Carbon inequality and economic development across the Belt and Road regions

Abstract

Given the aim of maintaining global warming below 2°C, carbon emission reduction has become a global top priority. Since the Belt and Road Initiative has increasing influence on manufacturing-oriented developing countries, more attention should be paid to carbon emission reduction in these regions. This study conducts a comprehensive analysis by analyzing the carbon inequality and regional development and compares the carbon emissions driven by final demand among countries in and outside the Belt and Road area from 1990 to 2015. It is found that the majority of the Belt and Road regions achieved a rapid GDP growth rate with increasing carbon emissions, in which the investment-driven type demonstrated a significant growth. In contrast, the developed countries outside the Belt and Road area maintained their economic growth while decreasing the carbon emissions owed to the declining of investment-driven emissions; however the consumption-driven emissions stably remained a relatively high level. Our results showed that the inequality of carbon emission within Belt and Road regions is lower than the global average, while the inequality of the investment-driven emissions showed an obviously increasing trend. By discussing the carbon inequality and regional development, rational and feasible strategies for countries and regions within and outside the Belt and Road area are essential, and different types of strategies such as low-carbon technologies transfers and overseas financial cooperation are suggested for regional carbon emission

reduction and sustainable regional development under the Belt and Road Initiative.

Keywords: Carbon inequality; Regional development; Belt and Road Initiative; Global climate change

1. Introduction

Climate change is often considered a global challenge, which poses a long-term threat to human survival and the ecosystem. The Fifth Assessment of the United Nations Intergovernmental Panel on Climate Change (IPCC) indicated that the human impact on the climate system is clear and continues to increase (Mastrandrea et al., 2010). As early as the 1990s, researchers began to pay attention to the environmental impacts of global production networks and the international division of supply chains (Copeland and Taylor, 1994, 2004; Chichilnisky, 1994).

Since the Kyoto Protocol in 1997, the attempts to identify carbon emission responsibilities have resulted in considerable controversies. Some studies showed that the existing assessments of national carbon responsibilities ignored trade-induced geographies of production and consumption (Davis and Caldeira, 2010; Feng et al., 2013; Peters and Hertwich, 2008). Other research drew on the consequences of economic globalization and international trade to identify the consumer responsibilities for embodied carbon emissions (Chen et al., 2018) and the implications for effective climate policies and international climate cooperation (Lenzen et al., 2007). Generally, developed countries had the greatest technological capacities to reduce such emissions and carried substantial responsibility from the consumption perspective (Feng et al., 2015); in contrast, emerging countries specialized in low-end manufacturing and unable to easily afford advanced environmental protection technologies were under pressure for reducing carbon emissions (Liu et al., 2015b; Wyckoff and Roop, 1994).

As a powerful analysis method, multi-regional input-output (MRIO) analysis has been gradually applied due to the deepening of globalization and the increasing acuteness of the natural resource and environmental issues associated with globalization (Liu et al., 2015a; Mi et al., 2017; Zhang et al., 2013). A number of such studies have revealed environmental linkages caused by the spatial shifts in industrial capacities from developed to developing countries and the consequent rapid increase in international trade (Hong et al., 2016; Li et al., 2018b, 2019; Wei et al., 2017). Especially, the cross-boundary carbon flows and linkages have been recently emphasized (Chen and Chen, 2016; Chen et al., 2019), especially by comparing the physical and virtual carbon metabolism of global cities (Chen et al., 2020). To clearly analyze the carbon emissions of multiple countries from the consumption-based perspective, this analysis is applicable to identify the resource and environmental impacts of geographies between production and consumption (Li et al., 2018a; Han et al, 2019), which is practical for the embodied carbon emission analysis on the Belt and Road regions.

To date, studies have applied different indicators to measure the carbon emission levels in countries and regions (Cai et al., 2018; Xie et al., 2019; Zheng et al., 2019), especially by comparing the relations between GDP and carbon emission per capita (Steinberger, et al., 2012). In addition, increasingly more attentions were paid to measure the inequality with regard to economic development and carbon emissions between developed and developing countries (Hubacek et al., 2017a). Present studies also addressed the consequences of international poverty alleviation from the perspective of balancing the regional economic development and the global climate target (Hubacek et al., 2017b). Recent studies have predominantly shown that developing countries may contribute to global economic development through resource consumption and environmental emissions (Erzi et al., 2018; Meng et al., 2018; Muhammad et al., 2013), and it is thus necessary to measure the regional development and carbon emission levels from the final demand perspective.

As an international cooperation platform, the Belt and Road Initiative (BRI) was proposed and promoted by China’s National Development and Reform Commission, Ministry of Foreign Affairs, and Ministry of Commerce of China (2015). The green silk road development was further proposed in the Second Belt and Road Forum for International Cooperation (2019), providing an opportunity for countries and regions within the Belt and Road area to share experiences, transfer technologies and increase capabilities to tackle climate change. Within this area, the GDP of countries and regions was approximately 23.56 trillion US$, accounting for 31.79% of the global total, and the population reached 4.58 billion, accounting for 62.61% of the global total (World Bank, 2015). As the geographical structures of global development and cooperation are greatly changing, developing countries are gradually participating in constructing the global development structures (Han et al., 2018; Hudson, 2016; Liu and Dunford, 2016). Up to now, increasingly more countries and regions got involved in the Belt and Road Initiative, which may bring more opportunities for global climate cooperation between developing countries as well as developed countries (The Belt and Road Portal, 2019).

As for the carbon emissions of the Belt and Road countries, it is essential to measure the relations among economic development, energy consumption and carbon emissions as the most essential factors (Fan et al., 2019; Liu and Hao, 2018; Mariana, 2016). In particular, with the fact that the Belt and Road was challenged by stimulating the growth of energy-intensive industries (Zhang et al., 2017), it is essential to further analyze the carbon inequality and economic development across the Belt and Road regions. Based on the necessity of economic development and structures of energy-intensive industries, the carbon emissions reduction in the Belt and Road areas desperately needs advanced technical transfers and financial support by cooperating with countries such as China (Wang and Wang, 2017). Accordingly, a comprehensive analysis on the trends and characters of carbon emissions within the Belt and Road area is indispensable while focusing on the economic development.

