The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 27, Pages 228-238

IConTech 2024: International Conference on Technology

# The Role of Digitalization, Industrialization and Green Innovation in the Green Growth Process: A GMM Panel VAR Approach

**Busra Agan**
OSTIM Technical University

**Abstract**: This study aims to investigate the influence of digitalization, industrialization and green innovation development, along with economic and environmental determinants on the green growth process. A dataset containing OECD countries from 2000 to 2022 utilizes a generalized method of moments (GMM) Panel VAR approach. This study also employs the panel Granger causality test. The findings of this study indicate that there is a significantly positive effect of green innovation development on the green growth process. There exists a significant positive association and causality between digitalization, industrialization and green growth. These findings carry substantial policy implications for the development and implementation of strategies that promote green growth and environmental-friendly innovation. Consequently, policymakers should prioritize integrating green innovation and adaptive measures in their sustainable development agendas to foster a greener, more resilient future. Therefore, this study offers important insights into the dynamic interplay among digitalization, industrialization, green innovation, and green growth, thus providing policymakers with actionable strategies to navigate the intersection of technological advancement and environmental sustainability toward a greener future. Moreover, this study also contributes to the existing literature by providing a nuanced understanding and actionable policy recommendations for policymakers and stakeholders seeking to navigate the evolving landscape of green growth amidst rapid technological and industrial transformations.

**Keywords:** Green Growth, Green innovation, Digitalization, Industrialization, GMM P-VAR model.

## Introduction

In recent years, the global community has increasingly recognized the importance of sustainable development to secure a viable future for future generations. Central to this pursuit is the concept of green growth, which harmonizes economic expansion with environmental preservation. This balance is not only desirable but necessary, given the pressing challenges posed by climate change, resource depletion, and ecological degradation.

Green growth extends beyond merely balancing economic expansion with environmental conservation. It emphasizes a high-quality, low-carbon, energy-efficient growth model that prioritizes value creation through clean technologies, natural infrastructure, and market innovation in environmental goods and services. As stated by the widely recognized Porter hypothesis (Porter, 1991), the advancement of green growth and green technology is closely tied to the enforcement of environmental protection regulations. Nonetheless, the evolution of green technologies and climate change adaptation is affected by a range of factors including economic, social, and political influences (Agan & Balcilar, 2022; Allan et al., 2013; Bilal et al., 2022; Hotte, 2020; Hussain et al., 2022; Lv et al., 2021a, 2021b; Nguyen et al., 2022; Song et al., 2024). The process of green growth is intricately linked to the evolving landscape of technology and industry.

Digitalization, industrialization, and green innovation play pivotal roles in shaping the pathways to sustainable development, as outlined in a recent study by Adeshola et al. (2023). Digitalization, marked by the integration of digital technologies across industries, drives efficiency and innovation. It fosters the creation of smart, interconnected systems that can lead to more sustainable practices and the optimization of resource use. Digitalization plays a critical role in this process, as it facilitates the transformation of traditional industries through the adoption of smart technologies. The integration of digital solutions in areas such as manufacturing, logistics, and energy management has been shown to improve efficiency and reduce waste. For instance, Murray et al. (2020) highlight how digitalization in the manufacturing sector can streamline production processes, optimize resource use, and ultimately contribute to more sustainable practices.

In the same vein, industrialization, traditionally associated with economic expansion, has been redefined in the context of green growth. Modern approaches emphasize cleaner, more sustainable industrial practices that incorporate circular economy principles. Studies such as Gao et al. (2024) and Raihan et al. (2022) demonstrate how industrial processes can be redesigned to minimize waste, reduce carbon emissions, and enhance resource efficiency, thereby aligning with the goals of green growth.

Furthermore, green innovation is another key driver of green growth, encompassing the development of products, technologies, and processes that minimize environmental impact while supporting economic advancement. (Song et al., 2024) investigate the asymmetric nexus between green technology innovation and energy efficiency, and the findings show that green technology innovation improves energy efficiency. Another study by Xu et al. (2021) analyzes the effects of environmental regulation and foreign direct investment on green technology innovation based on the 13 Chinese manufacturing sectors. Their findings indicate insights into shaping environmental regulations and managing foreign direct investment (FDI) inflows into China to enhance green technology innovation. Similarly, Kuang et al. (2022) examine the relationship between green technology innovation, renewable energy, and CO2 emissions and conclude that the creation of green technology innovation has positive externalities. In this extended introduction, examples of studies in the literature such as those by Appiah et al. (2023), He et al. (2023), Khan et al. (2023), Liu et al. (2023), Pérez-Suárez & López-Menéndez (2015), Wang et al. (2023) provide a contextual foundation for your research. These references illustrate the current trends and advancements in digitalization, industrialization, and green innovation within the broader framework.

