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# The Impact of Export Sophistication of the New Energy Industry on Carbon Emissions: An Empirical Study

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**Abstract:** Existing research has insufficiently explored the nexus between the new energy industry and $CO_2$ emissions from the standpoint of export sophistication. This study analyses the implications of the new energy industry's export sophistication on $CO_2$ emissions, regional heterogeneity, and its influencing mechanism by gathering data from 31 major economies throughout the world between 1996 and 2021. The study found that the new energy industry's export sophistication helps reduce carbon dioxide emissions, and this conclusion still holds after robustness testing; the carbon emission reduction effect of the export sophistication of the new energy industry is more significant in developed countries than in developing countries; the new energy industry's export sophistication possesses a crowding-out effect on domestic technological progress, which to a certain extent impedes carbon reduction effect. This paper's findings provide theoretical guidance for the global low-carbon energy transition.

**Keywords:** carbon emissions; export sophistication; new energy industry; influential mechanism; heterogeneity; fixed effects model; mediation effect model



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## 1. Introduction

The unprecedented globalization of international energy commerce in the past few decades has significantly contributed to the growth and prosperity of the global economy. Unfortunately, the fossil fuel-based energy trade structure has also emitted a large quantity of carbon dioxide ($CO_2$), resulting in global warming, which has posed a grave danger to human survival and development [1]. New energy, also known as unconventional energy, refers to non-traditional forms of energy, including solar, wind, biomass, geothermal, hydroelectric, and nuclear energy. Compared to traditional energy, new energy has the advantages of pure environmental protection, abundant reserves, and sustainability, which are crucial for resolving the severe environmental pollution problems and the greenhouse effect in the world today [2,3]. Statistics from *China's National Energy Administration* show that China's power production from renewable energy in 2022 is equivalent to lowering domestic $CO_2$ by approximately 2.26 billion tons and exporting wind power photovoltaic products to decrease $CO_2$ for other countries by nearly 573 million tons for a total reduction of 2.83 billion tons [4].

Despite worldwide governmental recognition of the potential for new energy to reduce carbon emissions, the latest data from BP's 2022 World Energy Statistics Review indicates that the global energy trade continues to be dominated by fossil fuels, including coal, oil, and natural gas, with new energy exports receiving notably less emphasis. This is mainly because new energy has a higher use cost than traditional fossil energy, and its export is heavily affected by policies, which makes it less competitive [5]. Due to the limited number of new energy exports, researching and enhancing the export sophistication of new energy, which demonstrates how competitive new energy is, is an additional effective strategy for attaining global carbon reduction goals [6].

Literature abounds with studies investigating the connection between $CO_2$ and new energy. The prevalent theory in academia is that increased energy use may adversely decrease carbon emissions [7–9]. Dong et al. (2018) [10] investigated the link between the new energy industry development and $CO_2$ and found that new energy development may considerably lower carbon dioxide emissions. The findings of Acheampong et al. (2022) [11], Habiba et al. (2022) [12], Rahman and Alam (2022) [13], Djellouli et al. (2022) [14] corroborate the conclusion that the new energy may contribute to the carbon reduction. In contrast to the conclusion that new energy can help reduce carbon dioxide emissions, Al-Mulali et al. (2015) [15] found that Vietnam's use of renewable energy has an insignificant impact on decreasing carbon dioxide emissions, and Zaidi et al. (2018) [16] came to the same conclusion in their sample of Pakistan. Additionally, Jebli and Youssef (2017) [17] found that long-term carbon dioxide emissions in the five nations of North Africa had grown due to the use of renewable energy.

Existing research on new energy and $CO_2$ primarily examines the impact of new energy on $CO_2$ from the perspective of total new energy use, while few scholars investigate its carbon reduction effect from the perspective of new energy competitiveness. Moreover, the contradictory conclusion between new energy and $CO_2$ indicates that more in-depth research on the relationship is required. Based on the existing literature, this study investigates the relationship between export sophistication of new energy and carbon dioxide, investigates the influence mechanism between the two, and examines whether this relationship exhibits regional heterogeneity.

This paper's contribution to the existing body of literature is summarized in three points. As an important indicator of new energy competitiveness, this study evaluates the new energy industry's export sophistication in 31 significant economies from 1996 to 2021 and empirically tests whether there is a carbon emission reduction effect using a fixed-effect model. Second, in order to avoid the similar phenomenon of the mixed conclusion of new energy and $CO_2$, we employ the mediation effect model to analyze in depth the mechanism of new energy export sophistication on carbon emissions, which has significant theoretical significance in terms of revealing the black box between them. Thirdly, there are numerous differences between countries, including economic development, the potential for new energy development, etc. Therefore, it is more plausible to analyze the regional heterogeneity of carbon emission reduction in the export sophistication of new energy, and this is useful for making emission reduction recommendations.

The remainder of the article is divided into six sections. Section 2 organizes the extant literature on the export sophistication of new energy and carbon dioxide. In Section 3, variable selection, data sources, and model methodology are introduced. Sections 4 and 5 illustrate the findings, mechanism, and regional heterogeneity of the impact of the export sophistication of new energy on carbon emissions. Section 6 contains the research findings and proposed countermeasures.

