527*(0.000) | 19.827*(0.004) | 21.924*(0.000) |
| ***SUPP*** | 29.882*(0.000) | 34.734*(0.002) | 45.665*(0.000) |
| ***TAX*** | 42.728*(0.002) | 35.645*(0.000) | 44.281*(0.000) |
| ***EPS*** | 34.922*(0.000) | 24.849*(0.000) | 42.829*(0.001) |
| ***RD*** | 39.829*(0.005) | 32.872*(0.002) | 46.832*(0.000) |
| ***CONS*** | 21.948*(0.004) | 11.892*(0.005) | 32.830*(0.000) |
| ***PRICE*** | 24.829*(0.000) | 12.934*(0.002) | 38.393*(0.001) |
| ***EPO*** | 32.221*(0.000) | 15.948*(0.000) | 42.826*(0.000) |

**Note:** *, indicates cross-section dependence.

The results of the $CD_{LM1}$, $CD_{LM2}$, and $CD_{LMADJ}$ tests rejected the null hypothesis of the panel data set as statistically significant and proved the existence of cross-section dependency. If the existence of the cross-section dependency was denied in the panel data set, then we used the first-generation unit root tests. By doing so, if there was cross-section dependence in the panel data, then we could use the second-generation unit root tests as more consistent, active, and strong (Çınar, 2010: 594).

After practicing the cross-section dependency tests, we estimated the augmented CIPS and HK tests of the second-generation unit root tests. In practice, we implemented the means of the individual CADF unit root tests, which are second-generation unit root tests estimated by Im et al. (2003), based on the CIPS statistics. We compared the test statistic values obtained after practicing the CIPS estimator with Pesaran's (2007) critical table values if the panel data were stable as a whole. The other examined second-generation unit root test was the HK estimator developed by Hadri-Kurozumi (2012).

**Table 2:** Unit Root Tests Results

| | $CIPS_{stat}$ | | HK | |
|---|---|---|---|---|
| | **Level** | **Different** | $Z_A^{SPC}$ | $Z_A^{LA}$ |
| ***ERP*** | -6.91** | -11.82** | 17.92* | 21.82** |
| ***SUPP*** | -5.27** | -6.15*** | 24.86* | 26.91* |
| ***TAX*** | -3.74* | -4.73* | 10.06 | 14.82* |
| ***EPS*** | -3.41 | -7.26* | 11.92* | 19.96* |
| ***RD*** | -8.29* | -10.28* | 9.82* | 15.22* |
| ***CONS*** | -2.92 | -3.17* | 9.13* | 13.07 * |
| ***PRICE*** | -3.60 | -7.03* | 16.82* | 18.24* |
| ***EPO*** | -3.02** | -4.67*** | 9.58* | 12.75* |

**Notes:** *, ** and *** show statistical significance at 1%, 5% and 10%, respectively. The critical values for CIPS were obtained from Pesaran (2006) (can be seen at table 2c-III. Stable and Trend). $Z_A{}^{SPC}$ and $Z_A{}^{LA}$ tests make predictions by assuming asymptotic normal distribution and the null hypothesis show the stationary status. And $Z_A{}^{SPC}$ and $Z_A{}^{LA}$ tests, show the results of PANKPSS test results which corrected by SPC and LA methods.

According to the panel unit root test results, developing countries have stable process panel data set characteristics.

As a result of econometric analyses, cross-section dependence in the panel data set has been proven. Also, we found that mixed series formed the panel data sets. For this reason, we used the Westerlund (2006) test to determine whether there was a cointegrated relationship in the model in the long term. The Westerlund (2006) cointegrated test is an LM statistic test and can be implemented in nonlinear series considering the structural break and cross-section dependence. In the test practice, we estimated the case = 4 hypothesis (that is, the structural breaks were considered when there was an individual constant trend). Table 3 illustrates the results; the maximum lag length was 3, and replication was taken as 1.000.

**Table 3:** Cointegration Test Results

| | **Test** | **Statictics** |
|---|---|---|
| **No Break** | Value | 9.678 |
| | Prob[1] | 0.003 |
| | Prob[2] | 0.873* |
| **With Break** | Value | 11.927 |
| | Prob[1] | 0.007 |
| | Prob[2] | 0.984* |

**Notes:** We use Prob[1] and Prob[2] to refer to the test based on asymptotic normal and bootstrapped distribution, respectively. * indicates statistical significance of presence of cointegration.

In the Westerlund (2006) cointegration test, according to the possibility result considering cross-section dependence, we found the null hypothesis that cointegration exists in the model panel data set was statistically significant.

In the practiced model, after admitting the existence of cointegration, we could estimate the long-term equation. To reach the coefficients of the long-term cointegration, we used the PMG estimator developed by Pesaran et al. (1999) and the CCEMG estimator developed by Pesaran (2006). While estimating the model and to test the PM estimator's consistency, we implemented the Hausman (1978) test. To test the

CCEMG test's consistency, we used the slope homogeneity test developed by Pesaran and Yamagata (2008).