Numerous studies have increasingly focused on micro-level green technology innovations. For instance, Cai & Zhou (2014) examine the key factors influencing green innovations in Chinese firms. Their findings suggest that a firm's integrative capability, or its ability to implement effective and eco-friendly strategies, plays a significant role in green innovation. Similarly, Xue et al. (2023) investigate the regional variation and distribution of green patents in Chinese cities, discovering that regional disparities in urban green innovation are minimal and contribute to economic differences across cities. Additionally, another study by Khanh Chi, (2022) analyze on farm households in Vietnam explores the factors driving green agricultural innovation and finds that environmental awareness is a crucial motivator for enhancing green production innovation. Additionally, Wang et al. (2023) investigate the impact of eco-innovation on CO2 emissions and its associated causal factors using the quantile regression method. Their results indicate that eco-innovation leads to a reduction in CO2 emissions in OECD countries. This aligns with the findings of Yu and Du (2019), whose empirical analysis also supports the notion that innovation significantly lowers emission levels.

Against this backdrop, this study employs a Generalized Method of Moments (GMM) Panel Vector Autoregression (VAR) approach to investigate the dynamic relationships between digitalization, industrialization, and green innovation development with economic and environmental determinants of the green growth process. This methodological framework enables a detailed examination of how these factors interact and influence one another over time. By investigating these relationships, the study aims to provide valuable insights for effective policies and strategies that promote sustainable development while fostering economic prosperity. The empirical findings of our study underscore the role of digitalization, industrialization, green innovation development, CO2 emissions, economic growth, and the environmental tax in OECD countries. This study proceeds with the data description and methodology are presented. Later, this study reports the empirical results and discussion. Lastly, this study ends with the conclusions and recommendations.

## Data and Methodology

### Data

This study utilizes annual data from 2000 to 2022 for 38 OECD countries. These countries and periods are chosen based on the data availability. The objective of this study is to investigate the effects of digitalization, industrialization, green innovation development, and carbon dioxide (CO2) emissions with causal factors of economic growth and environmental-related tax on the green growth process. In the field of environmental economics, the Environmental Kuznets Curve (EKC) framework emerges as a crucial empirical model for exploring renewable energy and eco-friendly technology, as demonstrated by research undertaken by Gu et al. (2023), Khan et al. (2021), Kostakis et al. (2023), Shah et al. (2023a), (2023b), Voumik et al. (2022), Xu et al. (2024), Zhang et al. (2022). Table 1 presents the definition and sources of the variable considered.

Table 1. Data descriptions

| *Variable* | *Definition* | *Source* |
|---|---|---|
| Green Growth Index (GGI) | The ratio of GDP per capita to total primary energy consumption | World Development Indicators (WDI) |
| Digitalization (DIG) | Individuals using the Internet (% of population) | WDI |
| Industrialization (IND) | Industry (including construction), value added (current US$) | WDI |
| Green Innovation Development (GTD) | Development of environment-related technologies, % all technologies (%) | OECD statistics |
| Carbon dioxide emissions (CO2) | CO2 emissions (metric tons per capita) | WDI |
| Economic Growth (GDP) | GDP per capita (current US$) | WDI |
| Environmentally related tax (TAX) | Environmentally tax revenues | OECD statistics |