## 2. Literature Review

### *2.1. Research into the Export Sophistication of New Energy Industry*

Export sophistication is a critical indicator for measuring the structure of national or regional export commodities, as it reflects the competitive advantage of export commodities. The introduction of export sophistication can be traced back to Michaely's (1984) [18] trade specialization index. The indicator implies that the degree of technology incorporated in an exported commodity is proportional to the per capita income of the exporting country. Hausmann et al. (2007) [19] took the initiative in elucidating the connotation of export sophistication and employing it as a measurement of the structure of export products. The greater the indicator value, the greater the likelihood that the product can achieve a competitive advantage in the face of fierce market rivalry. Since its proposal, export sophistication has shifted the emphasis of international commodity trade competition from export quantity to export competitiveness. With the expansion of research on export sophistication, different levels of export sophistication have been implemented. At the national level, Jarreau and Poncet (2012) [20] computed the export sophistication of 30 provinces in China from 1997 to 2009; Rehman et al. (2023) [21] assessed the export sophistication of renewable and non-renewable energy in OECD countries during 1990-2019, respectively; At the industrial level, Su et al. (2020) [22] took the manufacturing industry as the research object, calculating the sophistication of manufacturing exports in 36 countries from 2005 to 2014. At the enterprise level, Song et al. (2022) [23] assessed the export sophistication of 498,945 Chinese manufacturing enterprises by combining the Chinese customs database with the Chinese industrial enterprise database.

Existing research has provided a comprehensive discussion of the definition and measurement of export sophistication, and research on export sophistication involves different groups, including the nation, industry, and enterprise levels. However, research on export sophistication in the new energy industry is scarce. Zheng and Wang (2019) [24] used the United Nations Comrade database to measure the new energy industry's export sophistication in 30 countries around the world from 2000 to 2015, comparing and analyzing the evolution of the export sophistication of transnational new energy industries and their subdivisions. Cao et al. (2019) [25] calculated the dynamic changes in the export sophistication of China's new energy industry from 2007 to 2016 and discovered that the overall new energy industry's export sophistication exhibited a fluctuating growth trend, the proportion of high-tech sophistication was low, and the export structure exhibited a deteriorating trend.

### *2.2. Studies of Carbon Dioxide*

The methods for calculating carbon dioxide emissions concentrate primarily on three factors: the measuring method, the material balance method, and the carbon emission factor method. The measuring method uses the velocity, concentration, and flow rate of carbon dioxide sample emissions to calculate the total quantity of carbon emissions [26]. This method necessitates sophisticated measuring instruments and is primarily employed by environmental monitoring departments. Material balance is an approach for calculating the total quantity of carbon dioxide emissions based on the input and output material conservation theorem. This method requires maximum control over the enterprise's production and emission situation [27]. Based on the *2006 IPCC National Greenhouse Gas Inventory Guidelines* issued by the Intergovernmental Panel on Climate Change (IPCC), the carbon emission factor method multiplies and accumulates various forms of energy consumption and their respective carbon emission factors to obtain carbon emissions. This method is considered the most authoritative carbon emission accounting method in the world [28]. It serves as a significant foundation for countries to report their carbon emissions to the IPCC.

Scholars have been interested in the influencing variables of carbon dioxide emissions for a very long time. The relationship between economic growth and carbon emissions is one of the contemporary research hotspots, and the environmental Kuznets hypothesis is the main focus of related research. According to Ridzuan et al. (2020) [29], Malaysia's long-term economic growth and carbon emissions show an inverted U-shape. As the economy expands, carbon dioxide emissions first rise before starting to fall once they reach a critical threshold. The effect of urbanization on carbon emissions has received significant attention in terms of population growth. Sufyanullah et al. (2022) [30] discovered that the progress of urbanization in Pakistan has resulted in a rise in carbon dioxide emissions. The conclusion that there is a positive association between urbanization level and $CO_2$ also pertains to the Philippines [31]. One of the key elements impacting carbon emissions is foreign direct investment. According to Lu et al. (2023) [32], there is a pollution refuge in transition economies since there is a positive association between foreign direct investment and carbon emissions. The literature on export sophistication and carbon emissions is abundant, whereas the literature on examining carbon emissions from the perspective of export sophistication in the new energy industry is extremely scarce. Based on previous research, we investigate the relationship between the new energy industry's export sophistication and carbon dioxide, as well as the impact Mechanism of export sophistication on carbon emissions and potential heterogeneity in carbon emission reduction.

## 3. Methods

### *3.1. Model Specification*

#### 3.1.1. Econometric Model

This study employed a model with fixed effects [23] to investigate the impact of the new energy industry's export sophistication on $CO_2$. The econometric model is shown in Equation (1).

$$\ln CO_{2_{it}} = \alpha + \beta_1 \ln EXPY_{it} + \beta_2 \ln FDI_{it} + \beta_3 \ln IT_{it} + \beta_4 \ln Urb_{it} + \delta_i + \varphi_t + \varepsilon_{it} \quad (1)$$

where $\ln CO_2$ and $\ln EXPY$ are the logarithms of Carbon Dioxide and export sophistication; $\ln FDI$, $\ln IT$ and $\ln Urb$ are the logarithms of control variables, namely foreign direct investment, international trade and urbanization; $i$ and $t$ represent the country and year respectively; $\alpha$ is a constant term; $\beta_1$ and $\beta_2$-$\beta_4$ are the coefficients of $\ln EXPY$ and 3 control variables $\ln FDI$, $\ln IT$, and $\ln Urb$ on $\ln CO_2$, respectively. $\delta_i$ and $\varphi_t$ represent national fixed effects and temporal fixed effects, respectively; $\varepsilon_{it}$ represents the random error term.

