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# Moderating Effect of Financial Development on the Relationship between Renewable Energy and Carbon Emissions

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**Abstract:** This study investigates the moderating effect of financial development on the renewable energy–$CO_2$ emissions nexus in OECD countries. We find that both composite financial development and banking sector development have an inverted U-shaped impact on $CO_2$ emissions, while stock market development has a U-shaped impact on $CO_2$ emissions. Further, an increase in renewable energy will reduce $CO_2$ emissions, and this reducing impact is affected by different levels of financial development. When promoting financial development, policymakers should pay more attention to its role in enhancing renewable energy, which is related to emissions reduction.

**Keywords:** $CO_2$ emissions; renewable energy; financial development; nonlinearity

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## 1. Introduction

Environmental issues have become a major threat to human health, attracting worldwide attention. One of the most controversial and extensively discussed topics is carbon emissions, considered a major cause of global warming [1] by way of human activities [2]. The reduction of carbon emissions has become the focus of researchers and policymakers due to international environmental protection requirements, which could potentially hinder economic development [3].

In their pursuit of rapid economic growth, countries often use large quantities of conventional fossil fuel energy sources, leading to an increase in carbon dioxide ($CO_2$) emissions [4]. While member states of the Organization for Economic Cooperation and Development (OECD) benefit from this energy-driven economic growth, they produce approximately 35% of global $CO_2$ emissions from energy consumption [5]. Since signing the Kyoto Protocol, OECD countries have implemented low-carbon strategies to curb $CO_2$ emissions, resulting in a 9% decline in $CO_2$ emissions over the past decade. A key emissions reduction strategy is to increase the application of renewable energy, which is strongly encouraged by the fiscal policies of OECD governments [6]. Based on the data from the International Energy Agency [7], renewable electricity production in OECD countries accounted for 28.78% of total electricity production in 2019. The promotion of renewable energy not only brings environmental benefits but also helps to stimulate economic growth, ensure energy security, and improve energy structure [8]. Given these benefits, global economies are committed to increasing the proportion of renewable energy and reducing dependence on conventional energy to achieve the goal of reducing $CO_2$ emissions without hindering economic growth [9].

The literature also highlights the varying effects of renewable energy use on $CO_2$ emissions. Most studies confirm the positive role of renewable energy in reducing $CO_2$ emissions [10–14], while others suggest that there needs to be a certain proportion of renewable energy to produce this effect; otherwise, it will not reduce overall $CO_2$ emissions [15–17]. Given these inconsistent findings, the nexus between renewable energy and $CO_2$ emissions for OECD countries is worth further examination.

Along with renewable energy, financial development also plays a crucial role in environmental quality. Financial development can reduce financing costs for firms and consumers, facilitating access to loans for the purchase of machines, equipment, and large electronic items, which may result in increased energy consumption and $CO_2$ emissions [18,19]. However, development in the financial sector could also promote technological innovations and energy efficiency, leading to reduced energy consumption and increased use of renewable energies, thus decreasing $CO_2$ emissions [20–23]. Dogan and Seker [24] argue that the net impact of financial development on $CO_2$ emissions may be positive or negative relying on the impact that is dominant. In addition, some studies further confirm that different levels of financial development may have different impacts on $CO_2$ emissions, leading to an inverted U-shaped relationship between financial development and $CO_2$ emissions [25–27]. In other words, financial development could initially expand $CO_2$ emissions, but as the financial sector matures, $CO_2$ emissions may decline because of the increased funds available to promote energy innovations such as renewable energy [25–27]. These findings indicate that renewable energy may be an important means by which financial development contributes to emissions reduction.

The utilization of renewable energy involves high initial capital and information costs and asset specificity. Moreover, renewable projects require a longer repayment period, and consequently more financial support [28]. A well-developed financial market could overcome the problems of moral hazard and adverse selection, making it easier for the renewable energy sector to obtain low-cost financing. Some studies confirm the beneficial impact of financial development on renewable energy, contributing to a reduction in $CO_2$ emissions [21,22,29,30]. However, other scholars argue that because of the insufficient level of financial development, it has had little effect on promoting renewable energy consumption, increasing $CO_2$ emissions [16,31,32]. These mixed findings on the nexus of financial development, renewable energy, and $CO_2$ emissions suggest that the impacts of financial development on promoting renewable energy use may rely on its level of development [21,28,33]. Therefore, its effect on $CO_2$ emissions may be different for different countries and periods [3].

Based on the above analysis, it may be inferred that under different levels of financial development, renewable energy may be developed to varying degrees, thus affecting $CO_2$ emissions differently. Therefore, the main objective of this paper is to explore how different levels of financial development affect the renewable energy–$CO_2$ emissions nexus in OECD countries by using various indicators of financial development (i.e., a composite financial development indicator, a stock market development indicator, and a banking sector development indicator). In addition, this paper mainly contributes to the existing literature as follows. First, most of the existing literature focuses on the renewable energy–$CO_2$ emissions nexus [6,11,34], the financial development–$CO_2$ emissions nexus [35–37], or the financial development–renewable energy nexus [21,38,39]. Although some studies have considered both financial development and renewable energy when exploring the factors that affect $CO_2$ emissions, they have only explored the separate effects of financial development and renewable energy on $CO_2$ emissions, apart from a study by Zafar et al. [3] on Group of Seven (G7) and Next 11 (N11) countries. In fact, financial development may affect the nexus between renewable energy and $CO_2$ emissions, which are mostly ignored by the existing literature. To fill this gap, our research investigates the moderating impact of financial development on the link between renewable energy and $CO_2$ emissions in OECD countries.

Second, the existing literature mainly focuses on the linear nexus between renewable energy, financial development, and $CO_2$ emissions nexus. Our research is the first to examine the nonlinear effect of financial development on the renewable energy–$CO_2$ emissions nexus, which helps to provide a deeper understanding of how the renewable energy–$CO_2$

emissions nexus changes with different levels of financial development. Furthermore, we adopt a composite financial development indicator and two disaggregated financial development indicators (i.e., a stock market development indicator and a banking sector development indicator) to measure different aspects of financial development. Previous studies have seldom simultaneously taken composite, banking, and stock market aspects of financial development into account when investigating the financial development–renewable energy–$CO_2$ emissions nexus. By adopting different financial development indicators, our study compares different effects of composite financial development, banking sector development, and stock market development on the renewable energy–$CO_2$ emissions nexus.

The remainder of this study is arranged as follows. Section 2 summarizes the studies on the relationships between financial development, renewable energy, and $CO_2$ emissions. Section 3 presents the empirical model and data specification. Section 4 outlines the empirical results. Finally, the conclusions and policy implications are presented in Section 5.

