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Applied Energy 280 (2020) 115934

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Imbalance and drivers of carbon emissions embodied in trade along the Belt and Road Initiative

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HIGHLIGHTS

- Region contributed to 50% of global CO_2 emissions and 92% of increase in 1995–2015.
- Region was a net exporter of trade-embodied emissions despite high carbon intensity.
- Carbon leakage has gradually moved from China and India to other developing nations.
- The nations had diverse trends of carbon footprint due to technological differences.
- The drivers of changes in regional CO_2 emissions varied across nations and over time.

ARTICLE INFO

Keywords:
Carbon footprint
Technological difference
Carbon leakage
Multi-regional input–output (MRIO) analysis
Structural decomposition analysis (SDA)
Belt and Road Initiative (BRI)

ABSTRACT

A continuous growth of international trade, especially between developing countries, has greatly increased carbon dioxide (CO_2) emissions associated with energy consumption over the past two decades. Given the more intensified intraregional cooperation and trade within the Belt and Road Initiative (BRI), this study aims to trace the imbalance of CO_2 embodied in trade between nations in BRI and the rest of the world, providing new insights into the drivers of emissions growth by contrasting consumption, production and technological differences-based perspectives. Results indicate that the BRI contributed to over 50% of global carbon footprint and 92% of its increase in 1995–2015. The BRI was a net exporter of trade-embodied emissions, whose technological-adjusted carbon footprint remained remarkably large due to comparatively high carbon intensity. Geographically, carbon leakage has gradually moved from China and India to other BRI countries, especially to Southeast Asia, West Asia and Africa. Technological change was the key driver of emissions reduction, followed by the change in industrial structure. The growth in final demand per capita was the most important driver for the growth of CO_2 emissions in BRI. Improving carbon efficiency remains a critical step for BRI nations to slow down not only emissions growth but also carbon leakage. The paper managed to provide novel insights into the carbon leakage in BRI by contrasting the consumption, production and technological differences-based perspectives, thus being able to better inform policymakers on region-specific low-carbon transition and global climate governance.

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https://doi.org/10.1016/j.apenergy.2020.115934
Received 5 May 2020; Received in revised form 14 September 2020; Accepted 24 September 2020
Available online 14 October 2020

1. Introduction

The world has undergone unprecedented environmental change as a result of increasing international trade with profound implications for sustainable development [1,2]. Numerous studies have been conducted to measure the environmental footprint of international trade [3,4], with particular emphasis on carbon dioxide (CO_2) emissions regarding energy consumptions [5,6,7]. Prior research shows strong evidence of shifting CO_2 emissions from developed to developing nations through international trade (also referred to as 'carbon leakage', defined as an increase of CO_2 emissions in one country/region as a result of an emissions reduction by another country/region with a strict climate policy) [8,9], allowing some developed nations to maintain a relatively small magnitude of territorial emissions [5].

Most existing studies so far have focused on the attribution of worldwide carbon leakage to trade between developing and developed countries, and only few focused exclusively on the CO_2 emissions associated with the variation in trade between developing countries. For instance, Meng et al. [10] reported that the South–South trade was more than doubled between 2004 and 2011 and accounted for 46% of the increase in global CO_2 emissions. Han et al. [11] tracked the transfer of CO_2 emissions embodied in trade between the Belt and Road initiative (BRI) nations and others for the year of 2012, asserting that more than 95% of world's net embodied carbon exports came from BRI. This rapid growth reflects a new phase of globalization and might reshape the map of global carbon footprint. Here we made use of carbon footprint as a measure of CO_2 emissions, like most of other studies [12]. Nevertheless, the aforementioned research made use of a conventional multi-regional input − output (MRIO) approach which does not take into account the technological differences between nations in the production processes of traded goods.

The MRIO approach has been recognized as the most popular tool to perform a consumption-based accounting (CBA), aiming at determining national responsibility for climate change and evaluating the performance of mitigation policies [13]. Together with the production-based accounting (PBA), these two inventories (i.e., CBA and PBA) show different pictures of CO_2 emissions along the global supply chains by taking imports and exports into account, respectively [14,15]. Despite the wide application of both PBA and CBA, it has moved into a critical reflection of their methodologies, with a critique that national emissions accounting should reflect not only the total amount of carbon footprint in each single economy, but also the contribution to global emissions reduction [16]. Namely, the CBA and PBA only consider the CO_2 emissions associated with consumption or production, neglecting the comparative advantage of technology advances for responsibility allocation. If a country has more advanced production technologies than its trading partners, it brings a higher comparative advantage than the trading partners for equal value production. As a result, this country still contributes to global emissions reduction by exporting more products via international trade, and should not be criticized for its higher national emissions [17]. To precisely depict the national responsibility for emissions transferred by trade, it makes sense to take into account the differences of carbon intensities (equal to dividing the total carbon emissions by total industrial output) in the same sectors between importing and exporting nations in addition to CBA. Technology-adjusted consumption-based accounting (TCBA) has been proved to be effective in capturing the differences between the carbon intensities of different economies, but has not been applied widely in empirical studies for more validation [16].

Previous studies showed that developed economies (e.g., EU27 and USA) generally have much lower emissions based on PBA than on CBA due to their outsourcing emissions to less developed countries/regions. Conversely, developing countries (e.g., China and Brazil) produce and export a large number of goods to developed countries, leaving environmental damage and loss of biodiversity within their own borders [13]. Although the trends of TCBA in the USA and EU27 remained similar, only the latter had improved its domestic carbon intensity at a rate faster than the world average [16]. This approach has also been successfully applied to discussion on the trade between Sweden and the UK, where the estimate of carbon leakage under the TCBA approach was found less serious than the one based on conventional CBA for the period 1995–2009 [17]. With respect to developing countries, their carbon intensities were found to be more diverse due to huge technological differences, even though in general they were net carbon exporters [16].

The BRI was proposed by the Chinese government as an effort to support international trade and to provide collective investment funds for infrastructure development among developing nations in 2013 [18]. It spans more than 60 countries, covering 64% of the global population with 30% of global GDP [19]. In the past decades, the bilateral trade flows between these BRI countries experienced an increasing tendency [20], accounting for more than 25% of global trade [21]. Thus, tracing the CO_2 emissions of BRI nations can be of global significance. Despite the growing interest and discussions on the multiple socio-economic benefits, the BRI has led to a concern about carbon leakage which potentially drives up the regional and global emissions [22,23]. For instance, it has been argued that China may reallocate its domestic pollution and overcapacity through the BRI [24] and is playing the leading role in driving carbon footprints within this area [25]. The carbon inequality and economic development of the countries within and outside BRI were compared as well, but without investigating the driving forces for emission growth and the impact of technological differences on responsibility allocation among those nations [26].

In contrast to the growing cooperation and trade within BRI, the impact of trade and technological differences between BRI countries on their CO_2 emissions remains poorly understood. To fill in the research gaps, this paper attempted to make novel contributions by: (1) presenting a comprehensive spatio-temporal analysis of CO_2 emissions embodied in trade of nations within and beyond BRI; (2) contrasting PBA and CBA schemes, but also employing a revised MRIO analysis to account for technological-adjusted carbon footprint that adjusts for the difference in carbon efficiency (the inverse of carbon intensity) in exports; (3) identifying various drivers for the changes in BRI's carbon footprint to explicate the impacts of carbon leakage among nations over time; and (4) proposing policy recommendations for potential solutions to easing the carbon imbalance of international trade in BRI.

2. Materials and methods

2.1. Study area and data sources

The BRI covers a large number of countries in Asia, Europe and Africa, most of which are developing nations. While there is no consensus on the exact number of BRI members, this paper selected 62 countries as per the general definition of BRI and data availability [24,27], and divided them roughly into six geographical regions, including Central Asia, CMR (China, Mongolia and Russia), Europe, South Asia, Southeast Asia, and West Asia & Africa (the full list was presented in Supplementary Information S1).

A times series of monetary MRIO tables with a temporal coverage (1995–2015) were collected from Eora database (http://www.worldmrio.com/countrywise/), where the global economy is presented as 189 economies, split into 26-sector and 6-final-demand categories with matching environmental and social satellite accounts. We chose the Eora database because of its relatively high resolution of economies, wide coverage of countries in BRI, and up-to-date data (up to 2015) [28]. Eora26 was adopted for the consistency of sectoral classifications among all nations. We put together other nations or regions outside BRI as the rest of the world (RoW), as the aim of this paper is to measure the imbalance of CO_2 emissions embodied in trade between nations in BRI and RoW, with the belief that attempts to disaggregate the latter represent an unnecessary distraction. The data on total CO_2 emissions generated from energy consumptions in Eora satellite accounts were collected from EDGAR to keep consistent with other studies to measure the carbon footprint of nations [9]. Population data were derived from the World Bank's Public Database.

