



Role of Green Financing and Eco-Innovation for Energy Efficiency in Developed Countries: Contextual Evidence for Pre- and Post-COVID-19 Era

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Following the environmental concerns such as global warming, climate change, and environmental degradation, scholars and policymakers discovered energy utilization as the key factor in these issues. Therefore, economies are paying more attention to green finance and eco-innovation to reduce energy usage and enhance energy efficiency. The prime objective of this study is to explore whether the mentioned variables exhibit any influence on the energy efficiency target achievement. In this sense, the current study explores the association of green finance and eco-innovation with energy intensity in the group of seven economies from 1990 to 2020. By using panel data approaches, this study employs diagnostic tests that confirm the heterogeneous slopes and the existence of panel cross-section dependence. Also, the cointegration tests validate the existence of a long-run equilibrium relationship between the variables. Based on the asymmetric distribution of the data, this study employs the method of moments quantile regression. The empirical results reveal that green finance and eco-innovation significantly reduce energy intensity across the selected quantiles. Control variables such as urban growth and trade openness also adversely affect energy intensity. However, economic growth is the only significant factor that enhances energy intensity. The results are robust as validated by the panel quantile regression and the Granger panel heterogeneous causality test. Based on the findings, this study recommends that green finance be promoted and environmental-related technology innovation be encouraged to achieve the goal of energy efficiency in developed economies. This study also provides additional policies appropriate for environmental recovery.

Keywords: energy intensity, green finance, eco-innovation, urban growth, trade openness, method of moment quantile regression

1 INTRODUCTION

Extenuating climatic adversaries and achieving sustainable growth are prerequisites for every country's environmental and economic development worldwide. Though, the global pandemic has affected several countries and impacted the economic activities of the world. In retrospect, energy efficiency enhancements were quite slow, and Covid 19 has added an extra layer of ambiguity. The investments besides businesses were delayed and triggered market behavior changes that have impacted the progress of energy efficiency worldwide (Altarhouni et al., 2021). However, the economies are emerging globally, and revolution still has a long way to go in the future (International Energy Agency, 2020). Energy efficiency has enormous potential in accelerating sustainable economic development and vindicating pollution concerns besides promoting renewable energy consumption for a clean and green environment (Samour et al., 2022). Besides, eco-innovation and green financing sustenance create green business opportunities that support sustainable growth and development. According to Forbes, the United Kingdom, France, and Germany rank in the top 10 on the Environmental Performance Index, whereas Japan, Canada, and Italy ranked as average performers, and the United States is the poorest in terms of the level of green policies and environmental protection (EPI, 2022). The climatic trends have been changing due to extra-human activities. Attributable to IPCC (2014), world temperature is expected to rise by 2^o to 4.7^o Fahrenheit by the year 2100. Therefore, good governance, environmental regulation, and policy implementation could be beneficial in enhancing environmental quality (Habibullah et al., 2022).

Green financing helps boost energy efficiency and endorse environmental quality in challenging times. The association between green finance and energy intensity is usually negative, showing that green financing improves energy efficiency. Green finance provides green credits for projects for a better and sustainable environment (Qashou et al., 2022). It is sustainable in resource-abundant countries, where there is increasing economic dependence that supports energy efficiency optimization, such as developed economies. Liu et al. (2021a), Liu et al. (2021), and Tu and Rasoulinezhad (2021) reasoned that green financing can be highly operative and attractive in improving energy efficiency. Moreover, the group of seven nations has established strategic policies for green financial market development, whereas there are not any specific studies on eco-innovation and energy intensity because it is a non-debatable concept to date. However, in the case of Indonesia, Bahzar (2019) scrutinized the effect of eco-innovation on energy efficiency in their educational divisions. The empirical outcomes described the positive and constructive impact of eco-innovation on energy efficiency. The increasing eco-innovation in a country has positive and essential conservational benefits that optimize growth potential and increase economic savings and sustainability.

The study aims to investigate the influence of green finance and eco-innovation on energy efficiency in the group of seven

developed economies during 1990–2020. In order to accomplish this, environmental taxes as a proxy of green finance, energy intensity, and a factor of energy efficiency are employed. Eco-innovation and energy intensity are not much-discussed factors in the existing literature. This is obtained in two econometric models explained in Section 3. Model 1 examines environmental taxes on energy intensity, and in Model 2, we corroborate the impact of eco-innovation on energy intensity. It is attributable to less researched and discussed factors, and the linkage must be deeply assessed in G7 economies; therefore, the present study aims to scrutinize this as a new input for researchers and policymakers because G7 urges to invest in vulnerable communities of the world to support them from the crisis.

The foremost research objective is to evaluate the causal association of environmental taxes on energy intensity in Model 1. Other explanatory variables include economic growth, urbanization or urban growth, and trade openness as control variables on energy intensity. Trade openness, GDP, and urbanization substantially influence energy consumption and efficiency. The second objective is to assess the causal effect of eco-innovation on energy intensity in Model 2 with other explanatory variables. These are the control variables in both econometric models. The estimates of both models are obtained by employing panel cointegration techniques to examine long-run correlations of variables, quantile regressions (MMQR), and Dumitrescu–Hurlin panel causality analysis to inspect the causal associations among different study variable pairs.

The motivation of the study lies in inspecting the energy efficiency determinants and their causal connection in the G7 economies. The G7 countries are developed nations that lead the world and significantly influence global GDP and trade activities. Hence, the present study is beneficial in evaluating energy efficiency. After all, the desired countries have not sufficiently invested in low carbon technologies since the COVID pandemic though they always have encouraged renewable green energies over fossil energies. The countries include Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. The G7 group is the biggest carbon emitter in the world. Additionally, green finance is highly effective in developed resource-abundant economies, and eco-innovation provides sustainable environment advantages that support sustainable development. Therefore, aspects have incentivized the authors to extend the debate on exploring energy intensity through eco-innovation and green finance in seven advanced western economies of the world.

