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# DO FINANCIAL DEVELOPMENT AND GREEN TECHNOLOGICAL INNOVATIONS IMPROVE ENVIRONMENTAL QUALITY?*

## *FİNANSAL GELİŞME VE YEŞİL TEKNOLOJİK İNOVASYONLAR ÇEVRE KALİTESİNİ İYİLEŞTİRİYOR MU?*

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**Abstract**

This paper inquires the effects of financial development and green technological innovations on environmental quality between 2009-2021. For this purpose, the effects of financial development, informational globalization, renewable energy use, economic growth, trade openness and patent applications on CO2 emissions are analyzed using the System Generalized Method of Moments (GMM). The findings suggest that; while knowledge-based globalization and economic growth increase CO2, financial development, renewable energy, trade openness and patent applications significantly decrease it. Accordingly, promoting green technology and renewable energy is important for supporting environmental sustainability. Therefore, financial development and green technological innovation indicators will contribute to the support of environmental policies by positively affecting environmental quality.

***Keywords:*** *Financial Development, Financial Development Index, Green Technological Innovation, Environmental Quality*

**Öz**

Bu çalışma, 2009-2021 yılları arasında 22 ülkede finansal gelişme ve yeşil teknolojik yeniliklerin çevresel kalite üzerindeki etkisini incelemektedir. Sistem Genelleştirilmiş Momentler Metodu (GMM) yöntemi kullanılarak, finansal gelişme, patent başvuruları, yenilenebilir enerji kullanımı, ticari açıklık ve ekonomik büyümenin CO2 emisyonları üzerindeki etkileri analiz edilmiştir. Bulgular, finansal gelişme, patent başvuruları, yenilenebilir enerji ve ticari açıklığın CO2 emisyonlarını önemli ölçüde azalttığını, ekonomik büyüme ve bilginin küreselleşmesinin ise emisyonları artırdığını göstermektedir. Çalışma, çevresel sürdürülebilirliği desteklemek için yeşil teknolojilerin ve yenilenebilir enerjinin teşvik edilmesinin önemini vurgulamaktadır. Finansal gelişme ve patent başvurularının çevresel kalite üzerindeki olumlu etkisi, çevre dostu politikaların gerekliliğini ortaya koymaktadır. Bu bulgular, sürdürülebilir ve çevre dostu bir gelecek için yeşil teknolojilerin ve finansal büyümenin desteklenmesinin kritik olduğunu göstermektedir.

**Anahtar Kelimeler:** *Finansal Gelişme, Finansal Gelişme Endeksi, Yeşil Teknolojik İnovasyon, Çevresel Kalite*

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## GENİŞLETİLMİŞ ÖZET

**Çalışmanın Amacı:** Bu çalışmanın amacı, finansal gelişme ve yeşil teknolojik yeniliklerin çevresel kalite üzerindeki etkilerini detaylı bir biçimde incelemektir. Çalışma, bu iki unsurun karbon emisyonlarını azaltma potansiyelini ve çevresel sürdürülebilirliğe nasıl katkı sağlayabileceğini değerlendirmektedir. Çalışmada, 2009-2021 yılları arasında 22 ülkeden elde edilen verilere dayanılarak, finansal gelişme, patent başvuruları, yenilenebilir enerji tüketimi, ticari açıklık ve ekonomik büyümenin $CO_2$ emisyonları üzerindeki etkileri analiz edilmiştir.

**Araştırma Soruları:** Finansal gelişme $CO_2$ emisyonlarını nasıl etkiler? Bu etki çevresel kalite üzerinde nasıl bir yönlendirme sağlar? $CO_2$ emisyonlarını azaltmada, yeşil teknolojik inovasyonlar ne derece etkilidir?

**Literatür Araştırması:** Finansal gelişme ve çevresel kalite arasındaki ilişki konusunda literatürde farklı görüşler mevcuttur. Bazı araştırmalar, finansal kaynakların verimli kullanılmasının çevresel kaliteyi iyileştirebileceğini öne sürerken, diğerleri finansal gelişmenin ekonomik büyümeyi ve sanayi faaliyetlerini teşvik ederek çevreye zarar verebileceğini iddia etmektedir. Finansal gelişme, kaynakların etkin bir şekilde kullanımını sağlayarak çevre dostu projelerinin gelişimini destekleyebilir ve böylelikle $CO_2$ emisyonlarını azaltabilir. Diğer yandan, sanayileşme ve üretim artışı gibi ekonomik büyüme faktörleri ise emisyon seviyelerinin yükselmesine neden olabilir.

Yeşil teknolojik yenilikler, çevresel sürdürülebilirliği artırma amacıyla enerji verimliliği ve yenilenebilir enerji kullanımını teşvik eden ekolojik çözümler sunmaktadır. Özellikle yenilenebilir enerji kaynakları kullanılarak enerji üretiminin çevresel etkisi azaltılabilmekte, bu da karbon ayak izini düşürmektedir. Literatürde yeşil teknolojik yeniliklerin çevresel kalite üzerindeki olumlu etkilerine dair bulgular mevcuttur; bu yenilikler enerji verimliliğini artırmakta, çevreye zararlı faaliyetleri azaltmakta ve sürdürülebilir çevre politikalarının oluşturulmasına katkı sağlamaktadır. Bilgi küreselleşmesi ve uluslararası ticaretin çevresel kalite üzerindeki etkileri de incelenmiştir; bilginin daha hızlı ve geniş kitlelere yayılması çevre dostu teknolojilerin yaygınlaşmasını desteklerken, ticari açıklık ise ülkelerin enerji kaynakları ve sanayileşme seviyelerine bağlı olarak farklı sonuçlar doğurabilmektedir.

Bu çalışmada, finansal gelişme ile yeşil teknolojik yenilikler arasındaki ilişki detaylı bir şekilde ele alınarak literatürdeki eksiklikler giderilmeye çalışılmış ve mevcut araştırmalara katkı sağlanmıştır.

**Yöntem:** Çalışmada dinamik panel veri analizi için Sistem GMM öntemi kullanılmıştır. Bu yöntem, bağımlı değişkenin gecikmeli değerlerini modele dahil ederek finansal gelişme ve yeşil teknolojik yeniliklerin çevresel kalite üzerindeki etkilerini daha sağlam bir şekilde analiz etmeyi sağlar. Çalışmada yıllık olarak toplanan finansal gelişme endeksi, patent başvuruları, yenilenebilir enerji tüketimi ve ticari açıklık gibi değişkenler analiz edilmiştir. &rilerin dinamik yapısı, bu değişkenlerin çevresel kalite üzerindeki etkilerini zaman içinde daha doğru bir şekilde ortaya koymaktadır.

**Sonuç ve Değerlendirme:** Araştırmanın bulguları, finansal gelişmenin ve patent başvuruları ile temsil edilen yeşil teknolojik yeniliklerin $CO_2$ emisyonlarını azaltmada etkili olduğunu göstermektedir. Finansal gelişme, ülkelerin çevre dostu teknolojilere yatırım yapabilme kapasitelerini artırarak çevresel kalitenin yükseltilmesine katkıda bulunur. Ayrıca, patent başvuruları ile ölçülen yenilik faaliyetleri de çevre dostu teknolojilerin yaygınlaşmasını sağlayarak $CO_2$ emisyonlarını düşürmektedir. Ekonomik büyüme ve bilgi küreselleşmesi ise $CO_2$ emisyonlarını artıran faktörler olarak tespit edilmiştir.

Yenilenebilir enerji kullanımının çevresel kalite üzerindeki olumlu etkisi, enerji geçişini teşvik eden sürdürülebilir enerji politikalarının önemini vurgulamaktadır. Çalışmada elde edilen bulgulara göre, ülkelerin enerji politikalarında yenilenebilir enerjiye daha fazla yer vererek çevresel sürdürülebilirlik hedefine ulaşabilecekleri ortaya konulmaktadır. Ayrıca, ticari açıklığın çevresel kalite üzerindeki etkisi ülkelerin sanayileşme seviyesine, enerji kaynaklarına ve politikalarına göre değişkenlik göstermektedir. Bu nedenle, politika yapıcıların ticaretin çevresel etkilerini ulusal ve uluslararası bağlamda değerlendirmeleri önem taşımaktadır.

Çalışmanın genel sonuçları, yeşil teknolojik yeniliklerin çevresel sürdürülebilirliği artırmada uzun vadeli bir katkı sağladığını vurgulayan literatüre paralel bulgular sunmaktadır. Özellikle yenilenebilir enerjiye yönelik teşvikler, çevresel sürdürülebilirlik için önem arz etmekte ve çevreye duyarlı politikaların oluşturulmasında kritik rol oynamaktadır. Çalışmada elde edilen bulgular doğrultusunda, çevresel sürdürülebilirlik açısından yeşil teknolojilerin kullanımının teşvik edilmesi ve bu süreçte finansal sistemlerin destekleyici bir rol oynaması gerektiği sonucuna varılmıştır.

Sonuç olarak, bu çalışma çevresel sürdürülebilirlik için finansal gelişme ve yeşil teknolojik yeniliklerin önemini vurgulamakta ve politika önerileri sunmaktadır. Çevre dostu teknolojilerin geliştirilmesi için finansal teşviklerin artırılması gereklidir; şirketlerin bu teknolojilere yatırım yapması desteklenmeli ve çevreye duyarlı projeler için yeşil finansman çözümleri geliştirilmelidir. Özellikle, çevre dostu teknolojilere yapılan yatırımların teşvik edilmesi için vergi indirimleri sağlanmalı ve küçük ve orta ölçekli işletmelere yönelik finansman destek programları genişletilmelidir. Bu politika önerileri, çevresel kaliteyi artırmak ve çevre dostu teknolojilerin yaygınlaşmasını sağlamak için gerekli adımlar olarak öne çıkmaktadır.

## 1. INTRODUCTION

Scholars and policymakers have been increasingly focusing on two of the most pressing global environmental issues: rising carbon emissions and global warming. Fossil fuel combustion produces gases like carbon dioxide ($CO_2$), which have a major effect on both the rise in global warming and the diminishing of environmental quality (Karşıyakalı et al., 2024). One of the primary causes of the global rise in $CO_2$ is the usage of fossil fuels. This makes reaching environmental sustainability targets more difficult (Baloch et al., 2019).

Increases in carbon emissions and global warming, which are among the leading global environmental problems, have recently been the centerpiece of both academics and policy work. Gases such as carbon dioxide ($CO_2$), generated by the combustion of fossil fuels, have a notable impact on the deterioration of environmental quality and the increase in global warming (Karşıyakalı et al., 2024). The use of fossil fuels is regarded as one of the motor forces behind the global increase in $CO_2$. This creates a number of problems in achieving environmental sustainability goals (Baloch et al., 2019). Therefore, financial development and green technological innovations are emerging as leading tools to improve environmental quality. Green technological innovations enable the creation of a sustainable future by minimizing the factors that harm the environment (Lv et al., 2021). Financial development can significantly reduce $CO_2$ emissions by facilitating the utilization of environmentally friendly technologies (Özkan et al., 2023).