#### 3.1.2. Mediation Effect Model

Furthermore, we use the mediation effect model to find out how the export sophistication of new energy exports impacts carbon emissions [33]. The 3-step regression technique is suggested to assess if technological progress has a mediating influence with the aid of Baron and Kenny (1986) [34].

$$\ln CO_{2_{it}} = \alpha_0 + \alpha_1 \ln EXPY_{it} + \alpha_2 \ln X_{it} + \delta_i + \varphi_t + \varepsilon_{it} \quad (2)$$

$$\ln TP_{it} = \phi_0 + \phi_1 \ln EXPY_{it} + \phi_2 \ln X_{it} + \delta_i + \varphi_t + \nu_{it} \quad (3)$$

$$\ln CO_{2_{it}} = \gamma_0 + \gamma_1 \ln EXPY_{it} + \gamma_2 \ln TL_{it} + \gamma_3 \ln X_{it} + \delta_i + \varphi_t + \tau_{it} \quad (4)$$

where $\ln TP$ is the logarithm of technological progress; $\alpha_1$ in Equation (2) is the total effect of the $\ln EXPY$ on the $\ln CO_2$; $\phi_1$ in Equation (3) is the effect of $\ln EXPY$ on the $\ln TP$; In Equation (4), the coefficient $\gamma_1$ is the direct effect of the $\ln EXPY$ on the $\ln CO_2$ after controlling for the influence of the $\ln TP$. $X_{it}$ is the control variable mentioned above; $\varepsilon_{it}$, $\nu_{it}$, and $\tau_{it}$ are random error terms.

The intermediary effect of the explanatory variable $\ln EXPY$ on the $\ln CO_2$ is $\phi_1 \times \gamma_2$, and the relationship between the total effect, the intermediary effect, and the direct effect is:

$$\alpha_1 = \gamma_1 + \phi_1 \times \gamma_2 \quad (5)$$

### *3.2. Variables and Data*

#### 3.2.1. Explained Variable

The explained variable in this study is $CO_2$, and it has two measurement indicators: total carbon dioxide emissions [35,36] and per capita carbon dioxide emissions [37]. The former is an absolute number, while the latter is a relative one. We ultimately settled on the total carbon emissions as the indicator to measure $CO_2$ and used the per capita carbon dioxide emissions for the robustness test. This was done because the carbon emission reduction and carbon neutralization policies developed by nations around the world are based on the actual situation of total carbon dioxide emissions. The indicator value that is lower indicates lower national carbon dioxide emissions, and vice versa. The *2022 BP Statistical Review of World Energy* (accessed on 6 September 2022, from https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/co2-emissions.html) provides information on total carbon emissions.

#### 3.2.2. Explanatory Variable

Export sophistication depicts the degree of productivity connected with a national or regional array of exported commodities [38]. We rely on Hausmann et al.'s (2007) [19] measuring approach to calculate export sophistication.

First, assuming the export sophistication of the exported good $k$ is $PRODY_k$, which is calculated as follows:

$$PRODY_k = \sum_{k \in K_i} \frac{x_{ik}/X_i}{\sum\limits_{j \in K_i} x_{ik}/X_i} \times Y_i \tag{6}$$

where $i$ refers to the country or region $i$ that exports goods $k$; $x_{ik}$ represents the total export value of goods $k$ in country $i$; $X_i$ refers to the total export value of country $i$; and $x_{ik}/X_i$ represents the proportion of goods $k$ export value in the total export of that country; $Y_i$ is the per capita GDP of country or region $i$; and $k_i$ denotes the collection of all countries exported good $k$; $PRODY_k$ is the sum of the product of the export proportion of each country's good $k$ and the country's PGDP.

Based on the calculation of $PRODY_k$, we further assess the export sophistication of industry $j$. Considering that N represents the total number of exported goods $k$ produced by industry $j$ of country $i$, the export sophistication level $EXPY_{ji}$ of industry $j$ in country $i$ is as follows:

$$EXPY_{ji} = \sum_{k \in N} s_{kji} \times PRODY_k \tag{7}$$

Among them, $s_{kji}$ is the share of the export value of good $k$ in the total export value of industry $j$ in country $i$. $EXPY_{ji}$ is essentially the weighted average sum of $PRODY_k$ in industry $j$ of country $i$.

We used Wang et al.'s (2017) [5] assessment and categorization of the new energy industry to calculate its export sophistication. The new energy industry is comprised of four subindustries: wind energy, solar energy, biomass energy, and nuclear power technology. The HS1996 standard is adopted by the appropriate goods and classification codes. The original data on export value related to the HS 6-bit code in these four industries are all taken from the *UN Comtrade database* (accessed on 29 August 2022, from https://comtrade.un.org/data/). The raw data on total exports of various countries and PGDP are taken from the *World Bank Open Data* (accessed on 1 September 2022, from https://data.worldbank.org.cn/indicator).

#### 3.2.3. Control Variables

(1) Foreign direct investment (FDI)

As 1 of the most influential variables on carbon emissions, the influence of FDI on $CO_2$ has been the subject of extensive academic study. The pollution refuge theory and the pollution halo hypothesis are 2 competing theories about how FDI affects $CO_2$ emissions. According to the pollution haven hypothesis, developing countries tend to adopt lower environmental protection standards in order to attract more FDI, which brings in a lot of low-quality, pollution-intensive FDI and turns developing countries into the sources of developed countries' carbon emissions [39,40]; whereas the pollution halo hypothesis contends that FDI brings advanced technology and a wealth of management experience to host nations [41,42]. According to Ali et al. (2023) [43], we utilized the net inflow of FDI as a gauge of a country's ability to attract FDI. The original data regarding net FDI inflows were obtained from *World Bank Open Data* (accessed on 1 September 2022 at https://data.worldbank.org.cn/indicator).