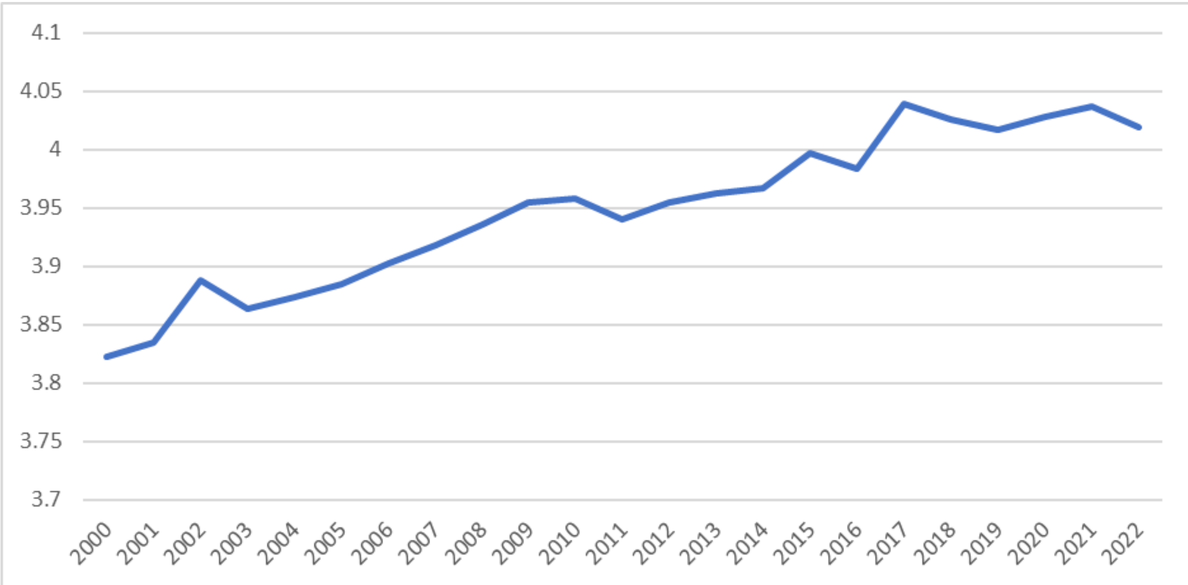


Figure 1. Time series plot of the average green growth index, 2000–2022.

Figure 1 illustrates a time series plot of the average green growth index across 38 OECD countries from 2000 to 2022. The global sustainable competitiveness index reaches a high level in the US, Japan, and Germany in 2022.

## Methodology

In this study, we investigate the impact of digitalization, industrialization, green innovation development, and carbon dioxide ($CO_2$) emissions on green growth process in OECD countries using a panel vector autoregression (PVAR) model within the Generalized Method of Moments (GMM) framework. Since Sims (1980) introduced time-series vector autoregression (VAR) models as an alternative to multivariate simultaneous equation models in macroeconomic econometrics, they have become prominent. In a VAR system, all variables are typically treated as endogenous.

The PVAR methodology, introduced by Love and Zicchino (2006) and Holtz-Eakin et al. (1988), combines the conventional VAR approach with a panel-data approach that incorporates unobserved individual heterogeneity. This allows for recognizing dynamic differences within the groups of countries being studied. Utilizing the PVAR approach enables comprehensive capturing of temporal variations in both coefficients and shock variances. Given the dataset's properties, which involve multiple entities observed across various time periods, PVAR modeling is more appropriate for our analysis.

Previous literature has predominantly focused on investigating the influence of green growth process on sustainable development. Several empirical studies (Chen et al., 2019; Mamkhezri & Khezri, 2023; Mitić et al., 2023; Mongo et al., 2021; Rahman et al., 2022; Sezgin et al., 2021; Shahzad et al., 2020; Tsimisaraka et al., 2023; Yao et al., 2020) aim to investigate the correlation between green growth, CO2 emissions, renewable energy sources and their potential repercussions on sustainable development objectives. We employ an empirical model to investigate the effects of digitalization, industrialization, green innovation development, carbon dioxide (CO2), economic growth, and environmental-related tax on green growth process. Our extendend model is estimated as follows:

$$LGGI_{it} = \alpha_i + \beta_{1i}LDIG_{it} + \beta_{2i}LIND_{it} + \beta_{3i}LGTD_{it} + \beta_{4i}LCO2_{it} + \beta_{5i}LGDP_{it} + \beta_{6i}LTAX_{it} + \varepsilon_{it}$$

where GGI represents the green growth index. DIG denotes digitalization, while IND is the industrialization. GTD represents green innovation development, while CO2 shows carbon dioxide emissions, GDP is the economic growth, and TAX is the environmental-related tax. All variables are taken their natural logarithm level. The error term is denoted by $\varepsilon$, where $i$ and $t$ respectively represent countries and time.

## Empirical Results

The main descriptive statistics for all variables are displayed in Panel A of Table 2. It shows that environmental-related tax exhibits the smallest mean value, whereas industrialization has the highest annual mean. The green innovation developments are more volatile. In a normal distribution, the skewness is expected to be approximately zero, and the kurtosis should be close to three. Therefore, the distribution of LGGI and LGTD series is positively skewed, while LDIG, LIND, LCO2, LGDP, and LTAX are negatively skewed. Also, the distribution of all series shows excess kurtosis as leptokurtic. The Pearson correlation estimates are represented in Panel B of Table 2. There is a positive correlation coefficient between the variables. However, the variable pairs of LTAX and LGGI is negatively correlated.

