Chapter 11
Proximate Causes of Worldwide Mega-Regional CO_2 Emission Changes, 1995–2009

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Abstract Evidence suggests that climate change is real and accelerating. This has led to a great deal of research on improving energy efficiency and reducing per capita energy consumption, as well as on the sources of air polluting emissions such as carbon, and possible policy options for limiting permanent environmental damage. The top regions in the world in terms of these carbon emissions are China, the United States, the European Union, India, Russia, and Japan. This chapter uses the World Input-Output Database (WIOD) and structural decomposition analysis to determine for these six countries and regions whether observed improvements in energy intensity and carbon dioxide emissions are due to the adoption of new energy technology or changes in trade relationships, final demand structures, or other structural economic changes.

Keywords Global climate change · Mega-regional carbon emissions · Energy and the environment · Structural decomposition analysis

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11.1 Introduction

Evidence suggests that climate change is real and accelerating. This evidence is based largely upon global surface temperature readings from around the world dating back to 1850 (Brohan et al. 2006). The increases in global temperature since the advent of the industrial revolution are unequivocally and directly a result of the addition of greenhouse gasses such as CO_2 to the atmosphere (Masson-Delmotte et al. 2018; Petit et al. 1999; Ramanathan 1988). The expectation of future climatic effects attributable to additional greenhouse gasses in the atmosphere has led to a great deal of research in areas centered around improving energy efficiency (Kangas et al. 2018; Brown et al. 2017; Zhang et al. 2017a), reducing per capita energy consumption (Chen et al. 2014; Ozan et al. 2011; Steinberger et al. 2009; Haynes et al. 1993), the sources of air polluting emissions such as carbon (Peters et al. 2011; Hertwich and Peters 2009; Wiedmann et al. 2007; Turner et al. 2007), and possible policy and other options for limiting permanent environmental damage (Minx et al. 2018; Moss et al. 2010; Hallegatte 2009; Haynes et al. 1997).

The top mega-regions in the world in terms of these carbon emissions are the United States, the European Union, India, Russia, Japan, and China. Figure 11.1 depicts the relative magnitudes and trends in CO_2 emissions among these regions from 1974 through 2014. The category "rest of Asia" here includes India and Russia, as well as a host of other relatively minor CO_2 contributors such as Iran, Saudi Arabia, Korea, Indonesia, Malaysia, and Vietnam. The relative CO_2 contributions of the United States and the European Union have steadily declined; Japan along with the "rest of the world" has slightly declined; and both China and the "rest of Asia" have significantly increased.

Figure 11.2 depicts CO_2 emissions among countries within Asia over the past two decades. Japanese and Russian emissions have remained more-or-less constant. Indian emissions have been slowly trending upward. Emissions from the "rest of Asia" region have increased considerably, and those from China have approximately tripled over this period. Figure 11.3 shows Chinese emissions relative to those from