## 2. Literature Review

### *2.1. Renewable Energy and $CO_2$ Emissions*

There has been heated debate on the impacts of renewable energy on $CO_2$ emissions over the past two decades [32]. Most existing studies conclude that the application of renewable energy will decrease $CO_2$ emissions and enhance environmental quality. Some of these studies focus on specific countries by employing autoregressive distributed lag regression. For example, Usama et al. [34] used the augmented framework of the environmental Kuznets curve (EKC) hypothesis, finding that renewable electricity generation reduced Ethiopia's $CO_2$ emissions over the period 1981–2015. Bölük and Mert [10] found that renewable electricity generation in Turkey may reduce $CO_2$ emissions in the long term, but the improvement effect on the environment will lag by one year. Sarkodie and Adams [11] note that as a country rich in fossil fuels, South Africa could diversify its energy mix through a combination of renewable and conventional energy generation, helping to improve air quality and reduce the vulnerability of the economy to price fluctuations. Other literature has focused on groups of countries. Liu et al. [30] examined Brazil, India, China, and South Africa, finding a negative relationship between renewable energy consumption and $CO_2$ emissions for all countries from 1999 to 2014, but that for India and South Africa, this negative relationship was at the expense of economic output. Other studies also found a negative correlation between renewable energy use and $CO_2$ emissions, including those by Shafiei and Salim [6] and Jebli et al. [8] for OECD countries, Zoundi [40] for 25 selected African countries, Bekun et al. [12] for 16 European Union countries, and Hao et al. [41] for G7 countries. Chiu and Chang [15] employed a panel threshold regression model to explore the share of renewable energy required by the OECD countries to reduce $CO_2$ emissions, finding that the supply of renewable energy must be at least 8.3889% of the total energy supply to decrease $CO_2$ emissions. Ehigiamusoe et al. [42] note that the effects of economic growth on $CO_2$ emissions are increasing as energy consumption rises for middle-income countries because these countries invest less in renewable energy.

On the contrary, other studies find that renewable energy insignificantly affects $CO_2$ emissions or even increases them. Employing a modified Granger causality test, Menyah and Wolde-Rufael [43] found no causal nexus between renewable energy consumption and carbon emissions in the United States, showing that the level of renewable energy consumption at the time did not contribute significantly to the reduction of emissions. Apergis et al. [16] also found an insignificant effect of renewable energy consumption on $CO_2$ emissions in 19 developed and developing countries, possibly because the proportion of renewable energy use in these countries was low. Al-Mulali et al. [17] proposed that because renewable energy use takes only 1% of total energy use in Vietnam, it has no significant impact on decreasing $CO_2$ emissions. Using both fixed and time-varying parameter estimation methods, Bulut [44] explored the impacts of renewable and non-renewable electricity generation on $CO_2$ emissions from 1970 to 2013, finding that in Turkey, renewable electricity generation was positively related to $CO_2$ emissions but produced fewer emissions compared with non-renewable electricity generation. Similarly, Bölük and Mert [45] found that in European Union countries, $CO_2$ emissions produced by renewable energy consumption are approximately one-half of that produced by fossil fuel consumption. Farhani and Shahbaz [46] also found that renewable electricity use increased $CO_2$ emissions in the Middle East and North Africa region.

Thus, the research on renewable energy and $CO_2$ emissions yields mixed conclusions, which is possibly the result of the wide range of econometric techniques, countries (e.g., a certain country or a group of countries), and time periods studied.

### *2.2. Financial Development, Renewable Energy, and $CO_2$ Emissions*

Based on the findings of studies on financial development and $CO_2$ emissions, financial development may have a positive [36,47], negative [37,48–51], or even no [35,52] effect on $CO_2$ emissions. Several studies also found a nonlinear nexus between financial development and $CO_2$ emissions. Shahbaz et al. [25] found an inverted U-shaped relationship between financial development (using real domestic credit to private sector per capita) and carbon emissions in Indonesia. Charfeddine and Khediri [26] confirmed this finding for the United Arab Emirates. Paramati et al. [27] found the same inverted U-shaped relation between stock market development and carbon emissions for both developed and developing market economies. Abbasi and Riaz [53] found that in Pakistan, both banking sector and stock market development had no significant effect on $CO_2$ emissions over the full sample period (1971–2011). This may have been attributable to the low level of financial development in Pakistan in the earlier part of this period, because later in the period (1988–2011), when Pakistan's stock market development reached a higher level, the increased stock market turnover positively affected $CO_2$ emissions.

Li et al. [54] employed a panel threshold regression model to test the nonlinear relation between stock market development and $CO_2$ emissions, finding that with economic growth, stock market development initially stimulates before mitigating $CO_2$ emissions. Omoke et al. [55] used a nonlinear autoregressive distributed lag model to investigate the asymmetric nexus between financial development and $CO_2$ emissions in Nigeria, finding that positive components of financial development reduce $CO_2$ emissions, while negative components of financial development increase $CO_2$ emissions.

Some researchers have also taken financial development into account when studying the nexus between renewable energy and $CO_2$ emissions. Dogan and Seker [24] proposed that increases in renewable electricity generation and financial development result in a reduction of $CO_2$ emissions in countries with the highest level of renewable energy use. Paramati et al. [56] found that stock market development in G20 countries may increase $CO_2$ emissions in developing economies while alleviating $CO_2$ emissions in developed economies. They also found that renewable energy consumption negatively affected $CO_2$ emissions in both the full sample and subsamples. Khoshnevis and Ghorchi [57] found, in 25 African countries, that renewable energy consumption reduces $CO_2$ emissions, while financial development expands $CO_2$ emissions, with similar results obtained by Iorember et al. [58] for Nigeria, and Wang et al. [19] for N11 countries. Pata [59] showed that $CO_2$ emissions increase under conditions of financial development but are not significantly affected by renewable energy consumption. Khan et al. [29] explored the relationships between $CO_2$ emissions and financial development, renewable energy, energy use, tourism, and trade for 34 high-income countries, finding that the causal relationships between financial development and $CO_2$ emissions, renewable energy and $CO_2$ emissions, and financial development and renewable energy vary between continents. Kutan et al. [22] researched renewable energy financing and sustainable development in Brazil, China, India, and South Africa, finding that stock market growth may promote renewable energy consumption, mitigating $CO_2$ emissions. Charfeddine and Kahia [32] conducted a study of 24 countries in the Middle East and North Africa region from 1980 to 2015, finding that both financial development and renewable energy slightly influenced $CO_2$ emissions, and renewable energy consumption was not increased by financial development. Shahbaz et al. [31] found, for both BRICS (Brazil, Russia, India, China, and South Africa) and N11 countries, that financial development promotes $CO_2$ emissions, and renewable energy consumption reduces $CO_2$ emissions. They also found that financial development reduces the share of renewable energy consumption in the total energy consumption of BRICS countries, but insignificantly affects the renewable energy consumption of N11 countries.

Further, Zafar et al. [3] suggest that financial development may indirectly affect $CO_2$ emissions by way of renewable energy. They added cross terms between financial development indicators and renewable energy consumption to their models, showing that with the development of the banking sector, renewable energy increases carbon emissions in N11 countries but decreases emissions in G7 countries. In contrast, with stock market development, renewable energy increases emissions in G7 countries but decreases emissions in N11 countries. Unlike in our study, Zafar et al. [3] did not consider the squared term of financial development, applying continuously updated fully modified and bias-corrected estimation methods, which do not consider endogeneity bias. Their study focuses on the consumption side of renewable energy, while our study focuses on the production side.