The originality of the study is presented by the following contributions:

To the best of the author's knowledge, the study contributes to the literature in scrutinizing the role of green finance along with eco-innovation on energy efficiency for the first time. Only a limited number of studies considered and debated energy intensity areas. Hence, we use three main variables in the models, environmental taxes, eco-innovation, and energy intensity for the case of G7 economies of the world. The purpose of selecting the sample countries is that they are the best performing advanced economies with approximately

32 percent of the world's GDP. In addition, G7 countries have an environmental tax to GDP ratio from 0.6% to 2.5%. The increasing implementation of environmental taxes and eco-innovation by G7 economies will increase clean and green energy usage, and organizations will adopt it, leading to environmental welfare. Second, they infused billions of dollars in fossil fuel energy instead of clean green energy since the arrival of the COVID pandemic despite their green promises (Laville, 2021). Therefore, it is quite essential to analyze the role of environmental taxes, eco-innovation, and energy intensity and their connotation in this specific group of economies in two modifications in contributing to the academic and empirical literature. Second, the study also undertakes the influence of urban growth, economic growth, and trade openness on energy efficiency because GDP, trade, and urbanization have significantly affected energy consumption. In the existing literature, none of the studies explored all these factors over energy intensity, specifically in the post-COVID perspective. However, some studies have mentioned the substantial effect of the variables in a few countries (Lv et al., 2019; Peng and Zheng, 2021; Chen et al., 2022). Hence, the present study contributes to the literature by examining the influence of the said aspects by employing novel econometric techniques such as the method of moments quantile regressions, which is a more powerful technique than the panel quantile regression as it provides empirical estimates at a specific scale and location of the quantile, and the causality analysis tests for assessing causal linkage between eco-innovation, green financing, and energy efficiency in G7 economies considering the Covid 19 era. The present research is a new input in evaluating the multiple variables on energy intensity which is a less investigated and intricate concept. Further, the techniques provide efficient and reliable results. They expand the present debate besides encouraging future research by considering other relevant factors and countries for empirical evidence.

Section 2 provides brief literature reviews of under consideration variables. **Section 3** demonstrates the data assembling, model, and methodology of the study. **Section 4** documents the results and their discussions. **Section 5** presents conclusions and policy implications.

2 LITERATURE REVIEW

An expanded review of prevailing literature on variables under consideration is mentioned in the upcoming subcategories. There are limited research studies concerning green finance and eco-innovation on energy intensity and other explanatory variables in post-COVID years to date. Therefore, the studies cited below cover the pre- and post-COVID perspectives (years) for the understanding of under consideration factors. However, in this segment, a brief description of green financing and eco-innovation is presented initially. After that point, the nexus between intensity and green finance and energy intensity and eco-innovation are elaborated with a few related pieces of evidence from

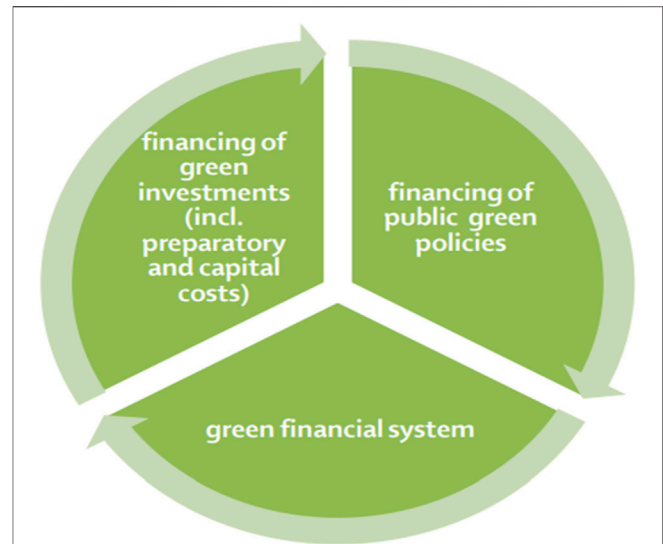


FIGURE 1 | Composition of green finance. Source: Lindenberg (2014).

existing literature that might elucidate the associations more deeply. Later, exclusive connotations from the existing literature between gross domestic product, urban growth, and trade openness on energy intensity are mentioned.

In the literature, there is no exact definition of “green finance.” However, according to the UN program for the environment, green financing refers to increasing the finance for sustainable development programs. It provides credits for projects for a better environment. Some interchangeably refer to green finance as green investments, but it is a broader component than investments. In the banking sector, some refer to it as financial services and products that promote sustainable environment-related investments, low-carbon technologies, and businesses, among others (Lindenberg, 2014). Additionally, the “green financing” progresses energy efficiency in the countries with substantial resource abundance, increasing economic dependence that supports energy efficiency optimization (Peng and Zheng, 2021). In **Figure 1**, the composition of green finance is demonstrated, which illustrates a clear definition of green finance. Zhao et al. (2022) proposed green financing as a new policy for environmental investment. They played a substantial role in promoting renewable energy investments required for clean and green energy (Li et al., 2022; Madaleno et al., 2022). Green financing policies are essential in transforming the economy and encouraging a green environment domestically and globally (Volz, 2018; Mumtaz and Smith, 2019).

A certain business approach gives lifelong product sustainability and encourages small and medium extent enterprises or SMEs (UN Environment Program, 2022). It is a substantial goal toward sustainable development that limits production modes. In general, it provides constructive environmental benefits and economical savings besides promoting social and organizational sustainable competitiveness (Carrillo-Hermosilla et al., 2009). Energy

intensity is a measure of energy that evaluates the efficiency of energy in an economy (Moyo et al., 2021; Samour and Pata, 2022; Shahzad et al., 2022). In the initial stages of economic development, an increase in energy intensity is usually expected due to the abundance of energy-intensive activities in the economy (Martinez et al., 2019). Certain factors impact the intensity or efficiency of energy. Below are some factors under consideration and their underlying linkage.

2.1 Energy Intensity and Green Finance Nexus

Energy intensity is a reciprocal of energy efficiency, which means that if energy intensity is reduced, it will be known as energy efficiency improvement. Liu et al. (2022) explored the role of different financing techniques on energy efficiency in the seven emerging nations. The empirical findings depicted that green financing is more powerful and supportive in enhancing energy efficiency. A green bond (green financing) is an essential tool for boosting energy efficiency and improving environmental quality in challenging times such as COVID-19. Azhgaliyeva et al. (2020) suggested that green bonds aid in promoting green finance and energy efficiency. Tu and Rasoulnezhad (2021) revealed that green bonds and regulatory quality positively influence the energy efficiency in 37 OECD members from the post-COVID time. The general findings showed that green bonds or green financing significantly improve energy efficiency. Additionally, He et al. (2021) analyzed the short- and long-run impacts of environmental taxes on the energy efficiency of OECD economies from 1995 to 2016. The results demonstrated that environmental taxes enhance energy efficiency in the long run. The manuscript is substantial in understanding the impact mechanisms related to environmental taxes on energy intensity. In another novel study of OECD economies from 1994 to 2018, Bashir et al. (2021) examined that green financing endorses energy intensity in those economies. The findings depicted those environmental taxes (green finance) that aid in controlling energy consumption and environmentally innovative technologies in the country. In the same direction, Rafique et al. (2022) concluded that environmental taxation reduces the ecological footprint in developed economies. Liu et al. (2021) professed that green financing is necessary to improve energy efficiency by 2030 (in the long run) in the United States. Rasoulnezhad and Taghizadeh-Hesary (2022) argued that green financing is an essential tool for encouraging green energy-related projects to promote energy efficiency that significantly mitigates carbon emissions. Peng and Zheng (2021) demonstrated that green finance has a stronger impact on energy efficiency and substantially enhances energy efficiency. The development of green technologies and innovation further enhances the efficiency of energy. Liu et al. (2021a) argued that green financing through renewable energy can be highly effective in enhancing and promoting energy efficiency. Zhou et al. (2022) documented the negative association of environmental taxes on the energy intensity of firms.

