Green bonds efficiency and renewable energy promotion: Insights from the Covid-19 Pandemic

Federico Tsipas[1], Zeinab Elrashidy[2], Davide Sandretto[3]

Abstract

This study investigates the efficiency of green bonds as a financial instrument for promoting renewable energy production, with a specific focus on their performance during the Covid-19 pandemic. Using a sample of 55 countries from 2014 to 2022, we find that green bond issuance positively impacts overall renewable energy generation. However, when examining specific sources of green energy, we find that wind energy benefits the most from green bond financing, while estimates show only marginal significance for hydro energy and no significance for solar energy. Finally, we observe that the efficiency of green bonds diminished during the Covid-19 pandemic, but this effect was not uniform across all energy sources.

Keywords: Green bonds, Renewable Energy, Covid-19, Green finance.

[1]F. Tsipas
Department of Management, University of Rome'' La Sapienza'', Via del Castro Laurenziano 9, 00161 Rome, Italy; E-mail federico.tsipas@uniroma1.it

[2]Zeinab Elrashidy
Business School, Cairo University, Cairo, Egypt; E-mail: zeinab.elrashidy@cu.edu.eg

[3]D. Sandretto
Department of Management, University of Turin, Corso Unione Sovietica 218 bis, 10134 Torino, Italy; E-mail: davide.sandretto@unito.it
Finance and Financial Accounting Research Group, School of Accounting and Finance, University of Vaasa, Wolffintie 34, 65200 Vaasa, Finland

1. Introduction

Sustainability has emerged as a central focus of international initiatives aiming to mitigate the rising threat of climate change observed over recent decades. In response to global warming, the 2015 Paris Agreement established international consensus to limit the rise in average global temperatures to below the 2°C threshold. Central to this effort are the Sustainable Development Goals (SDGs) of the United Nations Development Program. Among these goals, SDG 7, 'Affordable and Clean Energy,' underscores the imperative of ensuring “access to affordable, reliable, sustainable, and modern energy for all” (United Nations, 2015).

An imminent part of achieving this goal is moving away from fossil fuels as energy sources towards utilising renewable energy sources, such as wind, solar, and hydroelectric power. Businesses are moving towards green energy practices for three driving motives: green policies implemented by internal boards and management, green policies implemented by external governing bodies and the ever-growing public pressure (Zandi and Haseeb, 2019).

However, such large-scale renewable energy projects require substantial financial resources. Green finance has gained global popularity as a financing mechanism for environmentally sustainable projects by providing the necessary funds to support the development of renewable energy technologies (Taghizadeh-Hesary and Yoshino, 2020). Among these green financial tools, green bonds (GBs) play a crucial role in facilitating the promotion and development of sustainable energy projects, thereby contributing to the global reduction of CO_2 emissions (Rasoulinezhad and Taghizadeh-Hesary, 2022; Tu et al., 2020). As their name suggests, GBs distinguish themselves from conventional bonds in their purpose of specifically financing sustainable projects (ICMA, 2015). Since the issuance of the first GB by the European Investment Bank in 2007, the global GB market has experienced exponential growth, reaching $3 trillion by 2024 (Climate Bonds Initiative, 2024; Nguyen et al., 2022).

Research has investigated multiple facets of green bonds such as their impact on the cost of capital (Flammer, 2020), their impact on firm performance (Zhang and Du, 2020), and their benefits to shareholders (Tang and Zhang, 2020). However, this paper is concerned with measuring green bonds' efficiency in exhilarating the transition to green energy. In this context, research suggests that green bonds reduce CO_2 emission significantly on a global scale, however the extent of efficiency varies across countries, as it is stronger for developing countries when compared to developed nations (Saha and Maji, 2023).

Our paper contributes to the existing literature in several ways. First, we employ a larger sample of 55 countries from 2014 to 2022 to study the efficiency of GBs in increasing renewable energy production. Second, we extend the work by Alharbi et al. (2023) by analysing the impact of GBs on the production of various types of energy sources, viz. wind, solar and hydro. Third, to the best of our knowledge, this study represents the first attempt to examine whether Covid-19 influenced the relationship between GBs and renewable energy production. As suggested by Wang and Taghizadeh-Hesary (2023) and Taghizadeh-Hesary et al. (2023), research on the impact of Covid-19 on this relationship is needed, as it has disrupted and transformed many mechanisms in the economic markets of countries.

Our estimations show that GBs are efficient tools in promoting the green energy transition, as their relationship with renewable energy production is significantly positive. However, mixed results are found when looking at various renewable energy sources. Specifically, GBs are effective in enhancing wind energy but do not have a significant impact on solar energy. Additionally, only a weak relationship has been found between GB issuance and hydro energy production. These findings are consistent with past research (Alharbi et al., 2023; Wang and Taghizadeh-Hesary, 2023).