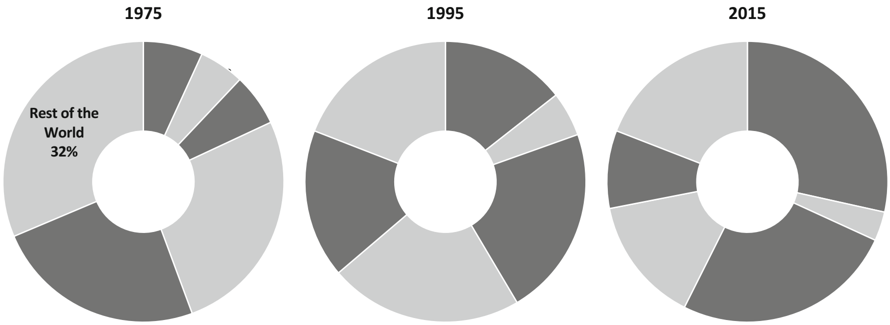

Fig. 11.1 Relative magnitudes and trends in regional CO_2 emissions

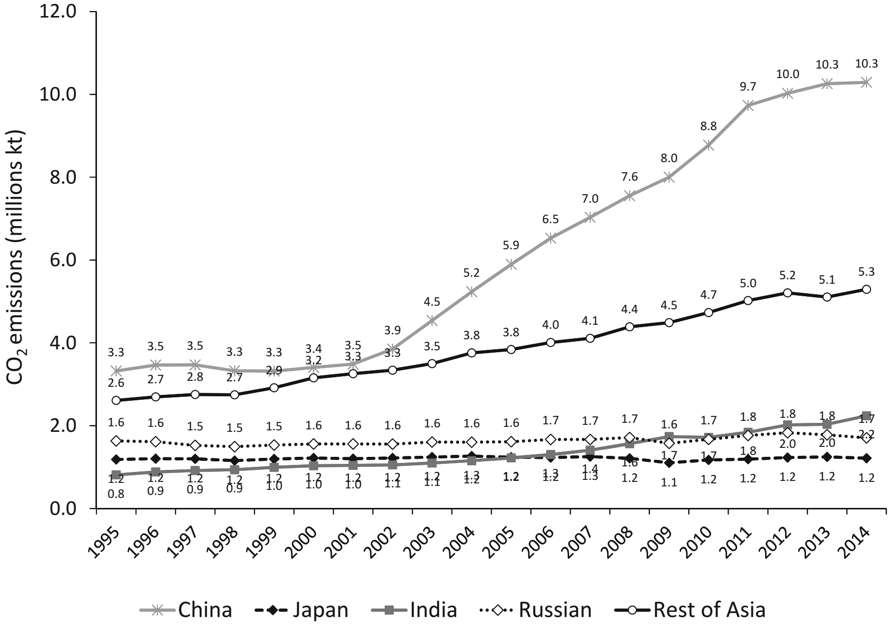

Fig. 11.2 CO_2 Emissions (millions kt) – Asia

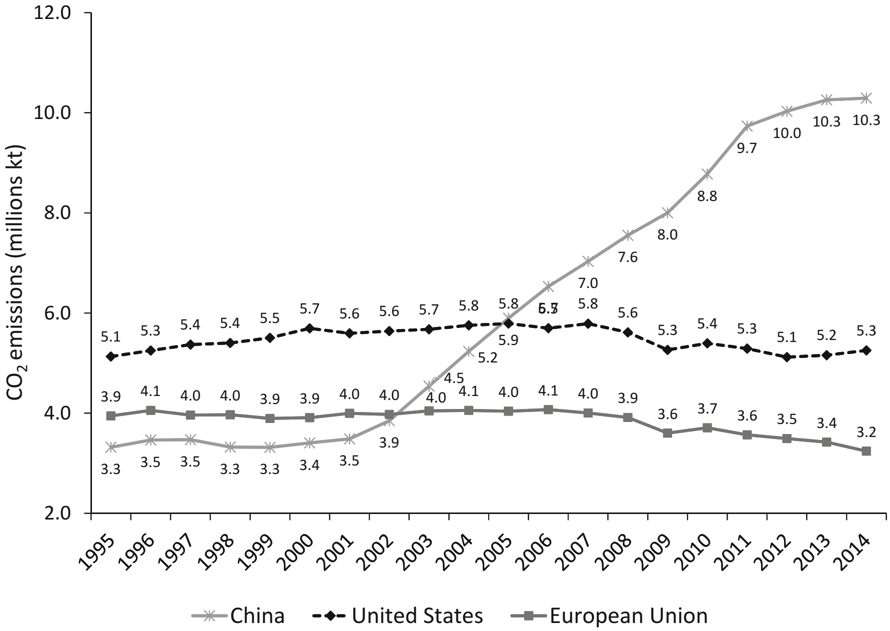

Fig. 11.3 CO_2 Emissions (millions kt) – China, United States and European Union

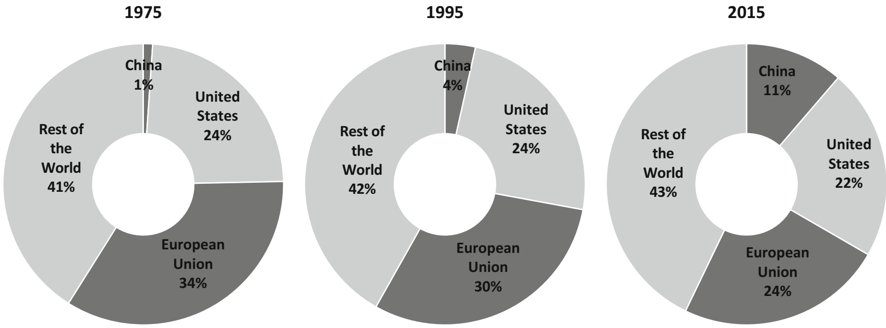

Fig. 11.4 Relative Magnitudes and Trends in Regional GDP

the United States and the European Union. Clearly, the most rapidly increasing worldwide CO_2 emissions among major emitters are Chinese.

China's rapidly expanding urban areas and booming economy have been major drivers behind its quickly increasing CO_2 emissions. Between 1980 and 2012, the percentage of China's population living in urban areas grew from 19.4% to 52.6% (Yang 2013) and on to 58% today and rising. While rapid urbanization has precipitated massive economic growth, at the same time, it has greatly increased mass production and consumption of industrial products, triggered a range of environmental problems, and brought proposals for new types of urbanization (Qu and Long 2018; Wang et al. 2015). Figure 11.4 provides insight into the economic trends: China grew from 1% of the world's GDP in 1975 to 4% in 1995 to 11% in 2014. Recent proposals for new forms of urbanization, slowing economic growth and decreases in energy intensity, all promise to help countervail against the trend toward increasing emissions (Meng et al. 2018). Figure 11.5 depicts these decreases in the rate of growth of the Chinese economy and shows them relative to growth in the United States and the European Union.