Table 2. Descriptive statistics and correlation coefficients

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Panel A:** Descriptive Statistics* | | | | | | | |
| | Mean | Std. Dev. | Max. | Min. | Skewness | Kurtosis | |
| LGGI | 3.948 | 0.5568 | 5.5087 | 2.8321 | 0.39749 | 3.8063 | |
| LDIG | 1.776 | 0.2510 | 1.9991 | 0.3424 | -2.1597 | 8.3602 | |
| LIND | 10.907 | 0.7145 | 12.620 | 9.1507 | -0.1085 | 3.6079 | |
| LGTD | 4.223 | 2.1860 | 10.696 | 0.2337 | 0.19498 | 3.7374 | |
| LCO2 | 0.834 | 0.2522 | 1.3948 | 0.0797 | -0.5597 | 3.4011 | |
| LGDP | 4.432 | 0.2696 | 5.0825 | 3.4385 | -0.8215 | 3.8028 | |
| LTAX | 0. 331 | 0.2017 | 0.7291 | -1.0012 | -1.7568 | 8.7773 | |
| ***Panel B:** Correlation Matrix* | | | | | | | |
| Probability | LGGI | LDIG | LIND | LGTD | LCO2 | LGDP | LTAX |
| LGGI | 1.0000 | | | | | | |
| LDIG | 0.2138* | 1.0000 | | | | | |
| LIND | 0.9494* | 0.2631* | 1.0000 | | | | |
| LGTD | 0.0930* | 0.6557* | 0.2013* | 1.0000 | | | |
| LCO2 | 0.1115* | 0.5581* | 0.1251* | 0.2462* | 1.0000 | | |
| LGDP | 0.6766* | 0.3176* | 0.7231* | 0.3030* | 0.3870* | 1.0000 | |
| LTAX | -0.3280* | 0.2043* | -0.2512* | 0.1531* | 0.1151* | -0.1431* | 1.0000 |

Note: * denotes significance at 5% level.

As an initial assessment, the outcome of the Pesaran (2004) cross-sectional dependence (CSD) test for our benchmark model reveals no cross-sectional dependence among the variables. Therefore, we proceed with analyzing panel unit root tests conducted by Levin et al. (2002) and Breitung (2000) to ascertain the stationarity characteristics of the variables.

The results of the panel unit root tests are presented in Table 3. We determine that there are no unit root concerns in either test at both constant and constant with trends levels. The subsequent step in the analysis involves presenting the impulse response functions and variance decomposition obtained from the panel VAR. Selecting the appropriate lag length is critical in panel VAR analysis, and it is determined based on selection criteria in the estimated models.

Table 3. Panel unit root test results

| Series | Model | LLC[a] | LLC[b] | Breitung[a] | Breitung[b] |
|---|---|---|---|---|---|
| LGGI | Constant | -6.9701*** | -10.5767*** | -8.3541*** | -10.4307*** |
| | Constant&Trend | -3.0833*** | -7.7591*** | -4.8607*** | -0.7711 |
| LDIG | Constant | -28.309*** | -18.646*** | -8.9998*** | -3.8188*** |
| | Constant&Trend | -56.337*** | -12.2051*** | -1.5471* | -8.4858*** |
| LIND | Constant | -10.056*** | -12.6755*** | -5.6241*** | -13.0285*** |
| | Constant&Trend | -7.0204*** | -11.8109*** | -0.3676 | -11.2639*** |
| LGTD | Constant | -4.3442*** | -11.2547*** | -7.6748*** | -12.1344*** |
| | Constant&Trend | -3.6181** | -10.0119*** | -0.1237 | -13.8957*** |
| LCO2 | Constant | -1.7217* | -12.3041*** | 0.1986 | -10.5039*** |
| | Constant&Trend | -1.8681** | -10.1146*** | -3.1867*** | -11.4534*** |
| LGDP | Constant | -9.7883*** | -3.9929*** | 14.7395 | -11.2859*** |
| | Constant&Trend | -2.4391*** | -3.5908*** | 6.7461 | -1.5589* |
| LTAX | Constant | -3.1270*** | -10.7369*** | -2.0762*** | -11.0274*** |
| | Constant&Trend | -5.6571*** | -8.8714*** | -1.1748*** | -10.0457*** |

Note: A refers to unit root test model at level and b refers to unit root test model at first difference. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

Table 4 displays the overall coefficient determination (CD), Hansen J-statistic of over-identifying restrictions, and three information criteria proposed by Andrews and Lu (2001). These criteria include a moment selection criterion for GMM estimation and adaptations of the commonly used Akaike, Bayesian, and Hannan-Quinn information criteria, denoted as MAIC, MBIC, and MQIC, respectively. The results in Table 4 indicate that at a lag order of 3, the null hypothesis that over-identified restrictions are valid cannot be rejected at the 5% significance level. Consequently, we proceed with fitting a third-order panel VAR model.