2.2 Energy Intensity and Eco-Innovation Nexus

Gerstlberger et al. (2014) observed that the topic of product innovation and energy efficiency has been less researched and is complicated. Bahzar (2019) analyzed the influence of eco-innovation on energy efficiency in the educational sectors in Indonesia. The results depicted the positive and constructive impact of eco-innovation on energy efficiency. Energy efficiency is observed as an important aim for mitigating environmental concerns. Hille and Lambernd (2020) examined the influence of eco-innovation and government expenses in South Korea from 2002 to 2017. The empirical findings showed a strong influence of eco-innovation since 2009, but there has been no such improvement observed in the total energy intensity since then. Additionally, Wurlod and Noailly (2018) examined the negative relationship between green innovation and energy intensity in the case of OECD economies.

2.3 Gross Domestic Product Urban Growth and Trade Openness on Energy Intensity

Chen et al. (2022) scrutinized the influence of Gross domestic product on energy intensity in the case of China. The empirical outcomes depicted negative associations between economic growth and energy intensity attributable to the inclusion of control variables, and economic growth lessens the energy intensity. Further, the impact is more noticeable than any other variable under consideration. Hosan et al. (2022) explored the association between economic growth and energy intensity in emerging countries. Energy intensity and sustainability have an inverse relationship with the sustainable growth of the economy (GDP). Emir and Bekun (2019) analyzed feedback causal association between energy intensity and economic growth in the case of Romania. Zhou et al. (2021) observed the sample of 21 developed economies. The empirical findings showed an inverse (negative) relationship between energy intensity and economic growth due to the inclusion of other development factors. However, it can be enhanced (reversed) with an increase in the consumption of renewable energy (Isiksal et al., 2019; Pata and Samour, 2022; Samour et al., 2022). Economic growth also has a decoupling effect on energy intensity (Zhang et al., 2022). Bayar and Gavriletea (2019) determined the positive impact of energy intensity and economic growth with a one-way directional association. Bataille and Melton (2017) found a positive relationship between energy intensity with economic growth (GDP), welfare, and employment level in Canada. Similarly, Adom et al. (2021) expressed the positive linkage between energy efficiency and economic growth.

Sadorsky (2013) explored the mixed effects of urban growth on energy intensity. Yan (2015) scrutinized that urban growth plays a substantial role in increasing energy intensity in China. In the same way, Lv et al. (2019) explored the negative association between urban growth and energy intensity in the cities of China, whether it is direct, indirect, or total. Lin and Zhu (2021) also analyzed a novel (new) type of urbanization effect on the cities of

TABLE 1 | Variable specification and data sources.

Variable	Specification	Data source
EIN	Energy intensity, TPES per capita	OECD Data statistics (2022)
GRF	Green finance is proxied as environmentally related taxes and measured as a % GDP	OECD Data statistics (2022)
ECIN	Patent applications, residents	World Bank (2022)
GDP	GDP measured as constant 2015 US\$	World Bank (2022)
URG	Urban population	World Bank (2022)
TO	Trade openness as % of GDP	World Bank (2022)

China's energy intensity. The empirical outcomes depicted a heterogeneous impact among the variables. Chen and Zhou (2021) found a positive influence of urbanization on energy intensity, but with the insertion of institutional variables, it weakens with a certain threshold value. In an empirical study in the case of OECD economies, Zhu et al. (2021) demonstrated an inverted U-shaped curve with heterogeneous impacts of urban growth on energy intensity depending on the type of country. In contrast, Shah, Naqvi, and Anwar (2020) found a positive association between urbanization and energy intensity in Pakistan.

The impact and association of trade openness with energy intensity are heterogeneous. However, trade openness has a significant impact on energy intensity in Bangladesh, which is highest in the long run (Pan et al., 2019a, Pan et al., 2019b). In another innovative study, Samargandi (2019) showed that trade openness is one of the driving factors in eliminating energy intensity. The results demonstrated that renewable energy consumption and trade openness are substantial factors limiting energy intensity in OPEC economies. Shah, Naqvi, and Anwar (2020) found a negative impact of trade openness on energy intensity in Pakistan during 1980–2017. Adom (2015) determined asymmetric effects between trade openness and energy intensity in Nigeria. In China, trade openness is negatively related to energy intensity (Chen et al., 2022).

3 DATA AND METHODOLOGY

3.1 Data and Model Specification

Following the objectives and literature presented above, this study investigates the influence of various economic and financial indicators on energy intensity (EIN). Nonetheless, the energy intensity or energy efficiency is now the leading concern across the globe and particularly in the developed economies. Since the traditional energy sources (such as oil, natural gas, and coal) are depleting natural resources, shortage of which could harm transportation, industry, and many other sectors. Consequently, economies are focusing on the proportion of energy efficiency or intensity. Therefore, it is essential to analyze whether innovative factors such as green finance and eco-innovation could help achieve the target of energy efficiency. Specifically, this study tends to analyze the influence of green finance (GRF) and econ-innovation (ECIN) on EIN. In recent times, economies have been struggling to boost their green finance and enhance environmental-related innovation not only to curb environmental degradation but also to reduce

energy usage, whereas the given literature does not provide clear evidence to identify the true impact of the said variables on EIN. In this sense, empirical investigation of such variables is required to establish appropriate policies to attain environmental and energy-related objectives. Furthermore, control variables indicating economic growth and captured *via* gross domestic growth (GDP), urban growth (URG) proxied *via* urban population, and trade openness (TO) are also added to analyze the nexus comprehensively. Because these variables are important factors of enhanced income level and encouraging economic activities, the energy demand significantly increases. Hence, it is critical to empirically analyze the influence of such variables on EIN for a comprehensive analysis of the said issue. Data for the said variables are obtained from various sources, covering the period of 1990–2020 for seven economies, including Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. Specifications of the variables and data sources for each variable are given in **Table 1**.

