# Nonlinear effects of Global Value Chain Participation on Carbon Dioxide Emission: Focusing on OECD Member States

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**Abstract.** The Organization for Economic Co-operation and Development (OECD) countries, which are the world's largest economies and energy consumers, have significant effects on the global greenhouse gas effect. And the emergence of GVCs has complicated the relationship between trade and Carbon Dioxide ($CO_2$) emissions. Under the GVC division of labor system, it is necessary to study its impact on $CO_2$ from the perspective of added value, which can make an important contribution to reducing world emissions. First, in this study, the global value chain participation indices of OCED countries are calculated using MATLAB, and second, whether there is an inverse "U" relationship between GVC participation and $CO_2$ emissions is verified using the STIRPAT model with 32 OECD countries from 2007 to 2020 as samples. According to the results of the regression analysis, first, OECD countries' participation in GVCs has an inverted U-shaped relationship with $CO_2$ emissions. This may be due to the fact that in the early stages of participation in global value chains, scale effects or growth effects dominate, while in the later stages technology spillover effects and competition effects dominate, resulting in an inverted U-shaped relationship. Second, the EKC hypothesis between economic development and $CO_2$ emissions was confirmed to be applicable to OECD countries too.

**Keywords:** Carbon Dioxide Emissions, GVC Participation, Inverted U-shaped relationship, OECD .

## 1. Introduction

Since the 1990s, global warming has become an important issue that the world has begun to focus on. $CO_2$ and CH4 are referred to as the main types of greenhouse gases, and these gases are generated from fossil fuels such as gasoline used in internal combustion engine vehicles or coal burned for heating. Global warming is mainly caused by large-scale greenhouse gas emissions, and $CO_2$ emissions are a general term for greenhouse gas emissions (Yan Geng, 2022). Cultivation of agricultural areas and forests, energy, industry, transport, buildings, agriculture, and land use are all major sources of $CO_2$ emissions (United Nations, 2021). According to data released by the World Resources Institute, $CO_2$ emissions in 2018 accounted for 74.5% of global greenhouse gas emissions, and $CO_2$ was identified as the main cause of greenhouse gases and a core element of temperature rise.

International trade promotes global economic development while being a major source of carbon emissions, generating approximately one quarter of global carbon emissions (Peters et al., 2011). As the specialization of global production has advanced, international specialization has transcended the boundaries between countries and accelerated the process of international production specialization. International specialization has gradually shifted from traditional specialization between products to specialization within products, giving rise to Global Value Chains, a new form of international specialization (Liu Cenjie and Zhao Guomei, 2021). In this model of specialization, production processes are distributed globally (Zhang Zengkai et al., 2017), and each country does not undertake the entire production process in its entirety but rather assumes responsibility for one or more parts of the GVCs. The emergence of GVCs has complicated the relationship between trade and $CO_2$ emissions.

In current research on international trade and $CO_2$, most scholars explore the relationship between them from the perspectives of import and export trade (Liddle, 2018) and trade openness (Muhammad Shahbaz et al., 2013; Obed Kwame Essandoh, 2020). However, the development of globalization has promoted the rapid growth of the share of intermediate goods trade, and official trade statistics based on traditional trade value can no longer reflect the true situation of international trade based on GVCs (Zengkai Zhang et al., 2017).

The Organization for Economic Co-operation and Development (OECD) countries, which are the world's largest economies and energy consumers, have significant effects on the global greenhouse gas effect (Cheng Cheng et al., 2021). According to statistics from British Petroleum (BP), energy consumption in OECD countries amounted to 2.6 times the total consumption of other countries in the world in 2019, and 80% of this energy supply comes from fossil fuels, the main cause of $CO_2$ emissions that cause environmental destruction. Additionally, these countries' $CO_2$ emissions account for 35% of the world's total emissions. Therefore, under the GVC division of labor system, it is necessary to study its impact on $CO_2$ from the perspective of added value, which can make an important contribution to reducing world emissions.