A possible explanation for the lack of impact on solar production is the nature of the market, which is composed of startups and private firms, hindering GBs' utility. Furthermore, during the Covid-19 pandemic, hydro energy projects suffered the most, which can explain the weaker relationship we found compared to the study by Wang and Taghizadeh-Hesary (2023). Lastly, we find that the Covid-19 pandemic had a negative impact on the efficiency of GBs in advancing the green energy transition.

The remainder of this paper is organised as follows: Section 2 provides a comprehensive overview of the existing literature. Section 3 presents the data and research methodology used to conduct the analysis. Section 4 presents the results and discussion. Section 5 concludes the paper.

2. Literature review and Hypotheses Development

The common goal to tackle climate change has brought the attention of research to renewable energy and green finance. Renewable energy has seen large technological advancement, for which innovation, market growth and policy all play an important role (Gross et al., 2003). However, for the energy transition to come into fruition, not only technological, but also financial innovations are needed (Bhutta et al., 2022). We review green bonds as an essential tool to achieve the SDGs.

The reasoning for using green bonds as an optimal tool to finance the energy transition are twofold. On the one hand, such funds invested in the green transition should be paid also by future generations, so that the current generation does not pay the whole price. Climate change is a process which overarches multiple generations, as greenhouse gasses have been existing for a long time, and their effects will be felt for long in the future. Furthermore, the benefits of investing in the present into the green transition will be enjoyed by future generations. Secondly, the investments in question are so large, which are not only needed in the energy sector, that it would be practically impossible to be strictly financed by bank landing or private debt and equity capital. This is due to the nature of the projects, which are concerned with infrastructure, therefore having the characteristics of high upfront investment which can be recovered only in the long-term (Sartzetakis, 2020). Furthermore, green bonds have also been found convenient for their issuers when compared to non-green conventional bonds. This convenience comes from lower returns paid to investors, even after taking into account green certification costs. Therefore green bonds can help fighting climate change without punishing issuers (Gianfrate and Peri, 2019). However, there is a mismatch between issuers' climate targets and green bond frameworks, along with post-issuance reporting issues (Tuhkanen and Vulturius, 2020).

Some studies have taken on the challenge to analyse the relationship between green finance and accelerating the green energy transition. Xu et al. (2023) focused on the agricultural industry and found that green bond issuance fastens agriculture's green economic growth rate. Furthermore, some researchers show how green bond issuance is significantly and positively correlated with increases in oil prices (Xiang and Cao, 2023). They suggest that the amount of green bonds issued in a country has a significant negative effect on CO_2 emissions. However, there is a difference of impact per country, while this relationship is strong in developing nations, it is weaker in developed ones (Saha and Maji, 2023). Similarly, Lucchetta (2023) suggests that the allocation of green bonds should consider the per capita use of fossil fuels, the heterogeneity of population growth and the Macro-Regional economic development.

Another worldwide research paper has found that green bond issuances are associated with an average of 14% reduction in CO_2 emissions, while carbon pricing initiatives - an alternative financial tool for the green transition - are associated with an 11% reduction on average (Dill, 2023). Green bonds also improve firms' environmental performance, and their ability to create new environmental technologies and processes (Benlemlih et al., 2022). Based on the research explored, we propose the following hypotheses:

H_1. Green bond issuance has a significant positive effect on renewable energy production.

H_2. Green bond issuance has a significant positive effect on solar energy production.

H_3. Green bond issuance has a significant positive effect on wind energy production.

H_4. Green bond issuance has a significant positive effect on hydroelectric power production.

Research maintains that green financial instruments, such as green bonds, are not the safest for investors, especially when considering extreme market conditions. The Covid-19 pandemic enters into the discussion as an extremely negative shock to the market. Indeed, it caused large fluctuations and significant negative abnormal returns not only in the traditional fixed-income market, but on the green bond market as well (Liu, 2022). Furthermore, while Naeem et al. (2022) found clean energy markets more efficient relative to traditional financing mechanisms, the Covid-19 pandemic had a large negative effect on both markets' efficiencies. Therefore, we propose our last hypothesis:

H_5. The Covid-19 pandemic has a significant diminishing effect on the relationship between green bonds and renewable energy production.

3. Data and Methodology

This study examines the efficiency of green bonds in promoting renewable energy production through analysing data for 55 countries from 2014 to 2022. The length and breadth of our sample are functions of the availability of green bond data.