We summarize some of the content of the existing literature as follows. First, with respect to the measurement of financial development, most studies have adopted domestic credit to private sector as a share of GDP (one aspect of banking sector development) or foreign direct investment to measure financial development, while others have added the relevant stock market to measure financial development. Therefore, financial development may be divided into banking sector development and stock market development. To further measure financial development, recent studies attempt to construct composite indicators of banking sector and stock market development by adopting multiple variables and principal component analysis (PCA) [3,28]. Second, the results of the nexus between financial development and $CO_2$ emissions are mixed. Although some studies have added financial development to their models when analyzing the nexus between renewable energy and $CO_2$ emissions, few studies have used an empirical model to explore how financial development affects the relationship between renewable energy consumption and $CO_2$ emissions.

## 3. Empirical Model and Data

### *3.1. Empirical Model*

This study mainly investigates the effects of renewable energy on $CO_2$ emissions and the moderating effects of financial development on the nexus of renewable energy and $CO_2$ emissions. We present the impact mechanism among the key variables in the concept map of Figure 1.

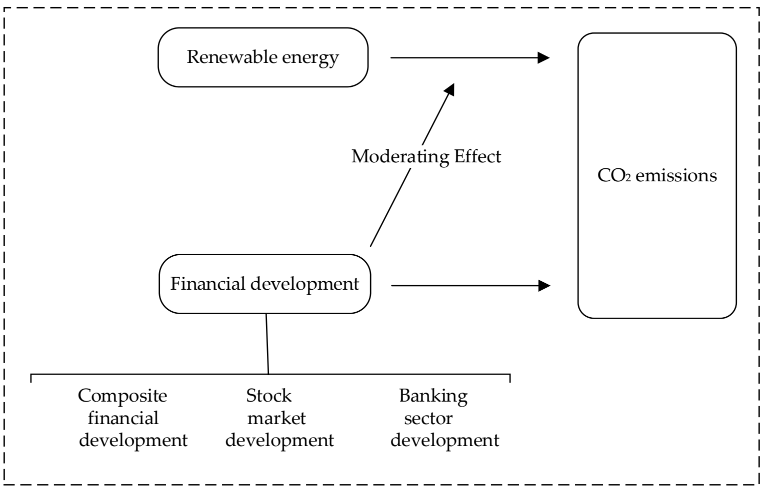


**Figure 1.** The concept map of this study.

To investigate how renewable energy and financial development affect $CO_2$ emissions, we define a basic dynamic panel data model as follows:

$$\begin{aligned} LnCO2_{i,t} = {} & \alpha_1 LnCO2_{i,t-1} + \alpha_2 LnRE_{i,t} + \alpha_3 LnFD_{i,t} + \alpha_4 LnGDP_{i,t} \\ & + \alpha_5 LnGDPSQ_{i,t} + \alpha_6 LnUP_{i,t} + \alpha_7 LnGI_{i,t} + \alpha_8 LnCR_{i,t}, \\ & + \mu_i + \lambda_t + \varepsilon_{i,t} \end{aligned} \quad (1)$$

To further investigate the impacts of financial development on the nexus of renewable energy and $CO_2$ emissions, we add the interaction terms of renewable energy and financial development to the basic model as follows:

$$\begin{aligned} LnCO2_{i,t} = {} & \alpha_1 LnCO2_{i,t-1} + \alpha_2 LnRE_{i,t} + \alpha_3 LnFD_{i,t} + \alpha_4 LnRE_{i,t} * LnFD_{i,t} \\ & + \alpha_5 LnGDP_{i,t} + \alpha_6 LnGDPSQ_{i,t} + \alpha_7 LnUP_{i,t} + \alpha_8 LnGI_{i,t} \\ & + \alpha_9 LnCR_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \end{aligned} , \quad (2)$$

To investigate the nonlinear impact of financial development on $CO_2$ emissions, we next add the squared term of financial development (*LnFDSQ*) to the model (1). To investigate the nonlinear role of financial development on the nexus of renewable energy and $CO_2$ emissions, we further add the squared term of financial development (*LnFDSQ*) and the interaction terms of renewable energy and the squared term of financial development ($LnRE * LnFDSQ$) to the model (2).

Where $i$ denotes country; $t$ denotes time period; $CO2_{i,t}$ denotes $CO_2$ emissions per capita; $CO2_{i,t-1}$ is the lag value of $CO2_{i,t}$, indicating the existence of persistent $CO_2$ emissions; RE represents renewable energy indicators, including renewable electricity output (*REO*) and renewable energy consumption (*REC*); FD denotes financial development indicators, including composite financial development indicator (*CFD*), banking sector development indicator (*BANK*), and stock market development indicator (*STOCK*); *FDSQ* represents the square of financial development, including the square of composite financial development (*CFDSQ*), the square of banking sector development (*BANKSQ*), and the square of stock market development (*STOCKSQ*); *GDP*, *GDPSQ*, *UP*, *GI*, and *CR* represent per capita real GDP, the square of per capita real GDP, urbanization, globalization index, and country risk index, respectively; and $\varepsilon$ is the error term. In addition, the coefficients $\mu_i$ and $\lambda_t$ allow for country-specific and time-specific effects, respectively.

Some studies have confirmed a bidirectional causality between $CO_2$ emissions and renewable energy [60], which may induce the endogeneity bias in our model. The presence of the lagged dependent variable ($CO2_{i,t\text{-}1}$) in the model also could induce the endogeneity bias. To reduce endogeneity bias and provide consistent coefficient estimates, this paper adopts the one-step difference generalized method of moments (GMM), which adopts the lags of variables as instruments.

### *3.2. Data Specification*

This study employed unbalanced panel data for a set of 37 OECD countries from 1990 to 2015. The 37 OECD countries include Australia, Austria, Belgium, Canada, Chile, Colombia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Republic, Latvia, Lithuania, Luxembourg, Mexico, The Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. $CO_2$ emissions per capita ($CO_2$) are proxied in metric tons, which is the dependent variable. The renewable energy variables are measured by the ratio of renewable electricity output to total electricity output (%, *REO*) and the ratio of renewable energy consumption to total final energy consumption (%, *REC*). Real GDP per capita (*GDP*) is calculated by constant 2010 USD, and urbanization (*UP*) is proxied by the ratio of urban population to total population (%). The data of above variables are from the World Bank's World Development Indicators database. For the globalization index (*GI*), this study adopts the overall globalization index from the Konjunkturforschungsstelle (KOF) database of the

Swiss Economic Institute. This index has been developed and improved by Dreher [61] and Dreher et al. [62], and is an effective measure of globalization because it is obtained by weighting economic (36%), social (37%), and political (27%) globalization indices. The overall globalization index scores from 0 to 100, and higher values indicate higher levels of globalization. The country risk index (*CR*) is a composite risk indicator obtained from the International Country Risk Guide, calculated from 22 risk components in financial, economic, and political aspects, thus comprehensively measuring the ability of a country to provide a stable development environment for market participants. The scores of composite risk indicators also range from 0 to 100, and higher scores indicate lower risk.