Studies examining the combined effects of financial development and green technological innovations on environmental quality are relatively limited. This paper uses a specially developed financial development index to assess financial development, exploring in depth the complex relationships between these factors. This index can be used in conjunction with the IMF's existing indices to analyze the performance and ranking of financial development from a new perspective, thus providing a more comprehensive assessment.

Moreover, this research also considers the effects of knowledge globalization on environmental quality and considers the environmental impacts of green technological innovations. Using the system GMM analysis method, this study aims to provide new perspectives for policy makers, environmental scientists and economists to develop new strategies to reduce carbon emissions and enhance environmental sustainability.

The necessity of this research stems from the lack of comprehensive studies that examine the detailed combined effects of financial development and green technological innovation on environmental quality. Our innovative financial development index allows us to examine the effects of these variables on the environment in more detail. It also addresses a less researched topic such as the effects of knowledge globalization on environmental quality. The use of dynamic panel data analysis allows us to better understand changes in environmental quality over time, which further increases the importance and urgency of the study.

By examining in detail the long-term effects of financial development and green technological innovation on environmental quality, this paper provides a more holistic and in-depth analysis that takes into account changes over time and their cumulative effects on the environment, which are often ignored in the existing literature using dynamic panel data analysis.In this paper, to reveal the effects of financial development and green technological innovations on environmental quality with a comprehensive analysis, the System GMM method, one of the dynamic panel data analyses that includes lagged values of the dependent variable, is used. The reason for choosing this method is that dynamic models, unlike static models, detect changes in environmental quality over time.

This study has six sections. After the introduction, the existing literature in the field is reviewed where studies examining the interdependencies between these factors and environmental quality are examined under separate headings. The third section provides information about the methodology of this study and the data used. Finally, the findings are brought together and completed with a discussion and conclusion section.

## 2. LITERATURE REVIEW

Financial development can improve environmental quality by facilitating efficient and effective use of resources, but it can as well negatively affect environmental quality. Therefore, it is of great importance to direct financial resources in the right way for eco-friendly solutions. Concurrently, green technological innovations enable a sustainable and cleaner environment by providing environmentally friendly solutions in areas such as renewable energy sources, energy efficiency and waste management.

Table 1 summarizes the work reviewed that examines the relationship between financial development and environmental quality. It is seen that the studies mostly concentrate on the effects of financial development on environmental quality in detail based on data from specific countries.

**Table 1.** The Relationship Between Financial Development and Environmental Quality

| Authors | Sample Group | Time Period | Methods | Research Findings |
|---|---|---|---|---|
| Tamazian et al. (2009) | BRIC countries | 1992-2004 | RE | Financial development has a negative impact on $CO_2$ emissions. |
| Tamazian and Rao (2010) | 24 Transition Economies | 1993-2004 | GMM | Financial development reduces $CO_2$ emissions. |
| Jalil and Feridun (2011) | China | 1953-2006 | ARDL | Financial development reduces pollution in the long term. |
| Öztürk and Acaravcı (2013) | Turkey | 1960-2007 | ARDL, Granger Causality | No significant long-term influence of financial development on $CO_2$ emissions. |
| Boutabba (2014) | India | 1971-2011 | ARDL, Granger Causality | Financial development has a positive long-term effect on $CO_2$ emissions. |
| Al-Mulali et al. (2015) | 129 countries | 1980-2011 | DOLS, Panel VECM, Granger Causality | Financial development improves environmental quality by reducing $CO_2$ emissions. |
| Omri et al. (2015) | 12 MENA countries | 1990-2011 | GMM, CIPS, LM | A developed financial system reduces $CO_2$ emissions by increasing R&D expenditures. |
| Abbasi and Riaz (2016) | Pakistan | 1971-2011 | ARDL, ECM, VECM, Granger Causality | Financial development increases $CO_2$ emissions. |
| Javid and Sharif (2016) | Pakistan | 1972-2013 | ARDL, VECM | Financial development worsens environmental quality by increasing $CO_2$ emissions. |
| Charfeddine and Khediri (2016) | UAE countries | 1975-2011 | Cointegration Tests, VECM, Granger Causality | An inverted U-shaped relationship was found between financial development and $CO_2$ emissions. |
| Doğan and Şeker (2016) | 23 countries | 1985-2011 | CADF, CIPS, FMOLS, DOLS | Increases in financial development reduce $CO_2$ emissions. |
| Shahbaz et al. (2016) | Pakistan | 1985-2014 | PCA, ARDL | Financial development negatively impacts environmental quality. |
| Abid (2017) | 58 MEA and 41 EU countries | 1990-2011 | Panel GMM | Financial development worsens environmental quality by increasing $CO_2$ emissions. |
| Dar and Asif (2018) | Turkey | 1960-2013 | ARDL, Cointegration Test | Financial sector development improves environmental quality. |
| Moghadam and Dehbashi (2018) | Iran | 1970-2011 | ARDL | Financial development accelerates environmental degradation. |
| Lu (2018) | 12 Asian countries | 1993-2013 | Cointegration Tests, CIPS | Financial development increases $CO_2$ emissions. |
| Saud et al. (2019) | 59 BRI countries | 1980-2016 | Panel Causality Tests | Financial development improves environmental quality. |
| Nasir et al. (2019) | ASEAN-5 | 1982-2014 | DOLS, FMOLS | Financial development leads to environmental |

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| | | | | degradation by increasing $CO_2$ emissions. |
| Zafar et al. (2019) | G-7 and N-11 countries | 1990-2016 | CUP-FM, Panel Causality | Banking development lessens $CO_2$ emissions in G-7 countries but boosts them in N-11 countries. |
| Baloch et al. (2019) | 59 BRI countries | 1990-2016 | Driscoll-Kraay Panel Regression | Financial development increases ecological footprints, worsening pollution. |
| Acheampong et al. (2020) | 83 countries | 1980-2015 | System GMM | Financial market development reduces $CO_2$ intensity in developed economies. |
| Aluko and Obalade (2020) | 35 Sub-Saharan African countries | 1985-2014 | Panel AMG, Panel Causality | Financial sectors should fund clean technologies to reduce $CO_2$ emissions. |
| Saud et al. (2020) | One BRI country | 1990-2014 | PMG, FMOLS | Financial development reduces environmental quality. |
| Fang et al. (2020) | China | 1990-2016 | ARDL-ECM | Financial expansion increases $CO_2$ emissions. |
| Ahmad et al. (2020) | 90 BRI countries | 1990-2017 | Panel Causality Tests | Financial development worsens environmental quality. |
| Atsu et al. (2021) | South Africa | 1970-2019 | ARDL, DOLS, FMOLS | Financial development reduces $CO_2$ emissions. |
| Usman et al. (2021) | 15 countries with the highest $CO_2$ emissions | 1990-2017 | AMG | Financial development prevents environmental degradation. |
| Nguyen et al. (2020) | 13 G-20 countries | 2000-2014 | OLS-FE, FMOLS | Financial development causes pollution. |
| Usman and Hammar (2021) | APEC countries | 1990-2017 | STIRPAT, Panel Causality | Financial development significantly improves environmental quality. |
| Xu et al. (2021) | Chinese provinces | 2001-2017 | Panel Regression Analysis | Financial development impacts environmental quality positively in low-finance regions but varies in high-finance areas. |
| Ahmad et al. (2022) | 17 Developing Countries | 1984-2017 | CS-ARDL | Financial development reduces ecological footprints. |
| Mesagan and Olunkwa (2022) | 18 African countries | 1996-2017 | PMG, Panel DFE | Financial development has a favorable impact on environmental environmental quality in the short term but the natüre of the impact is inverted in the long term. |
| Xu et al. (2022) | B5 countries | 1990-2017 | Panel Cointegration, FMOLS, DOLS | While financial development supports economic growth, it negatively impacts environmental quality. |
| Zafar et al. (2022) | Asian countries | 1990-2018 | Panel Causality Tests | Financial resources reduce $CO_2$ intensity. |
| Andrew et al. (2024) | BRICS | 1995-2017 | CS-ARDL | Financial development reduces $CO_2$ emissions in these countries. |

**Note:** ARDL: Autoregressive Distributed Lag Model, RE: Random Effects, FMOLS: Fully Modified Ordinary Least Squares, DOLS: Dynamic Ordinary Least Squares, OLS: Pooled Ordinary Least Squares Method, CIPS: Cross-Sectionally Augmented IPS (Pesaran-Shin), ADF: Augmented Dickey-Fuller Test, CADF: Cross-Sectionally Augmented Dickey-Fuller Test, VECM: Vector Error Correction Model, PMG: Pooled Mean Group, FE: Fixed Effects, VAR: Vector Autoregression Model

The findings on the connection between financial development and environmental quality are analyzed in three groups as positive, negative and uncertain effects:

Tamazian & Rao (2010), Jalil & Feridun (2011), Sun (2013), Al-Mulali et al. (2015), Omri et al. (2015), Doğan & Şeker (2016), Dar & Asif (2018), Saud et al. (2019), Acheampong et al. (2020), Atsu et al. (2021), Usman et al. (2021), Usman & Hammar (2021), Ahmad et al. (2022), Zafar et al. (2022) show that financial development can reduce $CO_2$ emissions. In these studies, it is stated that financial development encourages investment in environmentally friendly technologies and thus reduces environmental pollution.

Studies such as Boutabba (2014), Abbasi & Riaz (2016), Javid & Sharif (2016), Shahbaz et al. (2016), Abid (2017), Moghadam & Dehbashi (2018), Lu (2018), Nasir et al. (2019), Baloch et al. (2019), Saud et al. (2020), Fang et al. (2020), Ahmad et al. (2020b), Nguyen et al. (2020) and Xu et al. (2022) found that financial development negatively affects environmental quality by increasing $CO_2$ emissions. These findings suggest that financial development harms the environment by increasing economic growth and industrial activities.

Studies such as Zafar et al. (2019) and Mesagan & Olunkwa (2022) indicate that the influence of financial development on $CO_2$ emissions may vary across countries. Öztürk & Acaravcı (2013), on the contrary, conclude that the impact of financial development on environmental quality is insignificant. Charfeddine & Khediri (2016) found an inverted U-shaped relationship between the aforementioned variables.

As can be seen from the table, the studies were generally conducted in different regions and time periods using panel data analyses, regression analyses and causality tests.

