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Renewable Energy for Balancing Carbon Emissions and Reducing Carbon Transfer under Global Value Chains: A Way Forward

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Abstract: Research on the relationship between a country's renewable energy consumption and carbon emissions is of great significance for reducing carbon emissions embodied in international trade. There always exists a gap between production-based and consumption-based carbon emissions. Accordingly, this paper investigates the influence of renewable energy consumption on carbon emission balance, the ratio of production-based emissions to consumption-based emissions, in various countries using the ordinary least square (OLS) method and generalized method of moments (GMM) method. We found that a 1% increase in renewable energy consumption can decrease the carbon emission balance by 5.8%. Furthermore, renewable energy consumption can help narrow the gap between production-based and consumption-based carbon emissions in net emission exporters. In addition, renewable energy consumption can also weaken the negative impact of the global value chains (GVCs) division system on the carbon emission balance. The findings in this study fill the research gap by analyzing the heterogeneous impacts of renewable energy consumption on carbon emission balance embodied within a GVC division system in various countries and provide policy suggestions that renewable energy consumption should be encouraged in net emission exporters to reduce the carbon emission transfers.

Keywords: carbon emission balance; consumption-based carbon emissions; global value chains (GVCs); production-based carbon emissions; renewable energy consumption

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1. Introduction

Recently, countries around the world have put forward their own carbon emission reduction targets. For example, in September 2020, China set the goal of "carbon peaking" by 2030 and "carbon neutrality" by 2060. In December 2021, the US President Joe Biden signed an executive order requiring the US federal government to become carbon neutral by 2050. European Union countries have also set carbon neutrality targets in law. In short, carbon emission reduction has become an important consensus worldwide.

Thirty percent of the global carbon emissions were embodied in the international trade in 2010 [1]. International trade not only increase the global consumption demand, leading to more carbon emissions, but also confuse the responsibility of carbon emissions by transferring carbon emissions. This causes the trade-off between international trade and carbon emissions to be an important topic to discuss. To distinguish the responsibility of carbon emissions of different countries is the basis of carbon emission reduction.

Many studies have debated who is responsible for the greenhouse gases emitted into the atmosphere. The early research clarifies the responsibility of carbon emissions based on production activities [2–4], that is, a country that produces the products and services domestically should assume the full responsibility for carbon emissions [5]. With the deepening of the global production fragmentation, based on global value chains (GVCs), emission balance is closely related to the reallocation of production units and energy use.

However, considering consumption demand is the driving force of production, it is important to consider both production and consumption perspectives to divide responsibility for carbon emissions [6,7]. Therefore, focusing on the gap between production- and consumption-based carbon emissions, carbon emission transfers or carbon leakage within GVCs, as typical phenomenon in the trade field, are widely studied. Carbon emissions are transferred embodied in GVCs mainly for two reasons: Firstly, countries with technological superiority have priority in choosing the production links they participate in. They are more willing to engage in production links with low pollution to realize the environmentally friendly goals, while other countries, mostly developing countries, have to engage in production links with relatively high pollution [5]. Secondly, due to the different intensity of environmental regulations and production cost in countries within GVCs [1,8], carbon-intensive industries are easily absorbed by countries with relatively moderate environmental regulations. These countries are often labeled as "polluted havens" [9]. The carbon emission balance, referring to the consistency of CO_2 emissions attributed to production-based and consumption-based accounts [7], became an important indicator to describe and calculate the carbon transfer trend.

Theoretically, energy consumption is a factor causing CO_2 emissions and global warming [10]. The high consumption of fossil energy in industries is an important reason for the rise in global carbon emissions [11]. Renewables, including solar, wind, hydro, bio-fuels, and others are increasingly widely used since the renewable energy is much more friendly to the environment and also sufficient for decreasing the transportation cost of gas and oil [12]. As shown in the report of the IEA [13], 6.6% of the final energy consumption in the world was modern renewable energy in 1990 and the share increased to 10.5% in 2017.

To date, based on the sustainable development goals, the effect of renewable energy on the environment has drawn attention from scholars [14–18]. Various scholars have suggested that renewable energy consumption has a significant impact on international trade and the environment with different approaches [19–22]. Although it is realized that renewable energy might be beneficial for the trade-off between economic development and carbon emission, few scholars systematically investigate and summarize the relationship between renewable energy consumption and carbon emission balance from the perspective of carbon emission transfers.

The main objective of the current study is to investigate: (1) the impact of the renewable energy consumption on carbon emission balance; (2) the national heterogeneity of the impact of renewable energy consumption on the carbon emission balance; and (3) the moderating effect of GVCP in the relationship between the renewable energy consumption and carbon emission balance.

The rest of the paper is organized as follows: Section 2 presents the literature review; Section 3 puts forward the methodology, including the model specification, the measurement of variables, and the data sources. Section 4 describes the empirical results and discussion. The conclusion, implications, and limitations are presented in Section 5.