To measure financial development, this study adopted a banking sector development indicator (*BANK*), a stock market development indicator (*STOCK*), and a composite financial development indicator (*CFD*). These three financial development indicators are constructed using PCA. Specifically, the banking sector development indicator is constructed utilizing the following four variables: ratio of domestic credit to private sector to GDP (%, *DCPS*), ratio of deposit money bank assets to GDP (%, *DMBA*), ratio of liquid liabilities to GDP (%, *LL*), and ratio of private credit by deposit money banks and other financial institutions to GDP (%, *PCDMB*). The stock market development indicator is constructed using the following three variables: the ratio of stock market capitalization to GDP (%, *SMC*), the ratio of stock market total value traded to GDP (%, *SMTR*), and stock market turnover ratio (%, *SMTVT*). The composite financial development indicator is constructed using the above seven variables (i.e., *DCPS*, *DMBA*, *LL*, *PCDMB*, *SMC*, *SMTR*, *SMTVT*). These seven variables come from the World Bank Global Financial Development Database. Table 1 reports the results of the PCA. For the composite financial development indicator, the sum of the first three principal components accounted for 88.28% of the total variation and eigenvalues of these three components were close to or more than 1; thus, the first three principal components were adopted in this study to construct *CFD*. The sum of the first two principal components, respectively, accounted for 95.13% and 94.95% of the stock market development indicator and the banking sector development indicator, and the eigenvalues were also close to or more than 1; thus, the first two principal components were adopted to construct *STOCK* and *BANK*. It is thus clear that the financial development indicators constructed using PCA may reflect the main information of many variables, thus better reflecting the development of the stock market, banking sector, and composite financial market.

**Table 1.** Principal component analysis of financial development indicators.

| Principal Component | Eigenvalues | Proportion of Variance | Cumulative Proportion of Variance |
|---|---|---|---|
| *Composite financial development indicators* | | | |
| 1 | 3.7822 | 0.5403 | 0.5403 |
| 2 | 1.4423 | 0.2060 | 0.7464 |
| 3 | 0.9550 | 0.1364 | 0.8828 |
| 4 | 0.5312 | 0.0759 | 0.9587 |
| 5 | 0.1632 | 0.0233 | 0.9820 |
| 6 | 0.0989 | 0.0141 | 0.9961 |
| 7 | 0.0272 | 0.0039 | 1.0000 |
| *Stock market indicators* | | | |
| 1 | 1.9978 | 0.6659 | 0.6659 |
| 2 | 0.8561 | 0.2854 | 0.9513 |
| 3 | 0.1460 | 0.0487 | 1.0000 |
| *Banking sector indicators* | | | |

**Table 1.** *Cont.*

| Principal Component | Eigenvalues | | Proportion of Variance | | | Cumulative Proportion of Variance | |
|---|---|---|---|---|---|---|---|
| 1 | 2.9127 | | 0.7282 | | | 0.7282 | |
| 2 | 0.8853 | | 0.2213 | | | 0.9495 | |
| 3 | 0.1760 | | 0.0440 | | | 0.9935 | |
| 4 | 0.0261 | | 0.0065 | | | 1.0000 | |
| Variables | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 |
| *Composite financial development indicators* | | | | | | | |
| *SMC* | 0.3701 | −0.059 | 0.5475 | −0.5369 | 0.4068 | 0.3256 | 0.0021 |
| *SMTR* | 0.2141 | 0.6572 | 0.0920 | 0.5712 | 0.2448 | 0.3566 | 0.0215 |
| *SMTVT* | 0.3822 | 0.4674 | 0.2451 | −0.1712 | −0.2929 | −0.6785 | −0.0019 |
| *DCPS* | 0.4831 | −0.0973 | −0.2573 | −0.0205 | −0.3456 | 0.2685 | −0.7064 |
| *DMBA* | 0.4189 | −0.2465 | −0.3970 | 0.1613 | 0.6493 | −0.3982 | −0.0087 |
| *LL* | 0.1784 | −0.5123 | 0.5796 | 0.5730 | −0.1681 | −0.1151 | 0.0033 |
| *PCDMB* | 0.4801 | −0.1164 | −0.2683 | −0.0374 | −0.3458 | 0.2501 | 0.7074 |
| *Stock market indicators* | | | | | | | |
| *SMC* | 0.5091 | 0.7257 | 0.4628 | | | | |
| *SMTR* | 0.5288 | −0.6880 | 0.4970 | | | | |
| *SMTVT* | 0.6791 | −0.0083 | −0.7340 | | | | |
| *Banking sector indicators* | | | | | | | |
| *DCPS* | 0.5671 | −0.1559 | −0.4072 | 0.6988 | | | |
| *DMBA* | 0.5463 | −0.1011 | 0.8312 | 0.0184 | | | |
| *LL* | 0.2390 | 0.9702 | −0.0391 | −0.0002 | | | |
| *PCDMB* | 0.5682 | −0.1553 | −0.3764 | −0.7151 | | | |

Table 2 represents the descriptive statistics and Spearman's rank correlation coefficients of variables. It shows that in OECD countries, the average $CO_2$ emissions per capita are approximately 8.635 metric tons, the average ratio of renewable energy consumption to total energy consumption is approximately 16.707%, and the average ratio of renewable electricity output to total electricity output is approximately 28.734%. By comparing financial development indicators, we find that the degree of the banking sector is higher on average than that of the stock market. Figures 2 and 3, respectively, present the heat maps of renewable electricity output and $CO_2$ emissions for 37 OECD countries. It can be seen that Iceland and Norway have a higher ratio of renewable electricity output to total electricity output. Luxembourg and the United States have higher $CO_2$ emissions per capita. According to the results of the correlation coefficients in Table 2, both renewable energy consumption and renewable electricity output are significantly negatively correlated with $CO_2$ emissions, indicating that the use of renewable energy may help enhance environmental quality. Composite financial development, stock market development, and banking sector development are all significantly positively correlated with $CO_2$ emissions, suggesting that $CO_2$ emissions will rise as the financial market improves. In addition, the significant positive relation between other control variables and $CO_2$ emissions suggests that higher economic growth, higher urbanization, higher globalization, and a more stable environment will also increase $CO_2$ emissions.