The current study aims to comprehensively investigate the impact of GRF and ECIN on EIN. Therefore, this study constructed two separate models to provide robust association estimates. The two models are given as follows:

Model 1:

$$EIN_{it} = \alpha_1 + \beta_1 GRF_{it} + \beta_2 GDP_{it} + \beta_3 URG_{it} + \beta_4 TO_{it} + \varepsilon_{it} \quad (1)$$

Model 2:

$$EIN_{it} = \alpha_1 + \beta_1 ECIN_{it} + \beta_2 GDP_{it} + \beta_3 URG_{it} + \beta_4 TO_{it} + \varepsilon_{it} \quad (2)$$

From **Eqs 1, 2**, α 's and β 's are the intercept and slopes, whereas the cross-section and time series are denoted *via* "i" and "t" in the subscript. Moreover, ε indicates the random error term of the model.

3.2 Estimation Strategy

The empirical analysis portion of the present research begins with an evaluation of descriptive analysis and estimations of normality. In particular, the mean, median, and range (minimum and maximum) values that describe the complete dataset are examined. Furthermore, the standard deviation is evaluated to determine a variable's overall volatility. In addition, the normality of each variable under examination was evaluated. In other words, skewness and kurtosis reveal the breadth and height of distribution, respectively. Specifically, the range for each of these measurements is between -2 and +2 for skewness and

between -7 and $+7$ for kurtosis (Byrne, 2013). This research also employs a thorough test for normalcy, namely, the Jarque and Bera (1987) normality test, which treats the skewness and excess kurtosis concurrently and proposes that these components are equal to zero, replicating the null hypothesis. The typical formula of the aforementioned test is given as follows:

$$JB = \frac{N}{6} \left(S^2 + \frac{(K-3)^2}{4} \right). \quad (3)$$

After industrialization and international commerce, globalization expanded, despite variables that affect an economy's dependency on other nations. Specialization in particular commodities or services encourages other nations and territories that use them. This dependency is necessary to attain government-defined cultural, financial, social, technological, economic, environmental, and technological objectives and goals. Depending on such characteristics, a nation's economy may show similarities or differences in specific sectors compared to other countries' economies, causing slope heterogeneity and cross-section dependency issues. This research estimates panel data using slope heterogeneity and cross-sectional dependency. If slope heterogeneity and cross-section dependence are neglected, the econometric analysis may be unproductive (Le and Bao, 2020; Wei et al., 2022). Pesaran and Yamagata's (2008) slope coefficient heterogeneity (SCH) and Pesaran's (2004a) panel cross-section dependence (CD) diagnostic tests are utilized to evaluate two-panel data issues. The usual equation for estimating the SCH test is as follows:

$$\hat{\Delta}_{SCH} = \sqrt{N(2k)^{-1}} (N^{-1}\hat{\Sigma} - K). \quad (4)$$

This test also examines the adjusted SCH, which may be calculated using the following method:

$$\hat{\Delta}_{ASCH} = \sqrt{N} \sqrt{\frac{T+1}{2K(T-K-1)}} (N^{-1}\hat{\Sigma} - 2K). \quad (5)$$

The SCH test proposes that the slope coefficients are homogenous, whereas it accepts the alternative hypothesis only if the results are statistically significant.

Cross-section dependence may also provide biased econometric estimates if it prevails in data (Campello et al., 2019). In this scenario, Pesaran's (2004b) CD test is employed, expressed as follows:

$$CD_{Test} = \frac{\sqrt{2T}}{[N(N-1)]^{1/2}} \sum_{i=1}^{N-1} \sum_{k=1+i}^N T_{ik}. \quad (6)$$

The proposed test assumes the presence of panel cross-section dependence in the selected economies. If estimations are statistically significant at the 1%, 5%, or 10% levels, the alternative hypothesis will be adopted.

Because the current research employs panel data that satisfy the property of SCH and CD, a second-generation unit root estimator is employed to address these issues. This research employs the Pesaran (2007) CIPS testing approach. Pesaran

(2006) described cross-sectional dependency component modeling, where the unexplained cross-sectional means are examined. Pesaran (2007) adds mean and first difference lag cross-sections to Augmented Dickey-Fuller (ADF) regression. This method creates cross-sectional dependency even if the panel is unbalanced ($N > T$ or $N < T$). Quantifying ADF cross-section,

$$\Delta y_{it} = \theta_i + \beta_i^* y_{i,t-1} + d_0 \bar{y}_{t-1} + d_1 \Delta \bar{y}_t + \varepsilon_{it}, \quad (7)$$

where \bar{y}_t is the mean of observations. In order to cope with serial correlation, the following initial lags of \bar{y}_t and y_{it} may be inserted into the above equation:

$$\Delta y_{it} = \theta_i + \beta_i^* y_{i,t-1} + d_0 \bar{y}_{t-1} + \sum_{j=0}^n d_{j+1} \Delta \bar{y}_{t-j} + \sum_{k=1}^n c_k \Delta y_{i,t-k} + \varepsilon_{it}. \quad (8)$$

CIPS (Pesaran, 2007) may be investigated across the G7 economies by averaging t-statistics for each cross-sectional unit (CADFi). The CIPS formula is given as follows:

$$CIPS = N^{-1} \sum_{i=1}^N CADF_i. \quad (9)$$

CIPS assumed a time series unit root as the null hypothesis.

Because each variable is stationary, it is important to determine whether they have a long-run stable connection. This research employs two-panel cointegration methodologies, including Westerlund's (2005) variance ratio and Pedroni's (2004) cointegration test. The latter estimates the Modified Phillips-Perron, Phillips-Perron, and Augmented Dickey-Fuller tests. Both the experiments assume no long-run association between the parameters. Still, if the statistical results of these tests are significant at any of the 1%, 5%, or 10% levels, the proposition could be rejected that concludes the presence of cointegration between the variables.

The Jarque and Bera (1987) normality test illustrates the asymmetric distribution of the variables. Therefore, this study uses a novel approach that considers the issue of normality in data. Koenker and Bassett (1978) used panel quantile regression to calculate conditional variance and the mean dependent. Any kind of quantile regression works well with asymmetric or non-normal datasets (Shahzad et al., 2020; Hashmi et al., 2021; Iqbal et al., 2021; Shahzad et al., 2021; Akram et al., 2022). In response to this, Machado and Silva (2019) created a method of moment quantile regression (MMQR) approach. This approach studies quantile distributions and has recently been used in energy and environmental-related studies (Sarkodie and Strezov, 2019; Rehman et al., 2021; Yan et al., 2022).