2. Literature Review

2.1. Carbon Transfer and International Trade

Global production and trade facilitate the transfer of carbon emissions [6]. Developed countries, importing more but exporting less carbon-intensive products, transfer carbon emissions to developing countries [23–25]. In fact, the net carbon transfers from developing countries to developed countries through trade is also increasing [4,26]. One obvious feature triggered by carbon transfers is the inconsistency between the carbon emissions calculated based on consumption accounts and emissions based on production accounts, which causes it to be difficult to divide carbon emission responsibility among countries. Early researchers focus on the producers' responsibilities for carbon emissions [2], but given that demand is the driving factor of production, some scholars hold that consumers should take full responsibility [26,27]. Recent studies suggest that carbon emissions should be shared by producers and consumers [6,7,28].

To describe and calculate the carbon transfer trend, some indicators have been applied including the trade-embodied carbon emissions based on Input-Output tables and carbon emission balance [1,5,29]. The carbon emission balance is a wider index compared with trade-embodied carbon emissions, since trade-embodied carbon emissions only calculate the emissions related to global production while the former treats a country as a whole, with all production and consumption included. Tracking carbon emissions in different countries using multi-regional input-output tables is an important consideration [30,31]. For example, Ma et al. [32] analyze indirect carbon emissions reflected by intermediate inputs and find that, in China, indirect CO_2 emissions are much more than direct CO_2 emissions.

Actually, the paths of transferring CO_2 emissions have gradually shifted from traditional trade to GVC activities [33]. Under the GVCs division system, developed countries, with their technological advantages, transfer carbon-intensive manufacturing units to developing countries. Therefore, developing countries usually dominate global carbon-intensive industries leading to the increase in energy consumption and carbon emissions under production-based accounts [34]. There is also a contrary view that technology spillovers and labor transfer in GVCs contribute to the transfer of environmental and new energy technologies, reduce emissions, and increase the use of renewable energy [8,35,36]. In addition, participation in GVCs also means increased demand for transportation, which are regarded as a major carbon emitting sector of air pollutants [37,38]. Yan et al. [1] find that an economy's role within its GVCs matters for its emissions embodied in trade, with an extended environmental Heckscher-Ohlin-Vanek model constructed.

2.2. The Impact of Renewable Energy on Carbon Emissions

As recognized by many scholars, renewable energy, compared with fossil energy, has a significant impact on reducing carbon emissions [22,39–45]. Furthermore, carbon compounds are also the components of syngas, a source of renewable energy for heating and electricity generation [46]. There are also several empirical studies focusing on the negative impact of renewable energy consumption on CO_2 emissions [47,48]. Salem et al. [18] using the pooled mean group (PMG) method, find that renewable energy consumption and carbon dioxide emissions have an inverted U-shaped relationship. Furthermore, some scholars investigate the cointegration relationship between renewable energy consumption and CO_2 emissions in the short and long run, separately. In the short term, the consumption of renewable energy cannot reduce emissions for being limited by technology to continuous and stable supply [49], but two-way causality between CO_2 emissions and renewable energy consumption is proven to exist [40,50]. In the long run, both renewable and non-renewable electricity consumption increases CO_2 emissions [51], while the renewable electricity production reduces CO_2 emissions both in the short and long term [52]. Furthermore, there are also studies focusing on the impact of different kinds of renewable energy on carbon emissions, such as combustible renewable energy, renewable electricity from waste, and hydroelectric power, that have negative long-run effect on CO_2 emissions [39].

As carbon emission transfers and carbon emission responsibility are becoming a topic in the environment and trade fields, scholars investigate the impact of renewable energy consumption on carbon emission balance, calculated by production-based emissions and consumption-based emissions [7]. The use and export of renewable energy reduced consumption-based carbon emissions [53]. Furthermore, there also exists a positive long-run relationship between carbon trade balances and carbon emissions for high-income countries [7].

2.3. The Literature Gaps

Based on the above literature reviewed in Sections 2.1 and 2.2, renewable energy consumption is beneficial for reducing the amount of carbon emissions. However, the effect of renewable energy consumption on the carbon emission balance, as a typical feature of environmental issues in international trade, is worth considering and has not been reached. Furthermore, analyzing the heterogeneous impacts of renewable energy consumption on the carbon emission balance is quite conducive to developing an efficient policy system for cross-border carbon trade, but there are few studies considering the different influences of renewable energy consumption on carbon emission balances in various countries. In addition, although GVCs division system leads to carbon emission transfers in international trade, few researchers focus on the impact of renewable energy consumption on the balance of carbon emissions in countries with different GVC positions.

3. Methodology and Data

3.1. Model Specification

Based on the classic Impact of Population, Affluence, and Technology (IPAT) model first proposed by Ehrlich and Holdren [54], which has usually been adapted to measure the relationship between human activities and the environment, Dietz and Rosa [55] constructed the STIRPAT model to solve the unified elasticity problem [56]. Based on Dietz and Rosa [55]'s model and according to the study of Yang and Liu [57], we further investigate the impact of renewable energy consumption on the carbon emission balance by adding GVC Position, renewable energy consumption, and the related variables. In order to obtain more consistent and efficient results, we construct a log-transformed econometric model to help remove autocorrelation and heteroscedasticity issues from the data [12]. The econometric model is constructed as follows:

$$\mathrm{LnCO_2B_{it}} = \alpha_0 + \alpha_1 \mathrm{LnRECP_{it}} + \alpha_2 \mathrm{LnGVCP_{it}} + \sum_{k=3}^{5} \alpha_k \mathrm{LnX_{it}} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

where i denotes the country and t refers to the year. α_0 indicates the intercept term while α_i refers to the estimated coefficients. CO_2B_{it} is the carbon emission balance of country i in year t; $GVCP_{it}$ represents country i's position within GVCs in year t; $RECP_{it}$ represents renewable energy consumption penetration; X refers to the control variables, mainly including population intensity, real GDP at constant national price, and technology efficiency; μ_i and γ_t captures country and year-fixed effects; ε_{it} is an error term which is independently and identically distributed.