**Table 2.** Descriptive statistics and correlation coefficients of variables.

| Panel A: Descriptive statistics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variables | $CO_2$ | *REC* | *REO* | *CFD* | *STOCK* | *BANK* | *GDP* | *UP* | *GI* | *CR* |
| Mean | 8.635 | 16.707 | 28.743 | 71.823 | 51.659 | 83.798 | 32,782.070 | 75.249 | 76.060 | 76.481 |
| Minimum | 1.309 | 0.442 | 0 | 8.831 | 0.029 | 4.926 | 4467.394 | 47.915 | 41.200 | 41.335 |
| Maximum | 27.431 | 77.345 | 99.988 | 200.051 | 235.530 | 292.349 | 111,968.400 | 97.876 | 91.300 | 92.375 |
| S.D. | 4.368 | 15.269 | 28.749 | 37.398 | 40.492 | 46.832 | 20,786.960 | 10.974 | 10.519 | 7.949 |
| Observation | 947 | 962 | 962 | 885 | 892 | 939 | 946 | 962 | 954 | 919 |
| Panel B: Spearman's rank correlation coefficients | | | | | | | | | | |
| | $CO_2$ | *REC* | *REO* | *CFD* | *STOCK* | *BANK* | *GDP* | *UP* | *GI* | *CR* |
| $CO_2$ | 1.000 | | | | | | | | | |
| *REC* | −0.473 ***<br>(0.000) | 1.000 | | | | | | | | |
| *REO* | −0.423 ***<br>(0.000) | 0.833 ***<br>(0.000) | 1.000 | | | | | | | |
| *CFD* | 0.415 ***<br>(0.000) | −0.195 ***<br>(0.000) | 0.027<br>(0.429) | 1.000 | | | | | | |
| *STOCK* | 0.320 ***<br>(0.000) | −0.220 ***<br>(0.000) | −0.082<br>(0.014) | 0.785 ***<br>(0.000) | 1.000 | | | | | |
| *BANK* | 0.380 ***<br>(0.000) | −0.124 ***<br>(0.000) | 0.106 ***<br>(0.001) | 0.926 ***<br>(0.000) | 0.523 ***<br>(0.000) | 1.000 | | | | |
| *GDP* | 0.511 ***<br>(0.000) | −0.040<br>(0.220) | 0.154 ***<br>(0.000) | 0.743 ***<br>(0.000) | 0.525 ***<br>(0.000) | 0.756 ***<br>(0.000) | 1.000 | | | |
| *UP* | 0.317 ***<br>(0.000) | 0.005<br>(0.876) | 0.021<br>(0.510) | 0.410 ***<br>(0.000) | 0.372 ***<br>(0.000) | 0.403 ***<br>(0.000) | 0.436 ***<br>(0.000) | 1.000 | | |
| *GI* | 0.309 ***<br>(0.000) | −0.012<br>(0.720) | 0.036<br>(0.271) | 0.561 ***<br>(0.000) | 0.414 ***<br>(0.000) | 0.591 ***<br>(0.000) | 0.714 ***<br>(0.000) | 0.209 ***<br>(0.000) | 1.000 | |
| *CR* | 0.448 ***<br>(0.000) | −0.026<br>(0.436) | 0.111 ***<br>(0.001) | 0.587 ***<br>(0.000) | 0.491 ***<br>(0.000) | 0.547 ***<br>(0.000) | 0.739 ***<br>(0.000) | 0.279 ***<br>(0.000) | 0.603 ***<br>(0.000) | 1.000 |

Notes: S.D. denotes Standard Deviation. Parentheses show *p*-values. *** means the significance at 1% level.