In summary, while there have been numerous studies on the impact of international trade on $CO_2$ emissions, studies on the non-linear relationship between GVC and $CO_2$ are still insufficient. Therefore, in this study, first, the global value chain participation indices of OCED countries are calculated using MATLAB, and second, whether there is an inverse "U" relationship between GVC participation and $CO_2$ emissions is verified using the STIRPAT model with 32 OECD countries from 2007 to 2020 as samples. Finally, based on the empirical results, the relevant conclusions, policy recommendations, limitations in the study, and future study prospects are presented.

## 2. Literature Review

Studies on the relationship between GVCs and $CO_2$ emissions began with the study on the effect of international trade on $CO_2$ emissions initiated by Krugman (1995). Thus far, studies on GVC participation and $CO_2$ emissions have been actively conducted, and those studies have been conducted largely in three directions.

Studies in the first direction are those that argue that participation in GVCs has a positive correlation with $CO_2$ emissions. Jin Zhida et al. (2022) found that developed countries' participation in GVCs can reduce $CO_2$ emissions by transferring carbon emissions through the transfer of production to developing countries, but on the contrary, underdeveloped countries' participation in GVCs significantly increases $CO_2$ emissions. Jithin and Ashraf (2023) examined the effect of 61 countries' GVC participation on $CO_2$ emissions using OECD data from 2000 to 2018. According to the study findings, GVC participation promoted $CO_2$ emissions in underdeveloped countries while having a negative effect on highly developed countries.

Studies in the second direction are those that indicate that GVC participation can have a negative effect on $CO_2$ emissions reduction. Assamoi et al. (2020) used fully modified least squares (FMOLS), dynamic least squares (DOLS), cointegration, and causality tests to study the dynamic relationships between GVC participation and $CO_2$ emissions, economic growth, energy consumption, trade openness, and population density in 11 Asian countries. The results showed that there was a significant negative correlation between GVC participation and $CO_2$ emissions. That is, it was found that as GVC participation increases, $CO_2$ emissions decrease. Yang nana et al. (2022) estimated GVC participation and GVC status indices using panel data for 17 industrial sectors in China from 2005 to 2015. The interaction effects of GVC participation and R&D on carbon emissions were studied using the STIRPAT model and the feasible generalized least squares (FGLS) approach. The results showed that both GVC participation and R&D had negative effects on carbon emissions.

Because study findings on the effect of GVC participation on $CO_2$ emissions are still inconsistent, some scholars have begun studies on the non-linear relationship between GVC participation and $CO_2$ emissions. Wang Jing, Wan Guanghua, and Wang Chen (2019) estimated the effect of GVC participation on per capita $CO_2$ emissions using panel data from 62 countries and regions from 1995 to 2011. The results showed that there was an inverted U-shaped relationship between GVC participation and per capita $CO_2$ emissions. Wang Xiaoqing et al. (2023) recalculated the internal emissions of developing countries' export using the multi-regional input-output (MRIO) model from the viewpoint of value-added trade and thereafter studied the relationship between GVCs and $CO_2$ emissions, and the result showed that there was an inverted U-shaped nonlinear relationship between the degree of GVC internalization and carbon emissions in developing countries. That is, it was mentioned that low GVC participation is disadvantageous for improving the country's ecological environment, and on the other hand, GVC participation exceeding the inflection point is helpful for reducing the scale of internal emissions.

Therefore, based on the above analysis, the hypothesis is proposed:

H(1): There may be a nonlinear relationship between the GVC participation and $CO_2$ emissions.