The results show that while a myriad of work shows a positive relationship between financial development and $CO_2$ emissions, some others differ in conclusion. However, most studies suggest that financial development can improve environmental quality, especially in the long run. These studies highlight that the effects of financial development may also vary according to economic conditions and policies implemented.

Green technological innovation is a broad concept that includes the development of processes, technologies and products that aim to reduce energy consumption, raw material use and environmental pollution (Guo et al., 2018, p. 2). Table 2 summarizes the studies investigating the interdependence between green technological innovation and environmental quality over country samples.

**Table 2.** The Relationship Between Green Technological Innovation and Environmental Quality

| Authors | Sample Group | Time Period | Methods | Research Findings |
|---|---|---|---|---|
| Carrión-Flores and Innes (2010) | USA (127 manufacturing industries) | 1989-2004 | Panel GMM | Innovation has a limited effect on reducing $CO_2$ emissions in the long term. |
| Guo et al. (2018) | China (30 provinces) | 2009-2015 | Hausman Test, FE-RE | Environmental regulations significantly impact green technological innovation. |
| Sun et al. (2019) | 71 developed and developing countries | 1990-2014 | SFA | Green technological innovations help developed countries reduce $CO_2$ emissions and optimize renewable energy use. |
| Du et al. (2019) | 71 economies | 1996-2012 | Panel Threshold Model, Hausman Test, FE | The impact of green technological innovations on $CO_2$ emissions differs according to the income levels of countries., While the aforementioned independent variable increase emissions in low-income countries, the effect is opposite when it comes to high-income countries. |
| Hashmi and Alam (2019) | OECD countries | 1999-2014 | Panel GMM STIRPAT Model, Driscoll-Kraay Panel Regression, FE-RE | Increases in eco-friendly patents reduce $CO_2$ emissions. |
| Khattak et al. (2020) | BRICS countries | 1980-2016 | CCEMG Technique, AMG, Johansson-Fisher Panel Cointegration | Innovation activities have failed to reduce $CO_2$ emissions in China, India, |

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|---|---|---|---|---|
| | | | | Russia, and South Africa, except in Brazil. |
| Wang et al. (2020) | Chinese provinces | 1997-2015 | Panel Vector Autoregression (VAR) | Green investment must support technological innovation to reduce $CO_2$ emissions effectively. |
| Shan et al. (2021) | Turkey | 1990-2018 | STIRPAT Model, ARDL, Granger Causality | Both green technological innovation and renewable energy use reduce $CO_2$ emissions in the short and long term. |
| Saqib (2022) | 18 advanced economies | 1990-2019 | Panel Regression, ARDL (NARDL), PMG, Granger Causality | $CO_2$ emissions decrease with positive technological innovation shocks and increase with negative shocks. |

**Source:** This table is compiled of the authors of the existing reviewed literature.
**Note:** CCEMG: Common Correlated Effects Mean Group, SFA: Stochastic Frontier Analysis

It is seen in the table that the findings on the connection between green technological innovation and environmental quality are grouped under positive, negative and uncertain effects.

Shan et al. (2021) concluded that green technological innovation and renewable energy use reduce $CO_2$ emissions in Turkey. Studies such as Carrión-Flores & Innes (2010), Guo et al. (2018), Sun et al. (2019), Hashmi & Alam (2019), Wang et al. (2020), Saqib (2022), Obobisa et al. (2022) show that green technological innovation betters environmental quality and lowers $CO_2$ emissions.

Khattak et al. (2020) found that green technological innovations failed to reduce $CO_2$ emissions in BRICS countries, except Brazil.

Du et al. (2019) found that the influence of green technological innovations on $CO_2$ emissions differs according to the income levels of countries, in which for low-income countries they bear a facilitative nature for $CO_2$ emissions, whereas the impact is opposite when it comes to high-income countries.

Table 3 summarizes the studies investigating the interdependencies between financial development and green technological innovation with environmental quality.

**Table 3.** The Interdependencies Between Financial Development, Green Technological Innovation, and Environmental Quality Quality

| Authors | Sample Group | Time Period | Methods | Research Findings |
|---|---|---|---|---|
| Ibrahiem (2020) | Egypt | 1971-2014 | ARDL, FMOLS, DOLS, Toda-Yamamoto | Technological innovations reduce $CO_2$ emissions, while financial development increases them. |
| Lv et al. (2021) | 30 provinces of China | 2003-2017 | Panel GMM, DEA-SBM model, GML index | Environmental regulation is integrated with financial development and green technological innovation. |
| Zhou & Du (2021) | Chinese provinces | 2003-2018 | Panel Threshold Model, DEA Model | Improvements in environmental regulations enhance the impact of energy and environment-focused technological advancements. |
| Liao et al. (2023) | China | 1970-2021 | ARDL, NARDL, ADF | Financial development and technological innovation reduce environmental pollution. |
| Özkan et al. (2023) | China | 1990-2018 | DARDLS | Financial development and green technological innovation prevent environmental degradation by enhancing carbon efficiency in the long term. |
| Ullah et al. (2023) | 14 developed countries | 1990-2018 | Westerlund Cointegration Test, | The significance of technological innovations, |

| | | | | |
|---|---|---|---|---|
| | | | Panel AMG, D-H Causality Test | renewable energy use, and financial development in improving environmental quality is highlighted. |
| Hasan and Du (2023) | 30 provinces of China | 1995-2020 | Panel System GMM | In regions with low economic prosperity and strict environmental regulations, green technological innovation and the financial sector increase the ecological footprint. |
| Aytun et al. (2024) | 19 middle-income countries | 1980-2016 | CS-ARDL | Financial development lowers the ecological footprint, while technological innovations are found to bear no statistical significance over the aforementioned dependent variable. |

The studies presented in the table reveal that the nature of the impacts of financial development and green technological innovation on environmental quality can vary. These effects differ in terms of the sample group, time period and methods used in the studies. For example, Liao et al. (2023) and Özkan et al. (2023) examine this relationship in the context of a single country, while Lv et al. (2021), Zhou and Du (2021), Ullah et al. (2023), Hasan and Du (2023) and Aytun et al. (2024) analyze this relationship over multi-country samples. In terms of time dimension, Ibrahiem (2020), Liao et al. (2023) and Özkan et al. (2023) analyzed annual time series, while Lv et al. (2021), Ullah et al. (2023), Hasan and Du (2023) and Aytun et al. (2024) used panel data analysis methods. This study also categorized vis-a-vis the nature of the effects, the findings on the interdependencies between financial development and green technological innovation indicators with environmental quality.

Studies such as Ibrahiem (2020), Liao et al. (2023), Özkan et al. (2023) demonstrate that financial development and green technological innovation simultaneously can improve environmental quality, as while the former factor reduces $CO_2$ emissions, the latter can support environmental sustainability.

Khattak et al. (2020) and Hasan and Du (2023) propose that green technological innovation and financial development can have an unfavorable effect over environmental quality in selected regions.

A myriad of research such as Lv et al. (2021), Zhou and Du (2021), Ullah et al. (2023), Aytun et al. (2024) demonstrate that the influence of these aforementioned dependent variables on environmental quality are multifaceted, which can differ based on the economic and environmental conditions of the countries studied.

This study employs a financial development index constructed by us to evaluate the impact of financial development on environmental quality. Unlike traditional indicators frequently used in the literature, our index allows for a more comprehensive and detailed analysis of financial development, incorporating aspects such as financial depth, access, and efficiency. This approach enables a more precise assessment of the performance and sustainability of financial systems. The research utilizes a dataset spanning 22 countries from 2009 to 2021, providing a broader and more current perspective compared to many existing studies. This diversity and the time frame of the dataset allow for a unique comparative analysis. The necessity for this study arises from the limited academic work that simultaneously examines the impacts of financial development and green technological innovation on environmental quality. Additionally, the scarcity of studies focusing on the effects of informational globalization on environmental quality and the need to understand changes in environmental quality over time using dynamic panel data analysis are key motivations for conducting this research. In these aspects, our study stands out from others in the literature in terms of both the methodology employed and the breadth of analysis.

The study looks further than conventional financial development variables and develops a more comprehensive index that bears a more overarching view on the multifaceted nature of financial development and its subsequent influence over environmental sustainability. Additionally, the Net Foreign Direct Investment (FDI) seldom focused on in the existing research, is believed to be one of the value-added dimensions of this work that contributes to this comprehensive evaluation. The impact of foreign direct investment (FDI) on financial development is recognized as a vital factor to support economic growth and development, especially in developing countries (Gebrehiwot et al. (2016), Win et al. (2019), Bayar and Gavriletea (2018), Henri et al. (2019), Majeed et al. (2021). These investments strengthen the economic structures of countries by promoting capital accumulation, creating new job opportunities and contributing to the deepening of financial markets. In this context, the use of net FDI offers an important methodological improvement in assessing the effects of FDI on financial development. Research shows that assessing only FDI inflows can be misleading and may not fully reflect the true economic impact of investments. Studies such as Nissan & Niroomand (2010) and Desbordes & Wei (2017) emphasize that calculating net FDI, including both foreign capital inflows and outflows, allows for a more accurate assessment of a country's actual investment performance and sustainability. This approach can help policymakers and economists develop more informed and effective policies in shaping the investment decisions and strategies of multinational corporations. Hence, the paper proposes the use of net FDI as a methodological framework that aims to achieve more reliable and precise results in assessing FDI impacts on financial development. This will not only be a theoretical contribution but also a guide for applied economic policies. Finally, embedding informational globalization into the explanatory model and demonstrating its positive impact is believed to make a unique contribution to the field.

To conclude, this chapter reviews the existing work focusing on how financial development and green technological innovation impact environmental quality through various methodologies utilized, where the findings demonstrate that the aforementioned independent factors have compounded and dynamic influence over the explained variable. Thus, it can be put forward that the optimal allocation of financial resources and green technological innovations bear a non-negligible importance on the developing and execution of sustainable environmental policies. Therefore, in the process of developing and implementing sustainable environmental policies, the proper channeling of financial resources and green technological innovations is of great importance.

## 3. DATA AND METHODOLOGY

### 3.1. Data

In this study, we analyze the interplay between financial development, patent applications, renewable energy usage, gross growth rate, trade openness, informational globalization, and CO2 emissions using annual data from 2009 to 2021 across 22 selected countries: USA, Australia, Austria, Brazil, China, Finland, France, Colombia, India, Iceland, Japan, Mexico, Norway, Poland, Portugal, Russia, Greece, South Africa, Ireland, Italy, Sweden, and Türkiye. Data availability dictated the selection of starting and ending years for each country. Initially, we considered all countries listed in the World Bank Statistical Database (266 countries), narrowing down to 192 countries where the Financial Development Index data is available in the IMF Database. To thoroughly address the research question, “To what extent do financial development and green technological innovation affect environmental quality?”, we focused on a select group of 22 countries, chosen based on data quality and availability.