In this context, this work comprehensively measures the economic development and carbon emission levels of countries and regions along the Belt and Road and outside this area since 1990 to 2015 and compares with main developed countries in corresponding historical period from the final demand perspective. The related possible cooperation strategies and policy implications are suggested for regions along the Belt and Road and the regions outside this area based on the derived results. The remainder of this paper proceeds as follows: Section 2 articulates the method employed in this study; Section 3 analyzes the detailed results; Section 4 discusses the policy implications; and Section 5 draws some conclusions.

2. Methodology and Materials

Since the carbon emissions in regions are related to the economic development levels, the MRIO, decupling and inequality analysis are applied in this work to analyze the characteristics of the economic development and carbon emissions within and outside the Belt and Road area.

2.1 MRIO analysis

To quantifiably identify the embodiment of resources and emissions, this study uses the MRIO analysis for multi-regional environmental relations and transfers in different economic activities especially for developing countries (Peters and Hertwich, 2008; Wiedmann et al., 2007). The model integrates economic networks and ecological endowments by examining the physical balance of resource use and environmental emissions for a regional system composed of m regions, with region each involving n sectors.

The physical balance of carbon emissions for sector i in region r is defined as follows:

$$q_i^r + \sum_{s=1}^{m}\sum_{j=1}^{n} \varepsilon_j^s z_{ji}^{sr} = \varepsilon_i^r x_i^r \quad (1)$$

where q_i^r represents the direct environmental emissions of economic sector i in region r, ε_j^s represents the embodied intensity of sector j in region s, z_{ji}^{sr} represents the output from sector j in region s for intermediate input to sector i in region r, and x_i^r represents the gross output of sector i in region r. x_i^r is defined as follows:

$$x_i^r = \sum_{s=1}^{m}\sum_{j=1}^{n} z_{ij}^{rs} + \sum_{s=1}^{m} f_i^{rs} \quad (2)$$

where f_i^{rs} represents the output from sector i in region r satisfying the final demand of sector i in region s.

Defining $\mathbf{Q} = [q_i^r]_{1\times mn}$, $\mathbf{E} = [\varepsilon_j^s]_{1\times mn}$, and $\mathbf{Z} = [z_{ji}^{sr}]_{mn\times mn}$, the diagonal matrix $\hat{\mathbf{X}} = [x_{ij}^{rs}]_{mn\times mn}$, where $r,s \in (1,2,\ldots\ldots,m)$, $i,j \in (1,2,\ldots\ldots,n)$, $x_{ij}^{rs} = x_i^r$ when $(i = j) \cap (r = s)$ and $x_{ij}^{rs} = 0$ when $(i \neq j) \cup (r \neq s)$, and the diagonal matrix $\hat{\mathbf{F}} = [f_{ij}^{rs}]_{mn\times mn}$, where $r,s \in (1,2,\ldots\ldots,m)$, $i,j \in (1,2,\ldots\ldots,n)$, $f_{ij}^{rs} = f_i^r$ when $(i = j) \cap (r = s)$ and $f_{ij}^{rs} = 0$ when $(i \neq j) \cup (r \neq s)$, Equations (1) and (2) can be expressed in matrix form as follows:

$$\mathbf{Q} + \mathbf{EZ} = \mathbf{E}\hat{\mathbf{X}} \quad (3)$$

and

$$\hat{\mathbf{X}} = \mathbf{Z} + \hat{\mathbf{F}} \quad (4)$$

Therefore, given the direct inputs matrix $\mathbf{Q}$, intermediate inputs matrix $\mathbf{Z}$ and gross outputs matrix $\hat{\mathbf{X}}$, the embodied carbon intensity matrix can be obtained as follows:

$$\mathbf{E} = \mathbf{Q}(\hat{\mathbf{X}} - \mathbf{Z})^{-1} \quad (5)$$

Based on the embodied emission intensity matrix, the direct carbon emissions (**DE**) can be defined as the direct carbon emissions emitted within the territory of a region, and embodied carbon emissions (**EE**) can be defined as the carbon emissions embodied in local final demand, which can be obtained as follows:

$$\mathbf{DE}^r = \mathbf{Q}^r = \sum_{i=1}^{n} q_i^r \quad (6)$$

$$\mathbf{EE}^r = \sum_{i=1}^{n} \mathbf{EE}_i^r = \sum_{i=1}^{n}\sum_{s=1}^{m} (\varepsilon_i^s f_i^{sr}) \quad (7)$$

Here, the carbon emissions embodied in local final demand per capita (**EEP)** could be obtained through embodied carbon emissions and total population by country. Furthermore, f_i^{sr} denotes the domestic final demand of region *s* supplied by sector *i* in region *r*, which contains final consumption (c_i^{sr}) and investment (v_i^{sr}).

$$\mathbf{EEC}^r = \sum_{i=1}^{n} \mathbf{EEC}_i^r = \sum_{i=1}^{n}\sum_{s=1}^{m} (\varepsilon_i^s c_i^{sr}) \quad (8)$$

$$\mathbf{EEV}^r = \sum_{i=1}^{n} \mathbf{EEV}_i^r = \sum_{i=1}^{n}\sum_{s=1}^{m} (\varepsilon_i^s v_i^{sr}) \quad (9)$$

Here, the consumption- and investment-driven carbon emission mainly represents the carbon emissions driven by the consumption and investment within the territory of this region, which not only includes the carbon emission driven by the local consumption but also covers the carbon emission from other countries/regions along with the global supply chains.

2.2 Decupling and inequality analysis

From the global perspective, the carbon emissions and GDP per capita of countries and regions experienced different growth trends. To clarify the correlation of regional economic development and carbon emissions, the decoupling relationship between economic development and carbon emissions in countries and regions along and outside the Belt and Road area could be identified based on the Tapio decoupling model (Yang et al., 2019). The relationship could be presented as follows:

$$t_{C,G} = \frac{\frac{\Delta c}{c^0}}{\frac{\Delta g}{g^0}} = \Delta c \frac{g^0}{c^0 \Delta g} \tag{10}$$

where $t_{C,G}$ is the decoupling coefficient between carbon emissions and GDP per capita, c and g are the carbon emissions and GDP per capita obtained from the total carbon emissions, the total GDP, and the total population. Δc and Δg represent the carbon emission growth rate per capita and the GDP growth rate per capita respectively.