# 3. Research Model and Data description

## 3.1 Research Model

To study the relationship between global value chains and $CO_2$ emissions, the STIRPAT model was selected. And the square term of GVC participation degree index was added to the standard STIRPAT model referring to the approach of Shujin Zhu et al., (2021). In addition, the EKC hypothesis shows an inverted U-shaped trend in which environmental pollution increases and then decreases as the economic level develops, but this does not mean that all countries or regions show the same pattern. Therefore, to test whether the EKC hypothesis is applicable to OCED countries, the square term of economic development was introduced into the model. The formula for this model is as follows:

$$\mathrm{LnCO_2}_{it} = \beta_0 + \beta_1 \mathrm{GVC_{PAR}}_{it} + \beta_2 \mathrm{GVC_{PAR}}_{it}^2 + \beta_3 \mathrm{LnGDP}_{it} + \beta_4 \mathrm{LnGDP}_{it}^2 + \beta_5 \mathrm{RE}_{it} + \beta_6 \mathrm{LnPOP}_{it} + \beta_7 \mathrm{LnFDI}_{it} + \mu_{it} \quad (1)$$

Where $\mathrm{LnCO}_{2it}$ represents the $CO_2$ emissions of country i in year t. $\mathrm{LnPOP}_{it}$ refers to the total population of country i in year t. $\mathrm{GDP}_{it}$ refers to the level of economic development. $\mathrm{GVC_{PAR}}_{it}$ represents the role played by the state in the GVC division of labor system and the degree of participation in this value chain. REit represents the level of renewable energy consumption of country i in year t. LnFDIit represents the total FDI of country i in year t, and $\mu_{it}$ is the error term.

## 3.2 Data Description

The variables included in the model of this paper are explained as follows.

Dependent variable: $CO_2$ Emissions. Referring to the study conducted by Sultana et.al (2023), this paper adopts total $CO_2$ emissions as a variable and measures them in kilotons. Data for this variable was obtained from WDI data.

Core variable: GVC participation. This study used the ADB-MRIO input-output table to measure GVC indicators through the MATLAB statistical program based on the decomposition method presented by Meng Bo, Wang Zhi and Koopman (2013) and the measurement formula of Koopman et al. (2010). The measurement formula is as follows.

$$\mathrm{GVC\_PAR}_{it} = \frac{\mathrm{IV}_{it}}{\mathrm{E}_{it}} + \frac{\mathrm{FV}_{it}}{\mathrm{E}_{it}} \quad (2)$$

In this formula, i represents the industrial sector and t represents the country. $\mathrm{GVC\_PAR}_{it}$ indicates the role played by the state in the GVC division of labor system and the degree of participation in this value chain. And $\mathrm{IV}_{it}$ represents the indirect added value of exports from the i-industrial sector of country t. $\mathrm{FV}_{it}$ represents the foreign added value included in the exports of the industrial sector i in country t. $\mathrm{E}_{it}$ represents the total exports of the industrial sector i in country t.

Control variables: GDP refers to GDP per capita measured at constant prices in 2015. RE refers to the percentage of renewable energy consumption among the final energy consumed was introduced to measure the proportion of energy structure. POP refers to the total population of a country. In this study, foreign direct investment stock was used to measure the level of FDI in a country. Among them, the source of FDI data is UNCTAD, and data from WDI was used for other variable data. Concrete details appear as shown in Table 1, and Table 2 provides the results of descriptive statistics of the variables.

Table 1. Description of the variables used in the study for the period 2007–2020

| Variable | Description | Unit |
|---|---|---|
| $CO_2$ | Carbon dioxide emissions | Thousand tons |
| GVC_PAR | Global Value Chain participation | % |
| $GVC\_PAR^2$ | The square term of Global Value Chain participation | % |
| GDP | GDP per capita at constant prices in 2015 | Millions |
| $GDP^2$ | The square term of GDP per capita | Millions |
| RE | Renewable energy consumption (% of total final energy consumption) | % |
| POP | Population (total) | persons |
| FDI | Foreign direct investment stock | Millions |

Note. This article multiplies the GVC participation index by 100 based on formula (4), which is calculated as a percentage system.