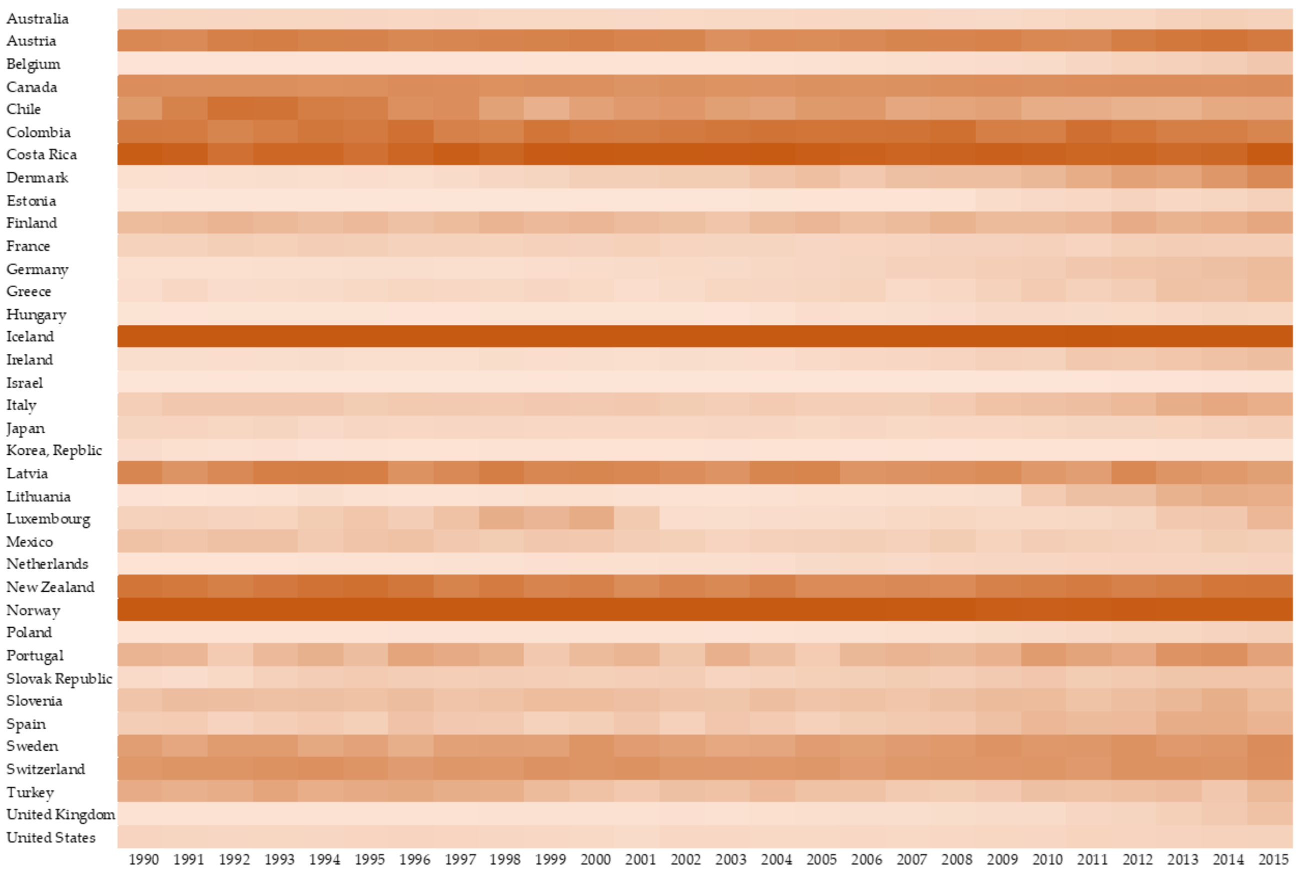


**Figure 2.** The heat map of REO for 37 OECD countries.

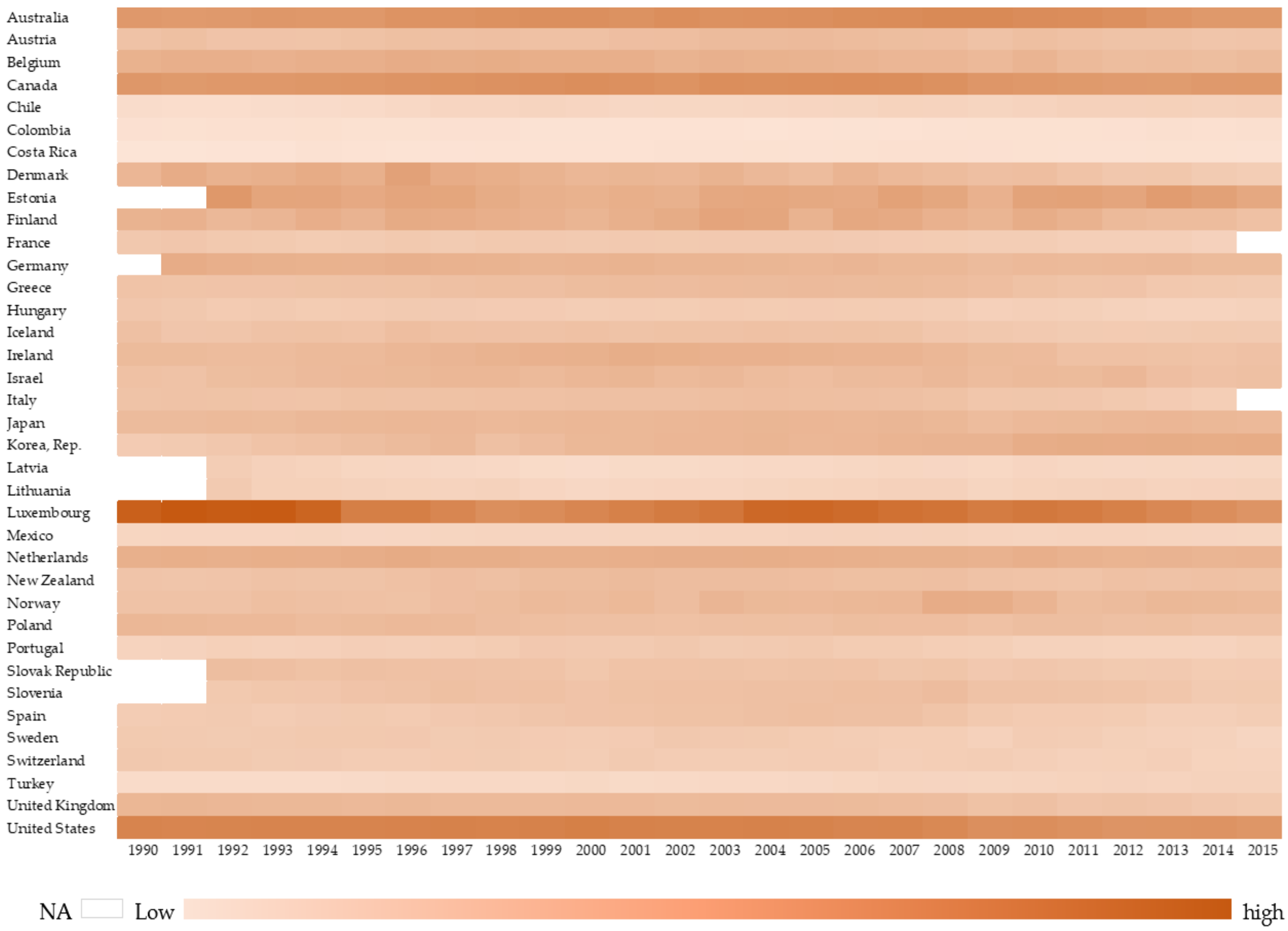


**Figure 3.** The heat map of $CO_2$ emissions per capita for 37 OECD countries.

## 4. Empirical Results

To test whether a unit root of each variable exists, this study applied the Fisher augmented Dickey–Fuller test built by Maddala and Wu [63], and the results show that both dependent and independent variables were stationary at their levels (Table A1 in Appendix A). The GMM-estimated results of all models are reported in Tables 3 and 4. As seen in Tables 3 and 4, the second-order serial correlation tests of all equations cannot reject the null hypothesis that there is no second-order serial correlation between residuals, which confirms the non-existence of second-order serial correlation of the residuals. Moreover, the Sargan tests of all equations also cannot reject the null hypothesis of over-identifying restrictions at the 1% level of significance, confirming the validity of the instrumental variables. Therefore, the results of the both tests ensure that we can obtain consistent estimators of the GMM model. Furthermore, the estimated results of $LnCO2_{i,t-1}$ in all equations are significant and positive, which suggests that the level of $CO_2$ emissions in the previous year will positively affect the level of $CO_2$ emissions in the next year.

**Table 3.** Results of GMM model with *LnREO* and without the squared term of financial development.

| Models | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $LnCO2_{t-1}$ | 0.664 *** (0.025) | 0.743 *** (0.020) | 0.688 *** (0.023) | 0.720 *** (0.021) | 0.778 *** (0.019) | 0.775 *** (0.019) |
| $LnREO_t$ | −0.023 *** (0.004) | −0.002 (0.014) | −0.023 *** (0.004) | −0.013 * (0.007) | −0.021 *** (0.004) | −0.001 (0.014) |
| $LnCFD_t$ | 0.026 ** (0.010) | 0.021 (0.013) | | | | |

**Table 3.** *Cont.*

| Models | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $LnREO_t \times LnCFD_t$ | | −0.006 * (0.004) | | | | |
| $LnSTOCK_t$ | | | 0.008 ** (0.004) | 0.017 ** (0.007) | | |
| $LnREO_t \times LnSTOCK_t$ | | | | −0.004 ** (0.002) | | |
| $LnBANK_t$ | | | | | −0.018 ** (0.009) | −0.004 (0.013) |
| $LnREO_t \times LnBANK_t$ | | | | | | −0.005 (0.004) |
| $LnGDP_t$ | 0.367 (0.289) | 0.617 *** (0.230) | 0.535 ** (0.268) | 0.656 *** (0.244) | 0.615 *** (0.225) | 0.597 *** (0.223) |
| $LnGDPSQ_t$ | −0.006 (0.015) | −0.023 * (0.012) | −0.015 (0.014) | −0.023 * (0.013) | −0.023 *** (0.011) | −0.022 * (0.011) |
| $LnUP_t$ | 0.328 *** (0.093) | 0.228 *** (0.072) | 0.365 *** (0.083) | 0.268 *** (0.075) | 0.214 *** (0.071) | 0.238 *** (0.070) |
| $LnGI_t$ | 0.067 (0.089) | −0.046 (0.072) | 0.044 (0.083) | −0.067 (0.076) | 0.008 (0.070) | −0.001 (0.070) |
| $LnCR_t$ | 0.293 *** (0.047) | 0.202 *** (0.039) | 0.213 *** (0.047) | 0.184 *** (0.043) | 0.164 *** (0.040) | 0.166 *** (0.039) |
| AR(2) test (*p*-value) | 0.251 | 0.301 | 0.322 | 0.328 | 0.145 | 0.142 |
| Sargan's test (*p*-value) | 0.078 | 0.114 | 0.100 | 0.077 | 0.135 | 0.120 |

Notes: Numbers in parentheses show the standard errors. ***, **, and * reflect significance at the 1%, 5%, and 10% levels, respectively.