Besides, the inequality of carbon emissions per capita between different countries and regions could be identified by the Theil index (Foster, 1983; Casilda et al., 2013). To measure the differences in per capita carbon emissions among countries and regions, the Theil index could be presented as:

$$t_c = \sum_i \left(\frac{c_i}{c} \times log\left(\frac{\frac{c_i}{c}}{\frac{p_i}{p}}\right)\right) \tag{11}$$

where t_c is the index to depict the carbon emission inequality, c_i is the carbon emissions of region i, $\boldsymbol{c}$ is the total carbon emissions, p_i is the population of region i, and p is the total population. By comparing the differences of carbon emission between different regions and activities, the inequality level can be further compared.

2.3 Case description and data sources

The countries within the Belt and Road area showed the great diversity and complexity, especially taking into consideration of economic development and fragile ecology. Most countries faced the contradiction of economic development and environmental protection, even though most of them are richly endowed with mineral resources, including oil, natural gas, coal, iron, and copper (Zhang, 2019; Zhang et al., 2019; Zhao et al., 2019). Although some countries are in relatively low economic levels, the potential for their economic development is tremendous together with related carbon emissions. In consideration of the historical origin of the ancient Silk Road, most studies applied the spatial scope of 65 countries in the Belt and Road related research. To measure the levels of carbon emissions under the traditional Belt and Road Initiative, the original countries mentioned in the Belt and Road Initiative are considered in this work, classified into Central Asia, Southeast Asia, South Asia, Mongolia & Russia, West Asia & Middle East, Central & Eastern Europe, and China (see Figure 1).

In this study, the multi-regional input-output table from the Eora database was applied. As the most detailed global-scale multi-regional input-output database, Eora covers the most countries and the longest time span, featuring 189 individual economies and a 26-sector harmonized classification (Lenzen et al., 2012, 2013). This database provides satellite accounts for energy use, carbon emissions and environmental pollution, which can be used to analyze embodied global carbon transfers and drivers of the Belt and Road regions. As for the economic and social data, the total and per capita GDP data came from the World Bank database (World Bank, 2015). For reference, the names of and abbreviations for the 65 countries and regions (including China) within the Belt and Road area are listed in Appendix Table A.1. The scope of the countries/regions within the Belt and Road area is identified according to the National Development and Reform Commission, Ministry of Foreign Affairs, and Ministry of Commerce of China (2015).

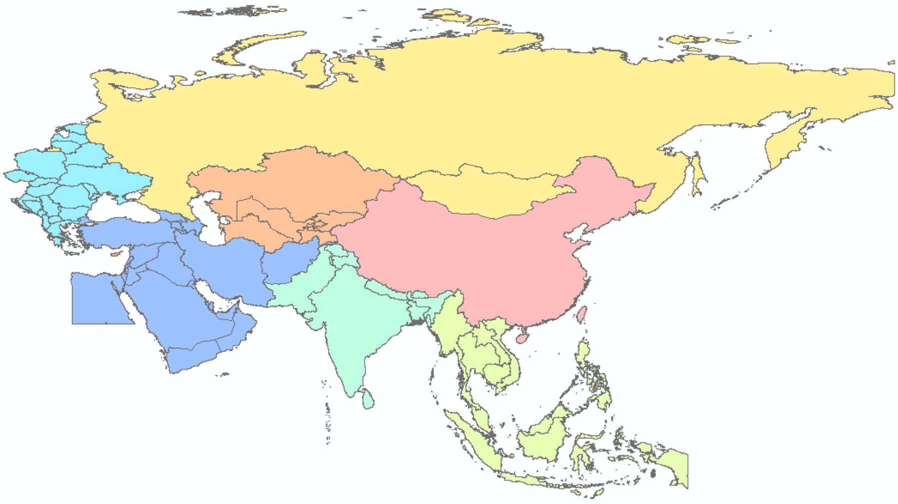


Figure 1 The research area of the Belt and Road regions.

3. Results

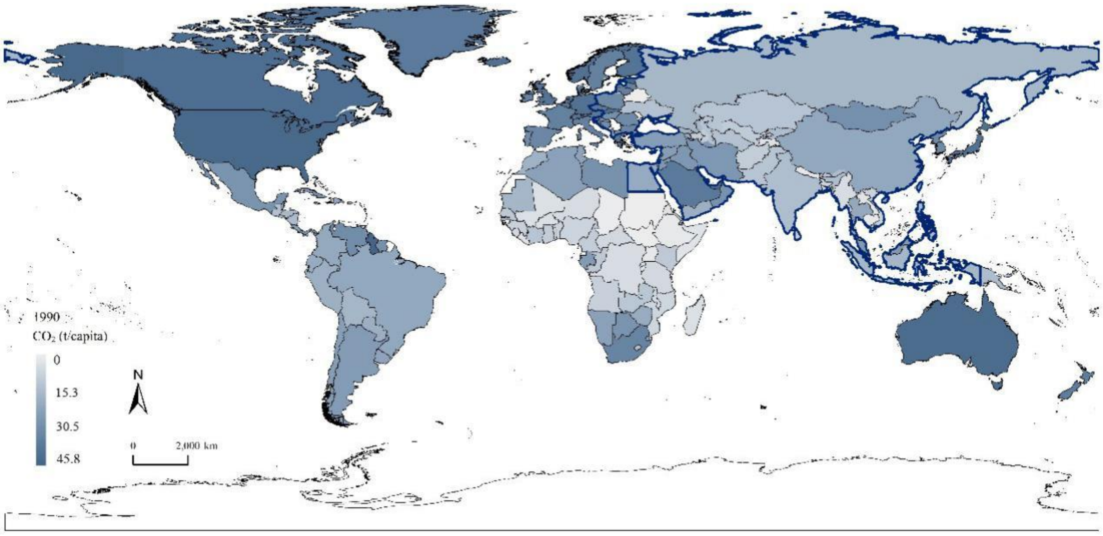
3.1 Carbon emission levels driven by final demand

Generally speaking, the carbon emission within a country could be measured not only from the direct perspective but also indirect perspective especially taking the final demand driven effects into consideration. Overall, the global average carbon emission level was between 3.3 and 4.4 t/capita from 1990 to 2015. However, the direct and indirect carbon emissions per capita for different countries varied, which are mainly influenced by the country's role in the globalized world. Here, the direct carbon emission per capita could be measured by the carbon emission emitted within a country's territory during production processes, while the carbon emission per capita to meet the country's final demand can be measured by carbon emissions embodied in global supply chains. The differences between the main countries and regions could be compared especially by comparing the relations between GDP and carbon emission per capita (Steinberger, et al., 2012), and a high similarity has been identified between the regional development and carbon emission levels from the final demand perspective (Han et al., 2018).

