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Dynamic Driving Forces of India's Emissions from Production and Consumption Perspectives

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Key Points:

- Increasing coal proportion and energy intensity push India's emissions upwards after 2003.
- India's domestic industrial chain has opposing effects on domestic and trade-related emissions after 2011, as well as demand structure.
- India's biggest final demand shifts from capital investment to household consumption after 2008.

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Abstract

Whilst India becomes one of the largest carbon emitters in the world with a high emission growth rate, existing studies fail to capture the recent trends and the key driving factors behind it. Here, by using multi-regional input-output analysis and structural decomposition analysis, we measure the contribution of factors to the changes of India's domestic consumption and trade-related emissions. This study finds that India's per capita consumption has a significant raising effect on India's consumption-based emissions during 2000-2014; increasing coal proportion (especially in industry and electricity) and ineffective energy efficiency (especially in electricity) continuously push India's production-based emissions upwards after 2003. Meanwhile, India's domestic industrial chain shows an increasing and decreasing effects on domestic consumption and export-related emissions after 2011, respectively. India's forward industrial chain always drive export-related emissions upwards. In addition, the major contributor of final demand in domestic consumption emissions transfers from capital investment to household consumption after 2008, while the increasing power of services in export-related emissions rapidly fades in the same period. India's climbing import-related emissions embodied in final products shift to light industries, and the intermediate products shift to heavy industries and construction over time.

1 Introduction

As a major factor in climate change, the annual carbon emissions aroused by the combustion of fossil fuels worldwide are stable after 2013 due to the global effort - through the United Nations Framework Convention for Climate Change (UNFCCC) and its Kyoto Protocol - to limit the global temperature increase to less than 2 degrees. Emissions in China, the largest emitter, have a constant decrease during 2013-2016 (133.9 Mt) owing to its economy entering a new normal by industrial structure upgrade and green production (Guan et al., 2018; Mi et al., 2018). In contrast, India becomes the new leader, with its emissions showing a rapid increase (225.0 Mt) in this period due to its economic success with an average annual growth rate of 7.0% in GDP.

India is at mid-stage of industrialization with low technology and added value (Mehta, 2012). Taking the manufacturing industry as an example, the output of that sector increases by an average annual rate of 6.3% from 2008 to 2014, which is lower than that of emissions emitted by manufacturing industry (9.4%). This illustrates that the manufacturing industry in India moves in a carbon-intensive direction. It can also be illustrated in **Figure 1a**, which shows that the proportion of emissions emitted by the manufacturing industry in India rapidly rises after 2008 and probably surpasses that of China in the following years. Meanwhile, the position index of global value chain, detailed algorithms refer to the existing paper (Koopman et al., 2010), of the manufacturing industry in India rapidly decreases after the international financial crisis (**Figure 1b**) due to the stimulation of low-end industries (e.g. labor-intensive or resource-intensive industries) by India's government to recover its economy (Carrasco, 2017). Furthermore, India's emission intensity outweighs that of China after 2008 and shows a rapid upward trend (**Figure 1c**). In addition, India promises to cut its emissions unitary GDP by 33-35% by 2030, compares with 2005 (Ray, 2015), yet this will pose a dilemma of realizing the commitment to restraining the emissions, while maintaining rapid economic growth.

Given the purpose of designing efficient and viable policies to defuse this contradiction, it is critical to cultivate a thorough understanding of the main drivers of India's emission changes. Meanwhile, the lessons learned from India will have implications for other emerging economies in Southeast Asia and Africa to rapidly realize a low-carbon economy.

Previous studies investigate the contributions of drivers to the changes of carbon emissions at country level by employing structural decomposition analysis based on global multi-regional input-output tables (Hoekstra et al., 2016; Jiang et al., 2016; Zhao et al., 2016), as well as national input-output tables , such as China (Minx et al., 2011; Zhu et al., 2012; Su et al., 2013), the United States (Weber, 2009), Australia (Wood, 2009), Singapore (Su et al., 2017), Italy (Cellura et al., 2012) and Norway (Yamakawa et al., 2011). Moreover, China is the main target for conducting investigations at a provincial level due to its perfect dataset (Feng et al., 2012; Li et al., 2018; Meng et al., 2018). In addition, some studies deliver detailed analysis for emission changes embodied in domestic consumption and trade (Lan et al., 2016; Malik et al., 2016; Soligno et al., 2019), as well as final and intermediate products (Meng et al., 2018). Furthermore, there are many literatures calculate the effects of factors on emission changes in industry level by using the index decomposition analysis (Tian et al., 2011; Fan et al., 2016; Li et al., 2017). Meanwhile, some literatures quantify the impacts of drivers on changes of water (Yang et al., 2016; Soligno et al., 2019), energy (Lan et al., 2016; Su et al., 2017) and air pollutants (Deng et al., 2016; Meng et al., 2016; Meng et al., 2019).

The conclusions of the above studies generally accept that expanding per capita demand and population scale are the major factors in pushing emissions upwards in developed and developing countries, the former and latter obviously arouse the increase of emissions abroad and at home, respectively (Hoekstra et al., 2016; Lan et al., 2016; Lenzen, 2016). Meanwhile, emission intensity is a major factor influencing emission changes in developed countries and regions (e.g. the United States (Liang et al., 2016), the European Union (Deng et al., 2016), Japan (Zhao et al., 2016)) and developing countries (e.g. China (Raghuvanshi et al., 2006; Ming et al., 2011)), with its effect in the latter being more conspicuous (Xu et al., 2014; Andreoni et al., 2016; Malik et al., 2016). Meanwhile, improving energy efficiency and cleaning energy structure are propitious to reduce emissions worldwide (Kim et al., 2012), especially in China (Guan et al., 2018). Another important factor is production structure, the effect of which is more remarkable in emerging countries (e.g. China and India) (Meng et al., 2018). In addition, with the globalization of the world economy, the international industrial chains (e.g. forward and backward industrial chains), as the main components of production structure, are an area of interest for researchers to investigate their impacts on emission changes and are confirmed as having inconsistent effects (Wood, 2009; Xia et al., 2015; Deng et al., 2019). Furthermore, consumption structure also has an increasing effect in countries with rapid industrialization and urbanization (e.g. China (Guan et al., 2009; Mi et al., 2017)).

There are limited studies that quantify the influence of factors on the emission changes in India. By employing the world input-output tables and structural decomposition analysis, some studies analyze the contributions of drivers (e.g. emission efficiency, production structure, demand structure, demand scale and population) on the changes of India's national emissions (Arto et al., 2014; Malik et al., 2016), as well as trade-related emissions (Xu et al., 2014; Deng et al., 2017; Jiang et al., 2017). Meanwhile, researchers investigate the relationship between India's economic development and carbon emissions by using index decomposition analysis (Andreoni et al., 2016), and some scientists report the contributions of factors on India's carbon emissions based on its own input-output tables (Zhu et al., 2018) and official yearbook data (Paul et al., 2004). In addition, there are some researchers who investigate the key transmission channels of India's carbon emissions through structural path analysis (Li et al., 2018) and the drivers of changes in India's energy consumption (Mukhopadhyay et al., 1999), as well as water footprint (Roson et al., 2015).

The major points delivered by existing papers analyzing emission changes in India can be summarized as follows: (i) India's increasing emissions come from household consumption, followed by capital investment during 2007-2013 (Zhu et al., 2018); (ii) Per capita consumption scale and population continuously exert positive effects on emission raise (Melanie et al., 1994; Malik et al., 2016; Zhu et al., 2018); (iii) Domestic consumption is always the major reason for India's emission increase compares to export (Arto et al., 2014; Zhu et al., 2018); (iv) Production structure exerts positive effect on India's emission rise during 2007-2013 (Zhu et al., 2018), and holds a dropping effect during 2008-2011 (Jiang et al., 2017); and (v) Consumption structure decreases India's emissions during 1995-2013. (Arto et al., 2014; Zhu et al., 2018).

However, the current studies lack time-series analysis about factors based on India's latest data and do not consider the influence of energy intensity and energy structure, both of which have outstanding contributions in the past (Guan et al., 2018). Meanwhile, they also pay less attention to in-depth decomposition of production structure to obtain detailed effects of industrial chains. To fill those gaps, this study presents a temporal picture about drivers (including energy intensity, energy structure and industrial chains) on the changes of India's domestic consumption and trade-related emissions from 2000 to 2014.