Eq. 10 provides the location and scale variant $Q_y(\tau|R)$:

$$Y_{it} = \alpha_i + \beta R_{it} + (\gamma_i + \rho Z'_{it}) \mu_{it}, \quad (10)$$

where the probability $p(\gamma_i + \rho Z'_{it} > 0)$ is considered as one. Besides, the estimated coefficients in the equation above are α , β , γ , and ρ , where the subscript "i" indicates the fixed effect represented by α_i and γ_i and $i = 1, 2, \dots, n$. Furthermore, the characteristic component R is a k -vector, represented by Z , and the component "6" displays a distinctive variant:

$$Z_{\parallel} = Z_6(R), \quad 6 = 1, 2, \dots, k. \quad (11)$$

In Eq. 11, in terms of fixed “ i ” and “ t ” (time), R_{it} is identically and independently distributed, which is orthogonal to “ i ” and “ t ” (Machado and Silva, 2019). As a result, the reserves and the external components stabilize. Following the backdrop, the primary models of this study presented as Eqs 1, 2 could be transformed into the following MMQR regression form:

$$Q_y(\tau|R_{it}) = (\alpha_i + \gamma_i q(\tau)) + \beta R_{it} + \rho \dot{Z}_{it} q(\tau). \quad (12)$$

Here, Eq. 12 indicates that R_{it} is a vector that collectively represents the independent variables, including the GRF , GDP , URG , TO in Model 1 and $ECIN$, GDP , URG , TO in Model 2, whereas the vector R_{it} also replicates Y_{it} as it captures the dependent variable EIN , which is also dependent on the quantile's position. All the selected variables are taken in the natural logarithmic form. Furthermore, the scalar coefficient, $-\alpha_i(\tau) \equiv \alpha_i + \gamma_i q(\tau)$, indicates the stable influence of τ quantiles on i . On the contrary, there is no influence of quantile on intercept. However, due to the variables' exogenous and temporal composition, other effects are subtle to adjust. In conclusion, $q(\tau)$ provides samples of the τ -the quantiles, which are considered as four in this specific study: 25th, 50th, 75th, and 90th. This study uses the following quantile equation:

$$\min_q \sum_i \sum_t \theta_\tau (R_{it} - (\gamma_i + \rho \dot{Z}_{it})q), \quad (13)$$

where $\theta_\tau(A) = (\tau - 1) AI\{A \leq 0\} + TAI\{A > 0\}$ reveals the check function.

In order to validate the empirical findings of the discussed approach, this study also utilizes the panel quantile regression, which could be translated into the following forms by altering Eqs 1, 2, respectively:

$$Q_{EIN_{it}}(\theta|\alpha_i, \varphi_t, X_{it}) = \alpha_i + \varphi_t + \varphi_{1,\theta}GRF_{it} + \varphi_{2,\theta}GDP_{it} + \varphi_{3,\theta}URG_{it} + \varphi_{4,\theta}TO_{it} + \varepsilon_{it} \quad (14)$$

$$Q_{EIN_{it}}(\theta|\alpha_i, \varphi_t, X_{it}) = \alpha_i + \varphi_t + \varphi_{1,\theta}ECIN_{it} + \varphi_{2,\theta}GDP_{it} + \varphi_{3,\theta}URG_{it} + \varphi_{4,\theta}TO_{it} + \varepsilon_{it} \quad (15)$$

where θ in the subscript indicates the quantile of each specified variable.

This study also uses the Granger panel causality heterogeneity test proposed by Dumitrescu and Hurlin (2012) because the previous methods cannot establish a causal link between explanatory and dependent parameters. Despite an imbalanced panel (when T does not equal N), this approach provides efficient statistics, is more robust, and tackles the panel CD and SCH issues (Banday and Aneja, 2020).

4. RESULTS AND DISCUSSION

This segment of the manuscript deals with the results and their discussions with tables and respective models' graphical outcomes.

4.1 Descriptive Statistics

The average values are nearly the same as their median values with some points difference. The data spread or dispersion from the mean position of the variables is demonstrated through the standard

deviations mentioned in Table 2. Data precision and symmetry are demonstrated with the help of skewness and kurtosis values. For symmetry of the distribution or skewness, the range is from -2 to $+2$, whereas the range from -7 to $+7$ shows the value of kurtosis or peaked distribution. The values of skewness and kurtosis lie in the mentioned range. Skewness is depicting positive with an approximately skewed distribution. Kurtosis describes the peak of the distribution. The probability values are also significant.

4.2 Slope Heterogeneity and Cross-Sectional Dependence

Tables 3, 4 denote the estimates of slope heterogeneity and cross-sectional dependence. Different countries under consideration across the panel have comparisons or distinctions that may give ineffective and inconsistent results. For unbiased results, slope heterogeneity and cross-section dependence tests are employed in panel analysis. The slope heterogeneity of both models (1 and 2) has significant values at one percent of the level of significance. The estimates reject the null hypothesis at 1% that the variables are not statistically homogeneous in both econometric models. Later, after confirming heterogeneity, the inter-dependence in the cross-sectional analysis of variables is examined. The findings of cross-sectional dependence describe that variables are significant and reject the null hypothesis at a 1% level of significance, portraying that the information is codependent across the panel. The variables are correlated and attributable to the presence of unobserved factors, each affecting the other in the panel.

4.3 Unit Root Test

The codependence of variables and heterogeneity leads to the analysis of unit root for level $I(0)$ and the first difference $I(1)$. Panel unit root tests are advanced forms of conventional unit root tests named Augmented Dickey–Fuller test. The panel unit root (Pesaran 2007) considers cross-sectional averages that were disregarded in conventional ADF unit root. At level, only energy intensity has a significant and negative value, whereas all the estimates are insignificant with negative values in Table 5. At first difference, all variables are significant with a 1% level of significance except for Urban growth is substantial at a 5% level of significance. In general, the results rejected the null hypothesis with negative values of coefficients demonstrating a higher occurrence of a unit root in the variables.

4.4 Cointegration Analysis

The cointegration analysis demonstrates the long-run association of the variables for a specific period in a time series (non-stationary) data. The unit root tests validate the presence of panel unit root in the information leading to examining the cointegration among the variables using Pedroni and Westerlund Cointegration tests. Pedroni cointegration analysis comprises three sets of tests, whereas the Westerlund cointegration test is based on the variance ratio of models (1 and 2) mentioned in Table 6. Both tests' null hypotheses display no cointegration in both models. The statistical estimates of Phillips–Perron and Augmented Dickey–Fuller test are significant in Model 1 and Model 2, with a 1% level of significance rejecting the hypothesis.

TABLE 2 | Descriptive statistics and normality check.

	EIN	ECIN	GRF	GDP	URG	TO
Mean	1.484429	10.28895	1.994816	28.71936	17.95291	48.73420
Median	1.382835	9.788806	2.167000	28.55584	17.77113	50.63172
Maximum	2.144754	12.86712	3.597000	30.62548	19.42876	88.43441
Minimum	0.841957	7.687997	0.719000	27.56247	16.86981	15.81031
Std. Dev.	0.380625	1.521035	0.763326	0.756052	0.675602	18.33408
Skewness	0.499617	0.375906	0.157903	1.086599	0.752704	0.031366
Kurtosis	1.961461	1.845179	2.245337	3.553008	2.724047	2.293297
Jarque–Bera	18.77985	17.16860	6.051133	45.46700	21.17926	4.551248
Probability	0.000084	0.000187	0.048530	0.000000	0.000025	0.102733
Observations	217	217	217	217	217	217

Note: the descriptive statistics are calculated based on log-transformed data.