This chapter follows an established body of research in regional science and development. Its focus is on energy and the environment, a research area in which Kingsley Haynes has had a long-standing interest (Haynes 1984; Haynes et al. 1977). It uses the World Input-Output Database (WIOD) and structural decomposition analysis (SDA) to help gather insight into the proximate causes of change in various indirect environmental costs, such as those embodied in CO_2. Among other related applications, it has been used to evaluate the environmental costs of European Union membership (Araújo et al. 2018); identify factors and sectors that affect production-source CO_2 emissions in China (Chang and Lahr 2016); help understand the effects of changes in trade patterns on global CO_2 emissions growth (Hoekstra et al. 2016); examine the worldwide shifting of emission-intensive production across borders (Malik and Lan 2016); understand the drivers of change in China's energy intensity and energy consumption (Zhang and Lahr 2014); provide an overview of the origin and destination of pollution in the Dutch economy (De Hann 2001); quantify the economic factors driving greenhouse gas emissions

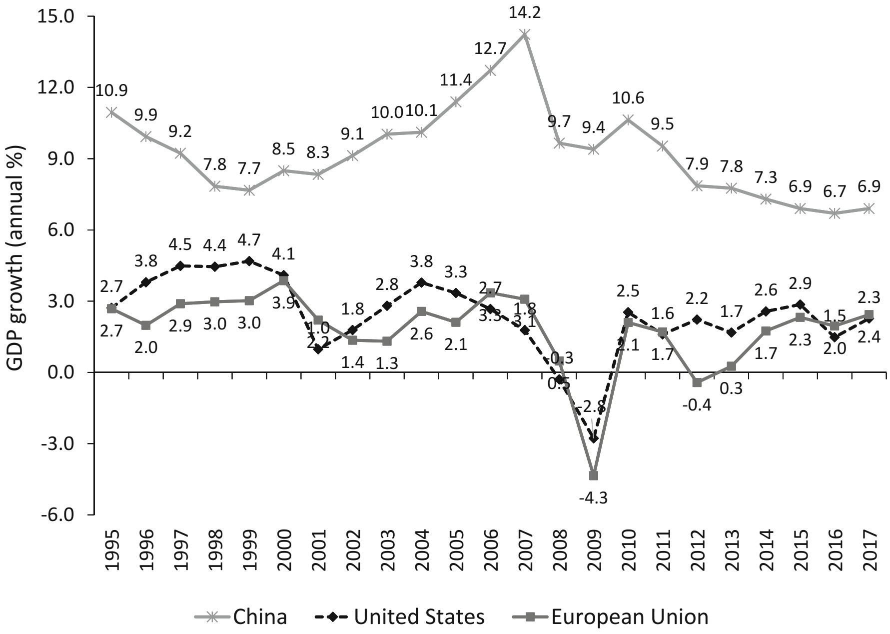

Fig. 11.5 Gross domestic product (GDP) growth (annual %)