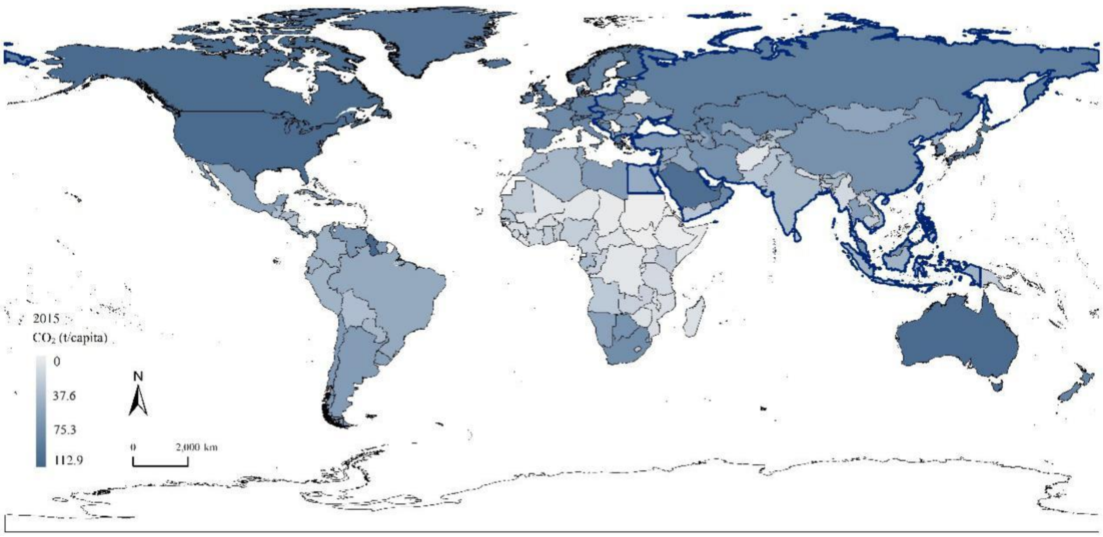
With the fact that many research has been conducted based on the direct carbon emission perspective, the comparisons of carbon emissions driven by final demand are conducted in this work. Specifically, the average carbon emission levels of the countries and regions within the Belt and Road area increased from 1.5 t/capita in 1990 to 3.6 t/capita in 2015. In contrast, the average carbon emission levels of regions and countries outside the Belt and Road area decreased from 6.6 t/capita in 1990 to 5.7 t/capita in 2015. Furthermore, the per capita carbon emissions of main developed countries and regions has demonstrated a steady even decreasing state, while the per capita carbon emissions of developing countries and regions within the Belt and Road area is relatively low when compared with the global average. It is noteworthy that the per capita carbon emissions of major countries and regions within the Belt and Road area revealed an increasing state. In terms of slowing down the climate change and releasing public concerns, it is an unwilling phenomenon to be seen.

Specifically, the per capita carbon emissions in regions such as North America, Western Europe, Oceania and East Asia were more than 10.00 t/capita in 1990 as presented in Figure 2. In particular, the carbon emission levels were 18.8 t/capita in the United States, 16.5 t/capita in Australia, 12.1 and 11.2 t/capita in Germany and the UK respectively, and 11.0 t/capita in Japan. Meanwhile, several minor countries and regions within the Belt and Road area possessed high per capita carbon emissions. Specifically, the carbon emission levels were 21.6 t/capita in Qatar, 21.5 t/capita in the UAE, 20.6 t/capita in Estonia, and 18.7 t/capita in Singapore.

In 2015, developed countries, including the United States, Germany, the United Kingdom, Australia, and Japan, maintained high levels of carbon emissions that were nearly unchanged since 1990 from the final demand perspective. Typically, the carbon emission levels of developed countries are steady and will maintain a high value in the short-term future. In contrast, the carbon emission levels of China, Mongolia, Russia and some countries in Central Asia and Central & Eastern Europe apparently increased compared with those in 1990. In particular, the carbon emission value increased from 1.9 t/capita to 5.9 t/capita in China, from 0.8 t/capita to 9.6 t/capita in Russia, from 0.5 t/capita to 9.7 t/capita in Kazakhstan, from 0.7 t/capita to 5.0 t/capita in Ukraine and from 1.6 t/capita to 4.0 t/capita in Thailand. Nevertheless, the carbon emission levels of the Belt and Road regions were still below 10 t/capita and were much lower than those in developed countries in 2015. It is inappropriate to condemn the rapid growth of carbon emissions in the Belt and Road regions without considering the constant high level of carbon emissions in developed countries.



(a) 1990



(b) 2015

Figure 2 Carbon emission levels per capita by region.

3.2 Carbon emission and regional development levels

For a better comparison, the world is divided into 15 regions, including seven regions within the Belt and Road area, i.e., Central Asia, Southeast Asia, South Asia, Mongolia & Russia, Western Asia & Middle East, Central & Eastern Europe and China, and the regions outside the Belt and Road area, i.e., North Africa, South Africa, Rest of Europe, Japan & Korea, Oceania, South America, Rest of North America, and the United States.

By analyzing the historical carbon emission levels, the carbon emissions of the countries and regions within the Belt and Road area presented a similar, as well as an increasing trend of economic development as in Table 1. The per capita embodied carbon emissions of the regions within the Belt and Road area were below 10 t/capita，mostly around 6 t/capita. From 1990 to 2015, per capita carbon emission increased from 1.9 to 5.9 t/capita in China, from 0.4 to 4.4 t/capita in Central Asia, from 0.9 to 9.5 t/capita in Mongolia & Russia, from 1.0 to 2.2 t/capita in Southeast Asia, from 0.6 to 1.2 t/capita in South Asia, from 3.3 to 5.3 t/capita in West Asia & Middle East and from 4.5 to 6.1 t/capita in Central & Eastern Europe. Except for Central Asia and Mongolia & Russia, most of the economic development rates were higher than the increasing rates of the related carbon emission levels, with an average annual rate of approximately 3%.