TABLE 3 | Slope heterogeneity.

Slope heterogeneity test	Statistics
Model 1	
$\bar{\Delta}$	19.621***
$\bar{\Delta}_{Adjusted}$	21.848***
Model 2	
$\bar{\Delta}$	19.979***
$\bar{\Delta}_{Adjusted}$	22.247***

Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.

TABLE 4 | Cross-section dependence.

Cross-section dependence	
EIN	GRF
17.665***	12.843***
ECIN	GDP
3.491***	23.504***
URG	TO
23.936***	16.533***

Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.

TABLE 5 | Unit root testing (Pesaran, 2007).

Variables	Intercept and Trend	
	I(0)	I(1)
EIN	-3.190***	-5.984***
GRF	-1.459	-4.563***
ECIN	-2.176	-4.839***
GDP	-1.978	-4.127***
URG	-2.425	-2.879**
TO	-1.866	-3.966***

Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.

The results portray the existence of cointegration in the econometric models. The Westerlund test also rejects the null hypothesis at a 10% level of significance. The variance ratio confirms the existence of cointegration. The results validate the long-run relationship of variables. Green finance, economic growth, urban growth, and trade openness are

TABLE 6 | Cointegration test.

Test	Statistics	p-value
Pedroni cointegration test		
Model 1		
Modified Phillips–Perron test	-0.2976	0.3830
Phillips–Perron test	-3.8696	0.0001
Augmented Dickey–Fuller test	-2.9183	0.0018
Model 2		
Modified Phillips–Perron test	-0.6004	0.2741
Phillips–Perron test	-5.2841***	0.0000
Augmented Dickey–Fuller test	-3.8831***	0.0001
Westerlund Cointegration Test		
Model 1		
Variance ratio	-1.4106*	0.0792
Model 2		
Variance ratio	-1.3883*	0.0825

Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.

correlated with energy intensity in Model 1. Eco-innovation, economic growth, urban growth, and trade openness are interrelated with energy intensity in Model 2.

4.5 Quantile Regression and Test for Robustness

In the authorization of long-run relationships above, the panel regressions, such as quantile regressions, are applied as a leeway of Ordinary least squares (linear regressions). The estimates of the method of moments quantile regressions (MMQR) are presented in **Tables 7, 8** for Model 1 and Model 2, respectively.

In Model 1, green finance (GRF) is negatively and significantly associated with energy intensity (EIN) in all quantiles at a 1% level of significance. Economic growth (GDP) is significant and positively associated with energy intensity in all quantiles (Bayar and Gavriltea, 2019). Similarly, the coefficient of urban growth (URG) and trade openness (TO) is negative at a 1% significance level depicting an increase in these two variables (URG, TO), substantially decreasing energy intensity in G7 countries (Lv et al., 2019; Shah, Naqvi, and Anwar, 2020). In Model 2, all quantiles represent significant results except in the first quantile Q (0.25). Eco-innovation is negatively associated with energy intensity in approximately all quantiles (Wurlod and Noailly, 2018). The other variables, such as GDP, have a positive linkage,

TABLE 7 | Estimates of quantile regression–MMQR (Model 1).

<!-- Col Count:7-->Variable	Location	Scale	Quantiles			
			Q _{0.25}	Q _{0.50}	Q _{0.75}	Q _{0.90}
GRF	-0.474*** [0.016]	-0.009*** [0.009]	-0.467*** [0.020]	-0.476*** [0.015]	-0.483*** [0.015]	-0.490*** [0.017]
GDP	0.589*** [0.099]	-0.089*** [0.059]	0.657*** [0.123]	0.576*** [0.096]	0.511*** [0.093]	0.446*** [0.108]
URG	-0.904*** [0.117]	0.143** [0.070]	-1.012*** [0.146]	-0.884*** [0.115]	-0.778*** [0.110]	-0.674*** [0.128]
TO	-0.004*** [0.001]	0.001* [0.001]	-0.005*** [0.001]	-0.004*** [0.001]	-0.003*** [0.001]	-0.002** [0.001]
Constant	1.945** [0.951]	0.089*** [0.569]	1.878 [1.180]	1.958** [0.924]	2.023** [0.894]	2.088** [1.044]

Note: EIN is the dependent variable. Significance level is denoted by *** for 1%, ** for 5%, and * for 10%. The standard error is in the bracket.

TABLE 8 | Estimates of quantile regression–MMQR (Model 2).

Variable	Location	Scale	Quantiles			
			Q _{0.25}	Q _{0.50}	Q _{0.75}	Q _{0.90}
ECIN	-0.196** [0.093]	-0.109** [0.046]	0.065 [0.149]	-0.179** [0.091]	-0.151** [0.071]	-0.239** [0.102]
GDP	0.946* [0.572]	0.364** [0.167]	0.608 [0.910]	0.956* [0.558]	1.327*** [0.431]	1.619*** [0.624]
URG	-0.916** [0.365]	-0.396* [0.205]	-0.549 [1.380]	-0.928* [0.545]	-1.33** [0.649]	-1.650* [0.944]
TO	-0.013*** [0.004]	-0.002** [0.001]	-0.001 [0.006]	-0.013** [0.005]	-0.006** [0.003]	-0.008** [0.004]
Constant	-8.688*** [2.433]	-1.816* [1.084]	-7.004* [3.941]	-8.738*** [2.407]	-10.587*** [1.835]	-12.045*** [2.690]

Note: EIN is the dependent variable. Significance level is denoted by *** for 1%, ** for 5%, and * for 10%. The standard error is in the bracket.

TABLE 9 | Robustness test–quantile regression.

Variable	Model 1 quantiles				Model 2 quantiles			
	Q _{0.25}	Q _{0.50}	Q _{0.75}	Q _{0.90}	Q _{0.25}	Q _{0.50}	Q _{0.75}	Q _{0.90}
GRF	-0.454***	-0.421***	-0.501***	-0.513***	–	–	–	–
ECIN	–	–	–	–	0.076	-0.147**	-0.215**	-0.226***
GDP	0.681***	0.638***	0.285**	0.175**	0.850***	0.150	1.002**	0.595**
URG	-1.030***	-0.939***	-0.512***	-0.340***	-0.771**	0.376	-0.892	-0.316
TO	-0.004**	-0.003***	-0.003***	-0.001	-0.001	-0.002	-0.010**	-0.001
Constant	1.426	1.027	3.799***	3.832***	-10.071***	-8.058***	-8.293***	-7.126***

Note: EIN is the dependent variable. Significance level is denoted by *** for 1%, ** for 5%, and * for 10%. The standard error is in the bracket.

whereas URG and TO have negative associations with energy intensity.