3.2. The Measurement of Carbon Emission Balance

With the deepening of the global production fragmentation and the cross-border trade, carbon emissions are transferred among countries. Countries prefer to reduce domestic emissions via transferring the emission-intensive industries to other countries. The transfers cause an emission gap between the production-based accounts and consumption-based account [7]. Yet, most previous works focused on production-based emissions. On one hand, consumption-based emissions are appropriate to be the basis for dividing carbon emission responsibilities for countries; on the other hand, cross-border consumption enable the transfer of the emissions through international trade. The works concentrated on consumption-based emissions and the comparison between two kinds of emissions are of a great significance [58–60]. Consumption-based CO_2 emissions are measured during a country's "consumption" of goods as well as services. According to Hotak et al. [7], consumption-based emissions are measured as follows:

$$CO_{2it}^{cons} = CO_{2it}^{dcon} - CO_{2it}^{exp} + CO_{2it}^{imp} \quad (2)$$

where I denotes the country and t refers to the year; CO_{2it}^{cons} refers to consumption-based CO_2 emissions, which means the CO_2 emissions caused by the countries' consumption of goods and services; CO_{2it}^{dcon} refers to CO_2 emissions from domestic final consumption; CO_{2it}^{exp} refers to CO_2 emissions embodied in the imports of goods and services; and CO_{2it}^{imp} refers to CO_2 embodied in the exports of goods and services.

Based on the Global Carbon Budge [61], we use territorial emissions to measure carbon emissions based on production. Additionally, the ratio of production-based emissions to consumption-based emissions is applied to measure carbon emission balance. As follows:

$$CO_2B_{it} = \frac{CO_{2it}^{prod}}{CO_{2it}^{cons}} \tag{3}$$

CO_{2it}^{prod} refers to the production-based CO_2 emissions that are commonly used by a country to report its emissions; CO_2B_{it} refers to carbon emission balance index. A country can be relatively considered as a net emission exporter (importer) if the CO_2B_{it} index is larger (smaller) than one. A smaller carbon mission balance index indicates that more of the country's carbon emissions from its own consumption are transferred to other countries. After calculating the carbon emission balance index, this study further draws the spatial distribution of the country-level carbon emission balance in 2000, 2007, 2014, and 2020 (Figure 1) to show the time-trend.

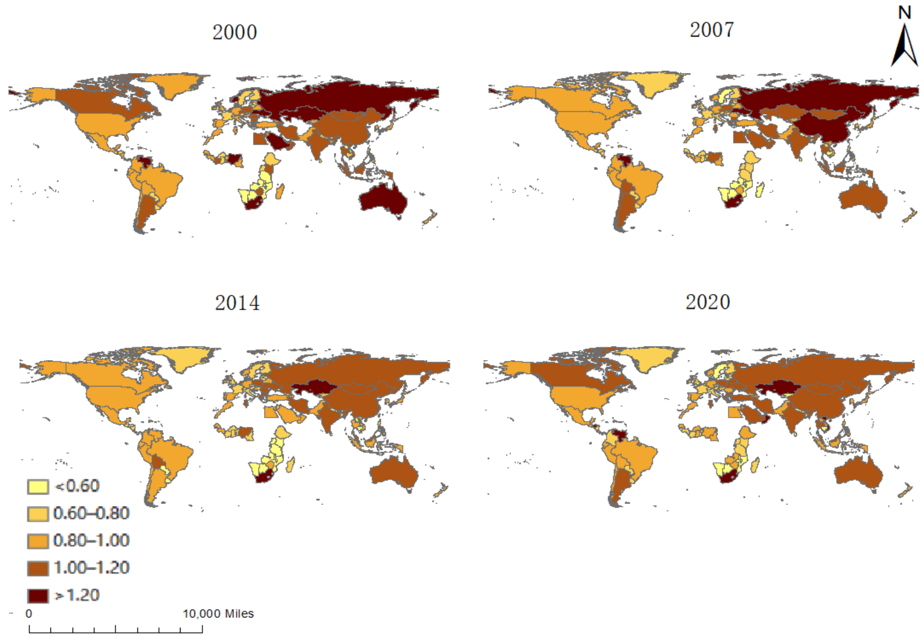

Figure 1. Spatial distribution of country-level carbon emission balance for selected years. Data source: calculated based on the Global Carbon Atlas database [62].