Table 2. Descriptive Statistics

| Variable | Obs | Mean | Std.dev | Min | Max |
|---|---|---|---|---|---|
| $LnCO_2$ | 448 | 11.519 | 1.397 | 8.843 | 14.052 |
| GVC_PAR | 448 | 31.899 | 4.177 | 20.868 | 45.849 |
| $GVC\_PAR^2$ | 448 | 1034.980 | 273.117 | 435.473 | 2102.131 |
| LnGDP | 448 | 10.3190 | 0.646 | 8.967 | 11.630 |
| $LnGDP^2$ | 448 | 106.899 | 13.278 | 80.413 | 135.256 |
| RE | 448 | 18.695 | 13.449 | 1.030 | 61.290 |
| LnPOP | 448 | 16.512 | 1.470 | 13.082 | 19.619 |
| LnFDI | 448 | 12.261 | 1.435 | 9.275 | 16.196 |

## 4. Empirical Results

### 4.1 Panel Unit Root Test

This study used four common unit root test methods: LLC test, IPS test, Fisher ADF test, and Fisher PP test. For the sake of rigor, all variables are considered stable only when they have passed all four-unit root test methods. The results of the unit root tests are shown in Table 3.

GVC participation and the square term of the corresponding variable are stable at I(0), that is, at the level, and other variables are first difference (I(1)), and data stability is ensured when data have gone through first difference. Therefore, it should be noted that bias may occur in the results when estimating the model. Because there are different orders of difference between these variables, a panel cointegration test must be additionally performed to determine whether there is a long-term equilibrium relationship between the variables.

Table 3. Results of panel unit root tests

| Variable | I(0) | | I(1) | | Stationarity |
|---|---|---|---|---|---|
| | IPS | Fisher-ADF | IPS | Fisher-ADF | |
| $LnCO_2$ | -0.973 | 90.766 | -9.436*** | 215.155*** | I(1) |

| | | | | | |
|---|---|---|---|---|---|
| GVC_PAR | -4.895*** | 110.537*** | -11.043*** | 213.031*** | I(0) |
| $GVC\_PAR^2$ | -4.711*** | 120.338*** | -10.274*** | 191.971*** | I(0) |
| LnGDP | -2.352*** | 297.298*** | -7.634*** | 242.442*** | I(1) |
| $LnGDP^2$ | -1.638* | 262.807*** | -7.632*** | 233.747*** | I(1) |
| RE | -0.325 | 78.853 | -9.117*** | 209.765*** | I(1) |
| LnPOP | -0.806 | 163.059*** | -5.831*** | 203.096*** | I(1) |
| LnFDI | -4.092*** | 102.269 | -9.648*** | 150.564*** | I(1) |

Note :*, **, *** Rejection of the null hypothesis at the 10%，5% and 1% significance level.

## 4.2 Panel Cointegration test

In this paper, the cointegration tests were performed mainly using the method of Pedroni and Westerlund. As can be seen in Table 4, the P values of both test results passed the 1% significance level, which rejects the null hypothesis and indicates that there is a long-term and stable cointegration relationships between variables.

Table 4. Results of panel cointegration test

| Pedroni test for cointegration | | |
|---|---|---|
| | Statistic | p-value |
| Modified Phillips–Perron t | 11.0109 | 0.000 |
| Phillips–Perron t | -38.8253 | 0.000 |
| Augmented Dickey–Fuller t | -13.9026 | 0.000 |
| Westerlund test for cointegration | | |
| Variance ratio | 4.2214 | 0.000 |

Note :*, **, *** Rejection of the null hypothesis at the 10%，5% and 1% significance level. () is the standard error values.