2.2. Consumption-based & production-based accounting

MRIO approach is frequently used to link the production emissions to consumption activities through domestic and international supply chains [15,29]. The approach was originally developed by Leontief in the 1930s [30], using the basic monetary balance shown as:

$$X = (I - A)^{-1} Y = LY \tag{1}$$

where X is a vector of total output, A is a technical coefficients matrix, and Y is a final demand vector. $(I - A)^{-1}$ is known as the Leontief inverse or the complete demand coefficient matrix, whose elements capture direct and indirect effects from a unit change in the final demand.

The basic model has been extended in two directions: by the subdivision of the economy in a number of regions/countries (hereafter regions) that are connected by trade, and by the addition of supplementary environmental accounts, for instance for CO_2 emissions.

In a MRIO framework, regions set-up can be implemented with vectors and matrices in block structure. For instance, matrix A is composited as:

$$A = \begin{bmatrix} A_{11} & A_{12} & \cdots \\ A_{21} & A_{22} & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix}$$

where A_{21} is the inputs from region 2 to region 1. The final demand vector y then becomes a matrix Y:

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots \\ y_{21} & y_{22} & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix}$$

Here y_{21} is the demand by region 1 for product produced in region 2.

The environmental extension is made by adding a matrix of environmental coefficients E. Note that, in our case, there is only one substance (CO_2) in each of the matrixes E_1, E_2, etc.

$$E = \begin{bmatrix} E_1 & 0 & 0 \\ 0 & E_2 & 0 \\ 0 & 0 & \cdots \end{bmatrix}$$

For instance, E_1 contains the per-sector intensities of CO_2 emissions for region 1, where the intensity means emissions divided by the industrial output of each sector in region 1.

The overall environmental multi-region set-up is:

$$F = ELY \tag{2}$$

Here, F is a matrix of emissions:

$$F = \begin{bmatrix} F_{11} & F_{12} & \cdots \\ F_{21} & F_{22} & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix}$$

For instance, F_{12} is a vector indicating the CO_2 emissions in region 1 that are attributed to the final demand in region 2.

We may clarify the computational structure further by mentioning the size of the different objects:

- there are p sectors;
- there are r regions;
- there are e environmental issues (note that $e = 1$ in case of a carbon footprint only).

Thus, we find that:

- matrix Y has $r \times p$ rows and r columns;
- matrix A has $r \times p$ rows and $r \times p$ columns;
- matrix E has e rows and $r \times p$ columns;
- matrix F has e rows and r columns.

By diagonalizing matrix E, we are able to keep track of the emissions per region. This is important for our study of emissions imbalance. In particular, the territorial emission under PBA, $F^{(PBA)}$, for region s, is calculated as [9,31]:

$$F^{(PBA)s} = \sum_{i=1}^{r} F_{si} \tag{3}$$

effectively adding up the emissions from production in region s to meet final demand in all regions ($i = 1, \cdots, r$). Likewise, the emissions based on CBA associated with region s, $F^{(CBA)s}$, is:

$$F^{(CBA)s} = \sum_{i=1}^{r} F_{is} \tag{4}$$

The balance of emissions embodied in trade (BEET), for region s, is therefore:

$$F^{(BEET)s} = F^{(PBA)s} - F^{(CBA)s} = \sum_{i=1}^{r} (F_{si} - F_{is}) \tag{5}$$

This balance can also be regarded as the result of comparing emissions through import to region s ($F^{(IM)s}$) and export from region s ($F^{(EX)s}$):

$$F^{(BEET)s} = F^{(EX)s} - F^{(IM)s} = \sum_{\substack{i=1 \\ i \neq s}}^{r} F_{si} - \sum_{\substack{i=1 \\ i \neq s}}^{r} F_{is} \tag{6}$$

The two expressions are logically equivalent because:

$$\sum_{\substack{i=1 \\ i \neq s}}^{r} F_{si} - \sum_{\substack{i=1 \\ i \neq s}}^{r} F_{is} = \left(\sum_{i=1}^{r} F_{si} - F_{ss} \right) - \left(\sum_{i=1}^{r} F_{is} - F_{ss} \right) = \sum_{i=1}^{r} (F_{si} - F_{is}) \tag{7}$$

2.3. Technology-adjusted consumption-based accounting

The purpose of using TCBA here is to better estimate how a country's exports affect global emissions, by replacing domestic carbon intensities with world market averages when calculating export-related emissions [32]. This will allow us to estimate how much emissions in average are saved or caused if the same product is produced using world-average technology represented by emission intensity. While following the general calculation principle of CBA, TCBA differs in the sense that it considers the technological differences between countries by subtracting export-related emissions based on the average carbon intensity for the relevant sector on the world market [33]. Thus, the world-average carbon intensity q_t for sector t under TCBA is given as [16]:

$$q_t = \frac{\sum_{i=1}^{r} F_i^t}{\sum_{i=1}^{r} X_i^t} \tag{8}$$

where F_i^t is the emissions of sector t in region i, and X_i^t is the output of sector t in region i. The emissions of region s under TCBA, which we will denote by $F^{(TCBA)s}$, can be expressed as follow:

$$F^{(TCBA)s} = F^{(CBA)s} + \sum_{\substack{i=1 \\ i \neq s}}^{r} F_{si} - F^{(TEX)s}$$

$$= F^{(CBA)s} + \sum_{\substack{i=1\\ i\neq s}}^{r} F_{si} - \sum_{\substack{i=1\\ i\neq s\\ t=1}}^{i=r,t=p} q_t X_{si}^t \quad (9)$$

where $F^{(TCBA)s}$ is the emissions of region *s* based on TCBA inventory, and $F^{(TEX)s}$ is adjusted emissions embodied in exports by multiplying export output of region *s* by the world-average intensity of each sector, shown as $\sum_{\substack{i=1\\ i\neq s\\ t=1}}^{i=r,t=p} q_t X_{si}^t$. In this case, the calculation will meet the requirements of sensitivity and additivity for national emissions accounting, which could refer to [16] for more details. Similar to Equation (6), $F^{(TBEET)s}$ is the technology-adjusted balance of emissions embodied in trade (TBEET) of region s, and therefore can be a good proxy for comparison with BEET by considering technological differences between national and global markets, following the formula:

$$F^{(TBEET)s} = F^{(TEX)s} - F^{(IM)s} \quad (10)$$

2.4. Structural decomposition analysis

To better understand how CO_2 emissions of BRI countries have changed over time, we employed a structural decomposition analysis (SDA) to identify the main drivers of emissions at the country and sector levels. While both SDA and index decomposition analysis (IDA) have proved effective in achieving that goal [5,34], the former makes more sense because it can distinguish a range of direct and indirect effects on industrial structure that the latter fails to capture [35].

Logarithmic Mean Divisia Index (LMDI) is recommended for implementing SDA due to its relatively simple computation, especially when the number of factors is large [36]. Thus, this study conducted the LMDI approach as an innovative way of SDA for measuring the drivers of emissions. Based on the Equation (2), the vector of final demand *Y* can be further divided into four drivers: *u* is commodity structure of final demand, representing the ratio of different final demands from sectors in total final demand, *b* is final demand structure of the economic system, *v* is final demand/capita (y/p), and *p* is population [36,37] (for details see Supplementary Information S2):

$$F = ELY = ELubvp \quad (11)$$

The central idea of SDA is to decompose the changes of its determinants resulting in a cumulative sum of contributions within a certain period of time [38]. Suppose that the total carbon footprint of production at time 0 and *t* is F^0 and F^t, respectively, the period is divided into four periods of time in this study (1995–2000, 2000–2005, 2005–2010 and 2010–2015). The variation in carbon footprint is decomposed into the following six factors:

$$\Delta F = F^t - F^0 = \Delta E + \Delta L + \Delta u + \Delta b + \Delta v + \Delta p \quad (12)$$

where ΔF is the change of CO_2 emissions, ΔE is the CO_2 intensity effect, ΔL is the Leontief structure effect, Δu is the effect of product structure of final demand, Δb is the final demand structure effect, Δv is the level of final demand per capita effect, and Δp is the population effect. Detailed calculations were shown in Supplementary Information S2.

3. Results

3.1. CO_2 emissions in BRI nations from 1995 to 2015

By tracing CO_2 emissions under PBA from 1995 to 2015 (Fig. 1), we observed that the emissions of BRI nations more than doubled during this period, especially those embodied in domestic uses and exports among BRI nations (marked with blue line) which increased from 7.85 Gt to 17.50 Gt. The CO_2 emissions embodied in the exports from BRI nations to RoW experienced a relatively stable rise (from 1.88 Gt to 3.31 Gt) across the whole period. In addition, Fig. 1 illustrates the CO_2 emissions of BRI nations and their contributions to global total emissions, where the proportion of emissions embodied in exports from BRI to RoW maintained at a relatively stable level (around 9%), while the proportion of emissions within BRI rose by 17% over the period, accounting for more than 50% of the global emissions.