As displayed in Figure 1, the carbon emission balance index of most countries in Asia and Oceania is bigger than those of countries in Europe (except Russia), Africa, and America, from 2000 to 2020. To be specific, the carbon emission balance index of the United States, Germany, France, United Kingdom, Italy, etc. is considerably lower than one, indicating that they are net carbon emission importers where production-based emissions are less than consumption-based emissions; however, the carbon emission balance index of China, India, Russia, Australia, etc. are quite higher than one, indicating that they are net carbon emission exporters where production-based emissions are more than consumption-based emissions. In addition, the carbon emission balance index of countries around the world shows a downward trend, from 2000 to 2020. It is worth noting that Egypt, the Czech Republic, Indonesia, Netherlands, and Norway have changed from net carbon emission exporters to net carbon emission importers and that Belarus, Brazil, Turkey, and Greece have transformed from net carbon emission importers to net carbon emission exporters, from 2000 to 2020.

3.3. The Measurement of GVC Position

With the deepening of the fragmentation of international production, global value chains (GVCs) have become an important feature of globalization. There are several measurements for the GVC position. Starting with Fally [63], two measures including "upstreamness" (the average number of stages between production and final demand) and "downstreamness" (the average number of production stages embodied in each product) have been proposed to measure the position within GVCs. However, the "upstreamness" and "downstreamness" measures do not coincide with each other. Therefore, Wang et al. [64] proposed a new measure regarding the relative distance of a particular production length to both ends of a value chain.

According to the production decomposition framework proposed by Wang et al. [64], production activities, with a world multi-regional input–output model is constructed, can be divided into three parts, including value added that is domestically produced and consumed, value added that is embodied in final product exports, and value added that is embodied in exports or imports of intermediate goods and services. The last part measures production activities related to GVCs. Furthermore, the GVC production length has two segments, including output and value added absorbed directly by the importer and re-exports. The average production length forward (PLv_GVC) is the ratio of GVC-related domestic value added to the induced gross output while the average production length backward (PLy_GVC) is the ratio of GVC-related foreign value added to the induced gross output [64]. Specifically,

$$\text{PLv\_GVC} = \frac{\text{Xv\_GVC}}{\text{V\_GVC}} \tag{4}$$

$$\text{PLy\_GVC} = \frac{\text{Xy\_GVC}}{\text{Y\_GVC}} \tag{5}$$

According to Wang et al. [64], the country-level GVC position index is measured by the ratio of forward to backward linkage based on GVC production, as follows:

$$\text{GVCP}_\text{i} = \frac{\text{PLv\_GVC}}{[\text{PLy\_GVC}]'} \tag{6}$$

where GVCP_i represents the global value chain position (GVCP) index, referring to the average production line position of country i. The greater the value of the Index, the higher position of the country i. It indicates that the country is closer to the production side (upstream) of the value chain while farther to the final consumption side of the value chain. The lower the value of the Index indicates that the country is closer to the final consumption side (downstream) of the value chain while farther to the production side of the value chain.

Figure 2 shows the global value chain position index and carbon emission balance index of the world's top 10 economies in 2000, 2005, 2010, and 2014. It can be seen from Figure 2 that the carbon emission balance index of countries located in the upstream of the global value chain is much lower than that of the countries located in the downstream of the global value chain. Specifically, developed countries such as the United States, the United Kingdom, and France are located in the upstream of the global value chain and the carbon emissions caused by their domestic final consumption is much higher than the carbon emissions brought by their domestic production. Moreover, from 2000 to 2014, developing countries, such as China and India, located at the downstream of the global value chain from 2000 to 2014, and their carbon balance index is always greater than 1, that is, the carbon emissions from production is greater than the carbon emissions from consumption.