During the same period, the per capita embodied carbon emissions of countries and regions outside the Belt and Road area decreased from 6.6 to 5.7 t/capita, with an apparent distinction with countries and regions within the Belt and Road area. Note that, there is also an obvious difference between the developed and developing countries outside the Belt and Road area. Among them, Japan & Korea, South America and North Africa show similar trends between economic development and carbon emission levels; however, the increasing rates are much lower than these countries within the Belt and Road area (approximately 1%). Details are presented in

Appendix Table A.2 and A.3 for reference.

Table 1 Economic development and carbon emission levels 1990-2015.

Region		GDP (US$ per capita)		EEP (t per capita)		△EEP/△GDP
		Range	Rate	Range	Rate	
1	B&R China	387~8,306	13.1%	1.9-6.0	4.7%	+/+
2	B&R C. Asia	972~4,371	6.2%	0.4-4.4	9.7%	+/+
3	B&R Mongolia & Russia	3,453~9,395	4.1%	0.9-9.5	10.0%	+/+
4	B&R SE. Asia	751~3,886	6.8%	1.0-2.2	3.3%	+/+
5	B&R S. Asia	355~1,545	6.1%	0.6-1.3	2.7%	+/+
6	B&R W. Asia & M. East	3,453~9,395	4.2%	3.3-5.7	1.9%	+/+
7	B&R C.& E. Europe	2,006~8,605	6.0%	4.5-6.1	1.2%	+/+
B&R Average		874~5,145	7.3%	1.5-3.7	3.7%	+/+
8	USA	23,956~56,404	3.5%	18.7-18.8	0.0%	-/+
9	R. N. America	5,490~12,953	3.5%	4.9-5.3	-0.3%	-/+
10	Japan & Korea	18,259~28,368	1.8%	9.3-10.1	0.3%	+/+
11	R. Europe	20,355~38,686	2.6%	9.1-9.7	-0.2%	-/+
12	S. America	2,678~9,328	5.1%	2.1-3.2	1.4%	+/+
13	N. Africa	2,102~3,667	2.2%	1.7-21.8	0.1%	+/+
14	S. Africa	602~1,499	3.7%	0.8-0.6	-0.8%	-/+
15	Oceania	13,934~40,896	4.4%	11.5-12.2	-0.2%	-/+
R. B&R Average		10,424~18,490	2.3%	5.7-6.6	-0.6%	-/+
World Average		4,295~10,134	3.5%	3.3-4.3	1.1%	+/+

Table 2 provides the decoupling status of carbon emissions and economic development within and outside the Belt and Road area. The decoupling statuses including strong decoupling, weak decoupling and expansion negative decoupling are identified based on the Tapio analysis. From 1990 to 2015, the decoupling relations between economic development and carbon emissions were weak for most countries along the Belt and Road except the Central Asia, Mongolia and Russia. In contrast, for countries outside the Belt and Road area, the carbon emissions basically showed a decoupling trend with economic development especially in the United States and some European countries, which has entered the period of low-carbon development. Even though South Africa also presents a strong decoupling status, it is highly related to the relatively lower industrialization and economic development levels.

Table 2 Decoupling between economic development and carbon emissions 1990-2015.

Region		$t_{C,G}$	Decoupling status
1	B&R China	0.11	Weak decoupling
2	B&R C. Asia	2.63	Expansion negative decoupling
3	B&R Mongolia & Russia	5.76	Expansion negative decoupling
4	B&R S. Asia	0.28	Weak decoupling
5	B&R SE. Asia	0.29	Weak decoupling
6	B&R W. Asia & M. East	0.33	Weak decoupling
7	B&R C.& E. Europe	0.11	Weak decoupling
8	USA	0.00	Strong decoupling
9	R. N. America	-0.05	Strong decoupling
10	Japan & Korea	0.16	Weak decoupling
11	R. Europe	-0.06	Strong decoupling
12	S. America	0.17	Weak decoupling
13	N. Africa	0.02	Weak decoupling
14	S. Africa	-0.13	Strong decoupling
15	Oceania	-0.03	Strong decoupling

Figure 3 further presents the relations between the economic growth and carbon emission levels in different countries and regions. Specifically, the economic development levels in the United States, Australia, European countries, Japan and South Korea are relatively high, and the capita carbon emissions in these developed countries showed a decreasing trend after reaching a peak. These countries had achieved the infrastructure construction and intense industrialization in the early stage, after which they were able to slash the carbon-intensive investment and present a decreasing trend of carbon emissions. Correspondingly, the countries and regions within the Belt and Road area are mainly in the lower left center, demonstrating the position of relatively low development and emission levels with enormous gaps with developed countries. For most of these countries, the construction of infrastructure such as plants and railways may increase the economic growth; however the relatively lower levels of purchasing and consuming abilities in these regions did not show significant impacts on the total carbon emissions.