We compared the emissions from 26 sectors of BRI nations in 2015 (Fig. 2). Large differences in emissions can be witnessed across a variety of sectors, in which the *Electricity, gas and water*, *Petroleum, chemical and non-metallic mineral products* as well as *Transport* sectors ranked the top three, both within BRI nations and in the exports to RoW. The CO_2 emissions from the sectors of *Electrical and machinery*, *Metal products*, *Construction*, *Food & beverages*, *Mining and quarrying*, *Agriculture* and *Transport equipment* ranged from 208 Mt CO_2 to 609 Mt CO_2 within BRI nations. For instance, the sector of *Mining and quarrying* had CO_2 emissions of 211 Mt CO_2 embodied in exports to RoW, and those of

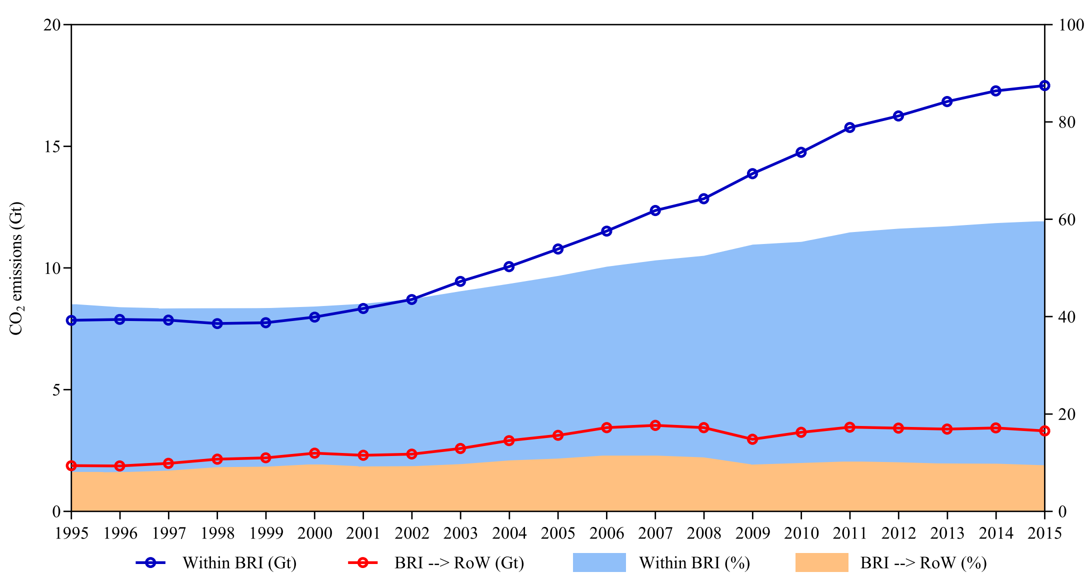

Fig. 1. CO_2 emissions within BRI nations and embodied in exports to RoW in 1995–2015. Within BRI means CO_2 emissions embodied in domestic uses and exports among BRI nations; BRI ->RoW means CO_2 emissions embodied in exports from BRI nations to the rest of the world.

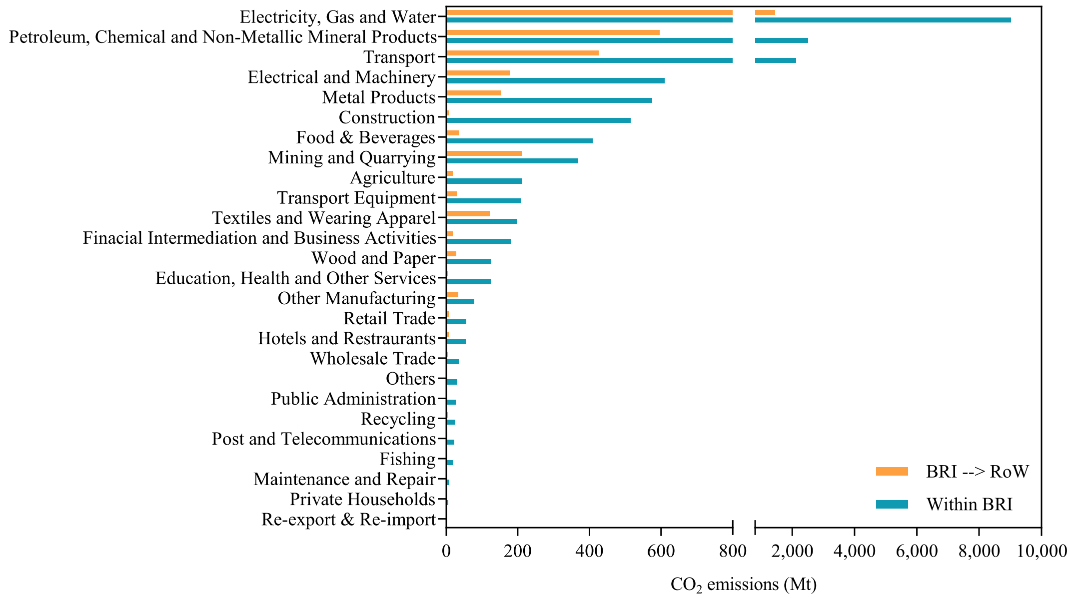

Fig. 2. CO_2 emissions of 26 sectors within BRI nations and embodied in exports to RoW in 2015.

Agriculture, *Construction*, and *Food & beverages* had relatively low emissions in exports to RoW.

3.2. Regional comparison of emissions under three inventories

The CO_2 emissions under PBA, CBA, and TCBA for BRI nations and RoW from 1995 to 2015 are discussed in a comparative analysis (Fig. 3). For the overall trend of BRI nations (Fig. 3a), all of the emissions under these three inventories soared during the study period. As the difference between PBA and CBA refers to the net emissions embodied in trade [39], we can see overall the BRI nations acted as a net exporter of emissions embodied in trade, with a value of net exports from 1.42 Gt in 1995 to 2.30 Gt in 2015. The carbon footprint of BRI nations with TCBA was always higher than that with CBA, and the gap continued to enlarge throughout the period.

In contrast, the RoW acted as a net importer of emissions embodied in trade (Fig. 3b), with small increases of carbon footprint under the three inventories between 1995 and 2007, and then fell to the bottom in 2009, with a slight rebound afterwards. Overall, the values under the three inventories remained stable across the period, showing that the results of CBA were the highest, those of PBA were the lowest, and those of the TCBA were medium.

We further investigated the BRI's CO_2 emissions by region (Fig. 4). Several trends can be observed. For CMR (Fig. 4a), the trend in emissions somehow coincided with the whole picture of BRI nations because of the inclusion of China that accounted for around half of the BRI's total emissions, although China's gap between CBA and TCBA was narrower than that of BRI. For South Asia (Fig. 4b) and West Asia & Africa (Fig. 4c), emissions increased rapidly since 1995 by implementing all the three inventories, but the trends seemed to be quite different. The

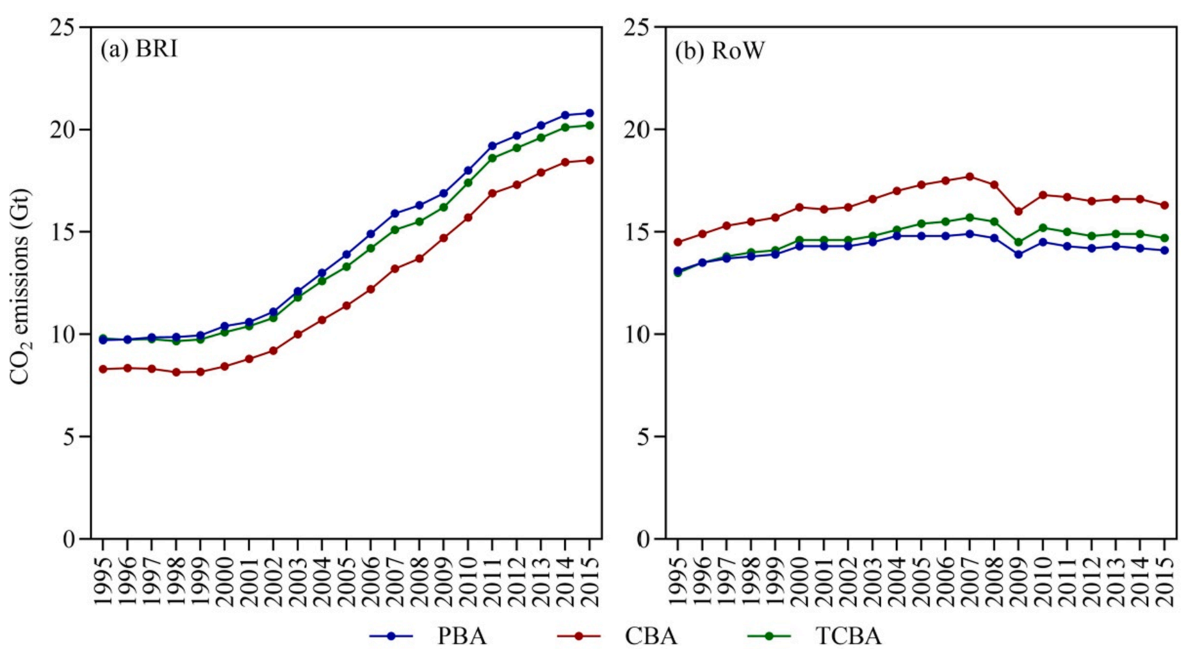

Fig. 3. CO_2 emissions of BRI nations and RoW under PBA, CBA and TCBA in 1995–2015.