First, we obtain the amount of renewable energy produced, expressed in Terawatt-hours, at the country level from the BP Statistical Review of World Energy. Data on solar, wind, and hydro energy production are retrieved from the same source. For our main explanatory variable, green bonds, we download the total annual issuance in US dollars for each of the 55 countries from www.climatebonds.net. This database tracks post-issuance reporting and green bond pricing in the primary market, green bond underwriter league tables and stock exchanges with green/sustainability bond segments. Finally, in accordance with existing literature (Al Mamun et al., 2018; Alharbi et al., 2023; Wang and Taghizadeh-Hesary, 2023), we include several control variables in our regression model: fossil fuel energy consumption, population, GDP per capita, and trade openness. Data for these variables is sourced from www.worldbank.org, except for fossil fuel consumption, which is obtained from the BP Statistical Review of World Energy as the sum of oil, gas, and coal consumption. For all the variables, we take their logarithmic transformation. Tables A1 and A2 provide the description of variables and countries in our samples, respectively, while Table 1 presents the descriptive statistics of the research variables.

Table 2 shows the correlation matrix. It can be noted that a simple correlation exists between our green bond and the renewable energy measures. Additionally, we notice that the correlations among most regressors do not surpass the standard threshold of 0.5. However, the population variable exhibits a high correlation with several other regressors, which suggests a potential violation of the full rank condition. This concern is further corroborated by the Variance Inflation Factor (VIF) analysis, which assigns a value of 11.78 to the population variable, exceeding the conventional cutoff value of 10. To mitigate this issue, we also run our models without including this variable in the regression equation. Results do not differ from our main conclusions[1].

In order to identify the appropriate model specification, we begin by analysing the statistical properties of our variables through panel unit root tests and cointegration tests. If variables are non-stationary at their levels, their mean and variance are not finite, rendering traditional statistical methods that rely on these properties invalid. To address the stationarity

[1] Results of these estimations are not reported, but they are available on request.

of our data, we employ two different tests. First, we analyse the stationarity property of variables through the Im, Pesaran and Shin (IPS) panel unit root test with constant levels (Im et al., 2003). Second, as a further check, we employ the Fisher-type ADF test which combines the results from individual unit root tests (Choi, 2001; Maddala and Wu, 1999). Both tests have a unit root null hypothesis. The results of these tests are presented in Table 3. As shown, most of the variables are non-stationary at their levels but are stationary when considered at their first differences.

Next, due to the non-stationarity of the time series, it is crucial to employ a panel cointegration framework to avoid spurious regression problems, which could result in potentially misleading statistical outcomes (Kao, 1999). Therefore, we employ the Kao (1999), Westerlund (2005), and Pedroni (2004) cointegration tests to assess the presence of long-run relationships within our panel data sample. These tests are conducted for four models, each corresponding to a different dependent variable. As presented in Table 4, we reject the null hypothesis of no cointegration for nearly all the tests. This indicates the presence of long-term relationships among the variables. Consequently, we adopt the Fully Modified OLS (FMOLS) framework proposed by Phillips and Hansen (1990) for our analysis. The FMOLS model is particularly advantageous as it accounts for the full endogeneity of regressors arising from reverse causality, omitted variables, and measurement errors. Under conditions of cointegration, this model demonstrates superior consistency properties, making it a more suitable choice compared to the Autoregressive Distributed Lag (ARDL) model, which assumes full exogeneity of independent variables (Pedroni, 2019).

We analyse the relationship between renewable energy production and green bond efficiency as follows:

$$\begin{aligned} LRenEnProd_{i,t} &= \beta_0 + \beta_{i,1} LGreenBond_{i,t} + \beta_{i,2} LFossilFuel_{i,t} + \beta_{i,3} LGDPpercapita_{i,t} \\ &+ \beta_{i,4} LPopulation_{i,t} + \beta_{i,5} LTradeOpeness_{i,t} + \epsilon_{i,t} \end{aligned}$$

$$LSolarProd_{i,t} = \beta_0 + \beta_{i,1}LGreenBond_{i,t} + \beta_{i,2}LFossilFuel_{i,t} + \beta_{i,3}LGDPpercapita_{i,t} + \beta_{i,4}LPopulation_{i,t} + \beta_{i,5}LTradeOpeness_{i,t} + \epsilon_{i,t}$$

$$LWindProd_{i,t} = \beta_0 + \beta_{i,1}LGreenBond_{i,t} + \beta_{i,2}LFossilFuel_{i,t} + \beta_{i,3}LGDPpercapita_{i,t} + \beta_{i,4}LPopulation_{i,t} + \beta_{i,5}LTradeOpeness_{i,t} + \epsilon_{i,t}$$

$$LHydroProd_{i,t} = \beta_0 + \beta_{i,1}LGreenBond_{i,t} + \beta_{i,2}LFossilFuel_{i,t} + \beta_{i,3}LGDPpercapita_{i,t} + \beta_{i,4}LPopulation_{i,t} + \beta_{i,5}LTradeOpeness_{i,t} + \epsilon_{i,t}$$

where the subscripts i and t represent the cross-sectional dimension (i = 1, 2, …, N) and time period (t = 1, 2, …, T), respectively, whereas $\epsilon_{i,t}$ is the error term.