Table 9 demonstrates the robustness of the MMQR. The robustness test is a goodness of fit test for examining the reliability and fitness of the model. The general results describe the goodness of fit of the MMQR (Models 1 and 2). In Model 1, all variables in all quantiles are robust with significant values. While in Model 2, nearly some quantiles depict significance and validate the robustness. Moreover, Figures 2, 3 show the graphical representation of quantiles of both models (1 and 2) with respective variables.

4.6 Dumitrescu–Hurlin Panel Causality

The Dumitrescu–Hurlin panel causality test governs the causal relationship among the study variable pairs. In Table 10, nearly all pairs have significant and causal associations. Pairs such as EIN ⇌ GRF, ECIN ⇌ EIN, EIN ⇌ ECIN, GDP ⇌ EIN, URG ⇌ EIN, EIN ⇌ URG, and TO ⇌ EIN have significant outcomes displaying causal associations. Attributable to the estimates of energy intensity and green finance, these variables are found in one-way causal connection, while eco-innovation, and energy intensity have a

bidirectional causal association; that is, eco-innovation causes a significant impact on energy intensity and vice versa. Economic growth and trade openness have one-way causality with energy intensity in the case of the group of seven developed countries. Lastly, urban growth is bidirectionally associated with energy intensity in G7 economies. The empirical findings of this study align with each variable’s substantial influence on the intensity of energy. The countries must endorse promoting green and efficient technologies for sustainable development. The legislators need to focus on introducing eco-innovation that will minimize the energy usage per unit and further management policies in the selected panel economies.

4.7 Discussion

First, the correlation (long run) results of green finance on energy intensity are somehow comparable to the case of Doğan et al. (2022) that increasing environmental taxes (green finance) lessens the intensity of traditional energy usage. The causality runs from energy intensity to the green finance that enhances energy intensity influences the green finance or environmental taxes. Further, the negative relationship between taxes and

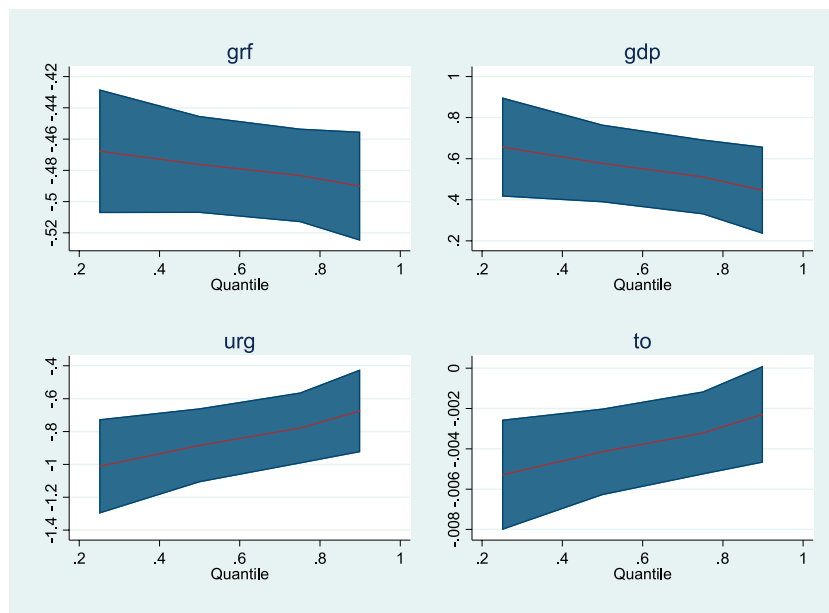


FIGURE 2 | Graphical presentation of quantile regression for Model 1.

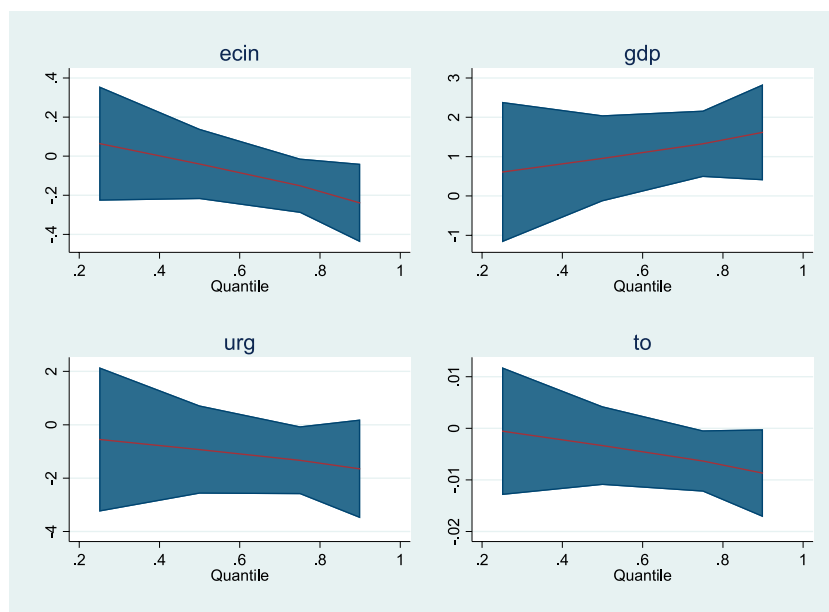


FIGURE 3 | Graphical presentation of quantile regression for Model 2.

energy intensity is consistent with the findings of Zhou et al. (2022) at the firm level. Second, the correlation between eco-innovation and energy intensity is also negative but with bidirectional causality that an increase in eco-innovation significantly affects energy intensity and *vice versa*. Wurlod and Noailly (2018) demonstrated that increasing green innovation or eco-innovation can be inversely linked with

energy intensity, thereby reducing the energy intensity. Hence, the negative and significant effects of eco-innovation and energy intensity of the present study are reliable with the study (Wurlod and Noailly, 2018).

Third, the economic growth and energy intensity have a unidirectional but positive association running from gross domestic product to energy intensity. Economic growth and

TABLE 10 | Dumitrescu–Hurlin panel causality.