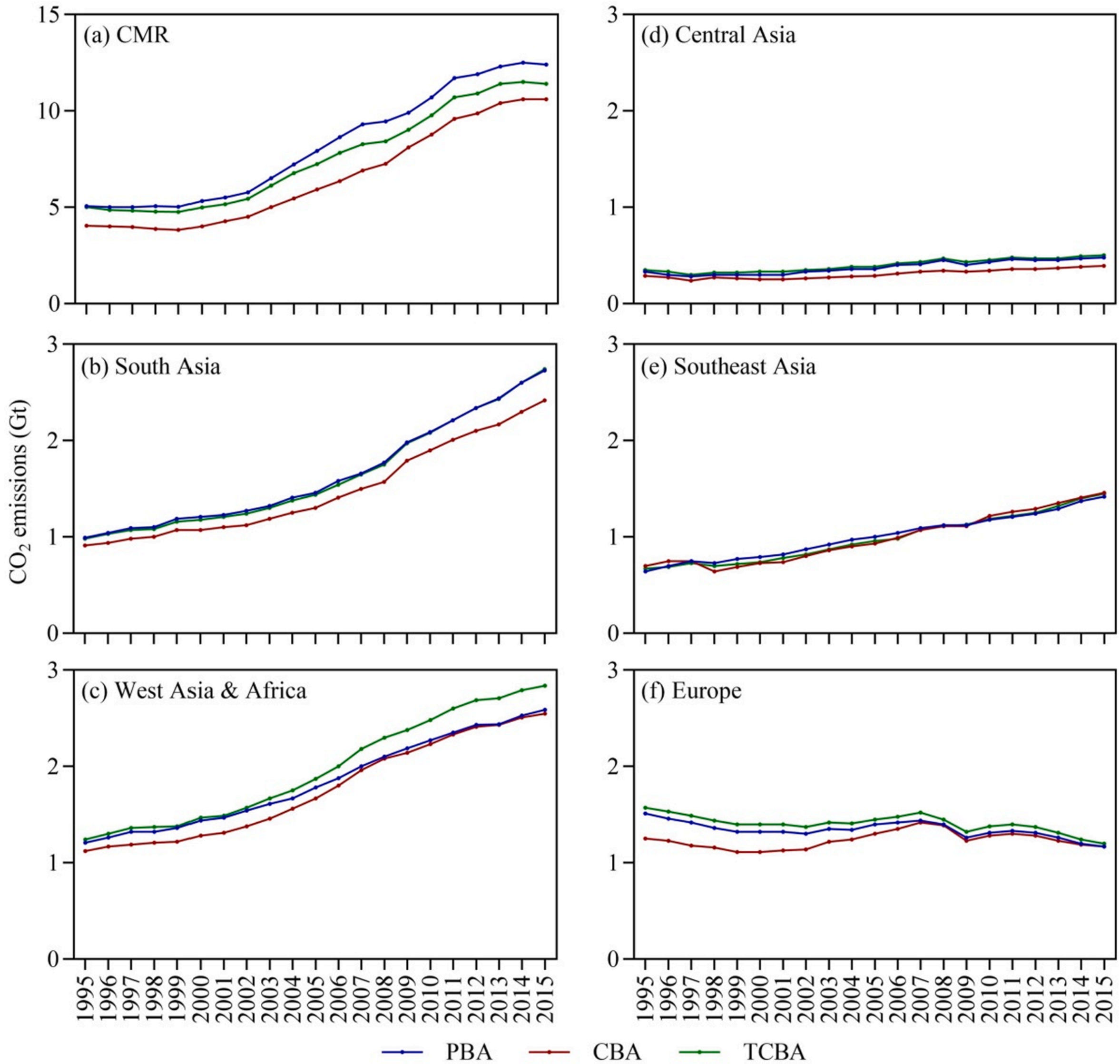

Fig. 4. CO_2 emissions of regions in BRI under PBA, CBA and TCBA in 1995–2015.

carbon footprint under TCBA in West Asia & Africa was substantially larger than that under PBA and CBA in the second half of the study period. When it comes to South Asia, the carbon footprints under PBA and TCBA were numerically close. The emissions of Central Asia (Fig. 4d) and Southeast Asia (Fig. 4e) showed similar values for the three inventories, where the carbon footprint under CBA in Southeast Asia was larger than that under PBA in the last five years. For European nations in BRI (Fig. 4f), the carbon footprint experienced a decreasing trend over the period, which was analogous to what can be observed in Fig. 3b, while the values of TCBA were larger than those of PBA, and those of CBA were the lowest.

3.3. Spatiotemporal variation of emissions under three inventories

By tracing the spatiotemporal variation in responsibilities for CO_2 emissions among BRI nations under the three inventories between 1995 and 2015 (Fig. 5), we found that around half countries had a higher carbon footprint with PBA than that with CBA (Fig. 5a, Fig. 5b). Over the past two decades, a shift in the nations' role from net importers to net exporters was observed for Malaysia, Thailand and Philippines, while Romania, Poland and United Arab Emirates were on the opposite. China, India and Russia ranked the top three net carbon exporters. In particular, China and India's emissions more than doubled and quadrupled, respectively in 1995–2015. Other nations showed relatively higher CBA than PBA. This was particularly true for the top three countries (Singapore, Turkey and Greece).

However, more than 40 nations in BRI showed greater TCBA than CBA in both 1995 and 2015 when it comes to the technological differences in exports (Fig. 5c, Fig. 5d), suggesting that these nations should take more responsibilities for CO_2 emissions than the results of CBA. China, India and Russia again led the trend, with substantially larger emissions under TCBA than under CBA. Singapore showed a tremendously large gap between CBA and TCBA than others, highlighting its import-oriented economy. The gaps between CBA and TCBA between 1995 and 2015 varied widely among nations. For instance, Russia experienced a substantial increase in the gap by 154.93 Mt CO_2, which showed an improvement in the gap between CBA and TCBA. India experienced a decline of 235.38 Mt CO_2 instead, indicating an enlarging gap between CBA and TCBA.

3.4. Carbon leakage among BRI nations

To measure the emissions embodied in imports and exports among BRI nations, we calculated the BEET for each country in 1995 and 2015,