(2) International Trade (IT)

The global trade system has altered as a result of increasing global economic integration, which has also sparked studies on how trade affects carbon emissions. The impact of international trade on $CO_2$ is currently primarily focused on 2 aspects: on the 1 hand, international trade encourages global economic growth through the specialized division of labor, which increases energy consumption and, in turn, increases total carbon dioxide emissions [44]; on the other hand, international trade enhances international exchange and cooperation, particularly promoting technology exchange between different countries, which helps to reduce global carbon emissions [45]. The *World Bank Open Data* is utilized to extract the pertinent statistics, which are used to measure total goods import and export trade (accessed on 1 September 2022, from https://data.worldbank.org.cn/indicator).

(3) Urbanization (Urb)

Another important element that has an impact on carbon emissions is urbanization (Urb). On the 1 hand, both centralized energy use and information spillover, as well as technological advancements brought about by urbanization, contribute to improving energy use efficiency and lowering $CO_2$ [46]. On the other hand, the advancement of urbanization will improve urban population density and the resulting increase in urban infrastructure, which leads to an increase in $CO_2$ to some extent [30,47]. According to Wang et al. (2021) [48], the ratio of the urban population to the overall population is chosen to properly depict the degree of urbanization. The raw data involved in the control variables are derived from the *World Bank Open Data* (accessed on 1 September 2022, from https://data.worldbank.org.cn/indicator).

### 3.2.4. Intermediate Variable

As 1 of the major determinants of a country's carbon dioxide emissions, the technological progress (TP) of the host nation has been the subject of extensive study. Technological progress at the source of energy consumption in host countries can reduce $CO_2$ production by substituting fossil fuels with clean energy; technological progress during the consumption of energy can reduce $CO_2$ production by increasing energy efficiency; and technological progress at the end of pollution emissions can revert $CO_2$ emissions through carbon capture and storage. Overall, technological progress in host nations contributes to the reduction of carbon emissions [49]. We determine the host country's overall technical advancement using the Cobb-Douglas production function [50]. The *World Bank Open Data* (accessed on 2 September 2022, from https://data.worldbank.org.cn/indicator) is the source of information on technological advancement.

The variable description and descriptive statistics are shown in Table 1.

**Table 1.** Variable description and descriptive statistics.

| Variable Types | Variable Abbreviation | Name | Definition | Unit |
|---|---|---|---|---|
| Explained variable | $CO_2$ | Carbon dioxide | Carbon dioxide emissions from energy | Million tons equivalent |
| Explanatory variable | *EXPY* | Export sophistication of new energy industry | Weighted average sum of export sophistication of different new energy products in a country's new energy industry | USD |
| Control variables | *FDI* | Foreign direct investment | The Net FDI | 100 Million USD |
| | *Urb* | Urbanization | The percentage of urban residents in the overall population | % |
| | *IT* | International Trade | The total amount of imports and exports | 100 Million USD |
| Intermediary variable | *TP* | Technological progress | Cobb-Douglas production function | - |
| **Variables** | **Mean** | **St.Dev** | **Max** | **Min** |
| Ln$CO_2$ | 5.523 | 1.345 | 9.261 | 3.290 |
| LnEXPY | 9.696 | 0.219 | 10.411 | 8.884 |
| LnFDI | 23.134 | 1.641 | 8.666 | −1.405 |
| LnIT | 7.833 | 1.297 | 10.533 | 3.108 |
| LnUrb | −0.347 | 0.274 | 0 | −1.316 |
| LnTP | 6.570 | 0.871 | 7.717 | 4.024 |

Note: Descriptive statistical analysis is performed using the *tabstat* command in the stata15.0 software.

We gathered yearly panel data for 31 major economies worldwide from 1996 to 2021 based on data availability to confirm the impact of EXPY on $CO_2$. These 31 economies (as indicated in Table 2), which accounted for 48.67% of the global GDP in 2021, are made up of 22 developed countries or regions (subsequently referred to as the countries) and 9 emerging countries. More than 85% of the world's carbon emissions come from these 31 economies' total emissions of carbon dioxide, while their total new energy exports account for more than 95% of the world's new energy trading market. The chosen economies are adequate and representative. To reduce the potential heteroscedasticity of the sample data, we logarithmized all of the data.

**Table 2.** Summary of sample countries.

| Sample Classification | Name of Economies |
| --- | --- |
| Developed countries | The United States (USA), Belgium (BEL), Germany (DEU), Canada (CAN), Austria (AUT), Switzerland (CHE), The Czech Republic (CZE), Denmark (DNK), Spain (ESP), Netherlands (NLD), France (FRA), Britain (GBR), Hong Kong (HKG), Hungary (HUN), Italy (ITA), Japan (JPN), Finland (FIN), Republic of Korea (KOR), Poland (POL), Portugal (PRT), Singapore (SGP), Sweden (SWE) |
| Developing countries | Brazil (BRA), Philippines (PHL), China (CHN), Thailand (THA), India (IND), Malaysia (MYS), Romania (ROU), Mexico (MEX), Russian Federation (RUS) |

Before starting to apply the econometric model, it is necessary to test the stationarity of the original data and select the specific form of the model. This study will highlight the methodology in accordance with the following conceptual framework (see Figure 1 [51]).