Table 4. Lag order selection criteria

| Lag | CD | J-statistic | P-value of J stat. | MBIC | MAIC | MQIC |
|---|---|---|---|---|---|---|
| 1 | 0.86926 | 208.2998 | 1.32e-09 | -430.7243 | 8.299771 | -162.6546 |
| 2 | 0.93618 | 107.6251 | 0.008065 | -371.6429 | -42.37489 | -170.5907* |
| 3 | 0.94853 | 49.2187 | 0.504677 | -270.2933* | -50.7813* | -136.2585 |
| 4 | 0.80627 | 24.57642 | 0.486301 | -135.1796 | -25.42358 | -68.16218 |

Note: The asterisk * denotes the selected optimal lag order.

Before estimating Impulse Response Functions (IRFs) and Forecast Error Variance Decompositions (FEVDs), we assess the stability condition of the estimated PVAR model. The results confirm the model's stability, as all roots are found to be within the unit circle. Figures 2 and 3 display the impulse response functions of benchmark model, and extended model, respectively. Based on the GMM Estimation, the effects of IRF of digitalization on green growth index has a positive, but insignificant shock. Likewise, the results of the IRF show that industrialization reacts positively to a shock to green growth index. Also, the IRF shows that CO2 emissions react positively to a shock to green growth index. Concerning the IRF of shows that economic growth react positive and significantly to a shock to green growth index. Similarly, the IRF of environmental-related tax reacts positively but insignificant shock to green growth index. Moreover, the results of IRF indicate that the positive shock to green innovation development leads to an insignificant increasing in green growth index.

The IRF plots in Figure 2 and 3 also reveal that the IRF impacts of green growth index on digitalization is postive and statistically insignificant over the whole horizon considered. Furthermore, the green growth index response is negative and insignificant to shocks in industrialization over the whole horizon considered. Also, the green growth index responds positively when faced with a stock in green innovation development, except for the third lag which has a negative stock. Similarly, the green growth index responds positively when faced with a stock in CO2 emission, except for the first lag which has a negative stock. On the contrary, the green growth index response is positive and insignificant to shocks in economic growth over the whole horizon considered, while green growth index response is negative and insignificant to shocks in environmental-related tax.

Table 5 presents the findings of the Granger causality test in the extended model. The test evaluates Granger causality using a Wald test based on the GMM estimates. In addition to we perform to Granger causality at the optimal lag order of three. According to the Wald test results, we are able to reject the null hypothesis indicating that *LIND* does not cause to *LGGI* at the 1% significance level. Similarly, we find that *LGDP* also granger causes to *LGGI.* However, all other variables do not causes to *LGGI* at any significance level.