2 Methodology and Data

2.1 Structural Decomposition Analysis

The well-acknowledged tool employed to investigate the contribution of drivers on emission changes is structural decomposition analysis (SDA), which can remedy the deficiency of index decomposition analysis (IDA) for its failure to deliver an in-depth and detailed understanding of direct and indirect socio-economic effects (Guan et al., 2014; Guan et al., 2018; Meng et al., 2018). For more detailed information about the comparison of SDA and IDA, please see the previous study (Hoekstra et al., 2003; Su et al., 2012).

Based on the multi-regional input-output table with *m* countries and *n* sectors, the emissions transferred from country *q* to country *p* (p, q = 1,2 … m) can be calculated as follows:

$$\mathbf{E}^{pq} = \mathbf{D}^{p}\mathbf{L}\mathbf{Y}^{q} \tag{1}$$

where $\mathbf{D}^p$ represents the matrix of direct emission intensity of country p, $\mathbf{L}$ represents the Leontief inverse matrix, and $\mathbf{Y}^q$ represents the matrix of final demand in country q. For more detailed information please see our previous studies (Meng et al., 2016; Wang et al., 2018). Therefore, theoretically change of $\mathbf{E}$ in equation (1) can be expressed as follows:

$$\Delta\mathbf{E} = \Delta\mathbf{D}\mathbf{L}\mathbf{Y} + \mathbf{D}\Delta\mathbf{L}\mathbf{Y} + \mathbf{D}\mathbf{L}\Delta\mathbf{Y} \tag{2}$$

Each of those terms in the right side of equation (2) indicates the contribution to the overall change in emissions triggered by one factor while keeping the other two factors constant. For example, the first item represents the contribution of emission intensity. However, any emission changes may be aroused by a variety of reasons, such as the energy structure, industrial chains, consumption structure and population (Ang et al., 2000; Haan, 2001; Minx et al., 2011). Based on previous studies (Yanmei et al., 2013; Guan et al., 2014; Zhang et al., 2016), we make a further decomposition of matrix $\mathbf{D}$ through distinguishing the emissions and energy consumptions by different fuel types, including coal, oil, natural gas and non-fossil fuels (e.g. solar, wind and other renewables).

Supposing the element $e_{c,j}^{p}$, $e_{o,j}^{p}$ and $e_{g,j}^{p}$ in matrix $\mathbf{E}_c$, $\mathbf{E}_o$ and $\mathbf{E}_g$ represent the emissions aroused by burning coal, oil and gas in industry j (j=1,2 … n) in country p, respectively. The emission coefficient of them can be calculated by $g_{c,j}^{p} = \frac{e_{c,j}^{p}}{r_{c,j}^{p}}$, $g_{o,j}^{p} = \frac{e_{o,j}^{p}}{r_{o,j}^{p}}$ and $g_{g,j}^{p} = \frac{e_{g,j}^{p}}{r_{g,j}^{p}}$, respectively. $r_{c,j}^{p}$, $r_{o,j}^{p}$ and $r_{g,j}^{p}$ represent the consumption scale of coal, oil and gas in industry j in country p, respectively. Notably, we do not consider the emission coefficient of non-fossil fuels due to the fact that their emissions are very small or zero (e.g. solar). Meanwhile, the element h_j^p in matrix **H** represents the energy structure in industry *j* in country *p* and can be written as follows:

$$h_j^p = \frac{r_{c,j}^p + r_{o,j}^p + r_{g,j}^p}{r_j^p} = \frac{r_{c,j}^p + r_{o,j}^p + r_{g,j}^p}{r_{c,j}^p + r_{o,j}^p + r_{g,j}^p + r_{n,j}^p} = h_{c,j}^p + h_{o,j}^p + h_{g,j}^p \quad (3)$$

where $r_{n,j}^p$ represents the consumption scale of non-fossil energy of industry *j* in country *p*. $h_{c,j}^p$, $h_{o,j}^p$ and $h_{g,j}^p$ represent the energy structure of coal, oil and natural gas in industry *j* in country *p*, respectively. Thus, the element D_j^p in matrix **D** can be written as follows:

$$D_j^p = \frac{e_j^p}{x_j^p} = \frac{\left(e_{c,j}^p + e_{o,j}^p + e_{g,j}^p\right)}{x_j^p} = g_{c,j}^p * h_{c,j}^p * k_j^p + g_{o,j}^p * h_{o,j}^p * k_j^p + g_{g,j}^p * h_{g,j}^p * k_j^p \quad (4)$$

where x_j^p represents the output of industry *j* in country *p*, and function (4) can be transferred to matrix format as follows:

$$\mathbf{D} = \mathbf{G}_c\mathbf{H}_c\mathbf{K} + \mathbf{G}_o\mathbf{H}_o\mathbf{K} + \mathbf{G}_g\mathbf{H}_g\mathbf{K} \quad (5)$$

where $\mathbf{G}_c$, $\mathbf{G}_o$ and $\mathbf{G}_g$ represent the matrix of emission coefficient of coal, oil and gas, respectively. $\mathbf{H}_c$, $\mathbf{H}_o$ and $\mathbf{H}_g$ represent the matrix of energy structure of coal, oil and gas, respectively. **K** represents the matrix of energy intensity.

To distinguish the effects of industrial chains from both domestic and international perspectives, we further decompose the matrix **L** as follows: $\Delta\mathbf{L} = \mathbf{L}_{\mathrm{t1}}\Delta\mathbf{A}\,\mathbf{L}_{\mathrm{t0}}$, where the subscript t1 and t0 represent the terminal and base year, respectively. Reference to existing researches (Liu et al., 2018; Zhou et al., 2018; Deng et al., 2019), the matrix **A** can be decomposed into four departments (Assuming $\mathbf{A_1}$, $\mathbf{A_2}$, $\mathbf{A_3}$ and $\mathbf{A_4}$) as follows:

$$a_{ij}^{pq} = a_{ij}^{pp} + a_{ij(q\neq p)}^{pq} + a_{ij(q\neq p)}^{qp} + a_{ij(q\neq p)}^{qq} \quad (6)$$

where the element a_{ij}^{pp} (i = 1, 2 … n) in matrix $\mathbf{A_1}$ represents the intraregional industrial chain of country *p*, the element $a_{ij(q\neq p)}^{pq}$ in matrix $\mathbf{A_2}$ represents the interregional forward industrial chain of country *p*, the element $a_{ij(q\neq p)}^{qp}$ in matrix $\mathbf{A_3}$ represents the interregional backward industrial chain of country *p*, the element $a_{ij(q\neq p)}^{qq}$ in matrix $\mathbf{A_4}$ represents the intraregional industrial chain of country *q*, which does not have direct trade relationship with country *p*. In detail, if the change in a_{ij}^{pq} has a positive effect on the increase of emissions, it needs to consume more intermediate products in period t1 than that in period t0 of industry *i* in country *p* when producing unitary output of industry *j* in country *q*, and this will arouse emission raise in industry *i* in country *p* due to produce more intermediate products to meet the demand of industry *j* in country *q*, thus stimulating the translation of emissions from country *q* to country *p*.

As illustrated in previous studies (Minx et al., 2011; Yamakawa et al., 2011; Wang et al., 2013), we consider the effect of social factors (e.g. population) on the emission changes through breaking down the final demand into the following forms:

$$\mathbf{Y} = \mathbf{SVC} \quad (7)$$

where the element $s_j^q = y_j^q / \sum_j y_j^q$ in matrix **S** represents the consumption structure in industry *j* in country *q*, the element $v^q = \sum_j y_j^q / c^q$ in matrix **V** represents the per capita consumption in country *q*, the element c^q in matrix **C** represents the population in country *q*.