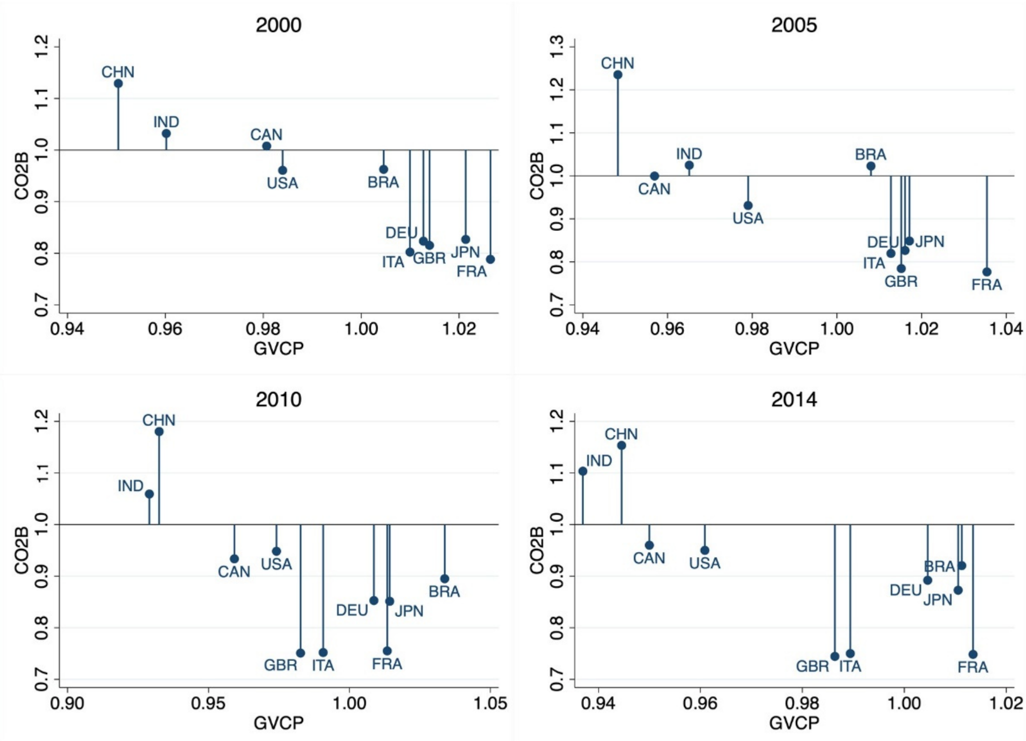

Figure 2. Global value chain position and carbon emission balance index of the world's top 10 economies in selected years. Data source: Calculated based on the Global Carbon Atlas database [62] and the World Bank Database [65].

3.4. The Measurement of other Variables and Data Sources

To investigate the influence of renewable energy consumption on carbon emission balance quantitatively, this article employs a panel dataset of 42 countries from 2000 to 2014 for the empirical analysis. The research framework is depicted in Figure 3.

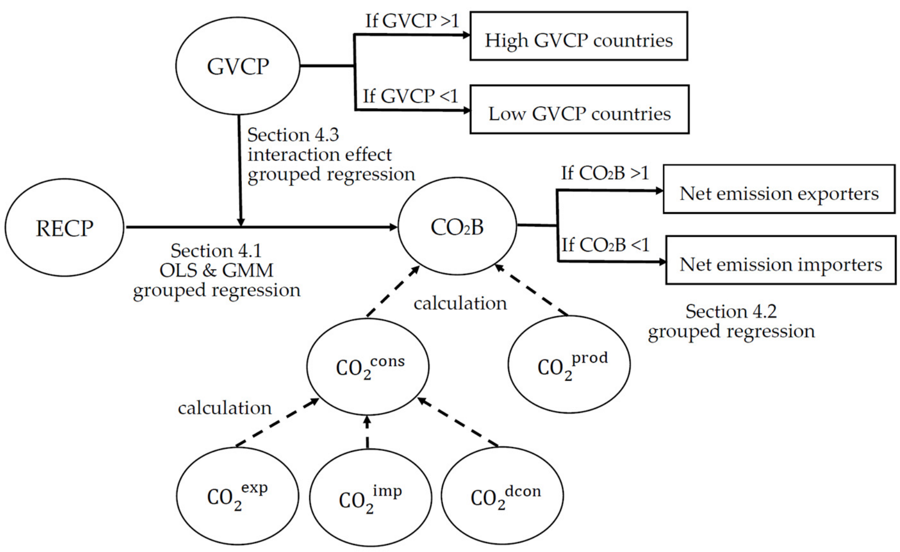

Figure 3. Research framework. Source: Author(s) depiction.

The carbon emission balance (denoted as CO_2B), as the main dependent variable, is measured based on production-based emissions and consumption-based emissions. Both data of production and consumption emissions are derived from Global Carbon Atlas [62] and obtained for the index using the calculation introduced in Section 3.2.

Renewable energy consumption penetration (denoted as RECP), as the main independent variable, is measured by the ratio of renewable energy consumption to total energy consumption [13]. The renewable energy includes bioenergy, geothermal, solar, tidal, and wind, as shown in Table A1 in Appendix A. We obtain the data of energy consumption from the World Bank and IEA [66].

The global value chain position (denoted as GVCP) is measured based on the data of global input-output tables from the World Input Output Database (WIOD 2016) [65], because this set of data is the most established dataset that is available considering the period, countries covered, and the data quality and it is also widely used in the GVCs-related literature. The WIOD 2016 contains world input-output tables from 2000 to 2014. We obtain the index from the calculation in Section 3.3.

According to the STIRPAT model [55], the following three control variables are adapted, including the population intensity (denoted as PI), technology efficiency (denoted as TE), real GDP at constant national price (denoted as RGDP) to, respectively, measure the level of population, technology, and wealth in countries. All the data of these control variables are derived from the World Bank [67]. Table 1 displays descriptive statistics of the variables.

Table 1. Descriptive statistics of the variables.

Variable	Definition	Mean	Std.Dev	Min	Max
LnCO_2B	Carbon emission balance	−0.1729	0.2489	−1.1482	0.3858
LnGVCP	GVC Position	0.0016	0.0344	−0.0780	0.1273
LnRECP	Renewable energy consumption penetration	2.3808	1.0821	0.9250	1.1358
LnPI	Population intensity	4.4444	1.2488	0.9135	7.2138
LnTE	Technology efficiency	2.0363	0.3929	0.4798	3.0072
LnRGDP	Real GDP at constant national price	9.7869	1.0866	6.0943	11.6854

Source: Author(s) computation.

4. Results and Discussion

4.1. Results of the Impact of RECP on CO_2B

Table 2 displays the double fixed-effect regression results, where column (1) only considers the impact of RECP on CO_2B, column (2) adds control variables including PI, TE, and RGDP, and column (3) further adds GVCP as another control variable. We also classify countries where CO_2B is more (less) than one as emission exporters (importers).