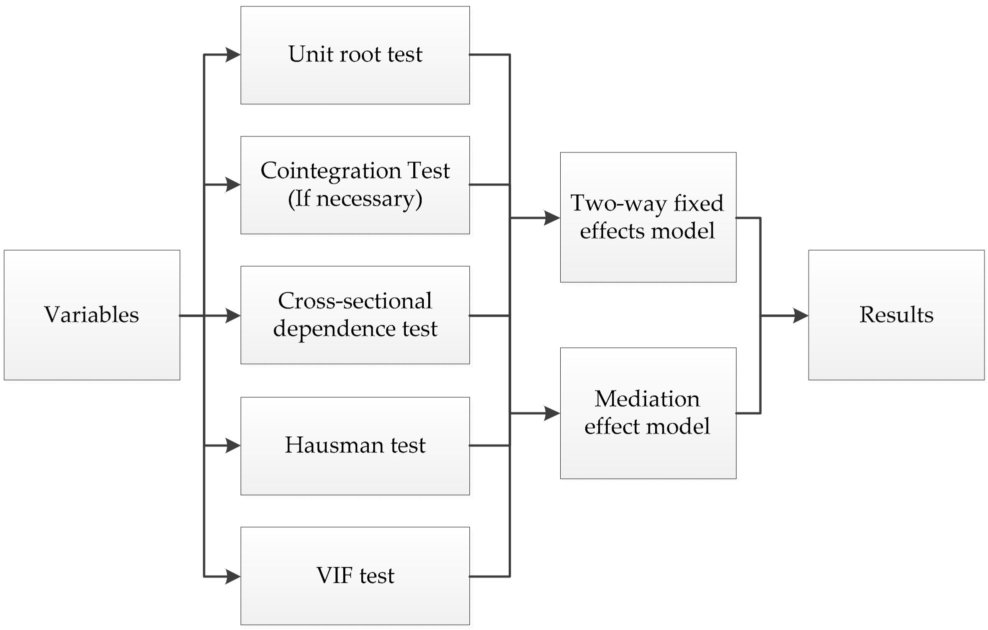


**Figure 1.** Conceptual framework.

## 4. Empirical Findings

When using the regression model to analyze the correlation between the explanatory variable and the explained variable, the phenomenon of pseudo-regression may occur, which means that the data of the explanatory variable and the explained variable is non-stationary, but the regression outcomes reveal that there is a statistical association between the two for some reason, and the regression results have no practical significance. To prevent pseudo-regression in the regression process, the original data must be tested for stationarity. The IPS test and Fisher test of the *xtunitroot* command are used to conduct a stationarity test on panel data; the results are presented in Table 3.

**Table 3.** The results of the unit root test.

| | IPS Test | | Fisher Test | | Order of Integration |
|---|---|---|---|---|---|
| | **Statistic** | ***p*-Value** | **Statistic** | ***p*-Value** | |
| Ln$CO_2$ | −3.3720 *** | 0.0004 | 5.1761 *** | 0.0000 | I(0) |
| Ln*EXPY* | −7.5256 *** | 0.0000 | 14.1506 *** | 0.0000 | I(0) |
| Ln*FDI* | −10.0535 *** | 0.0000 | 12.5743 *** | 0.0000 | I(0) |
| Ln*IT* | −1.6782 ** | 0.0467 | 9.2752 *** | 0.0000 | I(0) |
| Ln*Urb* | −5.1997 *** | 0.0001 | 9.0213 *** | 0.0000 | I(0) |
| Ln*TP* | −5.1702 *** | 0.0000 | 10.1308 *** | 0.0000 | I(0) |

Note: ** $p < 0.05$, *** $p < 0.01$.

As shown in Table 3, the *p* values of the explained variable (Ln$CO_2$), the explanatory variable (Ln*EXPY*), the control variables (Ln*Urb*, Ln*FDI* and Ln*IT*) and the intermediary variable (Ln*TP*) are all less than 0.05, rejecting the null hypothesis and accepting the alternative hypothesis, indicating that all variables are considered stationary.

In general, there are three varieties of panel models: fixed effects model, pool effect model, and random effect model. To ensure the validity and consistency of the estimated results of the regression model, it is necessary to identify the optimal model type based on the results of various tests. When comparing the fixed effect model with the pool effect model, the *xtcsd* command is used to assess the cross-section dependence of the panel data. The test statistic, 7.237, exceeds the critical value of 0.5811, which corresponds to a significance level of 1%. The initial assumption that there is no cross-section dependence is therefore refuted, and the model is regarded to have cross-section dependence. The *xtscc* command is then used to determine whether or not the model has individual effects. The test results indicate that the *p*-value is 0.000, allowing us to disapprove of the null hypothesis and assume that there are individual effects; therefore, the fixed effects model is superior to the pool effect model. The fixed effect model and the random effect model are commonly compared and chosen using the *Hausman* command. The test's findings show that the *p*-value is 0.000, failing to meet the 5% threshold for significance. Consequently, the initial hypothesis of the random effect model is refuted, showing that the fixed effects model is the preferable alternative. Combining the outcomes of the two comparisons, the two-way fixed effects model was subsequently applied to panel data regression.

Following model selection and the unit root test, the two-way fixed effects model (xtreg command for Stata 15.0) is used to examine the carbon emission effect of the new energy industry's export sophistication and the regression results are displayed in Table 4.