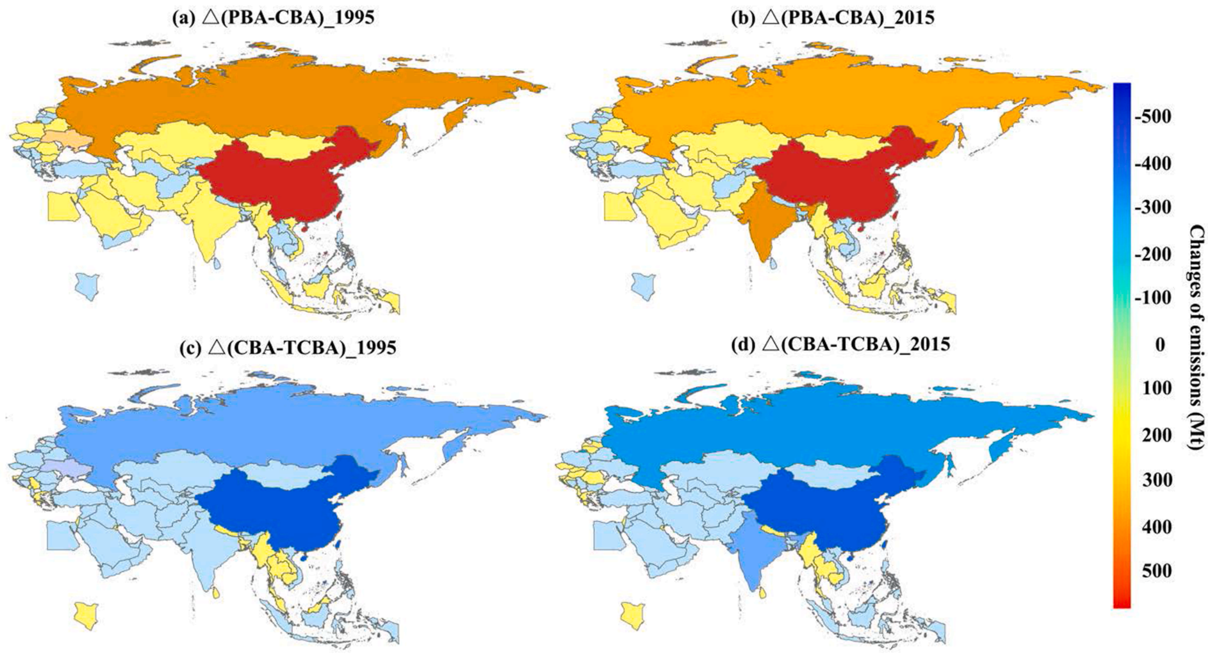

Fig. 5. The changes in CO_2 emission responsibilities of BRI nations between PBA, CBA and TCBA in 1995–2015.

respectively, compared to the TBEET (Fig. 6). Among these countries, China, India and Russia had the largest amount of emissions embodied in trade with BRI nations, and therefore, the changes of CO_2 emissions embodied in trade between the six regions of BRI and China (Fig. 6a), India (Fig. 6b) and Russia (Fig. 6c) were displayed both from the perspectives of BEET and TBEET.

China's net CO_2 emissions embodied in trade (marked with dark blue bars and light blue bars) more than doubled between 1995 and 2015, showing that China overall acted as a net carbon exporter in BRI area. The BEET between China and other nations or regions increased by two to six times. Singapore, Thailand, Turkey, Poland, UAE, India and Viet Nam were China's main exporters of emissions, all of which had more than 10 Mt CO_2 of BEET in 2015. Meanwhile, Central Asia and Russia were China's main importers of emissions which increased by more than five times over the period. By comparison, when considering the technology-adjusted factor for emissions embodied in trade between China and other regions or nations, similar trends were observed for both TBEET and BEET, with values of TBEET much smaller than those of BEET.

Central Asia and Europe were the main importers of emissions embodied in trade for Russia within BRI in 1995, while Russia was a net carbon exporter for other regions in BRI; China, Turkey and Slovakia were net exporters of emissions for Russia, with more than 10 Mt CO_2. In 2015, a shift of role from a net importer to exporter of emissions embodied in trade with Europe was found for Russia, while the CO_2 emissions embodied in imports from Central Asia increased by more than four times from 1995 to 2015. China and those nations in West Asia & Africa contributed more than other BRI nations to the BEET with Russia in 2015. The values for TBEET between Russia and other regions or nations were, in most cases, continuously smaller than those for BEET.

India's net CO_2 emissions embodied in trade with BRI nations increased by more than seven times over the last two decades. China and Russia served as its net importers, whereas West Asia & Africa and Southeast Asia served as its net exporters in which UAE and Bangladesh were the two-largest countries with net exported CO_2 emissions of more than 10 Mt in 2015. India changed from a net importer to a net exporter with respect to the emissions embodied in trade with Europe from 1995 to 2015. India and China had much in common in that they both acted as the net importers of emissions for Russia and Central Asia, as well as the net exporters of emissions for Southeast Asia, South Asia, West Asia & Africa, and Europe, even though India's emissions were less than those of China. Likewise, in most cases, the values for TBEET between India and other regions or nations remained smaller than those for BEET.

Overall, the carbon leakage of BRI was notable over the study period, particularly for China, Russia and India. The BEET values of these three countries with others were always positive in 1995 and 2015, except for Central Asia, who showed a negative BEET with these three nations. By comparison, the TBEET of the three nations were always much smaller than their BEET from 1995 to 2015.

3.5. Decomposition of drivers of emissions growth

We successively quantify various driving forces of the changes to CO_2 emissions of BRI nations by region among the divided periods (Fig. 7). Table 1 explicitly represents the contributions of all the drivers to emissions growth in BRI nations by period. The increment of CO_2 emissions in BRI nations experienced a rapid increase from 1995 to 2010, and then slowed down in the fourth period. The decreasing carbon intensity was the only factor that reduced CO_2 emissions from 1995 to 2010. A shift in the role of Leontief structure from driver to an inhibitor of emissions was observed for BRI nations from 2010 to 2015 and, in particular, for CMR. The change in final demand per capita was a major driving force for emissions growth in BRI nations, with a contribution of more than 200% to the final scores across the four periods. The effect of Leontief structure was the second driver in the period of 1995 to 2010, and then was replaced by the population effect between 2010 and 2015. By contrast, the effects of the changes in the product structure of final demand and in the final demand structure were relatively small.

The results at the regional level can help evaluate the contributions of different regions to the growth of emissions in BRI. For instance, the CMR showed a similar trend to BRI as a whole, as it contributed to 67% of total incremental emissions of BRI nations. Emission intensity as a measure of technical effect led to a decrease in the CMR's emissions over these four periods. Meanwhile, the Leontief structure effect contributed 0.78 Gt, 0.48 Gt, 1.61Gt, and −1.14 Gt to the emissions growth in these four periods, respectively. Apart from the CMR, a notable increase in emissions can be observed for South Asia and West Asia & Africa, with

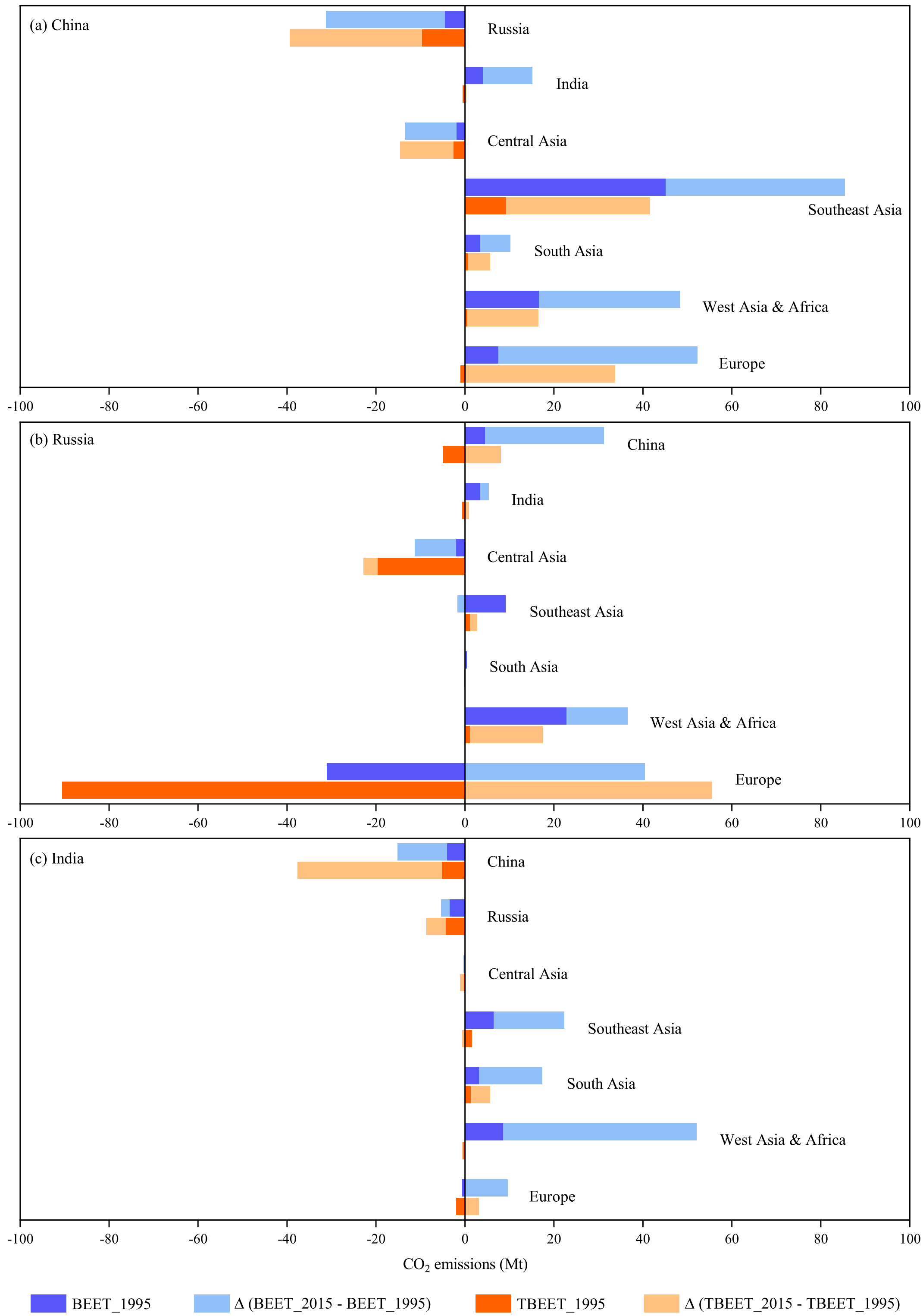

Fig. 6. Magnitude and changes of BEET and TBEET between China, India, Russia, and other BRI regions in 1995–2015. Dark blue bar marks the value for BEET in 1995, and light blue bar marks the added value of BEET from 1995 to 2015. Hence, the sum of the dark and light blue bars corresponds with the value for BEET in 2015, and so does TBEET. For instance, China was a net importer of emissions for Russia, and a net exporter for Southeast Asia. Here the CMR was excluded as two-thirds of its three members (China and Russia) were already addressed separately. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