In the FMOLS model, coefficients are estimated by considering the constant term and the correlation between the error term and the regressors. Specifically, the standard Ordinary Least Squares (OLS) estimation is modified to account for the serial correlation and endogeneity that can arise in a cointegrated panel. FMOLS adjusts for the correlations between the regressors and the error term by modifying the dependent variable, and it addresses serial correlation by adjusting the long-run covariance matrix of the residuals. FMOLS coefficients can be defined as follows:

$$\hat{\beta}_{FMOLS} = (\sum_{t=1}^{T} x'_{i,t}\, x_{i,t})^{-1} \sum_{t=1}^{T} (x'_{i,t} y *_{i,t} - T\, \hat{\tau}_i)$$

where $y *_{i,t}$ is the dependent variable adjusted for the correlation between the error term and regressors and $T\hat{\tau}_i$ is the adjustment for the constant term.

4. Results and Discussion

This study investigates the efficiency of green bonds in fostering renewable energy production. Accordingly, we utilize the total renewable energy production of sample countries as well as more granular measures of solar, wind, and hydro energy production. Table 4 presents the estimates of the FMOLS regressions, which account for the long-run relationship between the dependent variable and the regressors. In Model I, a positive and statistically significant relationship is observed between overall renewable energy production and the issuance of green bonds. This result confirms H_1 and aligns with the main findings of Alharbi et al. (2023), although we note a lower magnitude in the coefficient. Regarding the control variables, we find that a 1% increase in GDP per capita leads to a 1.92% increase in overall renewable energy production. This is consistent with the notion that higher purchasing power among citizens increases the demand for green energy. Additionally, we find that a 1% increase in trade openness leads to a 0.71% increase in renewable energy production. This supports Harrison's (1996) argument that openness to trade facilitates access to imported inputs, which can incorporate new technology and thereby foster innovation that enhances productivity. Furthermore, our estimation suggests that population size has a positive and significant effect on renewable energy production, whereas the consumption of fossil fuels have insignificant role. In the second and third models, solar and wind energy production are examined as dependent variables. Consistent with prior findings, we observe a long-term negative relationship between fossil fuel consumption and energy production, highlighting the substitutive nature of renewable energy for fossil fuels (Mutezo and Mulopo, 2021). Notably, while the impact of green bonds is positive and significant for wind energy production, supporting H_3, we find no significant association with solar energy, thereby rejecting H_2. This finding aligns with Wang and Taghizadeh-Hesary (2023), who similarly reported inefficiencies of green bonds in the solar energy market. This may be attributed to the sector's predominant composition of private companies and startups, which diminishes the role of green financing instruments as secondary tools. Moreover, in contrast to the aforementioned study, Model IV reveals a positive albeit weak relationship between green bonds and hydro energy, significant at the 10% level. Hence, H_4 is only partially supported. Additionally, within this model, the effect of openness to trade is negative, suggesting a lower technological transfer for hydro energy (Alharbi et al., 2023).

Next, we investigate how the Covid-19 pandemic at the beginning of 2020 impacted the relationship under study. As noted by Wang and Taghizadeh-Hesary (2023), the pandemic disrupted and transformed many mechanisms in economic markets worldwide, highlighting the need for an analysis of its impact to provide appropriate guidance for policymakers. To address this, we construct a Covid-19 binary variable as in Alkayed et al. (2024), which takes a value of 1 for the period 2020-2022 and 0 otherwise. We then create an interaction variable through multiplying Covid-19 by the amount of green bonds issued.

As reported in Table 5, we observe that during the Covid-19 period, the production of renewable energy increased across all our models. This result may be attributed to favourable past policies, regulations, incentives, and innovations introduced in many countries prioritizing renewable energy over fossil fuels, along with contributions from renewable energy projects that had already been initiated (European Commission, 2023; World Economic Forum, 2020). Furthermore, we find that the pandemic reduced the efficiency of green bonds on overall renewable energy production. Indeed, the interaction term between Covid-19 and green bonds is negative and significant, thereby supporting H_5. This finding corroborates the research by Zhao et al. (2023), who documented an inhibitory effect that made investing and operating renewable energy projects inconvenient during the Covid-19 epidemic. The impact of Covid-19 may also explain the divergence between our study and that of Wang and Taghizadeh-Hesary (2023). Considering hydro energy production, the coefficient on green bonds is no longer significant upon introducing the interaction term, which is negative and significant. This suggests that the efficiency of GBs was negatively affected by the Covid-19 pandemic in the hydro energy market. However, wind energy does not exhibit a similar decline in efficiency. This suggests that green investments in wind energy were more resilient. The heterogeneous impact of Covid-19 on the three different sources of renewable energy can be explained by differences in project infrastructure. Indeed, solar and wind projects typically require shorter timelines and less operational complexity compared to hydro projects.