The relationship among the decomposition types presented above is shown in **Table 1**, the overall formula applied to the structural decomposition analysis can be expressed as follows:

$$\Delta\mathbf{E} = \Delta\mathbf{GHKLSVC} + \mathbf{G}\Delta\mathbf{HKLSVC} + \mathbf{GH}\Delta\mathbf{KLSVC} + \mathbf{GHK}\Delta\mathbf{LSVC} + \mathbf{GHKL}\Delta\mathbf{SVC} + \mathbf{GHKLS}\Delta\mathbf{VC} + \mathbf{GHKLSV}\Delta\mathbf{C} \quad (8)$$

There are 7! = 5040 equally acceptable decomposition forms in our study and different programs will exhibit different results for the same components (Dietzenbacher et al., 1998; Hoekstra et al., 2002; Rørmose et al., 2005). In short, the total emission changes can be described by expression: $\Delta\mathbf{E} = \Delta\mathbf{E}_c + \Delta\mathbf{E}_o + \Delta\mathbf{E}_g$, and one of the possible decomposition forms of changes in emissions aroused by coal combustion can be expressed as follows:

$$\Delta\mathbf{E}_c = \Delta\mathbf{G}_c\mathbf{H}_{c,t1}\mathbf{K}_{t1}\mathbf{L}_{t1}\mathbf{S}_{t1}\mathbf{V}_{t1}\mathbf{C}_{t1} + \mathbf{G}_{c,t0}\Delta\mathbf{H}_c\mathbf{K}_{t1}\mathbf{L}_{t1}\mathbf{S}_{t1}\mathbf{V}_{t1}\mathbf{C}_{t1} + \mathbf{G}_{c,t0}\mathbf{H}_{c,t0}\Delta\mathbf{K}\mathbf{L}_{t1}\mathbf{S}_{t1}\mathbf{V}_{t1}\mathbf{C}_{t1} + \mathbf{G}_{c,t0}\mathbf{H}_{c,t0}\mathbf{K}_{t0}\mathbf{L}_{t1}(\Delta\mathbf{A}_1 + \Delta\mathbf{A}_2 + \Delta\mathbf{A}_3 + \Delta\mathbf{A}_4)\mathbf{L}_{t0}\mathbf{S}_{t1}\mathbf{V}_{t1}\mathbf{C}_{t1} + \mathbf{G}_{c,t0}\mathbf{H}_{c,t0}\mathbf{K}_{t0}\mathbf{L}_{t0}\Delta\mathbf{S}\mathbf{V}_{t1}\mathbf{C}_{t1} + \mathbf{G}_{c,t0}\mathbf{H}_{c,t0}\mathbf{K}_{t0}\mathbf{L}_{t0}\mathbf{S}_{t0}\Delta\mathbf{V}\mathbf{C}_{t1} + \mathbf{G}_{c,t0}\mathbf{H}_{c,t0}\mathbf{K}_{t0}\mathbf{L}_{t0}\mathbf{S}_{t0}\mathbf{V}_{t0}\Delta\mathbf{C}$$
(9)

The decomposition of $\Delta\mathbf{E}_o$ and $\Delta\mathbf{E}_g$ are similar to $\Delta\mathbf{E}_c$. To gain the ideal results, we take the arithmetic average of all equivalent first-order decomposition forms as the relative contribution of each driver, as popularly applied in the existing studies (Guan et al., 2008; Guan et al., 2009; Liang et al., 2016). Meanwhile, we deliver the computation program of full decomposition for seven factors in Supporting Information (SI) Text S1.

2.2 Data Sources

There are three datasets employed in our study: time-series input-output tables, energy consumption and carbon emission inventories. The input-output tables are derived from the World Input-Output Databases (WIOD, http://www.wiod.org/database/wiots16), which cover 44 countries and 56 industries. The energy consumption and carbon emission inventories come from the International Energy Agency (IEA, https://www.iea.org/subscribe-to-data-services), those datasets include 143 countries, 36 industries and five fuel categories (including coal, oil, gas, renewable and solar/wind electricity). Meanwhile, we adjust them into the classification of input-output tables, of which more details are described in our previous study (Wang et al., 2018). To avoid the influence of deflation and to facilitate the comparisons of results, we convert the data of input-output tables from current price into the constant price of year 2000 by dividing the GDP deflator, which can be obtained from the World Bank (https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS).

3 Results and Discussions

3.1 The Increasing Consumption in India

In this study, we divide the emissions into three parts: Part one is India's domestic consumption emissions, which are aroused by producing goods to meet the demands in India and directly emitted by itself. Part two is India's import-related emissions, which are aroused by producing goods to meet the demands in India and directly emitted by abroad. Part three is India's export-related emissions, which are aroused by producing goods to meet the demands abroad and directly emitted by India. Therefore, India's consumption-based emissions are the sum of part one and part two, India's production-based emissions are the sum of part one and part three.

As the major driver, India's per capita final consumption cumulatively contributes 957.6 Mt of India's increasing consumption-based emissions during 2000-2014, in which 851.2 and 123.1 Mt embodied in domestic consumption (**Figure 2a**) and import (**Figure 2b**), respectively. In detail, per capita final demand increases by 250.6 dollars for local goods (especially construction, 65.6 dollars) during 2003-2008 due to India's infrastructure development, which arouses domestic consumption emissions rapidly increase by 432.7 Mt (or 53.4%). However, this positive effect continuously weakens during 2008-2011 and 2011-2014 (210.0 Mt and 124.8 Mt, respectively) due to the influence of the international financial crisis, which sees India's per capita final consumption for local goods increases only by 128.2 dollars and 96.0 dollars, respectively. In addition, India's per capita final demand increases by 17.9 dollars for imports (especially transport equipment, 8.4 dollars) during 2003-2008 and arouses India's import-related emissions increase by 71.4 Mt (or 79.5%). However, this positive effect has an obvious decrease after 2008 and that finally transfers to negative during 2011-2014, in which India's per capita final demand for imports decreases by 11.8 dollars, especially for furniture (6.0 dollars). That has a dramatic increase in domestic identical product (8.7 dollars) due to the substitution aroused by the enhancing productivity in India. Meanwhile, the raising per capita final consumption abroad sees India's export-related emissions increase by 129.3 Mt during 2000-2014 (**Figure 2c**), however, its contribution consistently fades from 31.4 Mt in 2008-2011 to 25.0 Mt in 2011-2014 due to the influence of the financial crisis, which leads to a low growth rate of the global economy. Furthermore, another important ascender of India's consumption-based emissions is its increasing population, which cumulatively contributes by 253.0 Mt during 2000-2014, in which 221.0 Mt at home and 32.0 Mt abroad. This is coupled with India's population increasing by 22.9% from 1.05 billion in 2000 to 1.29 billion in 2014.

3.2 Increasing Coal Share and Energy Intensity Driving India's Emissions

Energy structure cumulatively decreases India's production-based emissions by 25.8 Mt during 2000-2008, and then exhibits a contrary effect (37.8 Mt) during 2008-2014 (**Figure 2a and 2c**). In detail, coal share has a decreasing effect (18.2 Mt) during 2000-2003 (**Figure 3a**) caused by its general decline in all selected sectors (**Figure 3b**). This is due to India ratifying the Kyoto protocol in 2002, which helps India acquire some technologies and funds to improve clean production technology and energy utilization efficiency, especially in coal (Gupta, 2003). However, coal proportion subsequently transfers to an increasing effect during 2003-2014 due to its share increasing from 48.4% to 56.5%, which is associated with the substitution of coal for oil to meet the rapid economic development. This is due to the abundant reserves and low price of coal comparing with oil in India (IEA, 2008). Meanwhile, oil share holds a continuous decreasing effect (82.2 Mt) during 2003-2014 due to India's poor oil supply with more than 70% of its consumption is imported from abroad, and the oil proportion consistently decreases from 36.3% in 2003 to 27.8% in 2014. Notably, the decreasing oil share in 2003-2008 is due to its surging price on the international market and in 2008-2014 is due to India's serious fiscal deficit, which leads to no significant increase in imported oil despite the international price having fallen during this period. Notably, the gas proportion has a rapid decreasing effect (38.2 Mt) during 2011-2014 due to the quantities of gas exploited by India reaching its Hubbert's peak in 2010 and India not having sufficient funds to import gas from abroad.

In addition, about 90.5% of the coal is consumed by electricity during 2000-2014, and that change of coal proportion will have important effect on India's production-based emissions. The coal proportion in electricity has a continuous decrease during 2003-2011 (**Figure 3b**) due to the implementation of the Electricity Act in 2003, which adopts the quota measure of renewable energy in power generation. However, coal proportion rapidly increases by 7.5% during 2011-2014 due to the expanding demand of power aroused by households as the proportion of population accessing to electricity rapidly increases from 67.6% in 2011 to 83.6% in 2014. This illustrates that renewable energy regrettably fails to provide adequate energy to be an effective substitution for coal in this period, even though India launches the Jawaharlal Nehru National Solar Mission in 2010 and the investment of renewable energy reaches its highest level in 2011 (BNEF, 2012).