**Table 4.** Results of GMM model with *LnREO* and with the squared term of financial development.

| Models | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $LnCO2_{t-1}$ | 0.747 *** (0.020) | 0.742 *** (0.020) | 0.741 *** (0.020) | 0.741 *** (0.020) | 0.772 *** (0.019) | 0.768 *** (0.019) |
| $LnREO_t$ | −0.027 *** (0.004) | −0.135 ** (0.061) | −0.025 *** (0.004) | −0.024 *** (0.006) | −0.022 *** (0.004) | −0.160 ** (0.070) |
| $LnCFD_t$ | 0.155 ** (0.061) | −0.015 (0.102) | | | | |
| $LnCFDSQ_t$ | −0.020 ** (0.008) | 0.005 (0.013) | | | | |
| $LnREO_t \times LnCFD_t$ | | 0.062 * (0.032) | | | | |
| $LnREO_t \times LnCFDSQ_t$ | | −0.009 ** (0.004) | | | | |
| $LnSTOCK_t$ | | | −0.011 ** (0.005) | −0.014 * (0.007) | | |
| $LnSTOCKSQ_t$ | | | 0.002 *** (0.001) | 0.004 *** (0.001) | | |
| $LnREO_t \times LnSTOCK_t$ | | | | 0.001 (0.002) | | |
| $LnREO_t \times LnSTOCKSQ_t$ | | | | −0.001 (0.0005) | | |
| $LnBANK_t$ | | | | | 0.138 ** (0.068) | −0.055 (0.115) |
| $LnBANKSQ_t$ | | | | | −0.018 ** (0.008) | 0.007 (0.014) |
| $LnREO_t \times LnBANK_t$ | | | | | | 0.074 ** (0.034) |
| $LnREO_t \times LnBANKSQ_t$ | | | | | | −0.010 ** (0.004) |
| *Controls* | Yes | Yes | Yes | Yes | Yes | Yes |
| AR(2) test (*p*-value) | 0.346 | 0.306 | 0.251 | 0.254 | 0.154 | 0.144 |
| Sargan's test (*p*-value) | 0.124 | 0.158 | 0.115 | 0.126 | 0.161 | 0.149 |

Notes: Numbers in parentheses show the standard errors. ***, **, and * reflect significance at the 1%, 5%, and 10% levels, respectively.

Table 3 reports the results of the GMM model with renewable electricity output and without the squared financial development term. The results show that renewable electricity output significantly negatively affects $CO_2$ emissions, suggesting that $CO_2$ emissions will be decreased as OECD countries produce more renewable energy. Some authors have found similar results, including Shafiei and Salim [6] for OECD countries, Zoundi [40] for 25 selected African countries, and Wang et al. [19] for N11 countries. The results for financial development show that $CO_2$ emissions will decrease with the development of the banking sector. This indicates that banking sectors in OECD countries have reached a level of maturity at which they can allocate more funds to advanced energy production technologies and green projects, thus reducing emissions [3]. However, composite financial development and stock market development increase $CO_2$ emissions, which may be attributable to companies in OECD countries utilizing funds from composite financial markets and stock markets to expand production and consume more energy resources, leading to higher $CO_2$ emissions. The estimated coefficients of the interaction term of renewable electricity output and three financial development indicators are all negative, implying that financial development enhances the negative relation between renewable electricity output and $CO_2$ emissions. This indicates that financial market development could encourage the deployment of renewable energy by making it easier for OECD countries to obtain external financing, contributing to the reduction of $CO_2$ emissions [20–22,28].

As for control variables, the results for real GDP show that economic growth has an inverted U-shaped impact on $CO_2$ emissions, verifying the effectiveness of the EKC hypothesis in our sample countries, which is consistent with Fujii et al. [64], Liddle and Messinis [65], Chang and Li [66], and Shahbaz et al. [67]. The positive coefficients for *LnUP* demonstrate that $CO_2$ emissions will increase with urbanization, implying that urbanization in OECD countries is at the expense of the environment. These results are supported by Poumanyvong and Kaneko [68], Zhang and Lin [69], and Shafiei and Salim [6]. Globalization has a positive but insignificant effect on $CO_2$ emissions. The positive coefficients for *LnCR* indicate that a country will emit more $CO_2$ emissions as its environment becomes more stable, which stimulates economic activities requiring energy, thus increasing $CO_2$ emissions [23].

Table 4 reports the results of the GMM model with renewable electricity output and with the squared term of financial development. It also shows that renewable electricity output is significantly related to reduced $CO_2$ emissions. The results of the squared term of stock market development show that stock market development initially reduces $CO_2$ emissions, then increases $CO_2$ emissions (i.e., there is a U-shaped relation between stock market development and $CO_2$ emissions). Under a lower level of stock market development, financing thresholds and costs are relatively high, meaning that companies may be unwilling to raise funds through the stock market to enhance their capacity. However, because of the risks and uncertainties associated with the development of green and energy-efficient technologies, equity financing may be an important financing channel, even under a lower level of stock market development [39]. Combining these two aspects, it can be inferred that when the level of stock market development is lower, most of its funds may flow to the green sector, helping to reduce $CO_2$ emissions. When stock market development reaches a higher level, most companies can easily obtain stock market funds for productive activities, resulting in higher $CO_2$ emissions.

The coefficients for the squared terms of composite financial development and banking sector development are both negative, supporting the existence of an inverted U-shaped relation between composite financial and banking sector development and $CO_2$ emissions. That is, as the composite financial market and banking sector improve, $CO_2$ emissions initially rise, then decline when financial development reaches a critical level. There also exists an inverted U-shaped impact of financial development (i.e., composite financial development, stock market development, and banking sector development) on the nexus between renewable electricity output and $CO_2$ emissions, indicating that with the development of financial markets, renewable electricity output initially increases $CO_2$ emissions before decreasing them. The reason for this may be as follows: Under a low level of financial development, improvements in the financial system decrease financing costs, encouraging companies to expand their manufacturing activities and consumers to purchase electronic items on credit. In this process, $CO_2$ emissions are consequently increased [19,29,32]. Once financial development reaches a critical point, any further expansion in the financial sector could increase energy and production efficiency and even the use of renewable energy through technological improvements, thereby leading to lower $CO_2$ emissions [20,24,30,70]. Furthermore, Table 5 summarizes the main results of the nexus between renewable energy, financial development, and $CO_2$ emissions.

**Table 5.** Summary of the main results.

| | |
|---|---|
| **Model without the squared term of financial development** | |
| The effects of *RE* on $CO_2$ | Negative |
| The moderating effects of *FD* on the *REO*-$CO_2$ nexus | Negative |
| **Model with the squared term of financial development** | |
| The effects of *RE* on $CO_2$ | Negative |
| The moderating effects of *FD* on the *REO*-$CO_2$ nexus | First negative and then positive |

To check for robustness, we further adopted renewable energy consumption as a renewable energy indicator. Tables A2 and A3, respectively, report the results of the GMM model without and with the squared term of financial development when adopting the renewable energy consumption indicator (see Appendix A). The estimated results of the model with renewable energy consumption shown in Tables A2 and A3 are basically consistent with the results of the model with renewable electricity output shown in Tables 3 and 4. Regardless of whether the relations between financial development, renewable energy, and $CO_2$ emissions are studied from the consumption or the production side of renewable energy, the estimated results are essentially the same.

## 5. Concluding Remarks and Implications

In the field of energy finance, the relationships between the development of the banking sector (or stock market) and energy consumption have been fully demonstrated [3]. However, there is little literature examining the role of composite financial development and different aspects of financial development (i.e., stock market development and banking sector development) in $CO_2$ emissions. To fill this gap, this research adopted both a composite financial development indicator and disaggregated financial development indicators to explore changes in the relationships among renewable energy and $CO_2$ emissions when the level of financial development varies. We used OECD country data from 1990 to 2015. Moreover, to improve endogeneity bias, we used GMM models.