in Norway (Yamakawa and Peters 2011); and explore the anatomy of Danish energy consumption and emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x) (Wier 1998). Here it is used to examine the aforementioned six regions to determine whether observed changes in CO_2 emissions are due to (a) the adoption of new energy technology or (b) changes in trade relationships, final demand structures, or other structural economic changes.

Therefore, the aim of this chapter is to decompose the change in level of CO_2 emissions in the top mega-regions in the world between 1995 and 2009 into six explanatory components. By doing so, we are able to quantify the proximate causes of these changes in CO_2 emissions and how they differ between the mega-regions which differ in terms of economic development. The remaining of the chapter is as follows: Sect. 11.2 describes the methodology and data; Sect. 11.3 presents and discusses the results; and Sect. 11.4 concludes the chapter.

11.2 Methodology and Data

The decomposition of CO_2 emissions growth starts with the basic interregional input-output model (Miller and Blair 2009). The solution of this model, with *I* sectors and *R* countries, may be summarized as:

$$\mathbf{s} = \widehat{\mathbf{e}}\mathbf{x} = \widehat{\mathbf{e}}\mathbf{L}\mathbf{f} \tag{11.1}$$

where **s** is an *IR* vector with total emissions directly and indirectly required to satisfy final demand per sector *i*, per country *r*, and $\widehat{\mathbf{e}}$ is the diagonal matrix vector **e** of emission intensity, i.e., the amount of CO_2 emission per unit of output *i*. **L** is the *IR* x *IR* interregional Leontief inverse. **f** is an *IR* vector with final demand for products from sector *i* in country *r*.

We follow Oosterhaven and Van Der Linden (1997) and Hoekstra et al. (2016) to distinguish trade and technology changes, both for intermediate and for final demand. Hence, instead of the basic interregional model of Eq. (11.1), we want to decompose the following extension of the basic model:

$$\mathbf{s} = \widehat{\mathbf{e}}\mathbf{L}\mathbf{G}\mathbf{y} = \widehat{\mathbf{e}}(\mathbf{I} - \mathbf{C}\circ\mathbf{A}^{*})^{-1}(\mathbf{F}\circ\mathbf{B})\mathbf{y} \tag{11.2}$$

where **I** is an $IR \times IR$ identity matrix. **A** is the matrix of technical coefficients decomposed into $\mathbf{A} = (\mathbf{C} \circ \mathbf{A}^{*})$. **C** is an $IR \times IR$ matrix of trade coefficients ($c_{ij}^{rs} = z_{ij}^{rs}/z_{ij}^{*}$), where z_{ij}^{*} is the total input requirements of industry *j* for input of industry *i* in country *r*, indicating which fraction of this intermediate demand for (worldwide) products *i* (exercised by sector *j* in country *s*) is actually satisfied by supply from country *r*. $\boldsymbol{A}^{*}$ is an $IR \times IR$ matrix, built up of *R* mutually identical $I \times IR$ matrices with technical coefficients ($a_{ij}^{\prime s}$), indicating the total need for products from (worldwide) sector *i*, per unit of output of sector *j* in country *s*. $\mathbf{G} = (\mathbf{F} \circ \mathbf{B})$ where **F** is an $IR \times R$ matrix with trade coefficients (f_{ij}^{rs}), which capture the trade coefficients for the final demand, and is created following the same steps presented for **C**, indicating which fraction of this final demand for (worldwide) products *i* in country *s* is actually satisfied by sector *i* from country *r*. **B** is an $IR \times R$ matrix, built up of *R* mutually identical $I \times R$ matrices with final demand composition or preference coefficients (b_i^s) indicating the total need for products from (worldwide) sector *i*, per unit of final demand in country *s*. **y** is a *R* column with the final demand, i.e., consumption, level, per country *s*. $\circ$ is the Hadamard product, i.e., cell-by-cell multiplication.