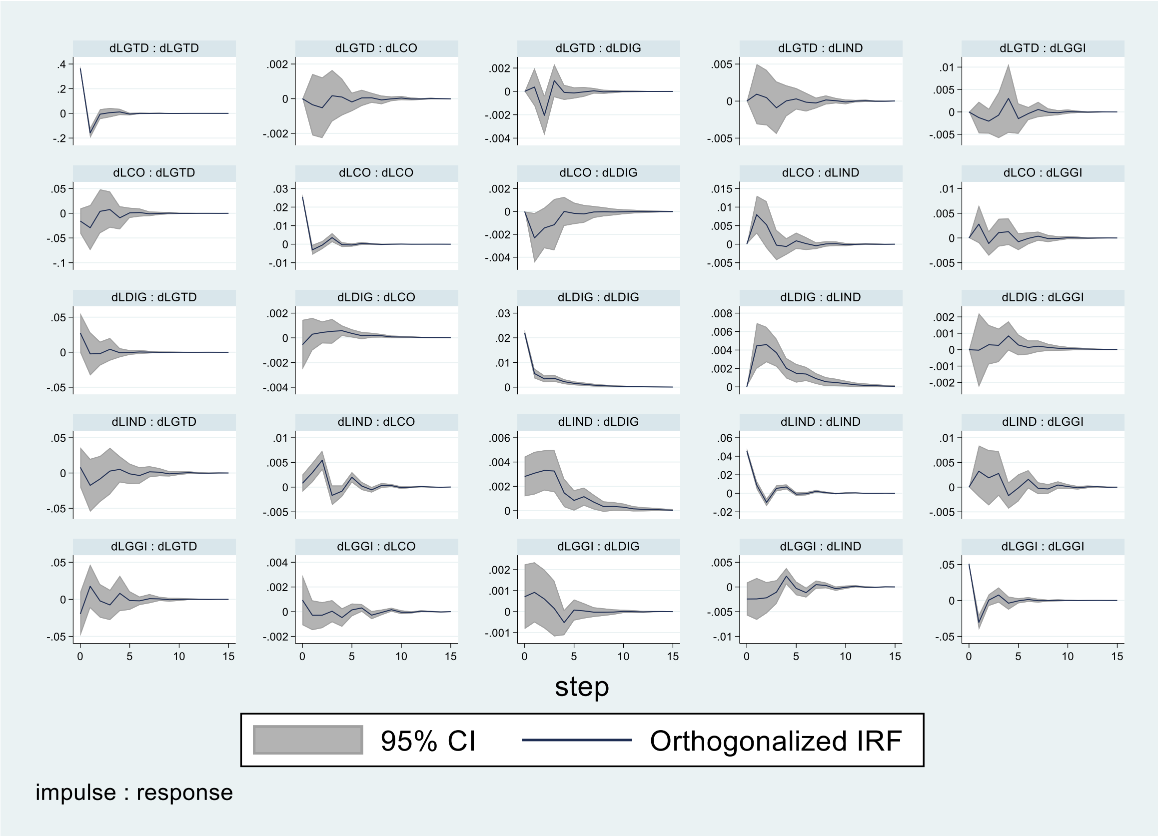


Figure 2.Impulse response with the benchmark model is estimated of dLGGI dLDIG dLIND dLCO dLGTD. Note: The optimal lag order is 3.

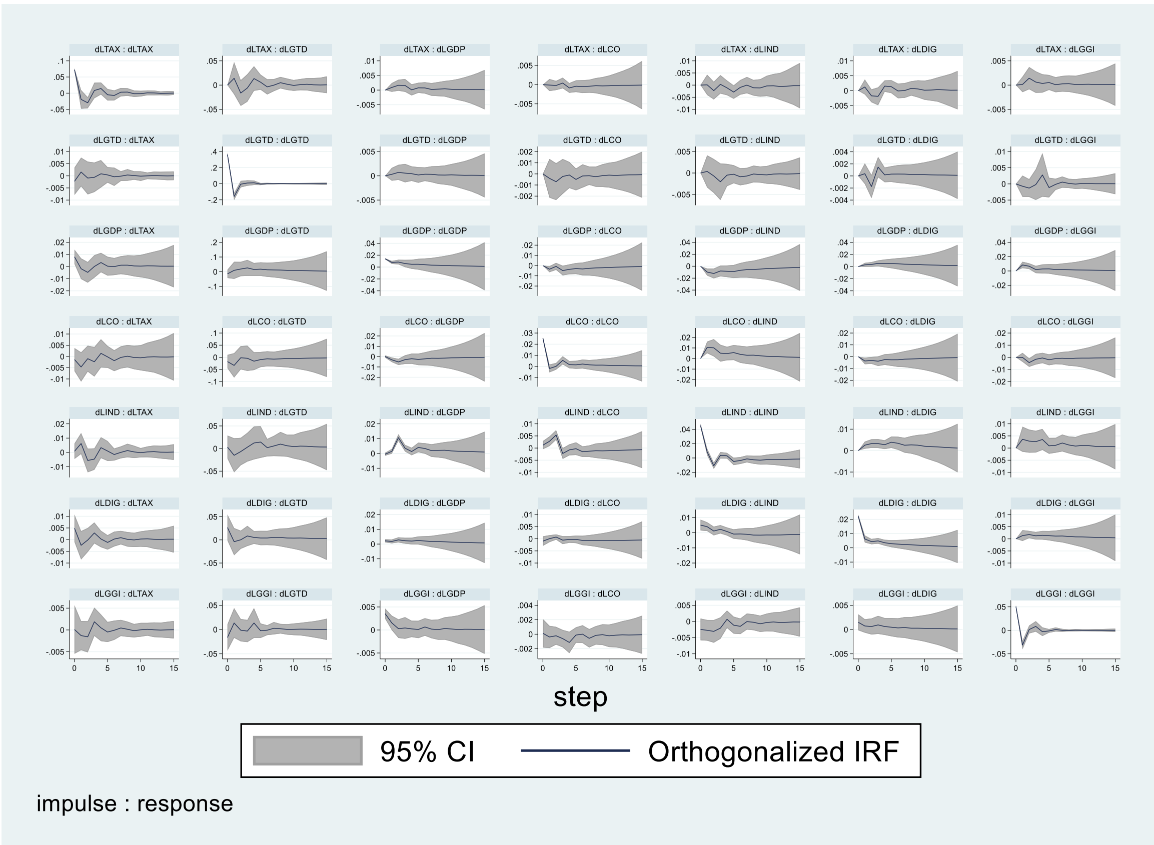


Figure 3. Impulse response with the extended model is estimated of dLGGI dLDIG dLIND dLCO dLGDP dLGTD dLTAX. Note: The optimal lag order is 3.