## 4.3 Verification of reference model

This paper evaluates the appropriateness of the random effects model and the fixed effects model using the Hausman test. If the Hausman test results indicate that the fixed effects model is applicable, country fixed effects and time fixed effects will be considered simultaneously. The Hausman test results rejected the null hypothesis at the 1% significance level. This indicates that the fixed effects model estimation is are reliable. First, the traditional environmental Kuznets curve model (EKC model) was reviewed, and the effect of GVC participation on $CO_2$ emissions was investigated thereafter. Lastly, the effect of GVC participation on $CO_2$ emissions was identified when GDP and square terms were controlled. The results are as shown in Table 5.

As can be seen in Table 5, the linear term of GDP in Model 1 was found to be significant at the 1% level, and the coefficient showed a positive (+) value, but the influence coefficient of the second term showed a significant negative (-) value indicating that the results are consistent with the EKC model.

In Model 2 and Model 3, the coefficient of the linear term of GVC participation was a positive (+) value, and the coefficient of the quadratic term could be identified to be a negative (-) value, which had a negative effect. It was shown that there is an inverted U-shaped relationship between GVC participation and $CO_2$ emissions. This is consistent with the study findings of Jing Wang, Wan Guanghua and Wang Chen (2019), who reported that there is an inverted U-shaped relationship between the degree of GVC participation and per capita $CO_2$ emissions in the entire economy and most single industries. The impact of participation in global value chains on the environment is mainly reflected in two opposing forces. On the one hand, driven growth in global value chain participation means more energy consumption, leading to greater harm to the environment or higher per capita $CO_2$ emissions. On the other hand, participation in global value chains enables a country to benefit from competitive effects and technological spillovers, helping to improve the environment. This may be due to the fact that in the early stages of participation in global value chains, scale effects or growth effects dominate, while in the later stages technology spillover effects and competition effects dominate, resulting in an inverted U-shaped relationship.

Table 5. Estimation results for $CO_2$ emissions

| Variable | Dependent Variable: $LnCO_2$ | | |
|---|---|---|---|
| | Model 1 | Model 2 | Model 3 |
| GVC_PAR | | 0.386***<br>(0.062) | 0.421***<br>(0.049) |
| $GVC\_PAR^2$ | | -0.006***<br>(0.001) | -0.006***<br>(0.001) |
| LnGDP | 4.069***<br>(0.204) | | 3.751***<br>(0.214) |
| $LnGDP^2$ | -0.180***<br>(0.011) | | -0.161***<br>(0.012) |
| RE | -0.017***<br>(0.001) | -0.015***<br>(0.000) | -0.019***<br>(0.001) |
| LnPOP | 0.885***<br>(0.015) | 0.820***<br>(0.004) | 0.965***<br>(0.012) |
| LnFDI | -0.107***<br>(0.018) | 0.057***<br>(0.014) | -0.132***<br>(0.021) |
| Constant | -24.180***<br>(0.913) | -8.673***<br>(1.143) | -31.140***<br>(1.671) |
| FE(id) | YES | YES | YES |
| FE(year) | YES | YES | YES |
| Hausman Test | 34.34***<br>(0.000) | 9.57**<br>(0.048) | 33.92***<br>(0.000) |
| $R^2$ | 0.890 | 0.895 | 0.913 |
| Obs | 448 | 448 | 448 |

Note :*, **, *** Rejection of the null hypothesis at the 10%，5% and 1% significance level. () is the standard error values.

## 4.4 Robustness test

### 4.4.1 Inverted U-shaped relationship test

In regression analysis, the existence of an inverted U-shaped relationship cannot be fully confirmed with only the significance coefficient of the square term. Therefore, the inverted U-shaped relationship should be tested (Haans, Pieters and He Zilin 2016). This study verified the inverted U-shaped relationship between global value chain participation and $CO_2$ emissions, and the results are as shown in Table 6. The section of global value chain participation figures is (20.868, 45.849) and the turning point is 31.9. The slope of the left section is 0.014, and the slope of the right section is -0.017. Both are significant at the 5% level. This verified the existence of an inverted U-shaped relationship between global value chain participation and $CO_2$ emissions In OECD countries.(see Figure 2).