The changes in **s** can be decomposed into different components using SDA.

11.2.1 Structural Decomposition Analysis

SDA is a major tool for distinguishing shifts in the growth in some variable over time and separating the changes in its constituent parts. The use of structural decomposition techniques allows us to quantify, analyze, and gather insight into the underlying sources of change in a wide variety of variables (Dietzenbacher and Los 1998).

In SDA, the effect of $\Delta\widehat{\mathbf{e}}$ on $\Delta\mathbf{s}$ in Eq. (11.2) represents the first component that relates to sectoral technology changes. The second sectoral technology component is derived from the change in the interregional Leontief inverse. We follow

Oosterhaven and Van Der Linden (1997) to separate the technological component from the trade component in ΔL. Therefore, the interregional input-output coefficients are decomposed into a trade part and a technical part, as follows:

$$\Delta \mathbf{L} = \mathbf{L}_1 - \mathbf{L}_0 = \mathbf{L}_1 \Delta(\mathbf{C} \circ \mathbf{A}^*)\mathbf{L}_0 \tag{11.3}$$

Pre- and post-multiplying Eq. (11.3) for $(\mathbf{I} - \mathbf{A}_1)$ and $(\mathbf{I} - \mathbf{A_0})$:

$$\Delta \mathbf{L} = \mathbf{L}_1 \left(\mathbf{C}_{1/2} \circ \Delta \mathbf{A}^*\right)\mathbf{L}_0 + \mathbf{L}_1 \left(\Delta \mathbf{C} \circ \mathbf{A}^*_{1/2}\right)\mathbf{L}_0 \tag{11.4}$$

where $\mathbf{\Delta L} = (\mathbf{L}_1 - \mathbf{L}_0)$ and the subscript 1/2 is the average of times $t = 0$ and $t = 1$, that is, $\mathbf{C}_{1/2} = \frac{1}{2}\mathbf{C}_1 + \frac{1}{2}\mathbf{C}_0$. This is the principle of polar decomposition by Dietzenbacher and Los (1998) used for analysis of the change in **L** between two points in time.

The first part of Eq. (11.4) indicates the magnitude of the change in the technical coefficients, whereas the second part indicates the effect of the change in the trade coefficients.

Similarly, the final demand in **G** relates final demand for products from sector *i* in country *r* to macroeconomic demand **y** in Eq. (11.2). To assess the effects of changes in products' geographical source locations (sourcing patterns) (**F**) from the effect of changes in the distributions of final demands (**B**), the matrix **G** is decomposed as follows:

$$\Delta \mathbf{G} = \mathbf{F_{1/2}} \circ \Delta \mathbf{B} + \Delta \mathbf{F} \circ \mathbf{B_{1/2}} \tag{11.5}$$

The first part in Eq. (11.5) indicates the effect of changes in consumers' preferences, and the second part indicates the effect of the changes in the sourcing pattern for final demand.

Using Eqs. (11.4) and (11.5), it is possible to rewrite Eq. (11.2). Doing so gives the following decomposition of $\mathbf{\Delta s}$ into six separate components:

$$\Delta \mathbf{s} = (\Delta \widehat{\mathbf{e}})\mathbf{L}_{1/2}\mathbf{G}_{1/2}\mathbf{y}_{1/2} \tag{11.6a}$$

$$+\widehat{\mathbf{e}}_{1/2}\left[\mathbf{L}_1\left(\mathbf{C}_{1/2} \circ \Delta \mathbf{A}^*\right)\mathbf{L}_0\right]\mathbf{G}_{1/2}\mathbf{y}_{1/2} \tag{11.6b}$$

$$+\widehat{\mathbf{e}}_{1/2}\left[\mathbf{L}_1\left(\Delta \mathbf{C} \circ \mathbf{A}^*_{1/2}\right)\mathbf{L}_0\right]\mathbf{G}_{1/2}\mathbf{y}_{1/2} \tag{11.6c}$$