On the other hand, the findings indicate that *LIND*, *LGTD*, *LCO2*, *LTAX*, and *LGDP* granger cause to *LDIG*. Also, we conclude that *LDIG, LGDP*, and *LCO2* granger cause to *LIND* at the 1% and 5% significance levels. The findings of granger causality test indicate that *LDIG, LIND*, *LCO2*, *LTAX*, and *LCO2* granger cause to *LGDP*, while *LIND*, *LGDP* granger cause to *LCO2*. Lastly, there is granger causality from *LCO2* to *LTAX* at the 10% significance level. On the contrary, we are unable to find a granger causality from all variables to *LGTD* at any significance level.

## Conclusion

Green growth is vital for sustainable development and the well-being of current and future generations. It promotes economic expansion while minimizing negative environmental impacts, and protecting ecosystems and natural resources. Furthermore, green growth plays a crucial role in driving digitalization, industrialization, and green innovation towards a sustainable future. By fostering the adoption of digital technologies in various industries, green growth enhances efficiency and productivity while minimizing resource consumption and waste. This digital transformation supports cleaner production methods and facilitates the use of renewable energy sources, leading to a reduction in carbon emissions and other pollutants.

In terms of industrialization, green growth promotes the development of eco-friendly industrial processes and practices. By encouraging the integration of green technologies and innovations into manufacturing and production, industries can improve their environmental performance and competitiveness. This, in turn, helps create sustainable supply chains and supports the transition to a low-carbon economy. Moreover, green growth stimulates green innovation by driving research and development in sustainable technologies. This leads to the creation of new products and services that address environmental challenges while contributing to economic growth. Through green innovation, businesses can gain a competitive edge, create new market opportunities, and contribute to global efforts to combat climate change.

The main objective of this study is to examine the potential role of digitalization, industrialization, green innovation development, CO2 emissions, economic growth, and the environmental tax on the green growth process in OECD countries using a GMM Panel VAR approach from 2000 to 2022. Through this methodology, the research reveals the significant roles each of these factors plays in promoting sustainable development and fostering green growth.

The empirical findings based on the GMM Panel VAR approach indicated that the IRF impacts of the green growth index on digitalization, green innovation development, CO2 emission, and economic growth are positive and statistically insignificant over the whole horizon considered. In contrast, the green growth index response is negative and insignificant to shocks in environmental-related tax and industrialization. On the other hand, the results of the IRF show that digitalization, industrialization, green innovation development, and CO2 emissions react positively and significantly to a shock to the green growth index. Moreover, the findings of the Granger causality test indicate that there is bidirectional causality between industrialization and the green growth index and economic growth and the green growth index. On the other hand, there is no causal relationship between digitalization, green innovation development, CO2 emissions, and environmental taxes to the green growth index. The findings from this study have important implications for policymakers and industry stakeholders. To facilitate green growth, there is a need to create an enabling environment that supports digitalization, industrial modernization, and green innovation. This may involve investing in research and development, fostering collaboration between the public and private sectors, and establishing regulatory frameworks that incentivize sustainable practices. Likewise, the study underscores the importance of international cooperation and knowledge sharing in advancing green growth. The transfer of technology, expertise, and best practices across borders can accelerate the adoption of sustainable solutions and address global challenges such as climate change and resource depletion.

## Recommendations

Based on the findings of this study, several key recommendations can be made to promote green growth through the effective integration of digitalization, industrialization, and green innovation. First, industries should be encouraged to adopt smart technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics to optimize resource management, reduce waste, and enhance energy efficiency. Additionally, supporting and incentivizing research and development (R&D) in green technologies, including renewable energy and energy-efficient infrastructure, will drive innovation across various sectors.