**Table 4.** Regression results of the baseline model.

| | **Model 1** | **Model 2** | **Model 3** | **Model 4** |
|---|---|---|---|---|
| Ln*EXPY* | −0.320 *** (0.000) | −0.290 *** (0.000) | −0.210 *** (0.001) | −0.219 *** (0.000) |
| Ln*FDI* | | 0.046 *** (0.000) | 0.028 *** (0.001) | 0.029 *** (0.000) |
| Ln*IT* | | | 0.244 *** (0.000) | 0.117 *** (0.000) |
| Ln*Urb* | | | | 1.467 *** (0.000) |
| Country | Y | Y | Y | Y |
| Year | Y | Y | Y | Y |
| Constant | 8.611 *** (0.000) | 8.179 *** (0.000) | 5.627 *** (0.000) | 7.265 *** (0.000) |
| Mean VIF | - | 1.01 | 2.20 | 1.96 |

Note: *p*-values in parentheses; *** $p < 0.01$.

This research uses the *vif* command to broaden the detection to guarantee that there is no multicollinearity across variables. The findings reveal that the VIF values of models 1 to 4 in Table 4 are both below 10, suggesting that there is no multicollinearity between variables.

According to the findings of the regression analysis, the correlation between Ln*EXPY* and Ln$CO_2$ is less than 0, and the significance test is passed at the 1% level, indicating that enhancing the new energy industry's export sophistication will substantially reduce carbon dioxide emissions. Carbon dioxide emissions will drop by 0.219% for every percentage rise in Ln*EXPY*. The explanation for the negative inhibitory effect between LnEXPY and Ln$CO_2$ is that as the new energy industry's export sophistication increases, the capital and technology content of the exported new energy commodities increases, and the demand for fossil energy for such capital- and technology-intensive commodities continues to decline. By optimizing the structure of energy consumption, carbon dioxide emissions are reduced.

At the 1% level of significance, the relationship between Ln*FDI* and Ln$CO_2$ has an elasticity value of 0.029, which is statistically significant. Each 1% increase in net foreign investment will result in a 0.029% increase in carbon dioxide emissions. Although there may be a Pollution Halo effect of FDI on carbon emissions, empirical evidence suggests that FDI's Pollution Haven effect inevitably increases the host country's carbon emissions [52].

The elasticity coefficient between Ln*IT* and Ln$CO_2$ emissions is 0.117, and it passed the 1% significance level test. The change of 1% in international trade will result in a change of 0.117% in carbon emissions. Promoting international trade, according to the principle of comparative advantage, would allow a country to develop goods with comparative advantages, lowering carbon emissions by boosting resource usage efficiency [53]. However, international trade-driven global economic growth has boosted demand for fossil fuels, resulting in rising global carbon emissions.

The positive impact of Ln*Urb* on Ln$CO_2$ was tested at a significance level of 1%, indicating that urbanization has worsened carbon emissions despite the fact that urbanization could reduce carbon emissions through resource agglomeration and large-scale management [54,55]. However, increased urbanization also drives up the need for infrastructure and energy utilization, resulting in an increase in $CO_2$ [56]. The study's findings show that urbanization causes carbon emissions to grow at a faster rate than agglomeration causes them to decrease, with an increase in carbon dioxide emissions as a result.

Despite the fact that the panel regression results indicate that the new energy industry's export sophistication is conducive to reducing carbon emissions, it is necessary to employ a series of methods to ensure the conclusions' objectivity, and the results are given in Table 5.

**Table 5.** Summary of different robustness regression results.

| | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|
| Ln*EXPY* | −0.140 *** (0.005) | −0.210 *** (0.003) | −0.141 ** (0.034) | −0.225 *** (0.000) |
| Ln*FDI* | 0.026 *** (0.000) | 0.028 *** (0.000) | 0.033 *** (0.000) | 0.027 *** (0.001) |
| Ln*TO* | 0.123 *** (0.000) | 0.156 *** (0.000) | 0.133 *** (0.000) | 0.126 *** (0.000) |
| Ln*Urb* | 1.382 *** (0.000) | 1.394 *** (0.000) | 1.404 *** (0.000) | 1.488 *** (0.000) |
| Ln*IS* | | | | −0.253 *** (0.005) |
| Country | Y | Y | Y | Y |
| Year | Y | Y | Y | Y |
| Constant | 2.819 *** (0.000) | 6.869 *** (0.000) | 6.331 *** (0.00) | 6.965 *** (0.000) |

Note: *p*-values in parentheses; ** $p < 0.05$, *** $p < 0.01$.

(1) Substitute the explained variable. Replace with the outlined variable. Model 5 shows the outcome of the robustness test using per capita carbon emissions rather than total emissions. The refitted regression result indicated a carbon reduction effect of the new energy industry's export sophistication, and the test was passed at the significance level of 1%. The regression coefficient symbols and significance for other variables are identical to the results of the standard regression. Overall, it can be concluded with confidence that improving *EXPY* can substantially reduce carbon emissions;

(2) Shrink the tail of explanatory variables. Due to the occurrence of singular values, there may be some variations between the regression estimate findings and the real scenario based on the derived explanatory factors. To avoid this situation, we use the fixed-effect model for panel regression and do a two-tailed treatment of 5% for the explanatory variables. The estimated coefficient of the ln$EXPY$ and ln$CO_2$ is $-0.210$ (see Model 6 in Table 5), suggesting that a 1% increase in ln$EXPY$ reduces carbon emissions by 0.210%. Other control variable regression coefficient symbols were consistent with the benchmark regression findings and passed the significance test, demonstrating the robustness of the benchmark regression results;