We employed the System Generalized Method of Moments (System GMM), as proposed by Arellano-Bover/Blundell-Bond, an approach well-suited for dynamic panel data structures that effectively addresses endogeneity issues in lagged dependent variables.

Specifying the limitations of the empirical findings of the study is thought to support the evaluation of the results in a broader perspective. In this context, the limitations of the study can be explained more compactly as follows:

*1. Methodological Justification and Country Selection:* The System GMM estimator used in dynamic panel data analysis is a powerful method for managing endogenous variables. However, the orthogonal deviations method is preferred in this study due to the limited time dimension. On the other hand, ignoring spatial effects led to the omission of regional dependencies in the analysis. This omission may miss cases where the results may be sensitive to spatial relationships.

The country sample, albeit limited to 22 due to data constraints, includes a diverse array of economies from different income levels and regions. This diversity enriches the analysis but also limits the generalizability of findings. Missing data points from some countries necessitated this restriction, potentially affecting the breadth of empirical insights.

*2. Data Compilation and Period Selection:* For the panel analysis, the period between 2009-2021 was preferred. There are two main reasons for this choice: First, although renewable energy indicators for Türkiye have started to be published since 2007, 2009 was taken as the beginning of the analysis due to the fact that this period coincided with the economic crises. Secondly, the most recent compilation of green technological innovation data is 2021, which has been influential in determining the boundaries of the analysis period.

The variables used in this model are selected by considering various theoretical and empirical findings in the field. First, the vitality of financial development on macroeconomic sustainability, and thus environmental performance needs to be emphasized. Global capital flows can improve this via facilitating the adoption of eco-friendly technologies and the employment of sustainable development strategies. Therefore, identifying the existence and nature of the influence of financial development on $CO_2$ emissions bears significance in environmental policy-making (Ahmad et al., 2020).

*3. Rationale Behind Using Patent Applications and Other Variables:* Patent applications, sourced from the WIPO database, serve as a proxy for technological innovation. Although this dataset predominantly captures general patents, it may underrepresent more specific green technology innovations, a limitation acknowledged in our study. Other variables like renewable energy consumption, trade openness, and informational globalization, derived from various credible databases, provide a multi-faceted view of the factors influencing environmental outcomes.

This work aims to contribute both methodologically and practically by providing nuanced insights into how financial development and green technological innovations influence CO2 emissions. By integrating green technology indicators such as patent applications and renewable energy usage, we highlight the potential of these innovations to bolster environmental sustainability.

This research not only enriches the existing body of knowledge but also offers tangible policy recommendations, advocating for enhanced support for green technologies and increased investment in renewable energy projects. The construction of a financial development index using PCA, which includes various financial dimensions like FDI and market depth, further aids in depicting the multifaceted impact of financial development on environmental quality.

This comprehensive approach ensures that the study's findings are robust and provide a reliable foundation for policymakers to develop strategies that align economic growth with environmental sustainability goals.

How to capture innovation has been frequently assessed in the field, where even though R&D expenditures are considered as a standard indicator, some studies have failed to show their direct impact on technological development (Li et al., 2021). In line with this finding, the number of patent applications can be regarded as a better-suited yardstick for innovation as these bear significance when it comes to signaling the innovative sub-processes that have the potential to advance into environmental technologies that lower $CO_2$ emissions (Hashmi and Alam, 2019). Hence, this work captures patent applications as the indicator of green technological innovativeness and regards it as the facilitator of the advancement of eco-friendly technologies. (Oltra, 2010). In addition, informational globalization and trade openness are also considered as indicators affecting environmental quality. In this context, the increasing liberalization of trade in every sense has made it possible for countries to participate more actively in foreign trade and to achieve a stronger integration with the international economy (Oğuztürk ve Çetin, 2012: 151).

The interdependencies between economic growth and $CO_2$ emissions has frequently been assessed in the field, where many concluded that the former having a positive impact on the latter (Baloch et al., 2019; Ibrahim and Vo, 2021). In line with these findings, it can be proposed that policy-makers in sustainable development should embed the environmental spillovers of economic growth into their analyses.

One of the engine powers of economic growth, trade, and the influence of its liberalization throughout the 21st century over the environment have attracted the attention of researchers, especially when it comes to the relationship between the aforementioned variable and CO2 emissions and its subsequent implications on economic growth and environmental sustainability (Managi et al., 2011).

Through reducing the usage of fossil fuel, renewable energy consumption is believed to have a direct negative impact on $CO_2$ emissions, and thus is embedded into this model as a control variable. (Sun et al., 2019).

Informational globalization is captured via the KOF Globalization Index and measures how integrated a country is to the global knowledge network. Le & Ozturk (2020) and Xu et al. (2022), in their respective research, assess the connection between globalization and $CO_2$ emissions and fail to reach a definitive conclusion as these interdependencies vary among countries and developmental levels.

The primary objective of this study is to explore the intricate relationship between financial development, green technological innovation, and CO2 emissions levels. In this context, we aim to construct a comprehensive financial development index using the Principal Component Analysis (PCA) methodology. This index will include selected variables such as Foreign Direct Investment (FDI), Banks and Other Financial Institutions (BFSI), Financial Depth (FD-FMD), Financial Depth - Stock Market (FD-FD), Financial Stability (FD-FI), Financial Markets (FD-FM), and Financial Depth - Financial Stability (FD-FID). These components are pivotal as they encapsulate broad and critical aspects of financial systems that potentially influence both economic growth and environmental sustainability.

Employing PCA allows us to distill these variables into principal components that explain the maximum variance and showcase interrelations within the data, thereby offering a robust measure of financial development. The PCA method efficiently condenses complex and multidimensional data into a simpler, uncorrelated set of indicators, thereby enhancing the interpretability of financial development impacts without significant information loss. This approach is particularly valuable in managing multicollinearity among financial indicators and uncovering underlying patterns that are not immediately evident through direct observation.

Support for using PCA in financial studies is well-documented in the literature. Nadkarni and Neves (2018) commend PCA for its ability to meet the analytical needs of investors by reducing dimensionality and focusing on the most significant factors that affect financial performance. Nobre & Neves (2019) illustrate how PCA can be used to derive key financial performance metrics that are predictive of market success. Additionally, Robu & Istrate (2015) highlight the effectiveness of PCA in identifying crucial components of financial statements that influence company performance. Li & Zhang (2011) further validate the application of PCA in diverse financial contexts by analyzing financial indicators within real estate stock exchanges.

By integrating these indicators through PCA, this study adheres to a proven analytical framework while also applying innovative methods to the analysis of financial development. The resulting index is anticipated to provide nuanced insights into the dynamics of financial development and enhance understanding of its implications for economic and environmental outcomes. The detailed methodology, variable selection, and PCA computational processes are extensively described in the annex of this paper, ensuring both transparency and reproducibility of our findings. This meticulous approach is expected to contribute significantly to the literature, offering both methodological insights and actionable data that can inform policy-making directed at aligning financial development with sustainable environmental practices.

"In line with this objective, and taking into account the existing research, the model is constructed as shown in equation (1) where $CO_2$, i, t, fde, pbs, ye, gdpbuy, dt, bglb and ε represent carbon dioxide emissions, country, time, financial development index, number of patent applications, the percentage of renewable energy consumption, annual GDP growth rate, trade openness, international globalization and random error term, respectively.

$$CO2_{it=}\beta_0 + \beta_1\, yCO2_{it-1} + \beta_2\, fge_{it} + \beta_3\, pbs_{it} + \beta_4\, ye_{it} + \beta_5\, gdpbuy_{it} + \beta_6\, dt_{it} + \beta_7\, bglb_{it} + \varepsilon_{it} \quad (1)$$

In addition, in order to test the connection between the aforementioned variables in question the dependent and independent variables are presented in logarithmic form. Therefore, our basic model is shown as follows;

$$lnCO2_{it=}\beta_0 + \beta_1\, lnCO2_{it-1} + \beta_2\, lnfge_{it} + \beta_3\, lnpbs_{it} + \beta_4\, lnye_{it} + \beta_5\, lngdpbuy_{it} + \beta_6\, lndt_{it} + \beta_7\, lnbglb_{it} + \varepsilon_{it} \quad (2)$$

Basic information on the dataset used in the analysis is reported in Table 4. Data on green technological innovation were collected from KOF, WB and WIPO, while data on environmental quality were collected from BP.

**Table 4.** Basic Information on the Variables Used in the Analysis

| Variable | Description | Abbreviation | Period | Source |
|---|---|---|---|---|
| Carbon Dioxide Emissions | Metric tons per capita | $CO_2$ | 2009-2021 | BP |
| Financial Development Index | Financial development | fde | 2009-2021 | KOF |
| Number of Patent Applications | Patent applications | pbs | 2009-2021 | WIPO |
| Renewable Energy | Share of total final energy consumption (%) | ye | 2009-2021 | BP |
| Informational Globalization | Sum of internet bandwidth, international patents, high-tech exports, television access, internet access, and press freedom | bglb | 2009-2021 | WB, KOF |
| GDP Growth | Gross domestic product growth rate (annual %) | gdpbuy | 2009-2021 | WB |
| Trade (Trade Openness) | Share of total exports and imports of goods and services in GDP (%) | dt | 2009-2021 | WB |

**Note:** Series are analyzed by taking their natural logarithms. BP: Statistical Review of World Energy, WB: World Bank, KOF: KOF Globalization Index, WIPO: World Intellectual Property Organization. *$CO_2$ emission data in BP is calculated by converting million tons of $CO_2$ emission data into metric tons per capita. *The financial development index is constructed by the authors.

In the study, trade openness and informational globalization are included in the analysis while investigating the influence of green technological innovation on environmental quality. Taking into account the studies of Lv and Lee (2021) and Zhou and Du (2021), a 22-country model for improving environmental quality is created. Therefore, financial development, number of patent applications, renewable energy, growth rate, foreign trade and informational globalization variables are included in the model. In addition, the percentage of renewable energy consumption and the number of patent applications are taken into account to measure green technological innovation. Trade openness is obtained by the ratio of countries' foreign trade volumes to GDP.

Table 5 reports the main descriptive statistics for the data presented which is analyzed on an annual basis. This table also shows that the panel is a balanced panel. For example, $CO_2$ emission consists of 286 observations while other independent variables consist of the same number of observations. The data in the panel are not logarithmized and represent the descriptive statistics of the raw data. However, the pairwise correlations between variables are presented in the bottom panel of Table 5. Binary correlation values are important in terms of showing whether there is a multicollinearity problem.