As shown in Table 2, after considering the control variables, including PI, TE, and RGDP, the influence coefficient of RECP on CO_2B is −0.076 and it is significantly negative at the 1% level. Furthermore, after regarding GVCP as another control variable, we find that the influence coefficient of the RECP on the carbon emission balance is −0.077 and it is also significantly negative at the 1% level, revealing that the consumption of renewable energy can reduce the carbon emission balance index. From the point of GVCP, the influence coefficient of GVCP ($\alpha = -0.573, p < 0.05$) is also negatively significant related to the carbon emission balance index.

To date, RECP has a negative effect on CO_2B, but it has different effects in net exporters (LnCO_2B > 0) and net importers (LnCO_2B < 0). Column (4) and column (5) in Table 2 show the grouped regression results on the impact of RECP in net emission importers and exporters, respectively. We can find that the influence of RECP is much stronger in net importers ($\alpha = -0.092, p < 0.01$) than that in net exporters ($\alpha = -0.064, p < 0.05$) from both the views of the coefficient and significant level. As for the influence of GVCP on CO_2B, the negative effect is only significant in net carbon importers (LnCO_2B < 0), which means, in importing countries, the carbon emission transfers could be decreased by further improving its position within GVCs, but it is not an efficient solution in exporting countries.

Table 2. Results of the impact of RECP on CO_2B.

Variable	Static Panel Estimation					Dynamic Panel Estimation	
	OLS					SYS-GMM	DIF-GMM
	All Countries			Importer	Exporter	All Countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$LnCO_2B_{i,t-1}$						0.487 ***	0.288 **
						(2.78)	(2.50)
LnRECP	−0.058 ***	−0.076 ***	−0.077 ***	−0.092 ***	−0.064 **	−0.044 **	−0.079 ***
	(−4.38)	(−5.50)	(−5.58)	(−7.39)	(−2.41)	(−1.99)	(−2.67)
LnRGDP		−0.091 ***	−0.090 ***	−0.140 ***	−0.030	−0.079 ***	−0.062 *
		(−3.68)	(−3.62)	(−4.43)	(−0.83)	(−2.85)	(−1.94)
LnTE		−0.218 ***	−0.230 ***	−0.162 ***	−0.202 ***	0.119	−0.160
		(−3.98)	(−4.21)	(−2.77)	(−2.95)	(1.21)	(−1.52)
LnPI		−0.990 ***	−0.946 ***	−0.718 ***	−0.573 ***	−0.064 **	−0.829 **
		(−8.29)	(−7.86)	(−5.84)	(−3.32)	(−2.22)	(−2.43)
LnGVCP			−0.573 * *	−0.636 **	−0.340	−0.384	0.186
			(−2.33)	(−2.49)	(−1.29)	(−0.59)	(0.52)
Constant	0.236 ***	2.474 ***	2.448 ***	2.645 ***	1.418 ***	0.825 ***	
	(6.34)	(8.66)	(8.60)	(7.03)	(3.41)	(2.44)	
Country-fixed effect	YES	YES	YES	YES	YES	YES	YES
Year-fixed effect	YES	YES	YES	YES	YES	YES	YES
R-squared	0.872	0.889	0.890	0.904	0.720		
AR (1)						0.026	0.055
AR (2)						0.631	0.891
Hansen test						0.966	1.000
Observations	627	627	627	469	158	586	544

Source: Author(s) computation. Notes: *, **, and ***, respectively, indicate statistical significance at the 10%, 5%, and 1% levels; the values in parentheses of static panel estimation represent t-statistics, while the values in parentheses of dynamic panel estimation indicate z-statistics.

For the robust analysis, considering the inertial effect of the economy and that the lagging variable ($CO_2B_{i,t-1}$) may have an impact on the level of $CO_2B_{i,t}$, we also add the lagging variable ($CO_2B_{i,t-1}$) as another independent variable into the model. Furthermore, considering that endogeneity problems might exist, the instrumental variable (IV) method is often applied. Since the lagging variables as instrumental variables need to meet the spherical disturbance term assumption [68], this study employs the generalized method of moments (GMM) methods, mainly including system GMM(SYS-GMM) model and first differenced GMM(DIF-GMM) model, that are employed to estimate the dynamic panel data; the results are reported in the last two columns of Table 2. To be specific, as shown at the last two columns of Table 2, the p-values of the first-order (AR (1)) and second-order (AR (2)) differences are, respectively, lower and higher than 0.1, implying that the GMM method is reasonable in this research. To add, the *p*-values of the Hansen test are not significant (higher than 0.1), indicating that all the instrumental variables used in this study are effective [69]. After adding $LnCO_2B_{i,t-1}$ into the regression model, the influence coefficient of RECP on the CO_2B is also significantly negative at the 1% level. Therefore, the empirical results in this study are reliable and robust.