H_0	WaldStats	\bar{Z} stats	p-value
$EIN \nRightarrow GRF$	13.5703***	12.6068	0.0000
$GRF \nRightarrow EIN$	3.24192	1.17352	0.2406
$ECIN \nRightarrow EIN$	6.75669***	5.06429	4.E-07
$EIN \nRightarrow ECIN$	4.43318**	2.49221	0.0127
$GDP \nRightarrow EIN$	8.43542***	6.92261	4.E-12
$EIN \nRightarrow GDP$	0.94535	-1.36874	0.1711
$URG \nRightarrow EIN$	8.00687***	6.44822	1.E-10
$EIN \nRightarrow URG$	3.76501*	1.75256	0.0797
$TO \nRightarrow EIN$	9.59982***	8.21159	2.E-16
$EIN \nRightarrow TO$	2.09384	-0.09739	0.9224

Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.

energy intensity associations and causal linkage (Bayar and Gavrilitea, 2019; Adom et al., 2021) have consistent findings, constructive and unidirectional. For the outcomes of urban growth and energy intensity, the present empirical findings depicted a negative association between urban growth and energy intensity with bidirectional causality. The developed countries are usually energy-intensive with significant but negatively associated energy intensity. Therefore, consistent with the study of Zhu et al. (2021), the findings of trade openness also have an inverse relationship with the one-way causal association. The results are somehow reliable (Shah, Naqvi, and Anwar, 2020; Chen et al., 2022).

In general, green finance and eco-innovation have significant effects with explanatory variables such as GDP, urban growth, and trade openness on developed economies. COVID-19 has affected most of the nations worldwide. The above empirical findings can be effective for researchers, academicians, and policymakers to re-evaluate economic, environmental, and energy-related policies and fulfill the country's requirements and support the betterment of the vulnerable economies for sustainable development.

5 CONCLUSION AND POLICY IMPLICATION

5.1 Conclusion

On the nexus between green finance and eco-innovation, a very limited number of studies are available in the prevailing literature with insufficient empirical evidence, especially considering the impact on energy intensity. Hence, the current study deliberately tries to fill the gap by examining the influence of green finance and eco-innovation on the energy intensity of the G7 countries from 1990 to 2020 (post-COVID 19 perspectives). The study uses novel variables such as environmental taxes (green finance) and eco-innovation along with GDP, urban growth, and trade openness to assess the connection. For analysis, the authors employed panel econometric approaches and tests for long-run causal relationships. The present study is, one way or another, reliable to the subsequent studies (Wurlod and Noailly, 2018; Adom et al., 2021; Zhu et al., 2021; Shah, Naqvi, and Anwar, 2020; Chen et al., 2022; Doğan et al., 2022; Zhou et al., 2022)

concerning the above-mentioned factors. However, the study is novel in examining green financing and eco-innovation on energy efficiency in G7 developed economies simultaneously.

In the unit root test, Pesaran (2007) detected the strong existence of unit roots among the variables of developing seven economies. The panel cointegration (Pedroni and Westerlund) tests revealed long-run associations between the variables of both Models (1 and 2). Further, the quantile regressions and robustness test signified substantial and momentous results. Green finance (GRF) and eco-innovation (EIN) are negatively and significantly associated with energy intensity in approximately all quantiles in the tables. An increase in green financing and eco-innovation negatively impacts the intensity of the energy in G7 countries. The general robustness results describe the goodness of fit and reliability of the MMQR. Then, the causality analysis in **Table 10**, which evident unidirectional causal influence form energy intensity to green finance. The association between eco-innovation and energy intensity has a bidirectional causal association; eco-innovation causes a noteworthy influence on energy intensity. Moreover, the explanatory variables such as economic growth and trade openness have unidirectional causality with energy intensity in the case of the group of seven developed countries. Lastly, urban growth has a bidirectional connotation with energy intensity in G7 countries.

Since the COVID pandemic, the G7 economies, including Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States, have not sufficiently invested in low carbon energy-efficient technologies. However, they always have encouraged renewable green energies over fossil energies. Energy efficiency has enormous potential in accelerating sustainable economic development and vindicating environmental concerns. Green finance and eco-innovation have substantial effects on the intensity of energy besides the role of GDP, urban growth, and trade openness playing a substantial part in the case of developed economies. The pandemic has affected numerous countries around the world. The above precise and pragmatic findings can be effective for researchers, academicians, and policymakers to re-evaluate the present study by inserting other factors such as quality of the environment, institutional quality, and technological advancement for future research. It further increases the present debate in literature besides encouraging forthcoming exploration of other countries concerning present factors for empirical evidence that will help understand the concept for in-depth analysis.

5.2 Policy Implications and Future Recommendations

Based on the study's findings, the succeeding mentioned some relevant policy implications. Specifically, energy efficiency and intensity are key factors for sustainable development. The present study has a significant influence on certain variables that help promote energy intensity for sustainable development. Overall, each variable has a considerable influence on energy intensity. In order to encourage sustainable energy, countries must endorse promoting green and efficient technologies. Policymakers and

strategists need to focus on introducing eco-innovation by companies that will minimize the energy usage per unit and further management policies. A green bond, investment, or security verifier must be established to authorize them before issuing in the country. The third party attempts to authorize the bonds, securities, and investments and evaluate them as green by estimating the project's benefits. Market reform policies are also necessary to initiate sustainable technologies and innovations by specifying the characteristics of products, appliance standards, and so on. The developed countries need to advance energy and environment policies as they have done in the past that aid in fulfilling the country's requirements of promoting green finance and eco-innovation. In addition, developed nations must support vulnerable economies to improve sustainable development.

Additionally, they should strengthen the environmental protection system and enhance the environmental regulatory systems, such as the formulation of green and technological innovation capability policies, pollution control, and protection standards. Likewise, environmental regulations are essential tools that enhance environmental quality. These ensure that all living beings, either animals or humans in the ecosystem, are not harmed; besides, governments do not cause harm and implement laws and policies that protect the environment.

The study is constrained to a group of seven economies. Therefore, it is necessary to investigate the present influence of under consideration variables in another set of developed economies (replicated) to scrutinize and assess the concept more deeply as a part of the future scope. It will provide additional empirical evidence to researchers, practitioners,

and energy strategists to revamp environmental and sustainable policies. Second, the influence of study variables would be different for developing countries. It will be substantial to expand the current research in developing nations for comparison. It would be useful for developing nations to evaluate the policies and implement them. The third restriction with the endorsement, energy intensity, and eco-innovation are less researched areas in empirical and academic literature. Energy is a broader concept, and its usage is important in our daily lives. The effect of environmental quality, technological innovation, and globalization can also be evaluated in the context of G7 countries. Therefore, it is recommended to inspect these factors with the inclusion of other relevant factors that help in the process of sustainable environment and development.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HW: concept, data, and theory. EW: literature review, preparing the draft, and analysis. DR: introduction, methodology, and software. MH-S: supervision, editing, data analysis, results, and discussion.

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