Table 6. The Results of Inverted U-shaped relationship test of $CO_2$ emissions and Global Value Chain participation

| Variable | Lower bound | Upper bound |
|---|---|---|
| Interval | 20.868 | 45.849 |
| Slpoe | 0.014 | -0.017 |
| t-value | 1.918 | -2.321 |
| P> \|t\| | 0.028 | 0.010 |

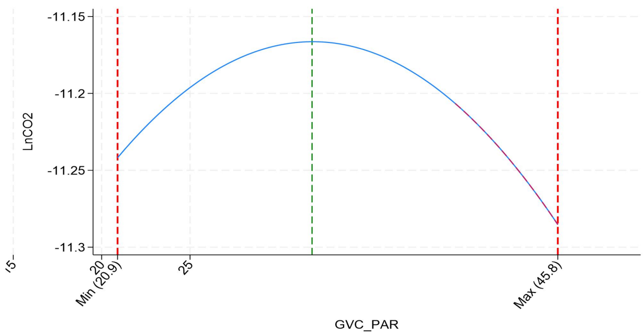


Fig2. Inverted U-shaped relationship between $CO_2$ emissions and Global Value Chain participation

4.4.2 Other robustness test

First, in this paper, four other regression methods, which are Newey-West standard errors (N-W), Feasible generalized least squares (FGLS), Panel corrected standard errors (PCSE), and Driscoll – Kraay standard errors (DK), were used to verify the reliability of regression results. As can be seen in Table 7, The coefficients and significance of core variable are almost identical to the results of the fixed effects model regression analysis, indicating that the results of this study are reliable.

Also,the paper replaces the source of the database used to measure the degree of global value chain participation indicators and uses the indicators in the OECD-TIVA database to simply calculate the GVC participation. The results show that the GVC participation and $CO_2$ emissions also have an inverted U-shaped relationship, and the Kunez environmental effect still exists in OECD countries, which once again verifies the credibility of this research result.

Table 7. The Results of Robustness tests

| Variable | Change the regression method | | | | Change the core variable |
|---|---|---|---|---|---|
| | FGLS | PCSE | N-W | DK | |
| GVC_PAR | 0.407***<br>(0.052) | 0.042**<br>(0.021) | 0.410***<br>(0.144) | 0.046**<br>(0.020) | 0.034***<br>(0.004) |
| $GVC\_PAR^2$ | -0.006***<br>(0.000) | -0.001*<br>(0.000) | -0.006***<br>(0.002) | -0.001**<br>(0.000) | -0.002***<br>(0.000) |
| LnGDP | 3.558***<br>(1.021) | 2.527***<br>(0.8841) | 3.568***<br>(1.279) | 1.611**<br>(0.606) | 3.402***<br>(0.232) |
| $LnGDP^2$ | -0.151**<br>(0.050) | -0.107**<br>(0.044) | -0.152**<br>(0.065) | -0.058*<br>(0.028) | -0.147***<br>(0.013) |
| Constant | -29.631***<br>(5.172) | -16.852***<br>(4.4941) | -29.709***<br>(6.465) | -6.062<br>(4.519) | -22.364***<br>(0.897) |

| $R^2$ | / | 0.994 | / | 0.693 | 0.902 |
|---|---|---|---|---|---|
| Obs | 448 | 448 | 448 | 448 | 448 |

Note :*, **, *** Rejection of the null hypothesis at the 10%，5% and 1% significance level. () is the standard error values.

### 4.5 Endogenous Verification

There is a possibility that a reverse causal relationship exists between GVC participation and $CO_2$ emissions. Since this may cause deviations in the estimation results, to solve the endogeneity problem, this paper refers to Liu Yao, Zhang Jun and Geng Yan(2023)’s study and uses The first-order lag of the linear term of global value chain participation and its quadratic term as instrumental variables. Subsequently, the two-stage least squares method (2SLS) is used to perform instrumental variable regression.