an increase of 1.74 Gt and 1.36 Gt over the past two decades, respectively. Europe was the only region whose emissions experienced a decrease of 0.35 Gt. For all the regions of BRI, the final demand per capita was the main driver of growth in emissions and, conversely, the carbon intensity was the main inhibitor. Population effect played an important role in emissions growth in all the regions, except for Europe, where it nevertheless acted as a negative factor. The same situation held true for the Leontief structure, which led to a decline in emissions of Europe in the first six years.

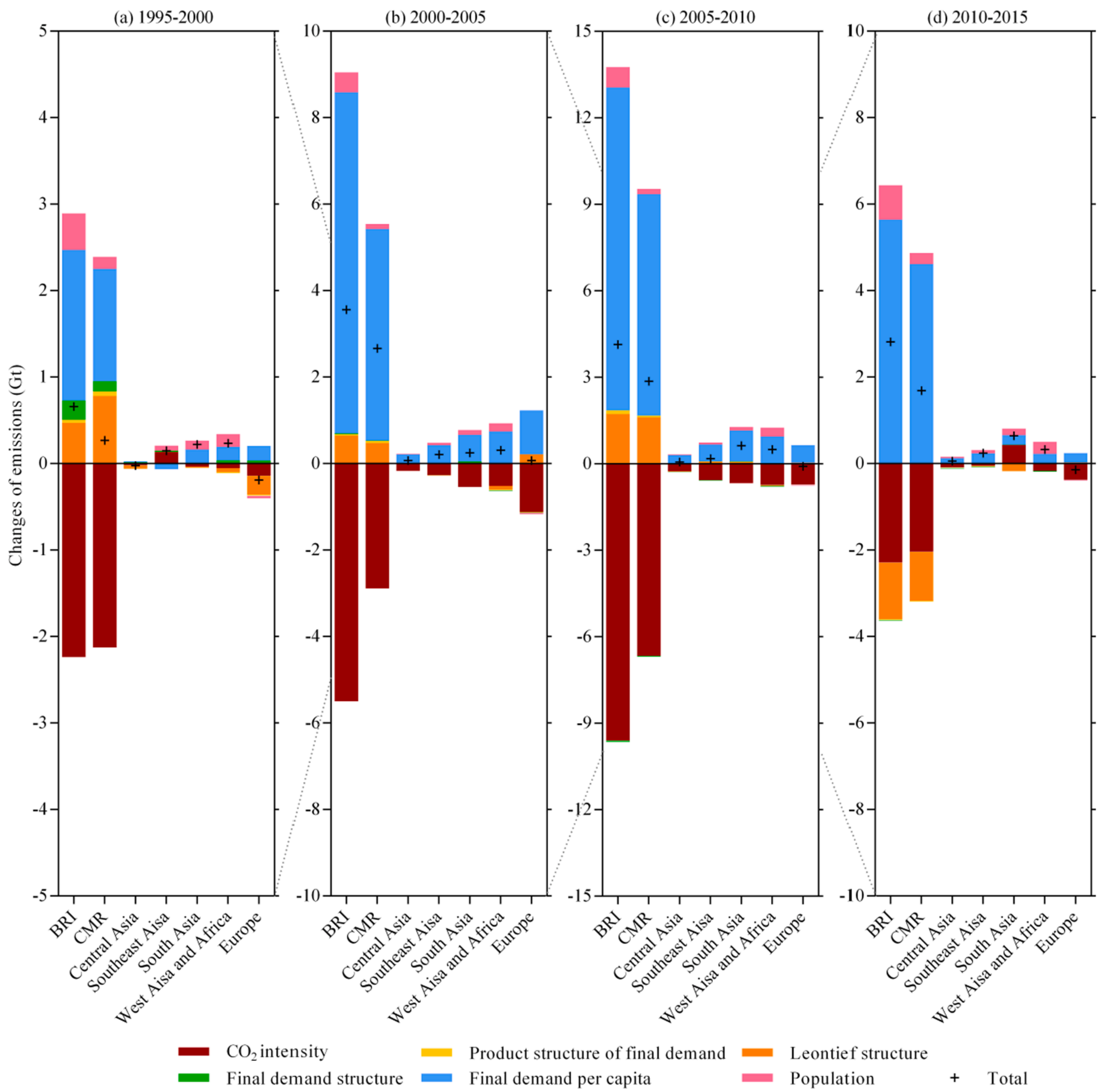

Fig. 7. Magnitude and changes of BRI's CO_2 emissions in 1995–2015. The plus signs represent the net changes of emissions over the past 5 years.

Table 1
Contributions of six factors to the change in BRI's CO_2 emissions in 1995–2015.

Year	CO_2 intensity	Leontief structure	Product structure of final demand	Final demand structure	Final demand per capita	Population
1995–2000	−339.07%	71.36%	5.86%	33.73%	264.05%	64.07%
2000–2005	−154.45%	18.15%	1.09%	0.55%	221.62%	13.04%
2005–2010	−231.79%	41.80%	3.08%	−1.03%	270.65%	17.29%
2010–2015	−81.23%	−46.47%	−0.44%	−0.56%	200.38%	28.33%

4. Discussion

Recently, BRI has attracted growing interest and discussions globally. There have been increasingly closed economic connections between Asia and Europe with latent consequences for international trade [21]. Environmental challenges have been a main area of concern over the BRI [40,41,42], like the impact on biodiversity conservation [43], the dynamics of virtual water footprints [44], as well as the trade-offs between social benefits and environmental hazards [45]. The BRI has also been predicted to trigger an increase in global CO_2 emissions [25] and speed up urbanization [10]. Even though we may take decades to witness these impacts, it is necessary to make some efforts to reduce potential hazards [45]. Of these, climate change is often at the center of discussion on BRI's changing environment for many years. Despite the increasing research on CO_2 emissions embodied in international trade, studies taking into account technological differences between countries in producing internationally traded goods are scarce, let alone those that made use of PBA, CBA and TCBA in a comparative sense. As such, there still seems to be ample room for discussions on this subject, particularly with a focus on BRI.

Our analysis showed that, over the past two decades, the total emissions of BRI nations experienced a considerable rise during the research period, with a much faster growth rate than the RoW. It contributed to over 50% of global carbon footprint both from CBA and

PBA perspectives, and around 53% of embodied carbon exports globally were from BRI in 2015. BRI had much higher emissions under PBA than under CBA, as the nations in BRI are mostly developing economies to which some emissions were shifted from developed economies. This was particularly true for China and India—the two largest emerging exported-oriented economies. Obviously, PBA on its own cannot fairly identify national responsibilities, especially for BRI nations, and CBA in principle seems to be both feasible and effective [46].

The improvement in carbon intensities and energy efficiencies, varied among these nations over time [47], which however could not be assessed through PBA or CBA, but rather through TCBA. For nations that have a higher carbon footprint under TCBA than CBA, it makes sense to take immediate actions to reduce carbon intensities to reach the world average. Among them, China showed a stable trend of reducing carbon intensity [47]. Its domestic carbon intensity was improved at a speed faster than the world average, leading to a slower growth rate of carbon footprint with TCBA than that with CBA. This, to some extent, can be attributed to Chinese Intended Nationally Determined Contributions (INDCs) aiming at not only reducing its CO_2 intensity by 60%–65% based on the 2005 level but also peaking the total emissions by latest 2030, by largely improving its energy efficiency and leveraging more renewable energy [48]. As another large emerging economy, India experienced faster growth in carbon footprint under PBA and TCBA, and a slower growth under CBA than China.