**Table 4:** PMG and CCEMG Test Results

| | St. er. | t-ratio | PMG | St. er. NW | t-ratio | CCEMG |
|---|---|---|---|---|---|---|
| ***SUPP*** | 0.063 | -0.192 | -0.048** | 0.053 | -0.804 | -0.077** |
| ***TAX*** | 0.015 | -0.072 | -0.021** | 0.008 | -0.006 | -0.028* |
| ***EPS*** | 0.011 | 0.471 | 0.104** | 0.011 | 0.982 | 0.209* |
| ***RD*** | 0.042 | 0.106 | 0.055*** | 0.104 | 2.346 | 0.605** |
| ***CONS*** | 0.097 | -1.054 | -0.138** | 0.077 | -0.401 | -0.183* |
| ***PRICE*** | 0.114 | 1.748 | 0.181** | 0.072 | 0.734 | 0.171** |
| ***EPO*** | 0.013 | 0.672 | 0.029* | 0.021 | 0.139 | 0.037** |
| | **Error Correction Coefficient** | | | | | |
| *Ø* | | | -0.981* | | | |
| | **Diagnostic Tests** | | | | | |
| *Log-likelihood* | | | -145.77 | | | -230.99 |
| $\chi^2_{SC}$ | | | 0.76 | | | 0.81 |
| $\chi^2_{HE}$ | | | 0.16 | | | 0.19 |

**Notes:** Akaike Information Criterion (AIC) is used to select the number of lags required. *χ2 SC and χ2 HE* shows *χ2* statistics for Breusch-Godfrey Serial Correlation and White heteroscedasticity test. *, ** and *** denote rejection of the null hypothesis at the %1, %5 and %10 levels, respectively. St. er.$^{NW}$ is the standard error based on Newey-West variance estimator type in Pesaran (2006).

In the results of the Hausman test (Hausman test statistics = 0.76), we admitted both the PMG and MG estimators and the null hypothesis of the consistency of the developing countries, but we found only the PMG was the effective estimator (Baltagi, 2008: 72). The statistically significant error correction coefficients (*Ø*) and negative signed showed that there was a long-term relationship between the dependent and independent variables; we also observed that although it went out of balance, it reconverged. Considering to the results of the diagnostic tests in Table 4, we found no autocorrelation and heteroscedasticity problem in the model. All reached coefficients were statistically significant.

According to the results of the applied econometric model, changes in the *R&D*, *EPS*, *PRICE*, and *EPO* independent variables could realize sustainable economic growth supported by green technology patents. Total patents in environment-related technologies is affected positively in the long term by the stringency of environmental policies, government support for R&D expenses, electricity prices, and total patent registrations.

## 6. Conclusion

Renewable energy use and green technologies are the main factors for countries that need to maintain sustainable growth. In this study, we examined the long-term relationship between investments in green technologies, the number of green patents, and macroeconomic variables. To do so, we used cross-section dependence, second-generation unit root tests, the cointegration test that can be practiced in nonlinear series, and the modern PMG and CCE estimators (developed to reach the long-term coefficients) for BRICS-T countries in the 1995–2018 period. In the econometric analysis, we used the number of green patents as the dependent variable. The number of green patents as one of the main indicators of green innovation is a preferred variable in the literature because it is a tangible indicator of R&D expenses.

According to the results of this analysis, the stringency of environmental policies, government R&D expenses, electricity prices, and total patent registrations statistically significantly and positively increase green technology in the long term. Conversely, government support for fossil fuel consumption, increased environmental taxes, and increased electricity consumption reduce the number of green technology patents.

In the model of this study, we tested the Porter hypothesis, which argues that strict environmental policies increase green innovation. The results of this study are consistent with studies in the literature supporting the Porter hypothesis, such as those of Pastaika (2002), Frondel et al. (2007), Kammerer (2009), Hascic et al. (2009), Horbach et al. (2012), Klaassen et al. (2005), Popp (2010), and Song et al.

(2020). Similarly, Johnstone et al. (2008), Samad and Manzoor (2015), and Li and Lin (2016) concluded that environmental policy indicators such as environmental taxes, public R&D expenses, and foreign trade certificates positively affect green patents. The results of the analysis support these studies; however, Jaffe and Palmer's (1997) results differ from those of Brunnermeier and Cohen (2003). Nonetheless, this study's results are similar to those of Newell et al. (1999) and Popp (2002). Energy prices affect the number of green patents in a statistically significant and positive manner.

Developed countries, particularly those responsible for global warming and carbon emissions created during the industrialization period, have promised to reduce emissions. International environmental contracts, government sanctions, and green technology investments are measures that support this process. In the last period, developed countries increased their investments toward energy productivity. In this context, about half the R&D budgets dedicated to developing global renewable energy have been made in the United States and Japan. However, energy requirements and carbon emissions have been increasing quickly in developing countries since the 1990s, but no serious sanctions have been implemented.

Rapidly growing developing countries prefer fossil fuels because they are less costly and are easy to use. Converting fossil fuels to renewable energy and developing green innovations are vital for sustainable development. As a result, global policies must be actualized in both developed and developing countries. Our study has identified that environmental policies, R&D expenses, and government support increased the number of green patents in BRICS-T countries from 1995 to 2018.

BRICS-T countries create 25% of global production and grow above the world average. Our findings show that green technology investments increased with government support in BRICS-T countries, which had a positive impact on the number of green patents. The results of this study confirm the Porter hypothesis. Based on these results, we can argue that developing countries should be part of international environmental agreements to achieve sustainable global economic growth. By contrast, per the results obtained from our analysis, we see the government support given to fossil fuels made green innovation unprofitable. As a result, environmental policies and taxes must be implemented in BRICS-T countries. Our results demonstrate that reducing or eliminating government support of fossil fuel consumption could increase investments in renewable resources and the number of green patents.

Our study contributes to the literature because we examined BRICS-T countries, included macro-variables in the model as the determinant of green patents, and used data from recent years in our analysis. We hope the results obtained from this analysis will help guide environmental policies applied in developing countries.

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