**Table 5.** Basic Descriptive Statistics and Correlation Matrix for the Dataset

| | co | fde | pbs | ye | gdpbuy | dt | bglb |
|---|---|---|---|---|---|---|---|
| **Mean** | 7.064428 | 29.65474 | 87753.54 | 1260.858 | 1.997832 | 66.94321 | 168.2762 |
| **Median** | 6.763632 | 30.46487 | 4534.000 | 353.5663 | 2.013070 | 59.18730 | 168.9071 |
| **Maximum** | 18.84654 | 63.06578 | 1542002. | 13049.75 | 24.37045 | 252.2495 | 190.6738 |
| **Minimum** | 1.302797 | 6.644093 | 1.580000 | 7.915138 | -10.14931 | 22.10598 | 122.9014 |
| **Standard Error** | 3.869796 | 12.56333 | 244036.6 | 2694.623 | 4.127326 | 38.69985 | 14.31195 |
| **Skewness** | 0.979955 | 0.298593 | 3.863112 | 3.383080 | 0.117026 | 2.434217 | -0.567175 |
| **Kurtosis** | 3.983187 | 2.273883 | 19.20564 | 13.84297 | 6.146261 | 10.50387 | 3.010279 |
| **Number of Observations** | 286 | 286 | 286 | 286 | 286 | 286 | 286 |

**Correlation**

| | lco | lfde | lpbs | lye | lgdpbuy | ldt | lbglb |
|---|---|---|---|---|---|---|---|
| **lco** | 1.0000 | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **lfde** | 0.3472 | 1.0000 | | | | | |
| **lpbs** | 0.1137 | 0.0058 | 1.0000 | | | | |
| **lye** | 0.2385 | 0.4535 | -0.2681 | 1.0000 | | | |
| **lgdpbuy** | -0.2194 | -0.2114 | -0.1349 | -0.2119 | 1.0000 | | |
| **ldt** | 0.1211 | 0.0070 | -0.5835 | 0.2654 | 0.0535 | 1.0000 | |
| **lbglb** | 0.6067 | 0.4083 | -0.1347 | 0.6247 | -0.3986 | 0.1047 | 1.0000 |

If we examine the VIF values of the independent variables in Table 6; informational globalization (1.92), number of patent applications (1.61), trade openness (1.56), renewable energy (1.97), financial development index (1.33) and gross growth rate (1.25). The VIF values of all variables are less than 5, suggesting that there is no multicollinearity problem. Moreover, since the average VIF value is (1.61), which is less than 5, the hypothesis of potential multicollinearity can be rejected.

**Table 6.** Multicollinearity

| Variable | VIF | 1/VIF |
|---|---|---|
| **lye** | 1.97 | 0.508660 |
| **lpbs** | 1.61 | 0.620616 |
| **ldt** | 1.56 | 0.641765 |
| **lbglb** | 1.92 | 0.520500 |
| **lfde** | 1.33 | 0.749309 |
| **lgdpbuy** | 1.25 | 0.802583 |
| **Mean VIF** | 1.61 | |
| **Variable** | **VIF** | **1/VIF** |

## 3.2. Method

This subsection of the empirical analysis provides a fundamental methodological explanation of the econometric technique used to address the main research question. Since the dataset compiled for the analysis spans multiple countries over a time period greater than one, it is evaluated in panel data form.

Dynamic structures are frequently preferred in panel data models. The key distinction between dynamic and static panel data models is that the former includes lagged variable(s) within the model. As a result, dynamic panel data models can be divided into two categories: autoregressive panel data models and distributed lag panel data models. In distributed lag panel data models, the lagged values of the independent variable(s) are included as independent variables. On the other hand, in autoregressive panel data models, the lagged values of the dependent variable are used as independent variables.

Due to the potential issues they address, autoregressive models are typically prioritized among dynamic models. The autoregressive panel data model with a one-period lag can be formulated as follows (Yerdelen Tatoğlu, 2020: 115-116):

$$Y_{it} = \delta Y_{it-1} + \beta X'_{it} + \mu_i + u_{it} \quad (3)$$

The one-period lag of the dependent variable is shown as an independent variable in Model (3). Another model, which includes no explanatory variables other than the lagged dependent variable, is expressed as follows:

$$Y_{it} = \delta Y_{it-1} + \mu_i + u_{it} \quad (4)$$

Although these models can be estimated mathematically using conventional estimation methods, distortions may occur in the properties of the estimators. The most significant problem is the endogeneity issue caused by the inclusion of the lagged dependent variable as an independent variable in the model. It is generally known in dynamic models that $Y_{it-1}$ is correlated with $u_{it}$ due to past shocks. In addition, in panel data models, $Y_{it}$ is considered a function of $\mu_i$, and $Y_{it-1}$ is also regarded as a function of μi. Therefore, in Model (3), it is concluded that $Y_{it-1}$ is correlated with the error term, which also includes μi. Therefore, the strict exogeneity assumption is violated, making the estimators inconsistent and biased.

In the empirical analyses of this study, the System GMM method, one of the panel data analysis techniques, has been chosen. Considering the compiled dataset, where the cross-sectional dimension is larger than the time series dimension (T = 13 and N = 22), the Arellano and Bover/Blundell and Bond System GMM estimator will be employed.

The Arellano and Bond estimator tends to have weak performance when the ratio of the variance of unit effects to the variance of the error term is very high or when there are too many autoregressive parameters. Additionally, when TTT is small or when working with unbalanced panel data, the first-difference transformation may also be insufficient. For this reason, forward orthogonal deviations or orthogonal deviations are recommended as alternative transformation methods to the first-difference transformation (Yerdelen Tatoğlu, 2020: 138). Arellano and Bover (1995) propose the orthogonal deviations method as an efficient instrumental variable estimator for dynamic panel data models. This method is obtained by taking the difference between the average of all future values of a variable and its current value.

## 4. ANALYSIS AND EMPIRICAL FINDINGS

The data set compiled for the analysis of the interdependency between financial development [1]and green technological innovation with environmental quality covers 22 countries and 13 years. For this reason, panel data analysis techniques will be applied. Within this panel data analysis, Dynamic panel data method, System GMM method is used since the analysis is performed with small T and large N type data set.

The validity of the instrumental variables is decided by Sargan and Hansen tests. Sargan's test tests for over-identification restrictions. The probability value for the Sargan and Hansen test is required to be greater than 0.05 (H0: accepted, H1: rejected).

H0: Instrumental variables are valid.

H1: Instrumental variables are not valid.

Since the dataset has T=13 and N=22 (T<N), applying the First Difference GMM estimator may lead to a reduction in the number of observations. This would be inappropriate for unbalanced panels and data sets where T is small and N is large. In this context, the System GMM estimator proposed by Arellano and Bover/Blundell and Bond is considered as a more appropriate method for the data set. This estimator uses forward orthogonal deviations instead of first differences and the results obtained are presented below (Yerdelen Tatoğlu, 2020: 138).

**Table 7.** System GMM Estimation Results

| Dependent Variable: Carbon Dioxide Emissions (log) | | | | |
|---|---|---|---|---|
| | Katsayı | Standart Hata | z | P>z |
| Carbon Dioxide Emissiont-1 | 1.163696* | .0757454 | 15.36 | 0.000 |
| Financial Development Index (log) | -.0517052* | .0236782 | -2.18 | 0.029 |
| Number of Patent Applications (log) | -.0103115* | .0028374 | -3.63 | 0.000 |
| Renewable Energy (log) | -.0131414* | .0047505 | -2.77 | 0.006 |
| Control Variables | | | | |
| GDP Growth Rate (log) | .0244605* | .0069568 | 3.52 | 0.000 |
| Trade Openness [(Imports + Exports) / GDP] (log) | -.0573317* | .0160136 | -3.58 | 0.000 |
| Informational Globalization (log) | .0496783* | .0125363 | 3.96 | 0.000 |
| System GMM Estimation Results | | | | |
| Number of Observations | 222 | | | |
| Number of Groups | 22 | | | |
| Number of Instrumental Variables | 18 | | | |
| Wald test | 293.59***<br>[0.000] | | | |
| Arellano–Bond Test for AR(1) Process in First Differences | -4.79<br>[0.000] | | | |

[1] The Principal Component Analysis for the financial development index is presented in tables and graphs in Annex-1, Annex-2, Annex-3 and Annex-4.

| | |
|---|---|
| Arellano–Bond Test for AR(2) Process in First Differences | 0.23 [0.819] |
| Sargan Test for Over-Identification Restrictions | 14.88 [0.188] |

**Note:** The symbols *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Values in square brackets represent p-values. Robust standard errors for the System GMM estimation are reported. The estimation was conducted using the Stata software package with the xtabond2 command.

Table 7 presents the System GMM estimation results obtained, which can be summarized as follows: The one-period lagged value of $CO_2$, which is considered as the dependent variable, is included in the model. One lagged value of $CO_2$ (p>z) is found to be less than the 0.05 significance level (p>z). However, while percentage of gross growth rate and informational globalization are significant and positive, financial development index (fde), number of patent applications (lpbs), renewable energy (ye) and trade openness (dt) are significant and negative. While a one unit change in financial development, number of patent applications, renewable energy and trade openness decreases $CO_2$ emissions by 0.05, 0.01, 0.01 and 0.05, respectively; a one unit change in informational globalization increases $CO_2$ emissions by 0.04. In this case, it is concluded that the financial development index, which we use as financial development variable, and renewable energy and patent applications, which we use for green technological innovation, have an increasing effect on environmental quality. When the GMM result is evaluated in terms of the number of instrumental variables, the number of instrumental variables is (18), which is below the number of groups (22).

When the GMM estimation results are analyzed, it is found that the first order autocorrelation is negative and the presence of first order autocorrelation (0.000) is observed at the 5% significance level. The z probability value of the 2nd order autocorrelation test results (0.819) is greater than 0.05 and it is concluded that there is no autocorrelation. According to the Sargan test results, the probability value (0.188) is greater than 0.05, indicating that the over-identification restrictions are valid.

Arellano and Bover/Blundell and Bond System GMM one- and two-stage estimators are used to test the validity of the instrumental variables used in the generalized moments estimation. According to the Sargan's test statistics, the overidentification restrictions are valid as the probability value is greater than 0.05.

## 5. DISCUSSION

The findings of our study clearly show the potential of green technological innovations and renewable energy consumption to better environmental quality. The model does not reject the hypothesis that financial development and patent application numbers have a significant impact in $CO_2$ emissions reduction, thus leading the author to a conclusion that global trade, and in particular, technological progress can play a significant role in pursuing the environmental sustainability goals. It should be stated that these outputs are in line with the existing work (Charfeddine and Khediri, 2016; Shahbaz et al., 2016) which propose the long-term favorable contributions green technological innovations can form on the environment.