The energy intensity has a decreasing effect (57.1 Mt) on India's production-based emissions during 2000-2003 (**Figure 2a and 2c**) due to India's Energy Conservation Act coming into force in 2001, which facilitates the improvement of energy utilization efficiency and energy saving technology in all selected sectors (**Figure 3c**). However, the energy intensity has an increasing effect (240.7 Mt) during 2003-2014, especially during 2003-2011 (216.7 Mt), in which the energy intensity in electricity rapidly increases by 10.8 kg/$. This is due to the following two reasons: one is that India's electric enterprises do not have enough funds to improve the outdated power generation technology due to the low and irrational electricity price controlled by the government (Rai et al., 2013), especially after the Electricity Act comes into force in 2003 and emphasizes the developments of the transmission and distribution facilities to connect the national power grid to each village (Thakur et al., 2005), which requires a huge amount of money; the other is that India adopts excessive subsidies in electricity to reduce the economic burden of residents and improve the competitiveness of export-oriented enterprises by decreasing their production costs. However, this leads to a waste of electricity resources (Chattopadhyay, 2004; Mishra, 2013). Notably, the energy intensity in electricity has a small decrease (0.3 kg/$) during 2011-2014 due to the following two reasons: one is the falling subsidy in electricity due to the serious fiscal deficit in government (Carrasco, 2017), and the other is the rapid decrease of transmission and distribution losses rate in electricity due to the upgrade of the electricity network as a result of the two severe power blackouts in 2012, both of which affect most of northern and eastern India and 400 million people (CERC, 2012). However, this decreasing effect on India's production-based emissions is completely offset by basic metals and non-metallic minerals, but the increasing emissions are small (24.0 Mt) in this period.

3.3 Two Distinct Industrial Chain Effects on India's Emissions

The global industrial chain cumulatively decreases India's production-based emissions by 249.3 Mt during 2000-2014 (**Figure 2a and 2c**), and 78.7% of them are aroused by India's domestic industrial chain (**Figure 4**), which dominates the changes of emissions embodied in final products. In detail, India's domestic industrial chain has an increasing effect during 2000-2003. It illustrates that there needs to be more direct consumption of domestic intermediate products when acquiring unitary output in India due to the influence of India's Second Generation Economic Reform in 2001, which aims to skip the industrial stage and directly move into the information age through vigorously supporting the development of technology-intensive industries (e.g. electronics and software) and ignoring the traditional industries (e.g. construction and metals). This leads to the low efficiency of traditional industries and more emissions when acquiring unitary output. However, this phenomenon subsequently takes a dramatic turn during 2003-2011 due to the general improvement of production technology and in turn needs less intermediate products to acquire unitary output in India (Topalova et al., 2011). The decreases in 2008-2011 (39.4 Mt) are smaller than that in 2003-2008 (352.8 Mt) due to the internal offset aroused by the drastic fluctuation of the economy after the financial crisis. For example, in 2008-2009, India's domestic industrial chain increases India's production-based emissions by 82.6 Mt, aroused by India's trade protection and import restriction policy (e.g. higher import tariffs and green barriers) to recover the economy (Kumar et al., 2009; WTO, 2009) and leads to the replacement of importing intermediate products by local ones.

Notably, India's domestic industrial chain has contrary effects on domestic consumption and export-related emissions during 2011-2014 due to the implementation of new economic strategies, named Made in India, which is launched by the government in 2014 with the aim of improving the share of manufacturing in GDP from 16% to 25% in the next 10 years (Modi, 2014). Therefore, India increases the production capacity in manufacturing (e.g. basic metals and furniture) and can provide more intermediate products used to import from abroad for domestic production processes. This increasing effect aroused by the expansive production scale outweighs the decreasing effect of domestic technological improvement in domestic consumption emissions, and sees weak export-related emissions. This is attributed to bulk domestic consumption emissions concentrates on heavy industries and constructions, and a lot of export-related emissions focuses on services, which are less affected by the expansive production scale in manufacturing.

Meanwhile, the forward industrial chain increases India's export-related emissions embodied in intermediate products during 2000-2014, especially in 2003-2008. This is due to India deeply integrating into the world economy and there being more intermediate products imported from India when producing unitary good abroad. However, the increasing effects of the forward industrial chain are weak during 2008-2011 and 2011-2014 because of economic adjustment, though the reasons for them are different. The former is due to the rise of trade protectionism worldwide aroused by the international financial crisis, especially during 2008-2009 (Kumar, 2009; Subbarao, 2009) and the latter is due to the expansion of domestic demands aroused by India's new economic growth model. Each of those two reasons will lead to the decreasing effect of India's forward industrial chain due to the declining export scale in intermediate products. Furthermore, the domestic industrial chain of other countries invariably has an increasing effect on India's export-related emissions embodied in intermediate products during 2000-2014 due to frequent commercial intercourse among them, but the volume are small (12.5 Mt). Notably, India's domestic consumption emissions embodied in intermediate products are very small (Wang et al., 2018), and as a result we do not consider them here.

3.4 Changing Structure of Final Demand in India

The decreasing effect of consumption structure on India's domestic consumption emissions continuously weakens (from 24.1 Mt in 2000-2003 to 10.8 Mt in 2008-2011) during 2000-2011 and finally transfers to an increasing effect during 2011-2014 (**Figure 2a**). This manifested with the products consumed in India moving in a carbon-intensive direction due to Indian rapid urbanization and industrialization (Meng et al., 2018).

As the biggest ascender, capital investment contributes by 59.4 Mt of India's domestic consumption emissions during 2000-2003, which rapidly increase to 175.0 Mt during 2003-2008 (**Figure 5**), and the proportion of heavy industry and construction together decrease by 14.1% (from 83.9% in 2000-2003 to 69.8% in 2003-2008), as well as the share of light industry increasing by 17.5% (from 9.7% in 2000-2003 to 27.2% in 2003-2008). This is due to India's higher unemployment rate in 2003 and increasing investment in light industries as well as the labor-intensive industries (e.g. furniture and rubber products), which can support many jobs and reduce unemployment. The investment scale of light industry expands 4.8 times during 2003-2008 compares with that during 2000-2003. However, capital investment retreats to second place during 2008-2011 due to the foreign direct investment (FDI) decreasing by 30.1 billion dollars compares with that during 2003-2008 and aroused by the international financial crisis, although India's government proposes some stimulus plans to expand domestic investment. Notably, the proportion of heavy industry and construction together rapidly increases to 92.0% in this period, and aims to offset the impact of the financial crisis on real economy and accelerate the pace of the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), which brings about the rapid development of real estate and its supporting facilities (e.g. railways and highways). Furthermore, the increasing effect of capital investment is weak during 2011-2014 due to the investment in India sharply decreasing by 23.0 billion dollars from 2011 to 2014. This is due to the following two reasons: (i) that government is unable to provide sustained investment subsidies due to its serious fiscal deficit because of more than 4.0 billion dollars of economic stimulus plans (e.g. reducing taxes and increasing subsides) during the period of financial crisis (Ram, 2008); and

(ii) the serious shortage of funds in enterprises due to its huge pre-investment and inability to recover the costs in the short term. Additionally, some subsidies (e.g. petrol and electricity) are reluctantly abolished to balance government deficits.

Furthermore, another important ascender of domestic consumption emissions is household consumption during 2003-2008, which becomes the primary force during 2008-2011. This is due to India's economy is driven by household consumption after the financial crisis as the result of the vulnerable industrial strength in India failing to support massive infrastructure construction and undertake the responsibility of restoring the economy (Kumar et al., 2010; Bajpai, 2011). Notably, the proportion of transportation and heavy industry in household consumption rises rapidly during 2008-2011 due to the decreasing commodity transaction taxes and expanding subsidies on durables (Murthy, 2009). For example, the scale of new cars brought by residents during 2008-2011 is 1.5 times than that during 2003-2008. In addition, the leadership of household consumption is more obvious during 2011-2014 and the proportion of electricity has a rapid increase, due to the improvement of the national grid in India and with more rural residents having access to electricity.