4.2. Results of the Impact of RECP on CO_2^{prod} and CO_2^{cons}

In order to further explore the reasons why RECP has a stronger effect in net importers, we investigate the mechanism of the impact RECP on CO_2B. Since CO_2B is measured based on production-based CO_2 emissions (denoted as CO_2^{prod}) and consumption-based CO_2 emissions (denoted as CO_2^{cons}) in Section 3, we explain the influence of RECP from the views of CO_2^{prod} and CO_2^{cons}. In this part, we consider CO_2 embodied in the production and consumption separately to analyze the impact of RECP on CO_2B in net emission exporters and importers. Table 3 shows the grouped regression results with country- and year-fixed effects, where column (1) and (4) show the influence of RECP on CO_2^{prod} and CO_2^{cons} within the whole samples, column (2) and (5) draw the impact of RECP on CO_2^{prod} and CO_2^{cons} in net importers, and column (3) and (6) reveal the same impact in net exporters.

Considering the net emission exporters ($LnCO_2B > 0$), the impact of RECP is negatively significant on both CO_2^{prod} ($\alpha = -0.241, p < 0.01$) and CO_2^{cons} ($\alpha = -0.177,\ p < 0.01$), which indicates that RECP lowers the carbon emissions through both production and consumption. The CO_2B goes down because the coefficient of the impact on CO_2^{prod} is much bigger than that on CO_2^{cons}, which means the CO_2^{prod} drops faster than CO_2^{cons}. In contrast, as for the net emission importers ($LnCO_2B < 0$), the impact of RECP is negatively significant on CO_2^{prod} ($\alpha = -0.058\ ,\ p < 0.01$) but positive on CO_2^{cons} ($\alpha = 0.034, p < 0.05$). The CO_2B decreases through the reduction in the CO_2^{prod} and the induction of the CO_2^{cons}.

The essential cause of the carbon emission imbalance is the differences of environmental regulations and the production costs in countries. As for the net emission importers, the environmental regulations are relatively stringent [21,41]. The consumption of renewable energy lower CO_2 emissions during production but raise the production economic cost, leading to the further transfer of production units abroad and the replacement of local products by imported products that are embodied with more CO_2 emissions. More reliance on imports causes the increase in CO_2^{cons}. In contrast, as for the net emission exporters, the environmental regulations are relatively friendly [7,31]. There are more CO_2 emissions but less cost embodied in products domestically produced than those overseas. Although the cost of domestic production is raised up by the application of renewable energy, it cannot easily reach the high cost in net emission importers. Therefore, the replacement of local products by imported products is limited. Even if the local products are partly replaced by imported products, the CO_2^{cons} is also induced for less CO_2 emissions embodies in imported products. Furthermore, the renewable energy consumption surely reduces the production-based CO_2 emissions, which in turn reduces the CO_2 emissions based on consumption and is not replaced, leading to the drop of CO_2^{prod} and CO_2^{cons}.

Table 3. Results of the impact of RECP on CO_2^{prod} and CO_2^{cons}.

Variable	CO_2^{prod}			CO_2^{cons}		
	All countries	**Importer**	**Exporter**	**All countries**	**Importer**	**Exporter**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
LnRECP	−0.09 ***	−0.058 ***	−0.241 ***	−0.013	0.034 **	−0.177 ***
	(−8.33)	(−5.54)	(−6.64)	(−0.79)	(2.21)	(−4.96)
LnRGDP	0.438 ***	0.395 ***	0.423 ***	0.527 ***	0.535 ***	0.453 ***
	(22.58)	(14.86)	(8.55)	(17.87)	(13.62)	(9.31)
LnTE	−0.596 ***	−0.516 ***	−0.775 ***	−0.365 ***	−0.354 ***	−0.573 ***
	(−13.89)	(−10.49)	(−8.26)	(−5.59)	(−4.86)	(−6.21)
LnPI	−0.156 *	−0.367 ***	−0.095	0.791 ***	0.350 **	0.478 **
	(−1.65)	(−3.56)	(−0.40)	(5.51)	(2.30)	(2.06)
LnGVCP	−0.978 ***	−0.443 **	−1.904 ***	−0.405	0.193	−1.565 ***
	(−5.08)	(−2.06)	(−5.27)	(−1.38)	(0.61)	(−4.40)
Constant	−14.034 ***	−13.681 ***	−13.387 ***	−16.481 ***	−16.326 ***	−14.804 ***
	(−62.91)	(−43.32)	(−23.47)	(−48.54)	(−34.97)	(−26.39)
Country-fixed effect	YES	YES	YES	YES	YES	YES
Year-fixed effect	YES	YES	YES	YES	YES	YES
R-squared	0.989	0.986	0.996	0.978	0.973	0.996
Observations	627	469	158	627	469	158

Source: Author(s) computation. Notes: *, **, and ***, respectively, indicate statistical significance at the 10%, 5%, and 1% levels; t-statistic is displayed as values in parentheses of static panel estimation.

4.3. Results of the Interaction Effect between RECP and GVCP on CO_2B

Table 4 shows the impact of the interaction effect of RECP and GVCP on CO_2B regarding the control variables, where column (1) displays the results within the whole samples, column (2) and column (3), respectively, summarize the interaction effect on CO_2B in countries with the position within GVC closer to the downstream and upstream.