With respect to other regions, there was no obvious improvement in TCBA, especially for South Asia, West Asia & Africa and Southeast Asia who had large emissions under TCBA which were even higher than those under PBA. Countries in these regions, such as India, Indonesia, Philippines and Thailand, were characterized by labor-intensive manufacturers, energy-intensive infrastructure and high-speed urbanization, causing their emission intensities to be much higher than that of China [49,50,51]. It implies that some production activities, particularly those conducted by carbon-intensive sectors, were likely to be relocated from China to other developing countries in the BRI. This is in keeping with recent studies reporting emission shifts among developing nations [6,47].

TCBA presents a new insight into testing the displacement hypothesis and measuring the impact of international trade on emissions [32]. The values of TBEET between these BRI nations indicated that carbon intensities between trading partners were higher than the intensity of the global market. Moreover, carbon-intensive heavy industries in BRI tended to have a relatively greater contribution to the emissions embodied in exports [52]. Thus, improving carbon efficiency is still a critical step for BRI nations to mitigate carbon leakage. This is similar to general recommendations for the optimization of international trade based on global analyses [8,35].

The growths in final demand per capita, population and technological changes were the key influencing factors for the growth of CO_2 emissions in BRI nations over the past two decades. The first two factors have boosted emissions, with a relatively reduced speed in the fourth period, while the third factor was the main driver of emissions reduction, which was consistent with previous results [5,36]. Remarkably, Leontief industrial structure changed from a driver to a hamper of emissions growth during the research period, implying that industrial structure has gradually been improved, particularly for China who has been intentionally transitioning to a more service-based economy [10]. Meanwhile, we found it interesting that the drivers of emissions growth in European countries were inherently different from others in BRI. One example is the decreasing population that served as a negative driver of emissions growth. The Leontief structure effect turning to a driver represents another example, suggesting there was not sufficiently substantial progress in improving industrial structure during the research period.

The emission growth in BRI slowed down during the period of 2010–2015, partly because of the Leontief industrial structure that started contributing to emissions reduction. However, the contributions of carbon intensity to emission mitigation have diminished since then, even though most BRI nations remained at a high level of carbon intensity. Improving industrial structure, final demand structure and carbon efficiency therefore still deserve policy priorities for the BRI countries. To that end, promoting energy efficiency and abatement technology would be the most critical step for BRI nations due to relatively poor technologies behind the world average. In the context of globalization, there has been a shift of global supply chains towards the developing countries [53], especially some around BRI inevitably. It is, therefore, important as well to improve the layout of industrial supply chains in support of a more reasonable geospatial separation of production and consumption [1]. Meanwhile, BRI is also potentially considered to be the largest infrastructure development ever, so making effective strategies to limit the environmental impacts associated with infrastructure construction is of particular importance for emission mitigation [22,45].

In common with other studies, some limitations remain in this study with respect to methodologies and data availability. First, we acknowledge the uncertainty of the original data of Eora database, such as the price errors, spatial and sectoral aggregation and the choice of MRIO tables [54,55]. Second, when calculating technological differences, we emphasized on measuring the impacts of export-oriented emissions on global emissions and carbon leakage, as most of BRI nations were net exporters of emissions embodied in trade. While we believe that TCBA represents a step ahead from the CBA by considering technological differences from the world average, it still has some methodological limitations that should be overcome in future work [16,32 33].

5. Conclusion

This study conducted an in-depth investigation into the seriousness of carbon leakage and the drivers of emissions growth in 62 nations partnering the BRI over the past two decades by establishing MRIO and SDA models. We accounted for the carbon footprint under the PBA, CBA and TCBA in a comparative sense, with the purpose of creating a more holistic view of responsibility allocation. Moreover, we broke down the drivers of emissions growth in these nations into six factors, namely the CO_2 intensity effect, the Leontief structure effect, the effect of product structure of final demand, the final demand structure effect, the final demand per capita effect, and the population effect.

We found it interesting that BRI countries contributed to over 50% and 92% of global carbon footprint and its increase between 1995 and 2015, respectively, with a much faster growth rate than RoW. The BRI overall acted as a large net exporter of emissions embodied in international trade, even though its carbon footprint with TCBA maintained at a very high level due to relatively high carbon intensity. China accounted for half of the CO_2 emissions in BRI while having shown some positive improvements in its energy efficiency, which was at a speed faster than the world average. Despite less improvement in TCBA, India experienced similar trends with China in terms of carbon footprint, whose growth under PBA and TCBA was faster than under CBA.

With respect to carbon leakage among BRI nations, China, India and Russia overall played essential roles as net carbon exporters for other BRI nations. Meanwhile, Southeast Asia and West Asia & Africa serving as exporters of emissions in the global market showed no obvious improvement in TCBA, thus would be likely to increase their carbon footprints under both PBA and CBA.

The growth in final demand per capita and population were found to be key drivers of emissions in most of the BRI nations, whereas technological change was the key driver of emissions reduction. Leontief industrial structure tended to decrease emissions in the last period, indicating gradual industrial structure upgrading, especially in the CMR. A different phenomenon occurred in Europe, however, where the population and Leontief structure effects acted as negative and positive drivers of emissions growth, respectively.

China, the major advocator for BRI, has been observed that it benefitted from CO_2 emissions embodied in the trade with other BRI countries. China has taken some policy actions for a low-carbon transition by adopting new clean technologies and higher environmental standards, increasing the use of green financing instruments, and expanding international cooperation on climate governance, which has been declared as part of the green BRI construction in its Ecological and Environmental Cooperation Plan [56]. However, more concrete policy measures are still required to reduce importing carbon-intensive products from BRI countries whose production technologies are lower than the world average. From a broader point of view, in struggling towards a sustainable society, more attention should be paid to creating policy synergies between the green BRI, the Paris Agreement, and the United Nations 2030 Agenda for Sustainable Development.

To sum up, this paper provided new insights into carbon leakage among these BRI nations by considering consumption and production and technological differences within BRI countries and their relationships with the whole world, as well as by identifying the drivers of emissions of BRI nations. Even though we have managed to conduct a multi-dimensional assessment of carbon leakage with a 20-year span among over 60 nations under CBA, PBA and TCBA, future work needs to explore this topic in a global context with a broader point of view. For instance, it remains to be seen whether every BRI nation will achieve its INDCs, whether the BRI will continuously drive the global map of carbon footprint, and how the transfer of specific power or manufacturing sectors from one BRI country to others affects the low carbon transition in this area. These research avenues are interesting to be pursued.

CRediT authorship contribution statement

Qinli Lu: Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Kai Fang:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Reinout Heijungs:** Methodology, Writing - review & editing. **Kuishuang Feng:** Formal analysis, Writing - review & editing. **Jiashuo Li:** Formal analysis, Writing - review & editing. **Qi Wen:** Writing - review & editing. **Yanmei Li:** Writing - review & editing. **Xianjin Huang:** Formal analysis, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank Ms. Jianjian He for her assistance in preparing a figure. This work was supported equally by the National Natural Science Foundation of China (72074193, 71704157, 71921003, 41871201), the Strategic Priority Research Program of Chinese Academy of Sciences (XDA20040400), the Natural Science Foundation of Zhejiang Province for Distinguished Young Scholars (LR19G030001), the Top Young Talent of Ten-Thousand Talents Program of Zhejiang Province (ZJWR0308040), and the Federal Office for the Environment FOEN, Switzerland.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apenergy.2020.115934.