The significance of energy transformation and sustainable energy policies are demonstrated in the model by showing the significant impact renewable energy consumption bears on $CO_2$ emissions reduction, once again emphasizing the need to enhance the usage of renewable energy similar to policy proposals submitted by previous work (Sun et al., 2019; Saud et al., 2019). Nevertheless, the positive correlation between economic growth and $CO_2$ emissions can be re-evaluated through the Environmental Kuznets Curve (EKC) approach, and it can safely be concluded that, for countries above a certain income, the potential unfavorable effect of the aforementioned independent variable on environment can be minimized by the employment of green technologies.

The negative link between financial development and $CO_2$ emissions show that global financial markets can facilitate the spread of green innovation and subsequently, eco-friendly technologies. The positive correlation between patent applications and the interest in green technologies can additionally be proposed as a causal relationship that triggers countries' employment of more environmentally-optimal production technologies. It should also be stated that these findings are consistent with previous work that demonstrate a similar link between innovation and environmental quality.

The environmental impact of trade openness may vary depending on the industrialization level of countries, policy scope, and the amount, availability, and use of energy resources. Therefore, policy makers need to effectively use financial development and green technology innovation indicators in line with their countries' specific environmental and economic goals.

The findings of the study show that while financial development and green technology innovations increase environmental quality, economic growth and informational globalization can increase CO2 emissions. This dual effect necessitates the development of strategies that prioritize environmental sustainability. In this context, comprehensive policy recommendations that are compatible with national and global environmental policies are presented as follows:

Increasing Financial Incentives: Increasing financial incentives is of great importance in order to support companies investing in environmentally friendly technologies. In this context, tax reductions for companies, accelerated depreciation practices for environmentally friendly investments, and the expansion of grant and financial support programs for SMEs are recommended.

Developing Carbon Pricing Mechanisms: Effective implementation of carbon pricing mechanisms is needed to economically incentivize the reduction of CO2 emissions. Expanding global carbon trading platforms can contribute to this goal by allowing low-emission countries to sell their excess carbon credits to high-emission countries.

Expanding Green Finance: Banks and financial institutions should be encouraged to offer low-interest green loans to support environmentally friendly projects, and government support should be increased. The widespread use of green bonds and the integration of fintech solutions can facilitate the financing of environmental projects by enabling more efficient use of financial resources.

Implementing Education Programs: In order to promote energy-saving habits in society and increase environmental awareness, comprehensive education programs and campaigns should be implemented in collaboration with the public and private sectors. These efforts will play an important role in guiding individuals towards sustainable lifestyles.

As a result, the synergy provided by financial development and green technological innovations makes it possible to achieve significant progress in terms of environmental sustainability with well-targeted policies. This holistic approach not only contributes to reducing global CO2 emissions, but also supports the climate action and clean energy goals under the Paris Agreement and the United Nations Sustainable Development Goals.

This study shows that while financial development and green technological innovations facilitate the exploitation of the potential of environmental quality development; economic growth and informational globalization, on the other hand, increase $CO_2$ emissions.

Considering this dual effect, developing strategies that promote environmental sustainability should be a critical priority for policy makers. In this context, comprehensive policy recommendations have been developed that are compatible with both national and global environmental policies;

Increasing financial incentives will be an important step to support companies investing in environmentally friendly technologies. Tax reductions should be provided to encourage companies to invest in these technologies, and practices such as accelerated depreciation for environmentally friendly investments should be put into effect. In addition, grant and financial support programs should be increased to encourage SMEs to develop environmentally friendly technologies. Developing carbon pricing mechanisms can provide a strong economic incentive to reduce $CO_2$ emissions. Global carbon trading platforms should be expanded and low-emission countries should be allowed to sell their excess carbon credits to high-emission counterparties.

The findings of the study are in line with important studies in the literature. For instance, the potential of green technological innovations and renewable energy consumption to improve environmental quality is in line with the positive long-term effects found by Charfeddine and Khediri (2016) and Shahbaz et al. (2016). Moreover, the positive relationship between economic growth and $CO_2$ emissions supports the Environmental Kuznets Curve (EKC) theory, which is often emphasized in the literature. According to this theory, above a certain income level, it is possible to improve environmental quality through the widespread use of green technologies.

In line with the findings of our study, the negative relationship between financial development and $CO_2$ emissions has also been emphasized by studies such as Omri et al. (2015). These studies suggest that global financial markets can facilitate the diffusion of green innovations and the adoption of environmentally friendly technologies. However, these studies usually focus only on the aspects of financial development that support economic growth and do not comprehensively address its specific contributions to green technologies.

Our study, on the other hand, allows for a more detailed and in-depth analysis of this relationship by evaluating the financial development indicator with a multidimensional index. Thus, the role of financial resources in reducing $CO_2$ emissions by channeling them to environmentally friendly technologies is more clearly revealed.

The expansion of green finance plays a critical role in increasing environmental sustainability. Banks and financial institutions should offer low-interest green loans to environmentally friendly projects, and state support should be increased. The widespread use of green bonds at national and international levels will also facilitate the financing of environmental projects. Fintech solutions can play an important role in this process and ensure that financial resources are used more effectively. These policy recommendations should be considered in line with not only national but also global environmental policies. These policies can assist countries in reducing their emissions towards the targets specified in the Paris Agreement and thus contribute to the worldwide ambition of limiting the annual global temperature increase to a 1.5°C. Moreover, the fostering of the eco-innovative environment and renewable energy usage will play a major part in pursuing of the 'Climate Action' and 'Clean Energy' targets of United Nations Sustainable Development Goals (SDGs).

Furthermore, overarching educational programs and campaigns should be implemented by seeking the cooperation of public and private sectors with the aim to increase awareness and facilitate societal energy-saving habits that direct individuals to sustainable lifestyles.

In short, the potential impact of financial development and green technological innovations on a sustainable environment can be harnessed with a widespread employment of these policy recommendations.

## 6. CONCLUSION

The global increase in total greenhouse gas emissions in recent years, the literature on models developed to improve environmental quality using green technological innovation indicators is beginning to gain momentum. In studies on the impact of green technological innovation on $CO_2$ emissions, the appearance in the literature is mixed.

This study examined the effects of financial development and green technological innovations on environmental quality using dynamic panel data analysis using data from 22 countries for the period 2009-2021. The System GMM method used in the study revealed that financial development, patent applications, renewable energy consumption and trade openness significantly reduce $CO_2$ emissions. On the other hand, it was determined that economic growth and informational globalization increase $CO_2$ emissions. These findings show that green technologies and renewable energy use should be expanded for a sustainable environment.

The effect of financial development in reducing $CO_2$ emissions indicates an increase in the capacity to invest in environmentally friendly technologies with a strong financial structure. Investments in green technologies and the increase in patent applications in this direction support the transition to a cleaner energy and production system, which contributes to the reduction of emissions. In addition, the effect of economic growth in increasing $CO_2$ emissions is consistent with the Environmental Kuznets Curve theory. According to this theory, economic growth has a negative impact on the environment up to a certain income level, but after this level is exceeded, environmental quality can be improved by the widespread use of green technologies.

However, some limitations of the study should be taken into consideration. First, spatial effects were ignored in the study. Since spatial dependencies such as geographical proximity and trade relations between countries were not analyzed, the results may not fully reflect these effects. Further studies can provide a more in-depth examination of environmental interactions among countries using spatial panel data methods. Second, because the sample used in this study consists of 22 data points, the generalizability of the findings can be limited. This can be increased in further research, by selecting a larger sample that consists of a more varying set of countries. Moreover, the study takes patent applications as an indicator for innovation, but without making any specifications regarding to which degree these patents were focused on environmental development. A more exhaustive assessment through that perspective can allow for a more accurate overview of the interdependencies between the variables in the model.

The limitation of the time frame plays a preventive role in observing the development of these impacts in a longer period, therefore, future work focusing on a wider span can shed light on the variability of these effects and the longer-term implications. Within this framework, incorporating both historical and current data would allow to more effectively evaluate these interdependencies. Additional suggestions for further research can be listed as: spatial econometric models, where spatial panel data analyses can be used to incorporate the influence of geographical dependencies and their subsequent link towards trade networks, thus, allowing for the uncovering of how regional interactions impact environmental sustainability, as well as diversifying the categories of countries, limiting the focus on eco-related patents and stretching the time spans. Studies conducted on different categories of countries can help demonstrate the nature and amplitude of eco-technologies' influence in various economic and social contexts. Limiting the scope to green-patents will allow the field to more accurately measure the potential impact of innovations, and data stretched to cover a longer time span is believed to bear significant value-add on the literature in capturing the longer-term implications of the variables studied on environmental sustainability.

In conclusion, while this study confirms the positive contributions of financial development and green technological innovations to environmental quality, the limitations and recommendations outlined provide guidance for future research. In order to increase environmental sustainability, policy makers can develop more effective and innovative strategies based on these findings.

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| **Makale ile ilgili notlar** | Bu çalışma etik kurul izni gerektirmemektedir.<br>Makale araştırma ve yayın etiğine uygun olarak hazırlanmıştır.<br>Yazarlar arasında herhangi bir çıkar çatışması bulunmamaktadır.<br>Araştırmanın tüm sürecine yazarlar eşit derecede katkıda bulunmuştur. |

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## APPENDIX

**Appendix 1.** Bartlett Sphericity Test Results

| | | |
|---|---|---|
| **KMO Örneklem Uygunluk Değeri** | | 0.803 |
| **KMO Sample Suitability Value** | **Approximate Chi Square Value** | 413.219 |
| | **Degree of Freedom** | 21 |
| | **Level of Significance** | 0.000 |