3.5 India's Change as a Trade Hub

The export structure has a decreasing effect (6.8 Mt) on India's export-related emissions during 2000-2011. However, this effect is weak from 2003-2008 (5.1 Mt) to 2008-2011 (1.4 Mt) and finally transfers to an increasing effect (0.7 Mt) during 2011-2014 (**Figure 2c**). This indicates that exports gradually concentrate on emission-intensive products. In detail, the increasing heavy industry in final products is small (8.9 Mt) during 2000-2008, then rapidly increases to 10.1 Mt in 2008-2011 and 12.7 Mt in 2011-2014, with 54.1% and 74.3% of them focus on transport equipment, respectively (**Figure 6**). This is due to India encouraging the development in manufacture of transport equipment by giving more preferential loans and tax incentives in export-oriented enterprises after the financial crisis (Joseph, 2009; Bajpai, 2011). Meanwhile, light industry in final products has a rapid increase (24.0 Mt) during 2008-2014, and 61.8% of which are focus on food and textiles. In contrast to that, the increasing emissions of services in final products have a rapid atrophy during 2008-2011 and even transfer to negative during 2011-2014, with 70.9% of them focus on information activities. This is due to the services not being able to support adequate employment for vast numbers of low-quality workers and diminish the higher unemployment rate aroused by the financial crisis. It also reflects that the service-oriented economic growth pattern in India is unsustainable and its ability to resist economic fluctuations is limited. In addition, the construction and heavy industry in intermediate products sharply rise during 2003-2008 and then see a rapid decrease in 2008-2011, which is contrary with that in final products. This is due to the rapid development of industry in India with a large number of intermediate products being used in the domestic production stage. Meanwhile, construction and heavy industry return to the expressway during 2011-2014 due to the enhancement of industrial production capacity in India. The services in intermediate products have a rapid atrophy after the financial crisis. In short, India's export structure obviously transfers from services to industries (especially heavy industry) and constructions after 2008 with the financial crisis prompting India to change its economic growth model and promote its economic reform process.

Furthermore, the consumption structure has an increasing effect (9.8%) on India's import-related emissions during 2003-2008 (**Figure 2b**), however, its effect is weak (6.4%) during 2008-2011 and even transfers to negative during 2011-2014. This illustrates that India's imports transfer to low-carbon products after the financial crisis. In detail, light industry and heavy industry are the major contributors of India's import-related emissions embodied in final products during 2000-2008. However, the share of heavy industry decreases to 14.8% during 2008-2011 due to India's trade protectionism after the financial crisis to encourage the development of domestic-related industries. For example, the import tariffs of steel and zinc increase by 10% and 5% in this period, respectively (IPCC, 2007; Kumar, 2009). Meanwhile, imports in light industry show a sharp increase (23.1 Mt) in this period due to most of them focus on daily necessities (e.g. textiles and foods). Their demands are further expanded by India's government lowering prices and declining the Central Value Added Taxes (CENVAT) (Kumar et al., 2010) and the volume of India's residents spend on imports increasing by 4.7 billion dollars in this period, 38.1% of which focus on light industry. Meanwhile, heavy industry, construction and light industry are responsible for India's increasing import-related emissions embodied in intermediate products during 2000-2011 due to the rapid development of infrastructures in India (Meng et al., 2018). Notably, the import-related emissions embodied in final and intermediate products have a rapid decline during 2011-2014, mainly due to the decreasing import scale, in which household consumption and capital investment decrease by 4.4 and 16.5 billion dollars, respectively. Meanwhile, the implementation of India's manufacturing revitalization plan reflects that India can support more intermediate and final products for domestic demands, which are previously imported from abroad.

3.6 National Contribution of the Changes in India's Trade-related Emissions

From the export perspective, the consumption in developing countries is the major contributor (77.7%) of India's increasing export-related emissions during 2000-2014 (**Figure 7a**). Their share has a rising trend during 2000-2011, in which the contribution of China rapidly decreases to 6.4% during 2003-2008 due to China's imports focus on construction and low-tech heavy industry, both of which are replaced by domestic goods at a time of its improving industrial level (Minx et al., 2011). Meanwhile, the contribution of China has a small increase (10.7%) during 2008-2011 due to its enormous demands aroused by the 4 trillion yuan investment to stimulate economic growth (Zheng et al., 2009). Notably, the contribution of other developing countries (excluding China and Russia) shows a significant decrease during 2011-2014 due to their improving capacity of self-sufficiency (IMF, 2015). In contrast, the share of developed countries continuously decreases from 19.7% to 15.0% during 2000-2011, in which the contribution of the European Union has a major increase (17.9%) during 2003-2008 due to the expanding demands (especially service activities) aroused by a booming economy. However, its share is very small (0.3%) during 2008-2011 due to the serious influence of the European debt crisis, which leads to its GDP decreasing by 4.1% in this period. On the contrary, the economy in the United States achieves a swift recovery and its GDP increases by 5.4% at the same time. Therefore, the contribution of the United States increases by 10.3% during 2008-2011, and notably, the share of developed countries increases to 35.0% during 2011-2014, 36.9% and 36.0% of which focus on heavy industry (e.g. motor vehicles) and light industry (e.g. textiles and leathers), respectively. This is due to the developed countries riding themselves of the adverse influence of the financial crisis and realizing high-speed economic growth.

From the import perspective, most of the changes in India's import-related emissions are contributed by developing countries during 2000-2014 (**Figure 7b**), and the share increases from 80.8% to 93.2% continuously during 2000-2011. This is due to India's rapid development of construction with a significant amount of the increasing imports focused on light industry (e.g. textiles and furniture) and low-tech heavy industry (e.g. steel and cement), both of which are the leading products exported by developing countries (especially China (Meng et al., 2018; Mi et al., 2018)). Notably, China has a smaller contribution on decreasing India's import-related emissions during 2011-2014 than that of an increasing one during 2000-2011 due to most of the products imported from China with lower price and strong market competitiveness (IMF, 2009). In contrast, the contribution of developed countries in increasing India's import-related emissions has a continuous decrease during 2000-2011 (from 19.2% in 2000-2003 to 6.8% in 2008-2011) due to their cleaner production technology and continuously upgrading of the industrial chain. Meanwhile, most of the products exported by developed countries focus on high-tech ones (e.g. electronic device and mechanical equipment), which will see the emergence of a mismatch with the real demands in India to some degree, and their imports are limited. Therefore, the proportion of the contribution of developed countries decreases much faster during 2011-2014 compares with their increasing contribution during 2008-2011 and the dominant role of developing countries is further clear.

4 Conclusions and Policy Implications

4.1 Conclusions

In this paper, we investigate the contributions of seven major factors (including emission coefficient, energy structure, energy intensity, industrial chains, consumption structure, per capita consumption and population) on the changes in India's production- and consumption-based emissions during 2000-2014 by using the multi-regional input-output analysis and structural decomposition analysis. Meanwhile, we further decompose the global industrial chain into four parts (including the domestic industrial chain of India, the forward industrial chain of India, the backward industrial chain of India and the domestic industrial chain of other countries). The new findings can be summarized as follows:

(1) The major contributor of increasing consumption-based emissions in India is per capita final consumption, however, its contribution declines after the financial crisis. Meanwhile, population is another driver in pushing India's consumption-based emissions upwards.

(2) Energy structure has negative effect on increasing India's production-based emissions during 2000-2008 and then transfers to positive effect during 2008-2014. Meanwhile, coal proportion holds decreasing effect during 2000-2003 and subsequently transfers to increasing effect. In addition, energy intensity has a negative effect on increasing India's production-based emissions during 2000-2003, then transfers to positive effect during 2003-2014, especially in the electricity sector.

(3) The global industrial chain has positive effect on increasing India's production-based emissions during 2000-2003 and transfers to negative effect during 2003-2011, then returns to positive effect during 2011-2014. 78.7% of the emission changes are aroused by India's domestic industrial chain, especially the emissions embodied in final products (90.5%). Meanwhile, India's forward industrial chain has a continuous positive influence on increasing India's export-related emissions embodied in intermediate products during 2000-2014, and the domestic industrial chain of other countries constantly has small positive effect on pushing India's export-related emissions embodied in intermediate products upwards.

(4) Capital investment and household consumption are the major contributor of India's increasing consumption-based emissions, and the major contributor transfers from capital investment to household consumption after the international financial crisis. Meanwhile, the capital investment structure focuses on light industries during 2003-2008 and then transfers to heavy industries during 2008-2011. The household consumption structure focuses on low-carbon products during 2003-2011 and then transfers to high-carbon products during 2011-2014.