From Table 4, we find that the interaction effect between GVCP and RECP ($\alpha = 0.529$, $p < 0.01$) is positively related to CO_2B, which indicates that the negative effects on the carbon balance index caused by GVCP can be weakened by RECP. To further explore the different impact of RECP on CO_2B, we decompose the countries into high GVCP countries (GVCP > 1) and low GVCP countries (GVCP < 1), according to whether the GVCP is greater than 1. Comparing the results of columns (2) and (3), the influence of RECP is obviously reflected in low GVCP countries ($\alpha = -0.102$, $p < 0.01$), while the coefficient of RECP in high GVCP countries is not significant ($\alpha = -0.017$, $p > 0.1$). This shows that the more renewable energy has been consumed, the lower the CO_2B index in low GVCP countries. At the point of GVCP, it can be found that the GVCP only has the negative impact in high GVCP countries ($\alpha = -1.387$, $p < 0.01$), while the coefficient of the GVCP in low GVCP countries is not significant ($\alpha = 0.357$, $p > 0.1$).

As for the countries with low GVCP, the renewable energy consumption can significantly reduce the carbon emission balance index. That could be caused by two reasons. Firstly, the usage of renewable energy in production activities can reduce the production-based carbon emissions that can directly reduce the carbon emission balance index. Furthermore, renewable energy, compared to traditional fossil energy, leads to higher production cost, so renewable energy consumption in low GVCP countries can narrow the gap of production costs between low and high GVCP countries, thereby reallocating carbon-intensive production links. Therefore, renewable energy consumption can weaken the negative impact of the GVCs division system on the carbon emission balance and enable lower GVCP countries to achieve carbon emission balance (carbon emission balance index = 1). As for the countries with high GVCP, the countries are mostly developed countries, which are in a leading position in product design and technological innovation and have relatively low carbon emissions. Renewable energy consumption has a limited effect on the reduction in carbon emissions in these countries, so it has no significant effect on the reduction in the carbon balance index [25].

Table 4. Results of the interaction effect between RECP and GVCP on CO_2B.

	All Countries (1)	Low GVCP Countries (2)	High GVCP Countries (3)
LnRECP	−0.082 ***	−0.102 ***	−0.017
	(−50.89)	(−70.39)	(−0.59)
LnGVCP	−10.83 ***	0.357	−10.387 ***
	(−30.15)	(10.04)	(−20.83)
LnRECP*LnGVCP	0.529 **		
	(20.38)		
LnRGDP	−0.091 ***	−0.083 ***	−0.106 **
	(−30.70)	(−30.46)	(−20.14)
LnTE	−0.221 ***	−0.275 ***	−0.167
	(−40.04)	(−40.83)	(−10.58)
LnPI	−0.987 ***	−0.816***	−10.186***
	(−80.15)	(−50.17)	(−50.95)
Constant	20.501 ***	20.372 ***	20.721 ***
	(80.79)	(70.40)	(50.21)
Country-fixed effect	YES	YES	YES
Year-fixed effect	YES	YES	YES
R-squared	0.891	0.959	0.819
Observations	627	319	308

Source: Author(s) computation. Notes: **, and ***, respectively, indicate statistical significance at the 5%, and 1% levels; t-statistic is displayed as values in parentheses of static panel estimation.

5. Conclusions

Using the panel data of 42 countries from 2000 to 2014, this study established an extended STIRPAT model to explain the impact of renewable energy consumption on the the carbon emission balance under global value chains. The main results are as follows:

Firstly, an economy's carbon emission balance can be reduced by renewable energy consumption; this conclusion still holds after a series of robustness tests. Secondly, the impact of renewable energy consumption on the carbon emission balance is different in carbon emission exporting and importing countries. Specifically, for a net exporter of carbon emissions, renewable energy consumption can help narrow the carbon emissions gap to achieve carbon balance; however, for a net carbon emission importer, renewable energy consumption could increase its carbon emissions gap. Thirdly, there exists an impact of the interaction effect between GVCP and renewable energy consumption on the carbon emission balance, indicating that increasing renewable energy usage reduces the carbon emissions in low GVCP countries transferred from high GVCP countries.

Following the results of this study, there are some policy implications. First, encouraging the renewable energy consumption is an efficient policy to relieve the trade-off between participating in GVCs and solving the environmental problems. Second, considering that production-based carbon emissions are easily to be transferred from high GVCP countries to low GVCP countries, carbon emissions based on consumption should be considered in the calculation of national carbon emission responsibility and it is reasonable for high GVCP countries to provide basic climate or technology aid to the carbon emissions exporting countries to realize the global sustainable development.

Certain limitations are in the research due to data availability. Since renewable energy is used more widely, investigating the effect of renewable energy consumption on carbon emission balance is valuable. In the current research, the impact of renewable energy consumption on the carbon emission balance is investigated at the country level. However, the heterogenous impact among industries is meaningful but not involved in this paper. The impact of renewable energy consumption on the carbon emission balance at a multi-scale industry-level still needs further research.

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Appendix A

Table A1. Breakdown of the renewable energy.

		Categories
Renewable Energy	Bioenergy	Purpose-grown crops or trees in highly land-intensive process
		Waste and residues
		Black liquor from paper production
	Solar	Solar photovoltaic
		Solar thermal
	Geothermal	
	Tidal	
	Wind	

Source: IEA (Renewables—Fuels & Technologies—IEA) and World Bank [66].

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