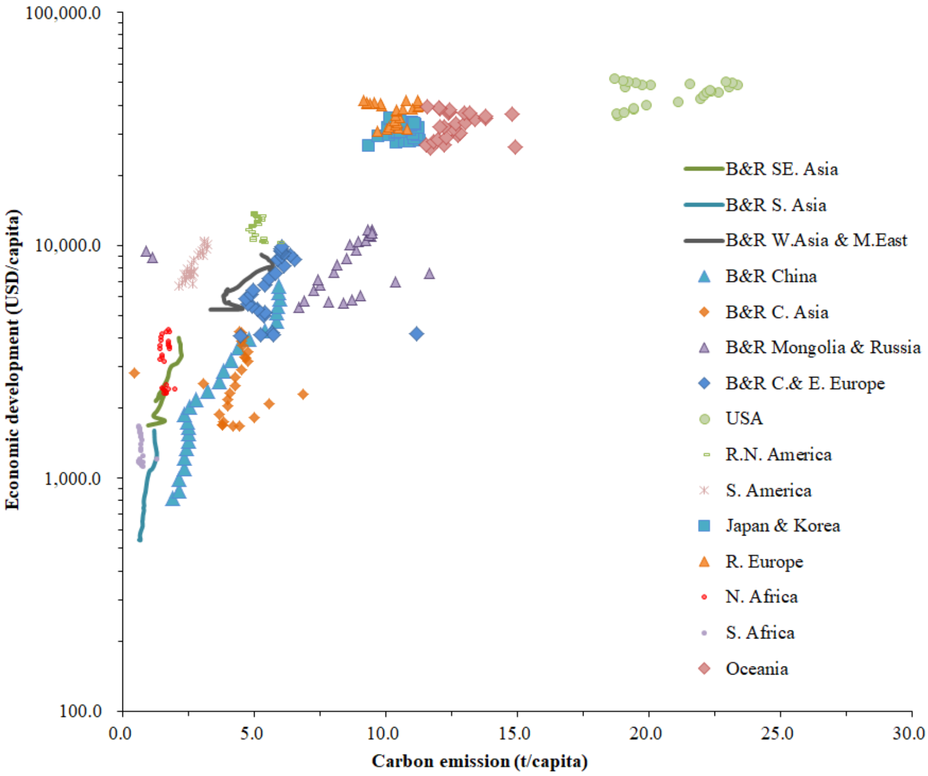


Figure 3 Economic development and carbon emission levels in the Belt and Road regions.

3.3 Consumption- and investment-driven carbon emission trends

From 1990 to 2015, the consumption-driven carbon emissions of countries and regions within the Belt and Road area accounted for a large proportion, approximately 70%. As for the changing trends, the consumption-driven proportions presented significant decreasing trends, while the investment-driven carbon emission levels increased significantly by contrast. Correspondingly, the consumption-driven carbon emissions of countries and regions outside the Belt and Road area maintained an essential proportion, approximately 70%, and investment-driven carbon emissions continued to maintain a small proportion.

Table 3 presents the inequality levels related to carbon emissions between 1990 and 2015. From 1990 to 2015, there are obvious decreasing trends for the carbon emission inequality from the global perspective, and the inequality index of carbon emissions decreased from 0.33 in 1990 to 0.22 in 2015, with a decline rate of 33.10%. As for the Belt and Road regions, the carbon emission inequality showed different trends when compared with economic development changing, even though the carbon emission inequality within the Belt and Road area narrowed from 0.19 to 0.06. By separating the consumption and investment- driven emissions, the consumption-driven carbon emission inequality decreased much faster than the investment-driven emission worldwide with a rate of 31.85%, while the consumption- and investment-driven emission inequality almost reached a same level near 0.20 in the global scale. As for the Belt and Road regions, the inequality increases from 0.20 to 0.38 when only taking the investment-driven carbon emissions into consideration, even though the consumption-driven emission inequality showed a decreasing level from 0.17 to 0.12. With the relatively same development levels for most countries, the Belt and Road regions show a possibility to decrease the carbon emission inequality; however when compared with the global average level, there is still a big gap in investment-driven emissions between countries and regions.

Table 3 Consumption- and investment-driven carbon emissions inequality 1990-2015.

Index	1990	2015	Variation ratio	Index	1990	2015	Variation ratio
B&R				Worldwide			
T_C	0.19	0.06	-69.97%	T_C	0.33	0.22	-33.10%
$T_C, consumption$	0.17	0.12	-28.12%	$T_C, consumption$	0.36	0.24	-31.85%
$T_C, investment$	0.20	0.38	84.37%	$T_C, investment$	0.26	0.22	-17.67%

Table 4 further presents the consumption- and investment-driven carbon emission levels in separate regions, considering the change ranges of less than 2% as a normal floating. Details are presented in Appendix Table A.4 for reference. The proportion of consumption-driven carbon emissions in Central Asia and China decreased significantly from 1990 to 2015. This result is mainly influenced by the declining trends of Kazakhstan and Uzbekistan (from 98.3% to 67.0% and from 79.3% to 68.3% respectively). For China, the proportion of consumption-driven carbon emissions changed from 61.1% to 48.9%, which is different from most of the other countries. Meanwhile, some countries presented an increasing trend of consumption-driven carbon emissions, such as the emissions in Mongolia and Russia rising slightly from 73.3% to 76.2%.

Except for Central Asia and China, the consumption-driven carbon emissions in Belt and Road regions still accounted for a large proportion of consumption-driven carbon emissions, which did not change significantly during this period. The consumption-driven carbon emissions in Central & Eastern Europe, South Asia, Southeast Asia and the Middle East maintained at approximately 78.8%, 66.3%, 68.9% and 75.3%, respectively. Specifically, the shares of consumption-driven carbon emissions in some countries such as Kazakhstan, Latvia, Uzbekistan, and China within the Belt and Road area presented evident declines, accompanied by a corresponding rise in investment-driven carbon emissions.

In contrast, the share of consumption-driven carbon emissions in Japan & Korea increased from 68.8% in 1990 to 75.3% in 2015, among which Japan's contribution was the most significant, rising from 68.6% to 77.9%. Notably, South Africa had the highest share of consumption-driven carbon emissions in the world, maintaining at approximately 82% over this period. Meanwhile, the share of consumption-driven carbon emissions outside the Belt and Road area in North Africa, North America, Oceania, Rest of Europe, South Africa, and South America were approximately 72.1%, 76.3%, 72.7%, 77.0%, 81.9% and 77.4%, respectively. Although the share of consumption-driven carbon emissions in the United States has fallen, the emissions in this country still accounted for approximately 77.5%.

Table 4 Consumption- and investment-driven carbon emission levels 1990-2015.