5. Conclusion and Implications

This empirical study investigates the efficiency of green bonds in accelerating the green energy transition as set by the UN's SDGs. Further, the research adds a new aspect to the current literature by reviewing Covid-19's impact on this relationship. The pandemic period was unique, revolutionizing market dynamics and thus providing an important opportunity to analyse the resilience of green financing instruments. To do so, we employed a large sample of 55 countries from 2014 to 2022. Our results confirm that GBs are indeed an efficient tool in promoting the green energy transition, even though their effect weakened during the pandemic period. Furthermore, we focus our analysis on three different renewable energy sources, namely wind, solar, and hydroelectric energy. On one hand, we found that GBs accelerate wind energy production. On the other hand, our results support that GB issuance does not affect the production levels of solar energy. Interestingly, during the pandemic period, the efficiency of GBs in fostering wind energy production has not diminished, making it the most resilient energy source. Finally, only a weak relationship is documented for hydropower, which is nullified when considering the impact of Covid-19.

This study has several implications. It adds to the existing body of literature further proof of GBs as a financial tool that facilitates the green energy transition. Additionally, by shedding light on the pandemic's diminishing impact, this research introduces a novel perspective and highlights green finance's sensitivity to global economic shocks. As suggested by Li et al. (2023), policymakers should create an infrastructure for the issuance of digital green bonds to break down the barriers of their physical counterparts. Considering Covid-19's negative impact, our research aligns with this suggestion. Policymakers should consider designing green bonds tailored to specific types of renewable energy projects, specifically wind energy, which has been shown to benefit positively from GB financing. In addition, given that GBs do not significantly impact solar energy production, they should investigate alternative financial incentives for this type of green energy. Moreover, the pandemic has highlighted the need for resilience planning in green finance policies. In this regard, government agencies must prepare coherent incentive packages to sustain the restart of green projects funded by green financial instruments. Additionally, actions that can mitigate the bureaucracy required for these projects must be addressed to streamline processes and make green financing efficient even under these particular market conditions.

The limitations of this study are twofold. First, we analysed GBs to measure the efficiency of green finance in the energy transition, while there are also alternative financial instruments to incentivize green funding. Second, we analyse Covid-19's impact to uncover the resilience of green finance during global economic shocks. However, the pandemic has its unique characteristics and may not accurately reflect other types of shocks. Therefore, we recommend future research to measure the efficiency of other green financial tools, such as green equity, and to understand different economic shocks' impact outside of the Covid-19 pandemic on the relationship between green finance and the energy transition. For instance, the Russo-Ukrainian War presents an important event for the energy market in the European context.

References

Al Mamun, M., Sohag, K., Shahbaz, M., & Hammoudeh, S. (2018). Financial markets, innovations and cleaner energy production in OECD countries. *Energy Economics*, *72*, 236–254. https://doi.org/10.1016/j.eneco.2018.04.011

Alharbi, S. S., Al Mamun, M., Boubaker, S., & Rizvi, S. K. A. (2023). Green finance and renewable energy: Awo rldwide evidence. *Energy Economics*, *118*, 106499. https://doi.org/10.1016/j.eneco.2022.106499

Benlemlih, M., Li, Y., & Assaf, C. (2022). Executive compensation and environmental performance: Evidence from CEO inside debt. Energy Economics, 116, 106403. https://doi.org/10.1016/j.eneco.2022.106403

Bhutta, U. S., Tariq, A., Farrukh, M., Raza, A., & Iqbal, M. K. (2022). Green bonds for sustainable development: Review of literature on development and impact of green bonds. Technological Forecasting & Social Change/Technological Forecasting and Social Change, 175, 121378. https://doi.org/10.1016/j.techfore.2021.121378

Choi, I. (2001). Unit root tests for panel data. *Journal of International Money and Finance*, *20*(2), 249–272. https://doi.org/10.1016/S0261-5606(00)00048-6

Dill, H. (2023). Carbon pricing initiatives and green bonds: are they contributing to the transition to a low-carbon economy? Climate Policy, 24(4), 529–544. https://doi.org/10.1080/14693062.2023.2210107