This paper mainly draws the following conclusions. First, the results from all models show that renewable energy use may significantly decrease $CO_2$ emissions, implying that OECD countries could promote their environmental quality by boosting the renewable energy sector.

Second, without consideration of the squared term of financial development, the results show that composite financial development and stock market development increase $CO_2$ emissions, while banking sector development reduces $CO_2$ emissions. This implies that companies in OECD countries do not use funds provided by the composite financial market and stock market to improve environmental quality. Moreover, financial development (i.e., composite financial development, stock market development, and banking sector development) has a negative moderating impact on the renewable energy–$CO_2$ emissions nexus. This suggests that financial development in OECD countries may encourage the production and consumption of renewable energy, contributing to an enhancement in environmental quality.

Third, when considering the squared term of financial development, we find that composite financial development and banking sector development have an inverted U-shaped impact on $CO_2$ emissions, while stock market development has a U-shaped impact on $CO_2$ emissions. This implies that composite financial development and banking sector development will reduce $CO_2$ emissions only once they reach a certain level, while stock market development will increase $CO_2$ emissions once it reaches a certain level. Further, composite financial development, banking sector development, and stock market development all have an inverted U-shaped impact on the renewable energy–$CO_2$ emissions nexus, indicating that under a higher level of financial development, the use of renewable energy could help reduce $CO_2$ emissions.

We have obtained the following related implications. First, given that renewable energy use decreases $CO_2$ emissions, governments should implement tax breaks and fiscal incentives to promote the proportion of renewable energy in the total energy use to benefit the environment. Second, different dimensions of financial development have contrasting effects on $CO_2$ emissions. While governments should strengthen the development of both the banking sector and stock market to promote economic growth, they should also formulate appropriate policies to develop the financial market, such as facilitating more finance to flow toward the implementation of green technologies, which may reduce energy consumption and $CO_2$ emissions. Third, due to the fact that different levels of financial development could affect the role of renewable energy use in $CO_2$ emissions, governments should pay more attention to enhancing the proportion of renewable energy while promoting financial development, which is related to emissions reduction.

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## Appendix A

**Table A1.** Results of Fisher's augmented Dickey–Fuller unit root test.

| Variables | *LnCO*$_2$ | *LnREC* | *LnREO* | *LnCFD* | *LnCFDSQ* |
|---|---|---|---|---|---|
| | 154.368 *** (0.000) | 166.133 *** (0.000) | 180.447 *** (0.000) | 263.693 *** (0.000) | 255.435 *** (0.000) |
| Variables | *LnSTOCK* | *LnSTOCKSQ* | *LnBANK* | *LnBANKSQ* | *LnGDP* |
| | 294.238 *** (0.000) | 277.629 *** (0.000) | 205.320 *** (0.000) | 195.581 *** (0.000) | 189.725 *** (0.000) |
| Variables | *LnGDPSQ* | *LnUP* | *LnGI* | *LnCR* | |
| | 182.947 *** (0.000) | 258.119 *** (0.000) | 423.507 *** (0.000) | 314.677 *** (0.000) | |

Notes: Parentheses show *p*-values. *** means the significance at the 1% level.

**Table A2.** Results of GMM model with *LnREC* and without the squared term of financial development.

| **Models** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** |
|---|---|---|---|---|---|---|
| $LnCO2_{t-1}$ | 0.714 *** (0.020) | 0.658 *** (0.024) | 0.658 ** (0.024) | 0.719 *** (0.020) | 0.733 *** (0.020) | 0.735 *** (0.020) |
| $LnREC_t$ | −0.055 *** (0.007) | −0.050 ** (0.029) | −0.049 *** (0.007) | −0.053 *** (0.009) | −0.055 *** (0.006) | −0.074 *** (0.021) |
| $LnCFD_t$ | −0.007 (0.008) | 0.002 (0.019) | | | | |

**Table A2.** *Cont.*

| Models | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $LnREC_t \times LnCFD_t$ | | $-4.8 \times 10^{-6}$ (0.006) | | | | |
| $LnSTOCK_t$ | | | 0.007 * (0.004) | 0.001 (0.006) | | |
| $LnREC_t \times LnSTOCK_t$ | | | | $-1.8 \times 10^{-6}$ (0.002) | | |
| $LnBANK_t$ | | | | | −0.028 *** (0.008) | −0.041 *** (0.015) |
| $LnREC_t \times LnBANK_t$ | | | | | | 0.005 (0.005) |
| *Controls* | Yes | Yes | Yes | Yes | Yes | Yes |
| AR(2) test (*p*-value) | 0.289 | 0.261 | 0.289 | 0.288 | 0.133 | 0.139 |
| Sargan's test (*p*-value) | 0.099 | 0.036 | 0.058 | 0.098 | 0.100 | 0.087 |

Notes: Numbers in parentheses show the standard errors. ***, **, and * reflect significance at the 1%, 5%, and 10% levels, respectively.

**Table A3.** Results of GMM model with *LnREC* and with the squared term of financial development.

| Models | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $LnCO2_{t-1}$ | 0.717 *** (0.020) | 0.717 *** (0.020) | 0.713 *** (0.020) | 0.700 *** (0.021) | 0.733 *** (0.020) | 0.733 *** (0.020) |
| $LnREC_t$ | −0.054 *** (0.007) | −0.501 *** (0.099) | −0.052 *** (0.006) | −0.056 *** (0.009) | −0.054 *** (0.006) | −0.618 *** (0.104) |
| $LnCFD_t$ | 0.029 (0.059) | −0.509 *** (0.135) | | | | |
| $LnCFDSQ_t$ | −0.005 (0.007) | 0.059 *** (0.016) | | | | |
| $LnREC_t \times LnCFD_t$ | | 0.217 *** (0.047) | | | | |
| $LnREC_t \times LnCFDSQ_t$ | | −0.026 *** (0.006) | | | | |
| $LnSTOCK_t$ | | | −0.010 ** (0.005) | −0.008 (0.008) | | |
| $LnSTOCKSQ_t$ | | | 0.003 *** (0.001) | 0.002 (0.002) | | |
| $LnREC_t \times LnSTOCK_t$ | | | | −0.001 (0.003) | | |
| $LnREC_t \times LnSTOCKSQ_t$ | | | | 0.0001 (0.001) | | |
| $LnBANK_t$ | | | | | 0.024 (0.066) | −0.647 *** (0.142) |
| $LnBANKSQ_t$ | | | | | −0.006 (0.008) | 0.069 *** (0.016) |
| $LnREC_t \times LnBANK_t$ | | | | | | 0.260 *** (0.048) |
| $LnREC_t \times LnBANKSQ_t$ | | | | | | −0.029 *** (0.005) |
| *Controls* | Yes | Yes | Yes | Yes | Yes | Yes |
| AR(2) test (*p*-value) | 0.299 | 0.279 | 0.228 | 0.222 | 0.135 | 0.142 |
| Sargan's test (*p*-value) | 0.107 | 0.204 | 0.124 | 0.115 | 0.121 | 0.276 |

Notes: Numbers in parentheses show the standard errors. *** and ** reflect significance at the 1% and 5% levels, respectively.

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