Table 5. Granger causality tests in Extended Model

| ***Extended specification*** **Hypothesis** | ***p=3*** | | ***p=3*** |
|---|---|---|---|
| LDIG⇏ LGGI | 1.204 | LGGI ⇏ LGDP | 3.052 |
| LIND ⇏ LGGI | 16.621*** | LDIG ⇏ LGDP | 6.365* |
| LGTD ⇏ LGGI | 3.947 | LIND ⇏ LGDP | 131.295*** |
| LGDP ⇏ LGGI | 21.610*** | LGTD ⇏ LGDP | 0.804 |
| LCO2 ⇏ LGGI | 1.925 | LCO2 ⇏ LGDP | 17.635*** |
| LTAX ⇏ LGGI | 1.476 | LTAX ⇏ LGDP | 9.462** |
| | | | |
| LGGI ⇏ LDIG | 0.566 | LGGI ⇏ LCO2 | 1.158 |
| LIND ⇏ LDIG | 16.466*** | LDIG ⇏ LCO2 | 0.373 |
| LGTD ⇏ LDIG | 11.270** | LIND ⇏ LCO2 | 36.392*** |
| LGDP ⇏ LDIG | 12.779*** | LGTD ⇏ LCO2 | 0.659 |
| LCO2 ⇏ LDIG | 11.119** | LGDP ⇏ LCO2 | 9.068** |
| LTAX ⇏ LDIG | 9.239** | LTAX ⇏ LCO2 | 3.868 |
| | | | |
| LGGI ⇏ LIND | 4.152 | LGGI ⇏ LTAX | 2.505 |
| LDIG ⇏ LIND | 42.892*** | LDIG ⇏ LTAX | 2.450 |
| LGTD ⇏ LIND | 0.176 | LIND ⇏ LTAX | 3.967 |
| LGDP ⇏ LIND | 10.986** | LGTD ⇏ LTAX | 0.364 |
| LCO2 ⇏ LIND | 12.762*** | LGDP ⇏ LTAX | 0.062 |
| LTAX ⇏ LIND | 3.641 | LCO2 ⇏ LTAX | 6.654* |
| | | | |
| LGGI ⇏ LGTD | 2.367 | | |
| LDIG ⇏ LGTD | 0.715 | | |
| LIND ⇏ LGTD | 0.684 | | |
| LGDP ⇏ LGTD | 1.331 | | |
| LCO2 ⇏ LGTD | 3.161 | | |
| LTAX ⇏ LGTD | 3.003 | | |

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

Moreover, policies and incentives should promote environmentally friendly manufacturing processes and circular economy principles, investing in cleaner production technologies and waste reduction initiatives. Facilitating partnerships between businesses, governments, and academic institutions can foster collaboration and knowledge sharing, accelerating the adoption of sustainable practices. Creating supportive regulatory frameworks with standards for emissions, energy efficiency, and incentives for sustainable practices can drive industry compliance and innovation. Investing in education and training programs is also essential to building a workforce skilled in digital and green technologies, supporting the transition to a low-carbon economy.

Furthermore, establishing systems to monitor and evaluate the progress of green growth initiatives is crucial, including tracking key performance indicators (KPIs) and conducting regular assessments to measure the effectiveness of policies and strategies. Engaging in international collaboration can facilitate the transfer of green technologies, expertise, and best practices across borders, accelerating the adoption of sustainable practices globally.

Lastly, green growth initiatives must be equitable and inclusive, benefiting all segments of society, with targeted support for vulnerable communities and industries transitioning to green practices. Encouraging continued research into the dynamic relationships between digitalization, industrialization, and green innovation will provide deeper insights and guide future policy and strategy formulation. By following these recommendations, stakeholders can effectively leverage digitalization, industrialization, and green innovation to drive sustainable development and achieve a resilient, prosperous future.

Future research may build upon the insights gained from this study by exploring the nuanced interactions between these factors across different sectors and regions. Such investigations will contribute to a deeper understanding of how to harness the potential of digitalization, industrialization, and green innovation to achieve sustainable development goals.

In conclusion, the study makes a substantial contribution to the body of knowledge on the intersection of digitalization, industrialization, and green innovation in the context of green growth. It highlights the need for an integrated approach that leverages these elements to drive sustainable development and create a prosperous, resilient future for all.

## Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

## Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology ( www.icontechno.net ) held in Alanya/Turkey on May 02-05, 2024.

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## Author Information

**Busra Agan**
OSTIM Technical University
Ankara, Turkiye.
Contact e-mail: *busra.agan@ostimteknik.edu.tr*

**To cite this article:**

Agan, B. (2024). The role of digitalization, industrialization and green innovation in the green growth process: A GMM panel VAR approach. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 27,* 228-238.