References

[1] Wiedmann T, Lenzen M. Environmental and social footprints of international trade. Nat Geosci 2018;11(5):314–21.
[2] Wood R, Grubb M, Anger-Kraavi A, Pollitt H, Rizzo B, Alexandri E, et al. Beyond peak emission transfers: historical impacts of globalization and future impacts of climate policies on international emission transfers. Climate Policy 2019:1–14.
[3] Fang K, Heijungs R, de Snoo GR. Theoretical exploration for the combination of the ecological, energy, carbon, and water footprints: Overview of a footprint family. Ecol Ind 2014;36:508–18.
[4] Hoekstra AY, Wiedmann TO. Humanity's unsustainable environmental footprint. Science 2014;344(6188):1114–7.
[5] Arto I, Dietzenbacher E. Drivers of the growth in global greenhouse gas emissions. Environ Sci Technol 2014;48(10):5388–94.
[6] Meng B, Peters GP, Wang Z, Li M. Tracing CO_2 emissions in global value chains. Energy Econ 2018;73:24–42.
[7] Chen J, Fan W, Li D, Liu X, Song M. Driving factors of global carbon footprint pressure: Based on vegetation carbon sequestration. Appl Energy 2020;267:114914.
[8] Peters GP, Minx JC, Weber CL, Edenhofer O. Growth in emission transfers via international trade from 1990 to 2008. Proc Natl Acad Sci 2011:8903–8.
[9] Kanemoto K, Moran D, Hertwich EG. Mapping the carbon footprint of nations. Environ Sci Technol 2016;50(19):10512–7.
[10] Meng J, Mi Z, Guan D, Li J, Tao S, Li Y, et al. The rise of South-South trade and its effect on global CO_2 emissions. Nat Commun 2018;9(1):1871.
[11] Han M, Yao Q, Liu W, Dunford M. Tracking embodied carbon flows in the Belt and Road regions. J Geog Sci 2018;28(9):1263–74.
[12] Wiedmann T, Minx J. A definition of 'carbon footprint'. Ecol Econ Res Trends 2008;1:1–11.
[13] Davis SJ, Caldeira K. Consumption-based accounting of CO_2 emissions. Proc Natl Acad Sci 2010;107(12):5687–92.
[14] Kanemoto K, Lenzen M, Peters GP, Moran DD, Geschke A. Frameworks for comparing emissions associated with production, consumption, and international trade. Environ Sci Technol 2011;46(1):172–9.
[15] Steininger KW, Munoz P, Karstensen J, Peters GP, Strohmaier R, Velázquez E. Austria's consumption-based greenhouse gas emissions: Identifying sectoral sources and destinations. Global Environ Change 2018;48:226–42.
[16] Kander A, Jiborn M, Moran DD, Wiedmann TO. National greenhouse-gas accounting for effective climate policy on international trade. Nat Clim Change 2015;5(5):431.
[17] Jiborn M, Kander A, Kulionis V, Nielsen H, Moran DD. Decoupling or delusion? Measuring emissions displacement in foreign trade. Glob Environ Change 2018;49:27–34.
[18] National Development and Reform Commission (NDRC). Vision and Actions on Jointly Building Silk Road Economic Belt and 21-Century Maritime Silk Road; 2015.
[19] Huang Y. Understanding China's Belt & Road initiative: motivation, framework and assessment. China Econ Rev 2016;40:314–21.
[20] Liu A, Lu C, Wang Z. The roles of cultural and institutional distance in international trade: Evidence from China's trade with the Belt and Road countries. China Econ Rev 2018.
[21] Konings J. Trade impacts of the Belt and Road Initiative. London, UK: Think; 2018.
[22] Zhang N, Liu Z, Zheng X, Xue J. Carbon footprint of China's belt and road. Science 2017;357(6356).
[23] Hannam PM, Liao Z, Davis SJ, Oppenheimer M. Developing country finance in a post-2020 global climate agreement. Nat Clim Change 2015;5(11):983.
[24] Cai X, Che X, Zhu B, Zhao J, Xie R. Will developing countries become pollution havens for developed countries? An empirical investigation in the Belt and Road. J Cleaner Prod 2018;198:624–32.
[25] Fan J-L, Da Y-B, Wan S-L, Zhang M, Cao Z, Wang Y, et al. Determinants of carbon emissions in 'Belt and Road initiative' countries: A production technology perspective. Appl Energy 2019;239:268–79.
[26] Han M, Lao J, Yao Q, Zhang B, Meng J. Carbon inequality and economic development across the Belt and Road regions. J Environ Manage 2020;262:110250.
[27] Shi K, Yu B, Huang C, Wu J, Sun X. Exploring spatiotemporal patterns of electric power consumption in countries along the Belt and Road. Energy 2018;150:847–59.
[28] Lenzen M, Moran D, Kanemoto K, Geschke A. Building Eora: a global multi-region input–output database at high country and sector resolution. Econ Syst Res 2013;25(1):20–49.
[29] Moran D, Wood R, Hertwich E, Mattson K, Rodriguez JF, Schanes K, et al. Quantifying the potential for consumer-oriented policy to reduce European and foreign carbon emissions. Climate Policy 2018:1–11.
[30] Leontief WW. Quantitative input and output relations in the economic systems of the United States. Rev Econ Stat 1936:105–25.
[31] Lenzen M, Kanemoto K, Moran D, Geschke A. Mapping the structure of the world economy. Environ Sci Technol 2012;46(15):8374–81.
[32] Kander A, Jiborn M, Moran DD, Wiedmann TO. Reply to'Consistency of technology-adjusted consumption-based accounting'. Nat Clim Change 2016;6(8):730.
[33] Domingos T, Zafrilla JE, López LA. Consistency of technology-adjusted consumption-based accounting. Nat Clim Change 2016;6(8):729.
[34] Lu Q, Yang H, Huang X, Chuai X, Wu C. Multi-sectoral decomposition in decoupling industrial growth from carbon emissions in the developed Jiangsu Province, China. Energy 2015;82:414–25.
[35] Wang H, Ang B, Su B. Assessing drivers of economy-wide energy use and emissions: IDA versus SDA. Energy Policy 2017;107:585–99.
[36] Lan J, Malik A, Lenzen M, McBain D, Kanemoto K. A structural decomposition analysis of global energy footprints. Appl Energy 2016;163:436–51.

[37] Wood R, Lenzen M. Structural path decomposition. Energy Econ 2009;31(3):335–41.
[38] Wachsmann U, Wood R, Lenzen M, Schaeffer R. Structural decomposition of energy use in Brazil from 1970 to 1996. Appl Energy 2009;86(4):578–87.
[39] Zhang Q, Fang K. Comment on "Consumption-based versus production-based accounting of CO_2 emissions: Is there evidence for carbon leakage?". Environ Sci Policy 2019;101:94–6.
[40] Ascensão F, Fahrig L, Clevenger AP, Corlett RT, Jaeger JA, Laurance WF, et al. Environmental challenges for the Belt and Road Initiative. Nat Sustainability 2018;1(5):206–9.
[41] Chen X, Liu Q, Fang K, He J, Chen Y, Wang T, et al. Tracking national sustainability of critical natural capital and the socioeconomic drivers in the context of the Belt and Road Initiative. Ecol Ind 2020;114:106315.
[42] Fang K, Wang S, He J, Song J, Fang C, Jia X. Mapping the environmental footprints of nations partnering the Belt and Road Initiative. Resour Conserv Recycl 2020;64:105068.
[43] Lechner AM, Chan FKS, Campos-Arceiz A. Biodiversity conservation should be a core value of China's Belt and Road Initiative. Nat Ecol Evol 2018;2(3):408.
[44] Zhang Y, Zhang J-H, Tian Q, Liu Z-H, Zhang H-L. Virtual water trade of agricultural products: A new perspective to explore the Belt and Road. Sci Total Environ 2018;622:988–96.
[45] Laurance WF, Arrea IB. Roads to riches or ruin? Science 2017;358(6362):442–4.
[46] Grasso M. The political feasibility of consumption-based carbon accounting. New Polit Econ 2016;21(4):401–13.
[47] Pappas D, Chalvatzis KJ, Guan D, Ioannidis A. Energy and carbon intensity: A study on the cross-country industrial shift from China to India and SE Asia. Appl Energy 2018;225:183–94.
[48] Fang K, Tang Y, Zhang Q, Song J, Wen Q, Sun H, et al. Will China peak its energy-related carbon emissions by 2030? Lessons from 30 Chinese provinces. Appl Energy 2019;255:113852.
[49] Yang C. Relocating labour-intensive manufacturing firms from China to Southeast Asia: a preliminary investigation. Bandung: J Glob South 2016;3(1):3.
[50] Pappas D, Chalvatzis KJ, Guan D, Li X. Industrial relocation and CO_2 emission intensity: Focus on the potential cross-country shift from China to India and SE Asia. Energy Procedia 2017;142:2898–904.
[51] Fang K, Wang T, He J, Wang T, Xie X, Tang Y, et al. The distribution and drivers of PM2. 5 in a rapidly urbanizing region: The Belt and Road Initiative in focus. Sci Total Environ 2020;716:137010.
[52] Feng K, Davis SJ, Sun L, Li X, Guan D, Liu W, et al. Outsourcing CO_2 within China. Proc Natl Acad Sci 2013;110(28):11654–9.
[53] Jiang X, Green C. The impact on global greenhouse gas emissions of geographic shifts in global supply chains. Ecol Econ 2017;139:102–14.
[54] Wiedmann TO, Schandl H, Lenzen M, Moran D, Suh S, West J, et al. The material footprint of nations. Proc Natl Acad Sci 2013;112(20):6271–6.
[55] Chen B, Han M, Peng K, Zhou S, Shao L, Wu X, et al. Global land-water nexus: agricultural land and freshwater use embodied in worldwide supply chains. Sci Total Environ 2018;613:931–43.
[56] Froissart C. From outsiders to insiders: the rise of China ENGOs as new experts in the law-making process and the building of a technocratic representation. J Chin Governance 2019;4(3):207–32.