Region		Consumption		Investment		Carbon emissions (Mt)	
		Range (%)	Trend	Range (%)	Trend	1990	2015
1	B&R China	[48.9, 61.1]	↘	[38.9, 51.1]	↗	2137.9	8174.5
2	B&R C. Asia	[69.7, 87.6]	↘	[12.4, 30.3]	↗	21.8	305.0
3	B&R Mongolia & Russia	[73.3, 76.2]	↗	[23.8, 26.7]	↘	130.9	1395.8
4	B&R SE. Asia	[68.9, 70.9]	→	[29.1, 31.1]	→	418.2	1335.7
5	B&R S. Asia	[66.3, 66.4]	→	[33.7, 33.7]	→	686.2	2065.5
6	B&R W. Asia & M. East	[75.3, 76.2]	→	[23.8, 24.7]	→	867.4	2261.0
7	B&R C.& E. Europe	[78.7, 79.9]	→	[20.1, 21.3]	→	873.6	1083.0

B&R Average		[60.9, 68.8]	↘	[31.2, 39.1]	↗	5,136.1	16,620.3
8	USA	[77.5, 81.1]	↗	[18.9, 22.6]	↘	4699.0	6002.6
9	R. N. America	[75.1, 76.3]	→	[23.7, 24.9]	→	902.2	1199.7
10	Japan & Korea	[68.8, 75.2]	↗	[24.8, 31.2]	↘	1738.4	2060.7
11	R. Europe	[77.0, 77.6]	→	[22.4, 23.0]	→	3654.0	3827.5
12	S. America	[77.4, 77.4]	→	[22.6, 22.6]	→	632.6	1267.7
13	N. Africa	[72.1, 73.1]	→	[26.9, 27.9]	→	108.2	160.0
14	S. Africa	[81.9, 82.8]	→	[17.3, 18.1]	→	395.2	627.9
15	Oceania	[72.7, 73.9]	→	[26.1, 27.3]	→	319.1	442.4
R. B&R Average		[76.9, 77.5]	→	[22.7, 23.1]	→	12,448.5	15,588.5
World Average		[68.6, 75.0]	↘	[25.0, 31.4]	↗	17,584.6	32,208.9

4. Discussion and policy implications

Given the aim of maintaining global warming below 2°C, carbon emission reduction has become a global top priority. Since the Belt and Road Initiative has increasing influence on manufacturing-oriented developing countries, more attention was being paid to carbon emission reduction in these regions. Based on the growth rate of gross domestic product and carbon emissions per capita from 1990 to 2015, the regional differences in carbon inequality along with economic development during this period could be analyzed.

Note that the per capita carbon emissions to meet the final demand of the countries within the Belt and Road regions are much lower than those of the global average, while the increasing rate is relatively high compared with that of the countries outside these regions. Overall, the carbon emissions per capita across the Belt and Road region increased from 1.5 to 3.7 t/capita, among which the corresponding investment-driven carbon emissions increased remarkably. In contrast, the developed countries outside the Belt and Road area maintained their economic growth while decreasing the carbon emissions owed to the declining of investment-driven emissions. When compared, the carbon emission inequality within the Belt and Road area narrowed from 0.19 to 0.06, but the inequality related to investment-driven carbon emissions increases from 0.20 to 0.38. With the relatively same development levels for most countries, the Belt and Road regions show a possibility to decrease the carbon emission inequality in the global scale. When compared with global average however, there is a big gap in investment-driven emissions between countries and regions.

From the regional development perspective, the world's GDP changed from 4,295.5 US$ per capita to 10,134.3 US$ per capita, with an average growth rate of 3.5%. When compared, the overall per capita GDP growth rate in the countries within the Belt and Road area is higher than the global average growth rate. Similarly, China's GDP growth rate is significantly higher than that of other regions in the world, with a per capita growth rate of 13.1%. In addition, Central & Eastern Europe, Central Asia, South Asia and Southeast Asia also have higher per capita GDP growth rates than the global average, with percentages of 6.0%, 6.2%, 6.1% and 6.8% respectively even though the share of GDP in these regions only accounts for around 2.0% and 4.0% in the world.

Regarding most countries and regions within the Belt and Road area, consumption- and investment-driven carbon emissions showed increasing trends. Regarding the regional of carbon emission shares, the main exception was Central & Eastern Europe, whose shares decreased from 5.0% to 3.4%. Separately, the consumption-driven carbon emissions showed a relatively rapid declining rate, from

5.3% to 3.4%, compared with investment-driven carbon emissions, which dropped from 3.9% to 2.3%. Although Central Asia and Mongolia & Russia accounted for only less than 1% of the world's total carbon emissions in 1990, these two regions showed the highest growth rate in carbon emissions worldwide, with the emissions increasing from 0.1% to 1.0% and from 0.7% to 4.3%, respectively. In particular, Central Asia, whose investment-driven carbon emissions growth rate increased rapidly, is the most significant region within the Belt and Road area.

Meanwhile, the situation outside the Belt and Road area is quite different. With the exception of a slight increase in total carbon emissions in South America from 3.6% to 3.9%, the share of total carbon emissions declined in all the other regions. It is worth noting that the share of investment-driven carbon emissions in all the regions outside the Belt and Road area declined to varying degrees. The investment-driven carbon emissions of most European countries and Japan & Korea fell, from 18.6% to 8.7% and from 12.3% to 5.1%, respectively. Outside the Belt and Road area, consumption-driven carbon emissions also declined, with the only increase of 0.7% in the United States. Note that the regions outside the Belt and Road area presented three different development situations: the GDP per capita growth rate in the United States is maintained at the global average of 3.5%, while for other developed countries, the GDP per capita growth rate is almost the lowest in the world, generally from 1.8% to 4.4%. For the developing countries outside the Belt and Road area, there is still a GDP per capita growth rate that is higher than the global average (from 4.1% to 13.1%), but the developing countries outside the Belt and Road area are developing at a relatively slower pace than those within the Belt and Road area.

In consideration of the carbon emissions and the economic development, the carbon inequality between the countries within the Belt and Road area is highly linked to the economic development. Besides, the carbon emissions driven by consumption and investment have shown different trends of inequality especially when compared with the global average. From 1990 to 2015, the relations between carbon inequality and regional development could be further divided into three types:

(1) The per capita GDP of the regions within the Belt and Road area increased sharply, also showing a correlation with the carbon emissions of these regions. By strengthening interregional economic and trade cooperation through the Belt and Road Initiative, the processes of industrialization and modernization increased, strengthening infrastructure investment and energy cooperation among these regions. However, it may also lead to challenges posed by higher resource consumption and carbon emissions.