European Commission (2023). *The development of renewable energy in the electricity market.* Publications Office. https://data.europa.eu/doi/10.2765/411281

Flammer, C. (2020). Green Bonds: Effectiveness and implications for public policy. *Environmental and Energy Policy and the Economy*, *1*, 95–128. https://doi.org/10.1086/706794

Gianfrate, G., & Peri, M. (2019). The green advantage: Exploring the convenience of issuing green bonds. Journal of Cleaner Production, 219, 127–135. https://doi.org/10.1016/j.jclepro.2019.02.022

Green Bond Principles. (2015). ICMA. https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/GBP_2015_27-March.pdf

Gross, R., Leach, M., & Bauen, A. (2003). Progress in renewable energy. Environment International, 29(1), 105–122. https://doi.org/10.1016/s0160-4120(02)00130-7

Harrison, A. (1996). Openness and growth: A time-series, cross-country analysis for developing countries. *Journal of Development Economics*, *48*(2), 419–447. https://doi.org/10.1016/0304-3878(95)00042-9

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, *90*(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2

Liu, S., & Li, S. (2024). Corporate green bond issuance and high-quality corporate development. Finance Research Letters, 61, 104880. https://doi.org/10.1016/j.frl.2023.104880

Lucchetta, M. (2023). Climate bonds: Are they invested efficiently? Journal of Environmental Management, 345, 118864. https://doi.org/10.1016/j.jenvman.2023.118864

Maddala, G. S., & Wu, S. (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 631–652. https://doi.org/10.1111/1468-0084.0610s1631

Mutezo, G., & Mulopo, J. (2021). A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renewable and Sustainable Energy Reviews*, *137*, 110609. https://doi.org/10.1016/j.rser.2020.110609

Nguyen, A. H., Hoang, T. G., Nguyen, D. T., Nguyen, L. Q. T., & Doan, D. T. (2022). The Development of Green Bond in Developing Countries: Insights from Southeast Asia Market Participants. *the European Journal of Development Research/European Journal of Development Research*, *35*(1), 196–218. https://doi.org/10.1057/s41287-022-00515-3

Pedroni, P. (2004).Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, *20*(3), 597–625. https://doi.org/10.1017/S0266466604203073

Pedroni, P. (2019). Panel Cointegration Techniques and Open Challenges. In *Panel Data Econometrics* (pp. 251–287). Elsevier. https://doi.org/10.1016/B978-0-12-814367-4.00010-1

Phillips, P. C. B., & Hansen, B. E. (1990). Statistical Inference in Instrumental Variables Regression with I(1) Processes. *The Review of Economic Studies*, *57*(1), 99–125. https://doi.org/10.2307/2297545

Quarterly Market Update. (2024). Climate Bonds Initiative. https://www.climatebonds.net/resources/reports/quarterly-market-update-q1-2024

Rasoulinezhad, E., & Taghizadeh-Hesary, F. (2022). Role of green finance in improving energy efficiency and renewable energy development. *Energy Efficiency*, *15*(2). https://doi.org/10.1007/s12053-022-10021-4

Saha, R., & Maji, S. G. (2023). Do green bonds reduce CO2 emissions? Evidence from developed and developing nations. *International Journal of Emerging Markets*. https://doi.org/10.1108/ijoem-05-2023-0765

Saha, R., & Maji, S. G. (2023). Do green bonds reduce CO2 emissions? Evidence from developed and developing nations. International Journal of Emerging Markets. https://doi.org/10.1108/ijoem-05-2023-0765

Sartzetakis, E. S. (2020b). Green bonds as an instrument to finance low carbon transition. Economic Change and Restructuring, 54(3), 755–779. https://doi.org/10.1007/s10644-020-09266-9

Sustainable development goals. (2015). UNDP. https://www.undp.org/sustainable-development-goals

Taghizadeh-Hesary, F., & Yoshino, N. (2020). Sustainable solutions for green financing and investment in renewable energy projects. *Energies*, *13*(4), 788. https://doi.org/10.3390/en13040788

Tang, D. Y., & Zhang, Y. (2020). Do shareholders benefit from green bonds? *Journal of Corporate Finance*, *61*, 101427. https://doi.org/10.1016/j.jcorpfin.2018.12.001

Tu, C. A., Rasoulinezhad, E., & Sarker, T. (2020). Investigating solutions for the development of a green bond market: Evidence from analytic hierarchy process. *Finance Research Letters*, *34*, 101457. https://doi.org/10.1016/j.frl.2020.101457

Tuhkanen, H., & Vulturius, G. (2020). Are green bonds funding the transition? Investigating the link between companies' climate targets and green debt financing. Journal of Sustainable Finance & Investment, 12(4), 1194–1216. https://doi.org/10.1080/20430795.2020.1857634