(5) India's export-related emissions gradually transfer to constructions and heavy industries, and the share of services has a rapid decrease, especially in 2011-2014. Meanwhile, India's import-related emissions embodied in final products generally transfer to light industries and the intermediate products transfer to heavy industries and constructions.

Furthermore, the prominent role of developed countries in increasing India's export-related emissions is further clear during 2011-2014, and the share of developing countries in India's increasing import-related emissions continues to rise during 2000-2014.

4.2 Policy Implications

(1) Upgrading the industrial chain in India is a significant way to reduce its production-based emissions (**Figure 2a and 2c**) by adjusting industrial structure. Services (e.g. information and software) are the protagonist of the modern economy with high added values and low emissions. However, it is unrealistic for India to quickly realize a complete service-oriented economy (e.g. the United States) due to its population characteristics with large-scale and low-skilled labors, which endogenously determines that it is the golden opportunity for India to vigorously develop the labor-intensive manufacturing industry (e.g. leathers and textiles) to eradicate mass poverty and then reduce government subsidies for paupers to reserve sufficient funds for infrastructure construction (e.g. electricity and road) to satisfy the basic conditions for large-scale industrial development. However, the prosperity of low-tech manufacturing industry is always accompanied by huge emissions (Sadavarte et al., 2014). Therefore, the feasible pathway is employing the carbon trading market to tighten India's domestic emission quota step by step and encourage manufacturing enterprises to apply energy-saving equipment in their production progress through self-researching or importing low-carbon technology. Services are the irresistible trend of industrial restructuring and it is meaningful for India to encourage enterprises to acquire their core technology through independent innovation to improve energy efficiency of services and avoid the lock-in status aroused by excessively undertaking the service outsourcing business at present. Meanwhile, many India's export-related emissions flow to developed countries in recent years (**Figure 7a**) and the implementation of India's pledge in the Paris Agreement heavily depends on climate finance and technology transfer from developed countries (Atteridge et al., 2009). Therefore, India can strive for advanced low-carbon technology and financial assistance from developed economies (e.g. the European Union and the United States) through the Clean Development Mechanism (CDM) to narrow the technology gap of clean production as quickly as possible and avert unnecessary emissions.

(2) Decreasing the proportion of coal in the energy mix can effectively curb the excessive increase of emissions emitted by India (**Figure 3a**). However, it is difficult for India to thoroughly change the coal-dominated energy structure in the short-term due to the rich reserves and low price of coal in India, but the quota of non-fossil energy (e.g. solar and nuclear) can be carried out in the major energy consumption sectors (e.g. electricity). Therefore, the priority for India is in encouraging the exploitation of renewable energy through providing subsidies and concessionary loans for enterprises, as well as continuously reducing the cost of utilization in renewable energy by promoting Indian self-innovation of related technology. In addition, increasing energy efficiency is another outlet for the decline of India's production-based emissions, especially in electricity (**Figure 3c**). About 16.3% or 210 million of India's population not access to electricity in 2014 (Timperley, 2019), and establishing the national smart grid is a better choice for India to improve the overall energy efficiency of the power system, which can be divided into three parts: namely generation, transmission and distribution. For the generation part, the major assignment is realizing the marketization of electrovalence to motivate electric companies to gradually replace outdated thermal power plants with more advanced ones (e.g. ultra-supercritical units), which can be imported from China under the cooperative framework of the Belt and Road Initiative. Meanwhile, prohibiting the off-grid power devices such as diesel engines in the marginal and populous areas by guaranteeing the electricity supply, covers the whole territory of India. In addition, improving the compatibility of the national grid to balance the continuous changes

in renewable power plants (e.g. wind and solar) helps realize the diversification of electricity generation. For the transmission and distribution parts, gradually upgrading obsolete electric wires and utilizing the superior transfer technology (e.g. ultra-high voltage direct current) to decrease the loss rate has a positive impact.

(3) Household consumption is the major ascender of Indian consumption-based emissions after the international financial crisis (**Figure 5**). However, it is unrealistic for India to decline the emissions through limiting consumption, about 21% or 270 million of India's population lived below the international poverty line (1.9 dollars per day) in 2014 and increasing per capita consumption scale is the precondition for residents to improve material and cultural living standards. Meanwhile, India's per capita emissions are 1.7 Mt in 2014, which are much lower than that of the United States (16.5 Mt) and the European Union (6.4 Mt) (Bank, 2019). Therefore, it is logical and reasonable for developed economies to moderately decrease their excessive consumption to compensate for the affluence increase in India (Parikh et al., 1994; Muradian et al., 2001) and maintain the fairness of emission mitigation responsibility (Hyder, 1992; Parikh, 1992). In addition, the emission intensity of household consumption in India is 1.9 Mt per thousand dollars in 2014, which is about four and six times than that in the United States (0.5 Mt per thousand dollars) and the European Union (0.3 Mt per thousand dollars), respectively. This means that India's household consumption generally focuses on low-quality and carbon-intensive products when coming out of poverty, though India's emission intensity of household consumption is still much higher than those in western countries. Therefore, other than the measures from the production side, it is a feasible plan for India to decrease emission intensity of household consumption through supporting the moderate government subsidy and preferential taxation for low-income households on low-carbon appliances (e.g. energy-efficient television and LED light), which are accredited by the Indian Bureau of Energy Efficiency. Furthermore, there is a big gap in the income of Indian residents and the Gini coefficient of India is about 0.36 in 2014 (Bank, 2019), however, most of the consumption-based emissions are contributed by high-income households (Hubacek et al., 2017; Wiedenhofer et al., 2017). Therefore, a wise economic strategy for India is to moderately curb the excessive consumption in wealthy households through increasing the personal income tax and commodity tax on luxury goods. Meanwhile, about 22.7% of the increasing emissions aroused by household consumption are contributed by transportation during 2011-2014 with rising incomes in residents (**Figure 5**). However, the share in cumulative registered vehicles of electric cars is about 1% in this period (Shukla et al., 2014). Therefore, culturing the low-carbon consumption patterns and encouraging residents to use the buses and subways to replace gasoline cars in the personal commutes can be potential pathways to mitigate India's consumption-based emissions. Furthermore, transportation will be a major source in pushing India's production-based emissions upwards by consuming a lot of oil. Therefore, increasing the government subsidies for new energy automobiles will be a better choice for India to reduce its territorial emissions. In addition, the urbanization rate (proportion of urban population) of India is still low (32.4% in 2014), and capital investment will inevitably play an important role in propelling India's consumption-based emissions upwards in the next decades due to the rapid and irresistible process of urbanization in India, despite its contribution on increasing emissions being weak in the last few years (**Figure 5**). Therefore, a critical step to decline emissions is realizing the green supply chain in the lifecycle of investment in construction by issuing the strict low-carbon standardization of building material and equipment.

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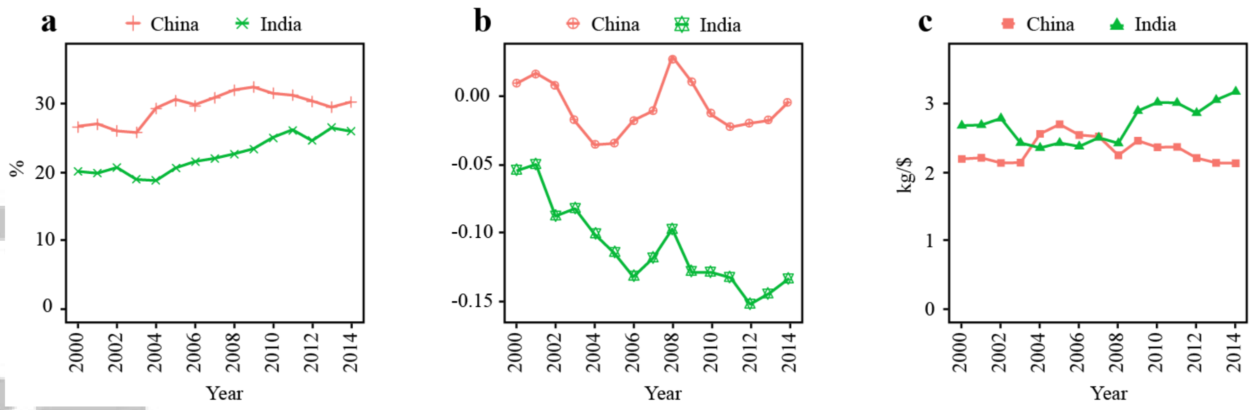

Figure 1. Comparison of manufacturing industry between India and China. **a** represents the share of emissions emitted by manufacturing industry. **b** represents the position index in global value chain of manufacturing industry. **c** represents the emissions acquired unitary added value in manufacturing industry. The data is calculated by the authors.