(3) Eliminate the interference of major international emergencies. Some unexpected large worldwide occurrences, such as the global subprime mortgage crisis in 2007 and the Corona Virus Disease 2019 (COVID-19), which caused varying degrees of recession in the export trade of major economies around the world, will have an effect on the estimates. In light of this, we delete data for a total of 5 years from 2007–2009 (the subprime mortgage crisis occurred in 2007 and ended in 2009) and 2020–2021 (COVID-19 occurred at the end of 2019 and rapidly evolved into a global event in early 2020) to eliminate the impact of these two major events on the regression results (as shown in Model 7). The correlation coefficient between ln$EXPY$ and ln$CO_2$ is less than zero, which is consistent with the benchmark regression findings. As a result, after controlling for big unexpected international events, the coefficient of the main independent variable is notably negative.

(4) Add a control variable. Taking into account the impact of missing variables, this paper controls the industrial structure variable and conducts panel regression once more. Model 8 shows that, after controlling for the industrial structure variable, the export sophistication of the new energy industry has a negative correlation with carbon dioxide emissions, and the other control variables' regression coefficients correspond to the benchmark regression. As a result, the carbon reduction effect of the new energy industry's export sophistication remains effective.

## 5. Further Discussion

### *5.1. Mechanism Inspection*

The findings of the benchmark regression indicate a negative correlation between ln$EXPY$ and ln$CO_2$; however, additional research is required to determine how this relationship is mediated. According to some academics, rising export sophistication indicates that the export sector is advancing technologically, which indirectly raises a nation's overall technological level through active transmission or passive spillover. And technological progress can also significantly lower carbon emissions [57]. Exploring the potential role of technological progress as a mediator between export sophistication and carbon emissions is a crucial matter. Results of empirical regression using technological advancement as a study's mediator variable are shown in Figure 2.

As shown in Figure 2, the elasticity coefficients of Ln$EXPY$ and Ln$TP$, as well as Ln$TP$ and ln$CO_2$, are all statistically significant at the 1% significance level, demonstrating that technological progress is one of the mechanisms by which the new energy industry's export sophistication affects carbon emissions. According to the change in coefficients, the direct effect of Ln$EXPY$ on ln$CO_2$ is $-0.230$, meaning that for every 1% increase in Ln$EXPY$, carbon dioxide emissions will decrease by 0.230%; however, with the intervention of technological progress, the total effect of Ln$EXPY$ on ln$CO_2$ is 0.219%. It's interesting to note that the new energy industry's export sophistication exhibits a negative relationship with technological progress in the mediated transmission process, i.e., an increase in the new energy industry's export sophistication will be detrimental to the domestic technological level. This is primarily because a country has a finite amount of innovation resources, and if it concentrates those resources on the new energy industry's export sophistication, it will exhaust those resources for domestic innovation.

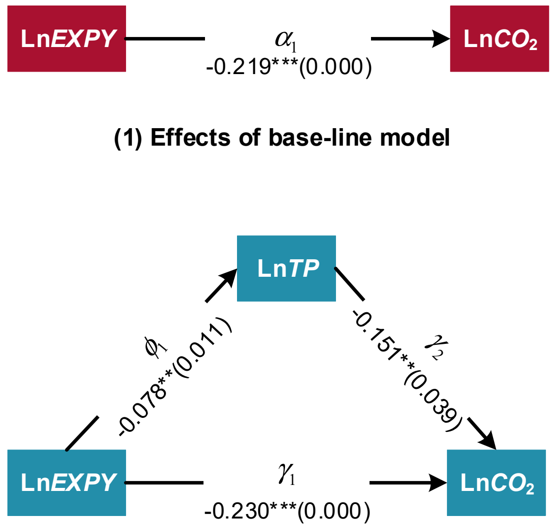


**Figure 2.** Analysis of moderator effects. Note: *p*-values in parentheses; ** $p < 0.05$, *** $p < 0.01$.

## 5.2. Heterogeneity Discussion

Given the vast differences in economic development between countries, the new energy industry's export sophistication may have various effects on carbon emission reduction in different countries. On this basis, we classified 31 sample countries according to their level of economic development into developed and less developed countries. The results of our investigation into the heterogeneity of the carbon emission reduction effects of the new energy industry's export sophistication at different economic development levels are presented in Figure 3.