Wang, Y., & Taghizadeh-Hesary, F. (2023). Green bonds markets and renewable energy development: Policy integration for achieving carbon neutrality. *Energy Economics*, *123*, 106725. https://doi.org/10.1016/j.eneco.2023.106725

Wang, Y., & Taghizadeh-Hesary, F. (2023). Green bonds markets and renewable energy development: Policy integration for achieving carbon neutrality. *Energy Economics*, *123*, 106725. https://doi.org/10.1016/j.eneco.2023.106725

Westerlund, J. (2005). New Simple Tests for Panel Cointegration. *Econometric Reviews, 24*(3), 297–316. https://doi.org/10.1080/07474930500243019

World Economic Forum (2020). Here's why COVID-19 is a game-changer for renewable energy. https://www.weforum.org/agenda/2020/06/covid-19-is-a-game-changer-for-renewable-energy/

Xiang, S., & Cao, Y. (2023). Green finance and natural resources commodities prices: Evidence from COVID-19 period. Resources Policy, 80, 103200. https://doi.org/10.1016/j.resourpol.2022.103200

Xu, Z., Mohsin, M., Ullah, K., & Ma, X. (2023). Using econometric and machine learning models to forecast crude oil prices: Insights from economic history. Resources Policy, 83, 103614. https://doi.org/10.1016/j.resourpol.2023.103614

Zandi, G., & Haseeb, M. (2019). The importance of green energy consumption and agriculture in reducing environmental degradation: evidence from Sub-Saharan African countries. https://www.semanticscholar.org/paper/The-Importance-of-Green-Energy-Consumption-and-in-Zandi-Haseeb/c3ee18d166213dba536438b6328ca5f2394e8614

Zhang, D., & Du, P. (2020). How China "Going green" impacts corporate performance? *Journal of Cleaner Production*, *258,* 120604. https://doi.org/10.1016/j.jclepro.2020.120604

Zhao, Q., Qin, C., Ding, L., Cheng, Y.-Y., & Vătavu, S. (2023). Can green bond improve the investment efficiency of renewable energy? *Energy Economics, 127*, 107084. https://doi.org/10.1016/j.eneco.2023.107084

Tables

Table 1. Descriptive Statistics.

	Obs.	Mean	StDv	Min	Max
LRenEnProd	495	2.55	1.53	0.04	7.22
LWindProd	495	1.74	1.55	0.00	6.64
LSolarProd	495	1.26	1.32	0.00	6.06
LHydroProd	495	2.55	1.84	0.00	7.19
LGreenBond	495	13.79	10.14	0.00	25.24
LFossilFuel	495	1.38	1.03	0.03	4.88
LGDPpercapita	495	10.39	0.68	8.53	11.68
LPopulation	495	16.97	1.66	12.70	21.07
LTradeOpeness	495	4.46	0.61	3.16	6.06

Table 2. Correlation matrix.

Variables	VIF	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) LRenEnProd	2.56	1.00								
(2) LWindProd	-	0.91***	1.00							
(3) LSolarProd	-	0.83***	0.75***	1.00						
(4) LHydroProd	-	0.56***	0.51***	0.44***	1.00					
(5) LGreenBond	1.40	0.47***	0.44***	0.44***	0.24***	1.00				
(6) LFossilFuel	6.19	0.61***	0.56***	0.70***	0.51***	0.25***	1.00			
(7) LGDPpercapita	3.86	-0.11**	-0.03	-0.07*	-0.32***	0.16***	-0.20***	1.00		
(8) LPopulation	11.78	0.62***	0.54***	0.62***	0.59***	0.20***	0.83***	-0.61***	1.00	
(9) LTradeOpeness	1.89	-0.54***	-0.46***	-0.39***	-0.68***	-0.12***	-0.53***	0.43***	-0.63***	1.00

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

Table 3. Panel unit root tests.

Variable	IPS test		ADF Fisher Chi-squared test	
	Level	First difference	Level	First difference
LRenProd	5.2312	-1,9973**	58.1624	145.754**
LWindProd	-3.0943***	-8.6759***	119.380	179.079***
LSolarProd	8.1847	-1.9109**	103.039	164.377***
LHydroProd	-2.6064***	-4.0850***	148.478***	178.117***
LGreenBond	-10.6011***	-11.6678***	179.128***	340.159***
LFossilFuel	0.27153	-6.9714***	113.987	261.088***
LPopulation	-1,95174**	2.0612	204.894***	123.607
LTradeOpeness	-1.6186*	-8.0288***	158.604***	281.652***
LGDPpercapita	0.0416	-6.8114***	109.299	256.814***

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

Table 4. Panel cointegration tests.