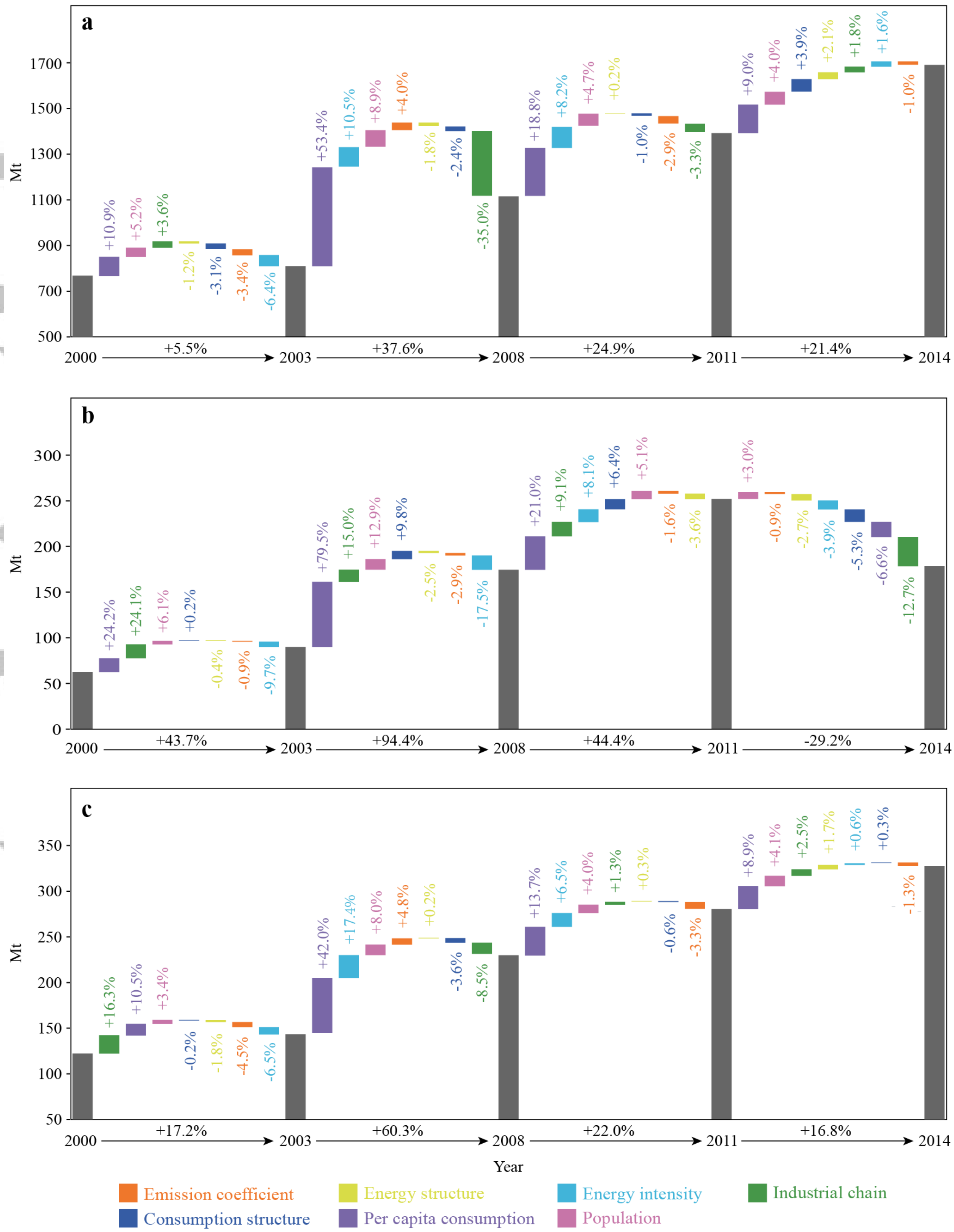

Figure 2. Contributions of socio-economic factors to changes in emissions embodied in India's domestic consumption (**a**), import (**b**) and export (**c**).

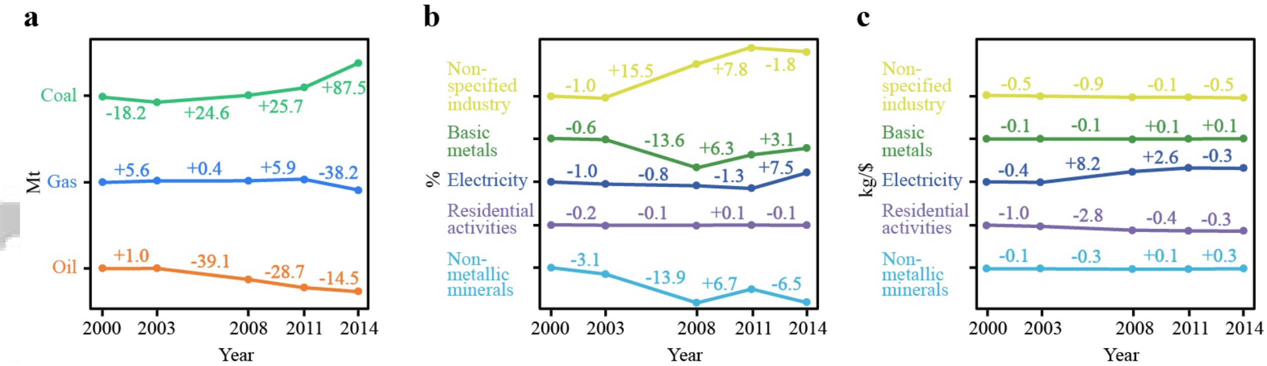

Figure 3. a represents the contribution of each energy structure to India's production-based emissions. **b** and **c** represent the changes of coal proportion and energy intensity in major sectors, which together consume 98.4% of coal in India during 2000-2014.

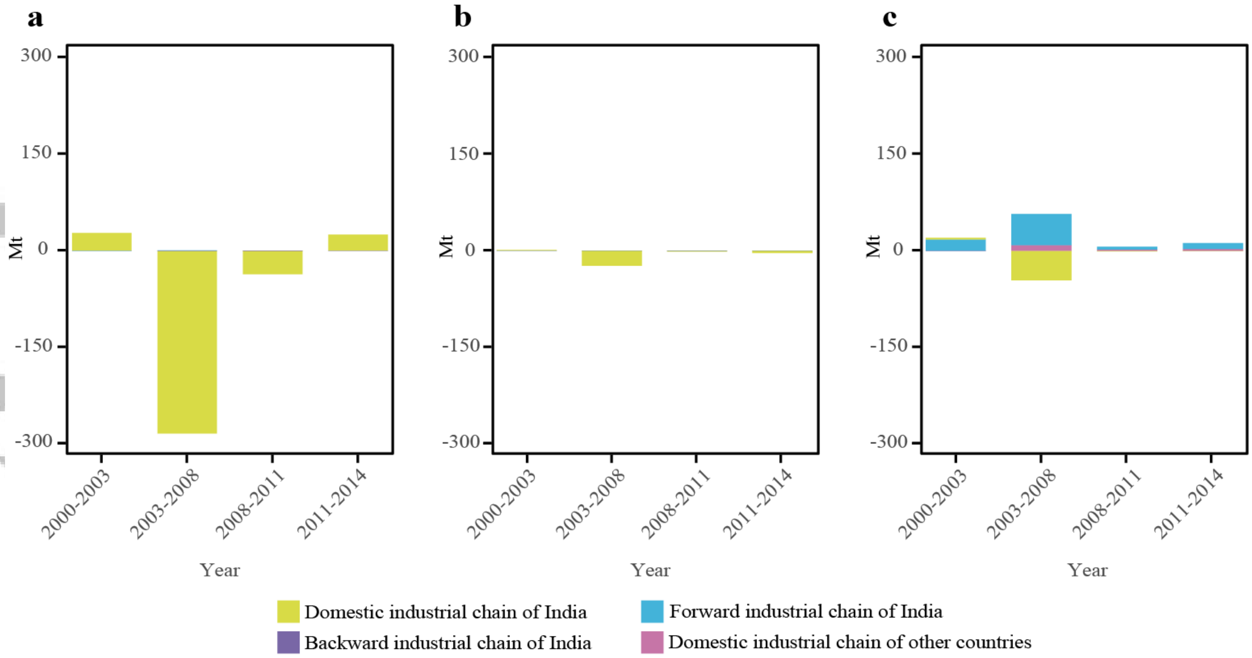

Figure 4. Contributions of industrial chains to changes in India's domestic consumption emissions embodied in final products (**a**) and export-related emissions embodied in final (**b**) and intermediate (**c**) products during 2000-2014. For more detailed information about the annual changes, please see SI Figure S1.