(2) Among the developed countries outside the Belt and Road area, these regions, especially the United States, shared the highest level of per capita GDP in the world. Due to the high industrialization in the earlier period, the per capita GDP growth rate in these countries was not as high as it was in some developing countries, and the growth rate of carbon emissions per capita, especially investment-driven carbon emissions, in these countries was not as high as it was in most developing countries. With their advanced technology and high level of industrialization, developed countries achieved low carbon emissions while maintaining a high per capita GDP.

(3) The economic development levels per capita and the growth rates of developing countries outside the Belt and Road area, such as some countries in South America and Africa, are not relatively high, nor do the carbon emissions of these regions. Overall, most of these developing countries are mainly based on agriculture and the labor-intensive mode of production, and their relatively low level of industrialization leads to lower development levels to some extent.

According to the Intended Nationally Determined Contributions, more than three-quarters of the countries within the Belt and Road area proposed emission reduction targets and committed to climate change mitigation and adaptation (UNFCCC, 2015). Among these countries, Bangladesh, Afghanistan, Sri Lanka, Cambodia, Malaysia, the Maldives and Iran all set conditional targets for voluntary emission reductions. At the early stage of the development stage, for most developing countries, it is hard to maintain a high level of per capita GDP while emitting a low level of carbon emissions. Thus, the key point is to achieve quantitative emission reduction targets with the international support of financial resources, technology transfers and capacity building. By discussing the carbon inequality and regional development among different areas, possible strategies for climate change mitigation and sustainable regional development under the Belt and Road Initiative are suggested and presented in Table 5.

Table 5 Carbon emission and economic development patterns, characteristics and policy implications.

Pattern		Characters	Policy implications
1	China, C. Asia, SE. Asia, S. Asia, W. Asia & M.	High growth rate of GDP per capita; High growth rate of carbon emissions per capita	Improving energy utilization efficiency, promoting the application of energy saving technology in production and infrastructure construction,

	East, Mongolia & Russia, C.&E. Europe		encouraging the application of renewable energy and CCS/CCUS technologies
2	USA, R.N. America, R. Europe, Japan & Korea, Oceania	High level of GDP per capita with medium growth rate in the world; High level of carbon emissions per capita especially the consumption-driven type in the world; Low growth rate of total carbon missions per capita and investment-driven carbon emissions per capita	Promoting low carbon consumption patterns from the public awareness, encouraging the application and utilization of distributed renewable energy
3	N. Africa, S. Africa, S. America	Low level of GDP per capita with low level of growth rate; Low level of carbon emissions per capita with low level of growth rate	Improving the level of manufacturing industry, enhancing cooperation and investment with developed countries

Under the potential development trends, the countries within the Belt and Road area have achieved a high speed of economic development, which is also accompanied by potential energy consumption and carbon emissions. In consideration of the different changing trends of consumption- and investment-driven carbon emissions, the countries involved in the Belt and Road Initiative represent enormous potential. Under the possible strategies of energy cooperation and infrastructure investment, the possible transfers of funds and technologies are necessary to improve energy efficiency, speed up the processes of modernization with relatively lower carbon emissions, and narrow the carbon inequality between developed and developing countries.

Given that carbon emissions will continue to increase in the countries and regions within the Belt and Road area, there are several feasible methods: (1) from the production perspective, encouraging renewable resources and promoting possible advanced technologies such as CCS/CCUS are essential. To control investment-driven carbon emissions, advanced infrastructure techniques and low carbon control construction are necessary to improve the utilization efficiency of resource consumption and environmental emissions. (2) For consumption-driven carbon emissions, to maintain a low level, the key point is to promote the low carbon consumption pattern and to promote transfers of low carbon technologies and funds, especially from developed countries. (3) Regarding global supply chains, the energy internet, renewable energy development, and climate governance platforms represent enormous potentials for further reducing carbon emissions, which could be practical strategies that the further development of the Belt and Road Initiative can focus on.

In the short-term future, the carbon emissions of developing countries may continue to increase due to transportation- and energy-related infrastructure, but in the following period the Belt and Road Initiative still has enormous potential to promote the green silk road development, encourage industrial innovation, and improve the level of industrialization, which is expected to finally achieve a high level of regional development with a low level of resource consumption and carbon emissions. From this perspective, the Belt and Road Initiative proposed in 2013 could be a proactive advocate and practitioner of international cooperation on climate change to promote South-South cooperation in climate change and to support developing countries by providing feasible technologies and carrying out targeted capacity building cooperation in areas such as policy, management, technology and public awareness with existing environmental cooperation mechanisms.

5. Concluding remarks

By comparing the economic growth and carbon emissions in developed and developing countries under the Belt and Road Initiative proposed in 2013, this work comprehensively measures the carbon emission levels driven by final demand, analyzes the correlations between the growth rate of economic development and carbon emissions in the regions within the Belt and Road area since 1990 and compares with the countries outside this area in the same historical period. By identifying the carbon emissions driven by different activities, including consumption and investment, the carbon inequality and economic development can be discussed, and some related policy implications are proposed in this work for green and sustainable development in related regions and for global climate mitigation worldwide.

In general, the Belt and Road Initiative accelerates carbon emissions to support the relevant economic development in countries and regions within the Belt and Road area, while the majority of these countries achieved a significant GDP growth rate. Based on comparisons with countries and regions outside the Belt and Road area, the rapid growth in investment-driven carbon emissions associated with infrastructure construction is one of the key points with regard to the related carbon emissions. In contrast, developed countries outside the Belt and Road area maintained the economic growth while simultaneously decreasing their carbon emissions due to the relatively low investment costs and the early stage of industrialization.

Based on the classification by development type in the countries within and outside the Belt and Road area, it is necessary to slow down carbon emissions while maintaining high economic growth with possible policies and strategies. From the production perspective, the investment-driven energy consumption and carbon emissions can be optimized by promoting the utilization of renewable energy and CCS/CCUS technologies, especially in newly built plants and projects. In addition, for consumption-driven carbon emissions, it is crucial to pay attention to technological and financial transfers to achieve high-tech industrialization and to promote the low carbon consumption model by increasing public awareness. Regarding global supply chains, the energy internet, South-South cooperation, and climate governance platforms between countries and regions can promote transfers of advanced technologies and funds and simultaneously improve energy efficiency and decrease carbon emissions worldwide.

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