However, the "inverted U-shaped" relationship between GVC participation and carbon emissions has been reaffirmed. Furthermore, other control variables also exhibited a significant impact on $CO_2$ emissions, consistent with the previous standard regression results. This confirms that the research findings were not substantially influenced by endogenous factors and are therefore deemed reliable.

Table 9. The Results of Endogenous tests

| Variable | Lag(1) | Lag(2) |
|---|---|---|
| GVC_PAR | 0.461***<br>(0.102) | 0.501***<br>(0.111) |
| $GVC\_PAR^2$ | -0.007***<br>(0.001) | -0.007***<br>(0.002) |
| LnGDP | 3.428***<br>( 0.825) | 3.291***<br>(0.895) |
| $LnGDP^2$ | -0.144***<br>(0.042 ) | -0.136***<br>(0.045 ) |
| Constant | -30.085***<br>(4.111) | -30.325***<br>(4.335) |
| Cragg-Donald Wald F statistic | 764.456 | 368.999 |
| Stock-Yogo 10% | 7.03 | 7.03 |
| Obs | 416 | 384 |

Note :*, **, *** Rejection of the null hypothesis at the 10%，5% and 1% significance level. () is the standard error values.

## 5. Summary

In this study, based on the ADB-MRIO input-Input-Output database from 2007 to 2020, the total export values of 32 OECD countries were studied according to export routes and final export regions using the research method of Meng Bo, Wang Zhi and Koopman (2013). Based on the foregoing, the GVC participation degree indices were calculated through MATLAB using the measurement method of Koopman et al. (2010) . Then the non-liner effect of the degree of GVC participation on $CO_2$ emissions was studied. The study results are as follows.

First, similar to the EKC model, the degree of GVC participation was found to have an inverted U-shaped relationship with $CO_2$ emissions. Participation in GVCs initially increases $CO_2$

emissions, but as the country's economy grows, energy consumption increases, and investment increases, $CO_2$ emissions gradually decrease along with the increase in the degree of GVC participation.

Second, the study results of this paper revealed that the EKC hypothesis for OECD countries, where GDP per capita has a quite clear and positive effect on environmental sustainability, is valid. When the economies of these countries grow rapidly, energy consumption and environmental pollution will increase in the process of industrialization and urbanization, and when the countries ’ economies reach a certain level, environmental quality will improve along with increases in per capita incomes.

Third, the results also showed that the population sizes of OECD countries have significant positive correlations with environmental pollution, and that renewable energy consumption and FDI reduce $CO_2$ emissions in OECD countries.

Based on the above study results, the following implications were presented.

First, GVC participation must be improved. In order to reduce environmental pollution in the GVC system, each country needs to make efforts to improve its participation in GVCs. For example, investing in R&D and innovation, adopting advanced production technologies to increase the added value of products and services, thereby enhancing participation in GVC.

Secondly, according to 2021 data, only 11.2% of the total energy supply in OECD countries came from renewable sources. This indicates a shortage in renewable energy supply. The utilization of green energy should be increased, and the cost of using green energy should be reduced through iterative upgrades of green energy technology. It is necessary to adjust the energy structure, reduce the consumption of primary energy sources such as coal, fully leverage clean energy sources such as natural gas and electricity, and optimize the allocation of energy resources to achieve emission reduction goals.

Thirdly, OECD governments should formulate policies and regulations to support participation in global value chains and provide a favorable business environment for enterprises. Enterprises should adopt sustainable development strategies, enhance their sense of social responsibility, and respond to the international market's demands for environmental protection and social responsibility.

Fourth, attention should be given to the cultivation of high-end talents, enhancing independent innovation capabilities. Governments should actively play a strategic guidance and supportive role in high-end production links, striving to achieve the goal of advancing to the high-end segments of GVCs.

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