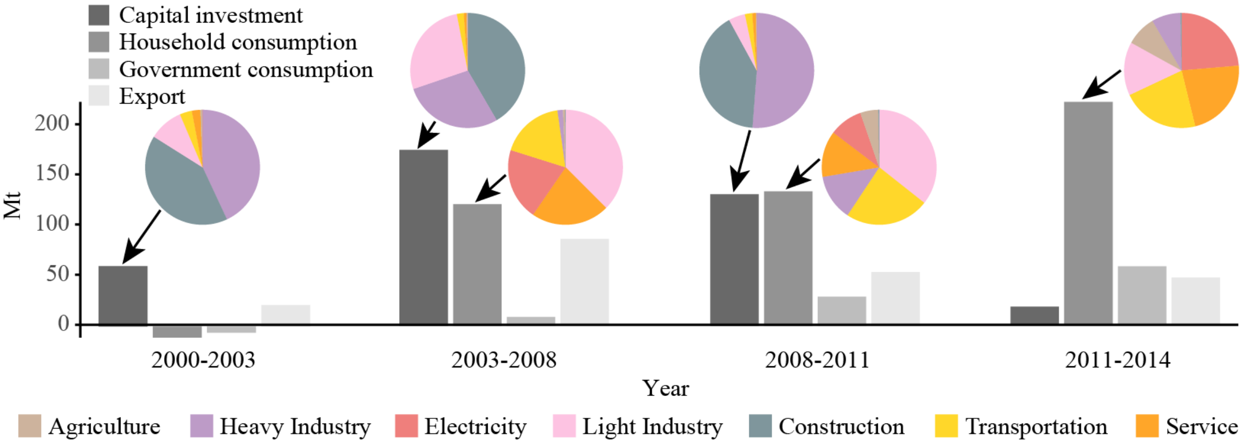

Figure 5. Bars represent the contributions of different final consumers (including export, household, government and capital investment, which is the sum of fixed capital formation and inventory) in the changes of India's production-based emissions. Pies show the sector distribution of the emission changes. For more detailed information about the aggregated sectors, please see SI Table S1.

Figure 6. Contributions of aggregated sectors in the changes of India's export- and import-related emissions embodied in final and intermediate products, respectively.

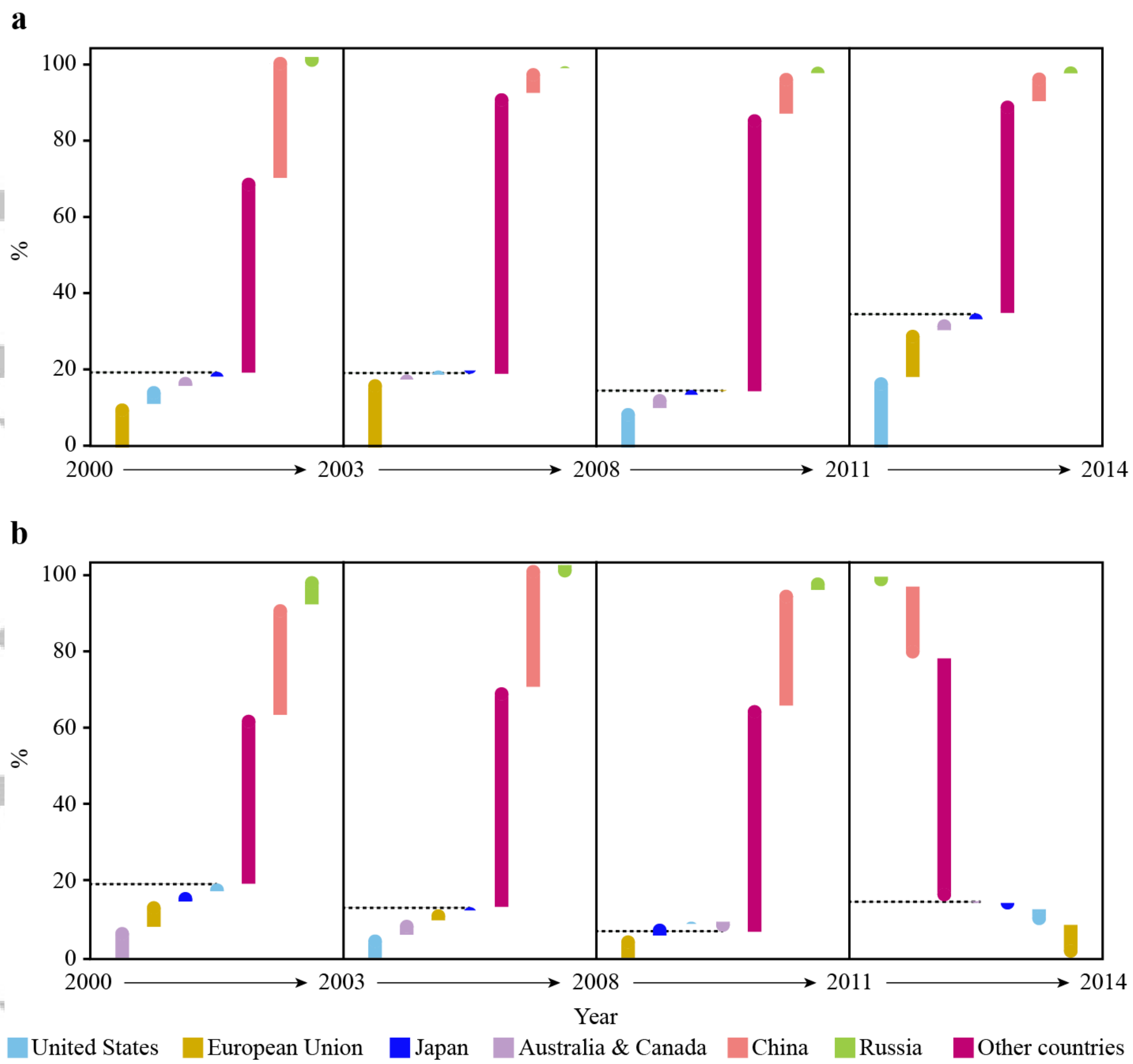

Figure 7. a and **b** represent country shares in the changes of India's export- and import-related emissions, respectively. Notably, the developed countries and regions included the United States, Japan, Australia, Canada and the European Union; the developing countries included China, Russia and others. The horizontal black dotted lines represent the percentage of developed countries and regions.

Table 1. Framework for Investigating the Determinants of India's Emission Changes.

Agglomerative factors	Detailed factors	Description
Emission intensity (**D**)	Emission coefficient (**G**)	Capacity of emissions unitary energy.
	Energy structure (**H**)	Proportion of energy categories, which include coal, oil, natural gas and non-fossil fuels.
	Energy intensity (**K**)	Quantity of energy consumption unitary output.
Industrial chain (**A**)	Domestic industrial chain of country p (a_{ij}^{pp})	Matrix **A** contains only the common element in rows and cols of country p, with zeros elsewhere.
	Forward industrial chain of country p ($a_{ij(q\neq p)}^{pq}$)	Matrix **A** contains only the element in rows of country p, with zeros in cols of country p and elsewhere.
	Backward industrial chain of country p ($a_{ij(q\neq p)}^{qp}$)	Matrix **A** contains only the element in cols of country p, with zeros in rows of country p and elsewhere.
	Domestic industrial chain of countries that do not direct trade with country p ($a_{ij(q\neq p)}^{qq}$)	Matrix **A** with zeros in rows and cols of country p.
Final consumption (**Y**)	Consumption structure (**S**)	Proportion of each goods, which are consumed finally by household, government, fixed capital formation and inventory.
	Per capita consumption (**V**)	Consumption of household, government, fixed capital formation and inventory in each person.
	Population (**C**)	Quantity of population.

Note: The letters in parentheses represent the abbreviations for each determinant.