**Appendix 2.** Principal Components Analysis: Eigenvalue

| 2009 | Value | Difference | Rate | Cumulative Value | Cumulative Rate |
|---|---|---|---|---|---|
| 1 | 4.449528 | 2.986731 | 0.6356 | 4.449528 | 0.6356 |
| 2 | 1.462797 | 0.893056 | 0.2090 | 5.912325 | 0.8446 |
| 3 | 0.569741 | 0.335302 | 0.0814 | 6.482066 | 0.9260 |
| 4 | 0.234439 | 0.055921 | 0.0335 | 6.716505 | 0.9595 |
| 5 | 0.178518 | 0.073542 | 0.0255 | 6.895024 | 0.9850 |
| 6 | 0.104976 | 0.104976 | 0.0150 | 7.000000 | 1.0000 |
| 7 | 1.02E-14 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2010** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.557469 | 2.954138 | 0.6511 | 4.557469 | 0.6511 |
| **2** | 1.603330 | 1.319805 | 0.2290 | 6.160799 | 0.8801 |
| **3** | 0.283525 | 0.022221 | 0.0405 | 6.444324 | 0.9206 |
| **4** | 0.261304 | 0.069109 | 0.0373 | 6.705628 | 0.9579 |
| **5** | 0.192195 | 0.090017 | 0.0275 | 6.897823 | 0.9854 |
| **6** | 0.102177 | 0.102177 | 0.0146 | 7.000000 | 1.0000 |
| **7** | 4.61E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2011** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.619749 | 3.360139 | 0.6600 | 4.619749 | 0.6600 |
| **2** | 1.259610 | 0.728292 | 0.1799 | 5.879360 | 0.8399 |
| **3** | 0.531318 | 0.236296 | 0.0759 | 6.410678 | 0.9158 |
| **4** | 0.295022 | 0.090855 | 0.0421 | 6.705700 | 0.9580 |
| **5** | 0.204167 | 0.114033 | 0.0292 | 6.909867 | 0.9871 |
| **6** | 0.090133 | 0.090133 | 0.0129 | 7.000000 | 1.0000 |
| **7** | 7.16E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2012** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.642067 | 3.263478 | 0.6632 | 4.642067 | 0.6632 |
| **2** | 1.378589 | 0.987775 | 0.1969 | 6.020656 | 0.8601 |
| **3** | 0.390814 | 0.152994 | 0.0558 | 6.411470 | 0.9159 |
| **4** | 0.237820 | 0.005320 | 0.0340 | 6.649290 | 0.9499 |
| **5** | 0.232500 | 0.114289 | 0.0332 | 6.881790 | 0.9831 |
| **6** | 0.118210 | 0.118210 | 0.0169 | 7.000000 | 1.0000 |
| **7** | 6.26E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2013** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.772709 | 3.704668 | 0.6818 | 4.772709 | 0.6818 |
| **2** | 1.068042 | 0.541481 | 0.1526 | 5.840751 | 0.8344 |
| **3** | 0.526561 | 0.239983 | 0.0752 | 6.367312 | 0.9096 |
| **4** | 0.286578 | 0.071512 | 0.0409 | 6.653890 | 0.9506 |
| **5** | 0.215065 | 0.084020 | 0.0307 | 6.868955 | 0.9813 |
| **6** | 0.131045 | 0.131045 | 0.0187 | 7.000000 | 1.0000 |
| **7** | 9.39E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2014** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.745630 | 3.591443 | 0.6779 | 4.745630 | 0.6779 |
| **2** | 1.154187 | 0.677615 | 0.1649 | 5.899816 | 0.8428 |
| **3** | 0.476572 | 0.151095 | 0.0681 | 6.376388 | 0.9109 |
| **4** | 0.325477 | 0.099916 | 0.0465 | 6.701864 | 0.9574 |

| | | | | | |
|---|---|---|---|---|---|
| **5** | 0.225560 | 0.152985 | 0.0322 | 6.927425 | 0.9896 |
| **6** | 0.072575 | 0.072575 | 0.0104 | 7.000000 | 1.0000 |
| **7** | 5.27E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2015** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.851476 | 3.721174 | 0.6931 | 4.851476 | 0.6931 |
| **2** | 1.130302 | 0.645184 | 0.1615 | 5.981779 | 0.8545 |
| **3** | 0.485119 | 0.216920 | 0.0693 | 6.466897 | 0.9238 |
| **4** | 0.268198 | 0.083293 | 0.0383 | 6.735095 | 0.9622 |
| **5** | 0.184905 | 0.104906 | 0.0264 | 6.920000 | 0.9886 |
| **6** | 0.080000 | 0.080000 | 0.0114 | 7.000000 | 1.0000 |
| **7** | 9.63E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2016** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.861636 | 3.848348 | 0.6945 | 4.861636 | 0.6945 |
| **2** | 1.013289 | 0.496597 | 0.1448 | 5.874925 | 0.8393 |
| **3** | 0.516692 | 0.221344 | 0.0738 | 6.391617 | 0.9131 |
| **4** | 0.295348 | 0.078588 | 0.0422 | 6.686965 | 0.9553 |
| **5** | 0.216760 | 0.120485 | 0.0310 | 6.903725 | 0.9862 |
| **6** | 0.096275 | 0.096275 | 0.0138 | 7.000000 | 1.0000 |
| **7** | 6.78E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2017** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.814147 | 3.768335 | 0.6877 | 4.814147 | 0.6877 |
| **2** | 1.045811 | 0.536536 | 0.1494 | 5.859958 | 0.8371 |
| **3** | 0.509275 | 0.181272 | 0.0728 | 6.369233 | 0.9099 |
| **4** | 0.328003 | 0.112756 | 0.0469 | 6.697236 | 0.9567 |
| **5** | 0.215247 | 0.127730 | 0.0307 | 6.912483 | 0.9875 |
| **6** | 0.087517 | 0.087517 | 0.0125 | 7.000000 | 1.0000 |
| **7** | 6.98E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2018** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.836433 | 3.831448 | 0.6909 | 4.836433 | 0.6909 |
| **2** | 1.004985 | 0.433323 | 0.1436 | 5.841417 | 0.8345 |
| **3** | 0.571661 | 0.220509 | 0.0817 | 6.413079 | 0.9162 |
| **4** | 0.351152 | 0.187300 | 0.0502 | 6.764231 | 0.9663 |
| **5** | 0.163852 | 0.091935 | 0.0234 | 6.928083 | 0.9897 |
| **6** | 0.071917 | 0.071917 | 0.0103 | 7.000000 | 1.0000 |
| **7** | 6.17E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2019** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.826987 | 3.709193 | 0.6896 | 4.826987 | 0.6896 |
| **2** | 1.117795 | 0.596419 | 0.1597 | 5.944782 | 0.8493 |
| **3** | 0.521376 | 0.222009 | 0.0745 | 6.466158 | 0.9237 |
| **4** | 0.299367 | 0.128259 | 0.0428 | 6.765526 | 0.9665 |
| **5** | 0.171108 | 0.107742 | 0.0244 | 6.936634 | 0.9909 |
| **6** | 0.063366 | 0.063366 | 0.0091 | 7.000000 | 1.0000 |
| **7** | 8.30E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2020** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.760099 | 3.635216 | 0.6800 | 4.760099 | 0.6800 |
| **2** | 1.124883 | 0.596156 | 0.1607 | 5.884983 | 0.8407 |
| **3** | 0.528727 | 0.203967 | 0.0755 | 6.413710 | 0.9162 |
| **4** | 0.324760 | 0.138924 | 0.0464 | 6.738470 | 0.9626 |
| **5** | 0.185836 | 0.110142 | 0.0265 | 6.924306 | 0.9892 |
| **6** | 0.075694 | 0.075694 | 0.0108 | 7.000000 | 1.0000 |
| **7** | 2.63E-15 | --- | 0.0000 | 7.000000 | 1.0000 |
| **2021** | **Value** | **Difference** | **Rate** | **Cumulative Value** | **Cumulative Rate** |
| **1** | 4.719351 | 3.672716 | 0.6742 | 4.719351 | 0.6742 |
| **2** | 1.046635 | 0.418964 | 0.1495 | 5.765986 | 0.8237 |
| **3** | 0.627671 | 0.322211 | 0.0897 | 6.393658 | 0.9134 |
| **4** | 0.305461 | 0.069976 | 0.0436 | 6.699118 | 0.9570 |
| **5** | 0.235485 | 0.170088 | 0.0336 | 6.934603 | 0.9907 |
| **6** | 0.065397 | 0.065397 | 0.0093 | 7.000000 | 1.0000 |
| **7** | 6.34E-15 | --- | 0.0000 | 7.000000 | 1.0000 |