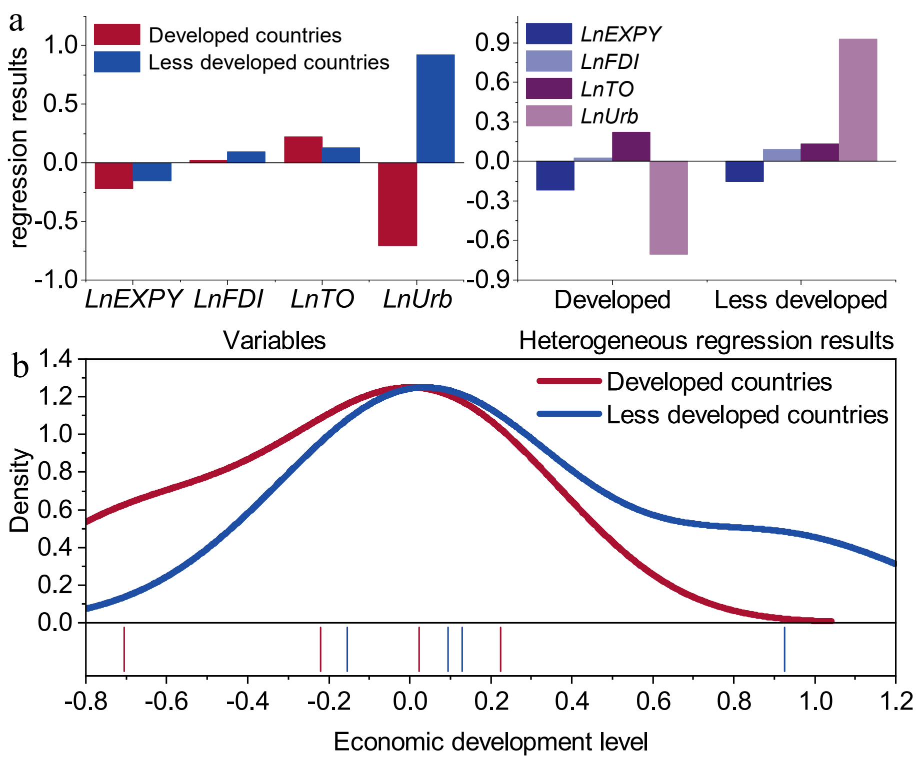


**Figure 3.** Heterogeneous regression outcomes for the effects of the new energy industry's export sophistication on carbon emissions. (**a**) represents the comparison of heterogeneity estimation coefficients, while (**b**) represents the distribution of lnEXPY coefficients estimated for different country types.

According to Figure 3, the elastic coefficient between Ln$EXPY$ and ln$CO_2$ in developed countries is −0.220, and it passes the 1% significance level test. While in less developed countries, $CO_2$ emissions will drop by 0.155% for every 1% improvement in Ln$EXPY$. The regression findings demonstrate that the new energy industry's export sophistication is helpful in lowering carbon emissions in both developed and developing countries. Furthermore, as compared to less developed countries, the new energy industry's export sophistication in developed countries has a greater influence on reducing carbon emissions. The explanation for this phenomenon is that economic development is the first priority for developing countries, and they prefer to continue consuming fossil energy rather than developing new energy for industries with high initial investment sunk costs, whereas developed countries prioritize environmental protection and are willing to invest heavily in the development of new energy industries and new energy technologies to achieve long-term goals.

## 6. Conclusions and Policy Implications

The optimization of energy consumption structure and the reduction of global carbon emissions are both greatly aided by the growth of the new energy sector. From the standpoint of export sophistication, this research investigates the direction, mechanism, and heterogeneity of the new energy industry's influence on carbon dioxide. To accomplish this, empirical experiments were conducted by gathering data from 1996 to 2021 from 31 of the world's major economies via the *UN Comtrade database*, *the World Bank Open Data*, and the *2022 BP Statistical Review of World Energy*. The findings indicate that the new energy industry's export sophistication may contribute to a decrease in carbon dioxide emissions, and this conclusion has withstood a number of robustness tests. The mechanism analysis reveals that the export sophistication of the new energy industry will have a crowding-out influence on domestic technological innovation, which is not conducive to achieving the global carbon emission reduction target. We also observe regional heterogeneity, as the effect of the new energy industry's export sophistication on carbon reduction is more pronounced in developed countries. In light of the significance of new energy in attaining carbon neutrality and a carbon peak, this research on the new energy industry provides a theoretical framework for the low-carbon transformation of the energy sector. This paper also provides evidence for the high-quality development of the new energy industry from the perspective of export sophistication, which is conducive to taking the initiative and the lead in the process of reshaping the global energy supply and demand pattern.

Based on the previous findings, this research proposes the three policy implications listed below.

Firstly, we should prioritize enhancing the new energy industry's export sophistication. Countries around the world should accumulate the production process of new energy products, actively enhance the production capacity of high-end new energy products, and cultivate their own international competitive advantage in the new energy industry. Secondly, innovation resources should be cultivated to mitigate the effect of export sophistication on domestic innovation resources being crowded out. In terms of the total amount of innovation resources, improve the training support for R&D personnel, and foster a group of scientific and technological innovators; In the development of the new energy industry, an additional new energy industry innovation fund will be established, which will be used for talent support and technological research and development in the new energy industry, and will increase support for the new energy industry. Finally, distinct new energy industry development plans should be developed, and the comparative advantages of various country types should be properly leveraged. Developed countries should speed up research into new energy utilization technologies, particularly those with zero carbon emissions, and accelerate the green energy transition. Developing countries should abandon the idea of development dependent on fossil fuels, lay out new energy products with comparative advantages, and gradually join the global new energy industry's international division of labor system.

It is important to note that this study is primarily based on the data from 31 of the world's major economies; however, if the countermeasures and suggestions in this study are used to guide the development of the new energy industry in a particular country, the effect may be greatly diminished due to the unique characteristics of the country. To overcome this limitation, future research will concentrate on a specific nation in order to devise countermeasures that are more compatible with the growth of the nation's new energy industry.

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## Abbreviations

| | |
|---|---|
| $CO_2$ | Carbon dioxide |
| PGDP | Per capita GDP |
| EXPY | The export sophistication of the new energy industry |
| FDI | Foreign direct investment |
| IT | International trade |
| Urb | Urbanization |
| TP | Technological progress |

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