Cointegration test	Model I (LRenProd)	Model II (LSolarProd)	Model III (LWindProd)	Model IV (LHydroProd)
Pedroni				
Modified Phillips–Perron t	10.63***	10.91***	9.89***	9.85***
Phillips–Perron t	-13.66***	-11.76***	-20.03***	-11.58***
Augmented Dickey–Fuller t	-17.59***	-15.64**	-24.46***	-18.31***
Kao				
Modified Dickey–Fuller t	4.93***	4.72***	4.10***	1.36*
Dickey–Fuller t	5.67***	4.60***	4.69***	-2.44***
Augmented Dickey–Fuller t	1.84**	1.52*	2.24**	0.02
Unadjusted modified Dickey–Fuller t	4.02***	3.48***	3.44***	-8.11***
Unadjusted Dickey–Fuller t	4.30***	2.85***	3.79***	-8.94***
Westerlund				
Variance ratio	1.59*	4.57***	3.60***	0.61

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

Table 4. Fully modified OLS regression.

	Model I (LRenProd)	Model II (LSolarProd)	Model III (LWindProd)	Model IV (LHydroProd)
LGreenBond	0.010***	0.006	0.006***	0.002*
	(0.000)	(0.118)	(0.006)	(0.078)
LFossilFuel	-0.519	-1.217*	-1.478***	0.205
	(0.285)	(0.068)	(0.002)	(0.179)
LGDPpercapita	1.92***	2.763***	1.117***	0.262*
	(0.000)	(0.000)	(0.002)	(0.060)
LPopulation	4.17***	5.362***	3.431***	0.349
	(0.000)	(0.00)	(0.000)	(0.232)
LTradeOpeness	0.71***	1.571***	0.945***	-0.368***
	(0.009)	(0.000)	(0.000)	(0.000)

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

Table 5. Fully modified OLS regression: the role of Covid-19.

	Model I (LRenProd)	Model II (LSolarProd)	Model III (LWindProd)	Model IV (LHydroProd)
LGreenBond	0.011***	0.004	0.007**	0.002
	(0.002)	(0.387)	(0.017)	(0.158)
LFossilFuel	1.754***	1.418	-0.237	0.349
	(0.006)	(0.115)	(0.668)	(0.117)
LGDPpercapita	0.484	0.988	0.402	0.214
	(0.366)	(0.192)	(0.389)	(0.253)
LPopulation	0.298	1.132	1.065	0.258
	(0.808)	(0.513)	(0.318)	(0.546)
LTradeOpeness	0.137	1.01**	0.655***	-0.362***
	(0.631)	(0.013)	(0.009)	(0.000)
Covid-19	0.804***	0.894***	0.400***	0.148***
	(0.000)	(0.000)	(0.001)	(0.003)
Covid-19*LGreenBond	-0.015**	-0.015	-0.005	-0.006**
	(0.028)	(0.113)	(0.339)	(0.017)

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

Appendix

Table A1. Variable definitions

Variable	Definition	Unit	Sources
RenEnProd	Total renewable energy produced in a year.	TWh	BP Statistical Review of World Energy
WindProd	Total wind energy produced in a year.	TWh	BP Statistical Review of World Energy
SolarProd	Total solar energy produced in a year.	TWh	BP Statistical Review of World Energy
HydroProd	Total hydroelectricity energy produced in a year.	TWh	BP Statistical Review of World Energy
GreenBond	Total amount of green bond issued by private and public institutions in a year.	US Dollars	www.climatebonds.net
FossilFuel	Sum of Coal, Gas and Oil consumption in a year.	Exajoules	BP Statistical Review of World Energy
GDPpercapita	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.	US Dollars	www.worldbank.org
Population	Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship. The values shown are midyear estimates.	Person	www.worldbank.org
TradeOpeness	Sum of exports and imports of goods and services measured as a share of gross domestic product.	% of GDP	www.worldbank.org

Table A2. Countries in the sample

Countries				
Argentina	Finland	Japan	Peru	South Africa
Australia	France	Korea, Rep.	Philippines	Spain
Austria	Germany	Latvia	Poland	Sweden
Belgium	Greece	Lithuania	Portugal	Switzerland
Brazil	Hong Kong	Luxembourg	Qatar	Thailand
Canada	Hungary	Malaysia	Romania	Turkey
Chile	Iceland	Mexico	Russian Federation	Ukraine
China	India	Morocco	Saudi Arabia	United Arab Emirates
Colombia	Indonesia	Netherlands	Singapore	United Kingdom
Czechia	Ireland	New Zealand	Slovak Republic	United States
Denmark	Italy	Norway	Slovenia	Vietnam