**Appendix 3.** Principal Components Analysis: Eigenvectors

| 2009 | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 |
|---|---|---|---|---|---|---|---|
| **DYY** | -0.108937 | 0.681947 | 0.665350 | 0.190719 | 0.145348 | 0.151297 | 6.05E-08 |
| **B_SK** | 0.342428 | -0.462025 | 0.225537 | 0.714948 | 0.283930 | 0.163224 | 8.03E-08 |
| **FD_FD** | 0.456755 | 0.172775 | -0.016467 | 0.072266 | -0.377988 | -0.105435 | -0.775912 |
| **FD_FI** | 0.432937 | -0.121489 | 0.329815 | -0.206451 | -0.606973 | 0.252255 | 0.462988 |
| **FD_FID** | 0.420848 | -0.132388 | 0.346418 | -0.475596 | 0.476420 | -0.481858 | -1.09E-07 |
| **FD_FM** | 0.359301 | 0.444131 | -0.386187 | 0.353932 | -0.028622 | -0.463485 | 0.428490 |
| **FD_FMD** | 0.410617 | 0.249183 | -0.358115 | -0.230590 | 0.398961 | 0.654762 | -1.40E-08 |
| **2010** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.030761 | 0.747878 | 0.156282 | 0.511732 | 0.295880 | 0.256698 | -8.38E-08 |
| **B_SK** | 0.327394 | 0.457625 | 0.508590 | -0.572222 | -0.276655 | -0.144057 | 5.00E-08 |
| **FD_FD** | 0.455770 | -0.121387 | -0.018888 | -0.063323 | 0.376454 | 0.112090 | -0.786696 |
| **FD_FI** | 0.430031 | 0.148686 | -0.427842 | -0.164622 | 0.502818 | -0.372569 | 0.437245 |
| **FD_FID** | 0.413255 | 0.182586 | -0.558526 | 0.065875 | -0.573830 | 0.387699 | 5.35E-08 |
| **FD_FM** | 0.391284 | -0.368299 | 0.395160 | 0.050859 | 0.175080 | 0.576139 | 0.435805 |
| **FD_FMD** | 0.418725 | -0.159481 | 0.255743 | 0.610456 | -0.285377 | -0.528899 | 2.52E-09 |
| **2011** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.050023 | 0.822334 | 0.426995 | 0.364375 | -0.021104 | 0.075663 | -4.30E-08 |
| **B_SK** | 0.337808 | 0.261848 | -0.793968 | 0.386974 | 0.187092 | 0.046737 | 2.26E-08 |
| **FD_FD** | 0.451727 | -0.109180 | 0.135408 | 0.137692 | -0.362234 | -0.043029 | -0.783366 |
| **FD_FI** | 0.424989 | 0.173234 | -0.067693 | -0.336251 | -0.655700 | 0.216636 | 0.441422 |
| **FD_FID** | 0.411476 | 0.261217 | 0.078453 | -0.472155 | 0.359751 | -0.635569 | -6.11E-08 |
| **FD_FM** | 0.379965 | -0.370204 | 0.310692 | 0.585692 | 0.012977 | -0.295564 | 0.437589 |
| **FD_FMD** | 0.430146 | -0.089368 | 0.248371 | -0.139614 | 0.523265 | 0.672311 | 6.82E-08 |
| **2012** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.019395 | 0.802710 | 0.415893 | 0.206028 | 0.371130 | 0.046126 | 1.14E-08 |
| **B_SK** | 0.329097 | 0.390836 | -0.852070 | 0.070095 | 0.083945 | 0.030989 | 1.67E-08 |
| **FD_FD** | 0.449418 | -0.125601 | 0.140163 | 0.366073 | -0.067711 | 0.020669 | -0.789671 |
| **FD_FI** | 0.425860 | 0.137380 | 0.179613 | 0.295577 | -0.593251 | -0.378102 | 0.430390 |
| **FD_FID** | 0.416785 | 0.165486 | 0.180804 | -0.606689 | -0.272684 | 0.569022 | -6.61E-08 |
| **FD_FM** | 0.392472 | -0.362063 | 0.076340 | 0.370191 | 0.461662 | 0.409502 | 0.437246 |
| **FD_FMD** | 0.424550 | -0.098890 | 0.102886 | -0.475555 | 0.459560 | -0.601702 | 2.46E-08 |
| **2013** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.054737 | 0.933818 | 0.284236 | 0.192260 | 0.056645 | 0.063449 | 4.85E-08 |
| **B_SK** | 0.342542 | 0.180431 | -0.821201 | 0.415391 | 0.055467 | 0.010554 | 1.06E-08 |
| **FD_FD** | 0.445255 | -0.039770 | 0.212799 | 0.116532 | -0.335378 | -0.037550 | -0.792095 |
| **FD_FI** | 0.420380 | 0.131531 | -0.023518 | -0.369043 | -0.652777 | 0.233220 | 0.434425 |
| **FD_FID** | 0.411595 | 0.165031 | -0.043189 | -0.532105 | 0.382849 | -0.609737 | -2.63E-08 |
| **FD_FM** | 0.396607 | -0.206726 | 0.416926 | 0.589160 | 0.041818 | -0.305650 | 0.428789 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **FD_FMD** | 0.421888 | -0.081096 | 0.152674 | -0.102318 | 0.553891 | 0.689101 | 4.10E-08 |
| **2014** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.121518 | 0.866381 | -0.015874 | 0.419038 | 0.115338 | 0.213236 | -2.71E-08 |
| **B_SK** | 0.347503 | 0.198159 | 0.856179 | -0.307855 | -0.058664 | 0.093356 | -9.86E-10 |
| **FD_FD** | 0.447206 | -0.019393 | -0.101838 | 0.263715 | -0.318382 | -0.019958 | -0.786097 |
| **FD_FI** | 0.405349 | 0.204425 | -0.368170 | -0.256897 | -0.606147 | 0.205712 | 0.427348 |
| **FD_FID** | 0.402675 | 0.300171 | -0.239360 | -0.296002 | 0.419656 | -0.653245 | 5.17E-08 |
| **FD_FM** | 0.399316 | -0.229763 | 0.173057 | 0.710055 | 0.019608 | -0.231989 | 0.446571 |
| **FD_FMD** | 0.422580 | -0.158298 | -0.183148 | -0.047906 | 0.581359 | 0.650039 | -9.61E-09 |
| **2015** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.068830 | 0.905442 | 0.234929 | 0.272424 | 0.006597 | 0.214447 | -1.78E-09 |
| **B_SK** | 0.336717 | -0.264972 | 0.866157 | 0.037518 | -0.101446 | 0.233421 | 3.24E-08 |
| **FD_FD** | 0.443635 | 0.059467 | -0.180574 | 0.131504 | -0.331770 | -0.067719 | -0.796928 |
| **FD_FI** | 0.410242 | 0.183826 | -0.207968 | -0.504476 | -0.527467 | 0.240443 | 0.405128 |
| **FD_FID** | 0.406398 | 0.253949 | 0.153869 | -0.412335 | 0.464396 | -0.600826 | -1.37E-07 |
| **FD_FM** | 0.418103 | -0.060441 | -0.133125 | 0.690000 | -0.113162 | -0.337835 | 0.448082 |
| **FD_FMD** | 0.420481 | -0.067033 | -0.278074 | 0.080425 | 0.610658 | 0.601669 | 5.20E-08 |
| **2016** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.139205 | 0.922168 | 0.219306 | 0.204372 | 0.158452 | 0.123527 | -1.07E-08 |
| **B_SK** | 0.333637 | -0.154925 | 0.907299 | 0.115977 | -0.144162 | -0.085202 | 4.60E-08 |
| **FD_FD** | 0.440091 | 0.110523 | -0.194519 | 0.148261 | -0.288654 | 0.141171 | -0.794377 |
| **FD_FI** | 0.396161 | 0.316128 | -0.164058 | -0.363005 | -0.593639 | -0.260225 | 0.405348 |
| **FD_FID** | 0.407334 | 0.048584 | 0.057548 | -0.639151 | 0.483539 | 0.431374 | 5.45E-08 |
| **FD_FM** | 0.417813 | -0.089180 | -0.194569 | 0.585596 | 0.025045 | 0.481055 | 0.452391 |
| **FD_FMD** | 0.422134 | 0.056030 | -0.150968 | 0.198975 | 0.532864 | -0.687268 | -1.02E-07 |
| **2017** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.102766 | 0.922311 | 0.301962 | 0.189771 | 0.045912 | 0.097369 | 1.55E-08 |
| **B_SK** | 0.334858 | -0.300088 | 0.801235 | 0.244027 | 0.294925 | 0.096483 | 9.22E-09 |
| **FD_FD** | 0.441347 | 0.121481 | -0.232714 | 0.029643 | 0.280299 | -0.153142 | -0.795865 |
| **FD_FI** | 0.406330 | 0.162583 | -0.138375 | -0.583766 | 0.489456 | 0.224907 | 0.397972 |
| **FD_FID** | 0.403734 | 0.114838 | 0.285113 | -0.434169 | -0.624291 | -0.405313 | 2.15E-08 |
| **FD_FM** | 0.415387 | 0.070082 | -0.285200 | 0.560836 | 0.061998 | -0.463255 | 0.456309 |
| **FD_FMD** | 0.426464 | 0.000273 | -0.175809 | 0.244410 | -0.446310 | 0.726836 | 4.97E-08 |
| **2018** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.112454 | 0.959755 | 0.098458 | 0.022288 | 0.191518 | 0.139123 | 8.79E-10 |
| **B_SK** | 0.331593 | 0.014904 | 0.885041 | 0.144927 | -0.269690 | -0.113096 | 5.38E-08 |
| **FD_FD** | 0.440494 | 0.116767 | -0.236856 | -0.023508 | -0.296307 | 0.129816 | -0.794372 |
| **FD_FI** | 0.399413 | 0.184690 | -0.178143 | -0.661059 | -0.323912 | -0.273379 | 0.397455 |
| **FD_FID** | 0.413917 | -0.159135 | 0.165332 | -0.354451 | 0.654820 | 0.470734 | -3.62E-08 |
| **FD_FM** | 0.416170 | 0.042126 | -0.255466 | 0.531331 | -0.232149 | 0.461040 | 0.459350 |
| **FD_FMD** | 0.423451 | 0.061687 | -0.163021 | 0.364692 | 0.463885 | -0.664919 | 1.21E-07 |
| **2019** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DYY** | -0.083370 | 0.887992 | 0.384321 | -0.024361 | 0.199467 | 0.128206 | 6.11E-09 |
| **B_SK** | 0.332137 | -0.374466 | 0.705840 | 0.270202 | 0.407164 | 0.111620 | 8.06E-08 |
| **FD_FD** | 0.440588 | 0.121652 | -0.255501 | -0.005395 | 0.247168 | -0.175759 | -0.796110 |
| **FD_FI** | 0.411520 | -0.004999 | -0.222932 | -0.643687 | 0.419918 | 0.194876 | 0.390239 |
| **FD_FID** | 0.405826 | 0.047322 | 0.398366 | -0.393558 | -0.613027 | -0.379051 | -3.28E-08 |
| **FD_FM** | 0.411151 | 0.213612 | -0.251688 | 0.533811 | 0.071141 | -0.466947 | 0.462518 |
| **FD_FMD** | 0.430729 | 0.092479 | -0.130637 | 0.268686 | -0.419696 | 0.735199 | -5.90E-08 |
| **2020** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.091310 | 0.875805 | 0.404106 | 0.077050 | 0.213621 | 0.098774 | -2.10E-08 |
| **B_SK** | 0.335761 | -0.392052 | 0.609675 | 0.451371 | 0.378799 | 0.120960 | -7.69E-09 |
| **FD_FD** | 0.443594 | 0.123794 | -0.243834 | -0.050746 | 0.246347 | -0.183196 | -0.794746 |
| **FD_FI** | 0.415083 | 0.000974 | -0.080489 | -0.641679 | 0.460531 | 0.208927 | 0.392091 |
| **FD_FID** | 0.399064 | 0.029473 | 0.492099 | -0.344490 | -0.588360 | -0.364522 | -7.65E-08 |
| **FD_FM** | 0.409661 | 0.211534 | -0.350159 | 0.456009 | 0.032837 | -0.491075 | 0.463296 |
| **FD_FMD** | 0.427531 | 0.135353 | -0.185170 | 0.222224 | -0.436870 | 0.724134 | 6.23E-08 |
| **2021** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC6** | **PC7** |
| **DYY** | -0.130021 | 0.869569 | 0.448363 | -0.054602 | 0.035437 | 0.147234 | -2.72E-08 |
| **B_SK** | 0.334183 | 0.396242 | -0.542368 | 0.572606 | -0.313201 | -0.105729 | -5.79E-08 |
| **FD_FD** | 0.447621 | -0.074968 | 0.209137 | -0.105829 | -0.247666 | 0.221542 | -0.792880 |
| **FD_FI** | 0.414800 | 0.092364 | -0.038912 | -0.635241 | -0.472958 | -0.182447 | 0.396722 |
| **FD_FID** | 0.390704 | 0.171364 | -0.404372 | -0.295886 | 0.696055 | 0.287100 | 5.71E-08 |
| **FD_FM** | 0.411521 | -0.207725 | 0.391866 | 0.363430 | -0.018887 | 0.536237 | 0.462551 |
| **FD_FMD** | 0.420708 | -0.013262 | 0.377464 | 0.186493 | 0.361624 | -0.717495 | -3.32E-08 |

**Appendix -4.** Financial Development Index