$$+\widehat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}\left(\mathbf{F_{1/2}} \circ \Delta \mathbf{B}\right)\mathbf{y}_{1/2} \tag{11.6d}$$

$$+\widehat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}\left(\Delta \mathbf{F} \circ \mathbf{B_{1/2}}\right)\mathbf{y}_{1/2} \tag{11.6e}$$

$$+\widehat{\mathbf{e}}_{1/2}\mathbf{L}_{1/2}\mathbf{G}_{1/2}(\Delta \mathbf{y}) \tag{11.6f}$$

Accordingly, the change in CO_2 emissions between two points in time ($\mathbf{\Delta s}$) may be decomposed in emission intensity, i.e., the emission per unit of output, $(\mathbf{\Delta}\widehat{\mathbf{e}})$ in

Eq. (11.6a); technology change, i.e., changes in the region's production structure, ($\mathbf{\Delta A}^*$) in Eq. (11.6b); intermediate trade sourcing, i.e., changes in where intermediate goods are being purchased, ($\mathbf{\Delta C}$) in Eq. (11.6c); consumer's preferences, i.e., changes in the mix of final demand goods, ($\mathbf{\Delta B}$) in Eq. (11.6d); final demand sourcing, i.e., locations from which final demand goods are being purchased, ($\mathbf{\Delta F}$) in Eq. (11.6e); and consumption level, i.e., how much is being purchased, ($\mathbf{\Delta y}$) in Eq. (11.6f).

11.2.2 Database

Our research used the World Input-Output Tables (WIOTs) and the environmental accounts for CO_2 emissions provided in the World Input-Output Database (WIOD) Release 2013 (Timmer et al. 2015). The database covers 27 EU countries and 13 other major countries in the world for the period from 1995 to 2009. The WIOD provides details for 35 industries classified according to the International Standard Industrial Classification scheme (see Table 11.3 in the Appendix). According to Genty et al. (2012), the CO_2 emissions in the WIOD accounts include emissions from energy use and process-based emissions.[1]

SDA requires the use of input-output tables expressed in constant prices (Lenzen et al. 2012). Therefore, we used the input-output tables in previous year's prices available from WIOD. These tables were constructed using exogenous value added as per the RAS approach proposed by Dietzenbacher and Hoen (1998) and the generalized RAS (GRAS) algorithm, originally proposed by Junius and Oosterhaven (2003) and modified by Lenzen et al. (2007). Los et al. (2014) discuss more details about the construction of WIOTs in terms of previous year's prices.

11.2.2.1 Characterization of Countries

This subsection presents a description of the production structure and CO_2 emissions of the selected countries based on the World Input-Output Database (WIOD). This description is made by specifying the industrial characteristics of the countries. The groups of activity sectors are classified according to the intensity of energy consumption (Table 11.3 in the Appendix).

Table 11.1 presents value added and CO_2 emissions from 1995 and 2009. The services sectors have the greatest single percentage of value added in all countries. However, the relative percentages from these sectors in China, India, and Russia are smaller than in developed countries. At the same time, with the exceptions of 1995 energy-intensive industrializing China and 1995 then-relatively-nuclear-intensive

[1]Please refer to Genty et al. (2012) for a detailed explanation of the environmental accounts in the WIOD.

Table 11.1 Value added and CO_2 emissions by group of sectors

		Value added (%)		CO_2 emissions (%)		CO_2 emissions (Mt)/value added (bi US$)	
		1995	2009	1995	2009	1995	2009
China	Non-manufacturing	24.0	14.7	7.4	5.0	1.2	0.4
	Energy-intensive	20.5	17.9	40.9	29.9	7.5	2.1
	Non-energy-intensive	14.3	14.7	5.8	2.5	1.5	0.2
	Electricity	2.2	2.7	38.6	53.5	66.0	24.3
	Services	39.0	49.9	7.3	9.0	0.7	0.2
India	Non-manufacturing	28.0	19.4	9.3	10.6	0.7	0.7
	Energy-intensive	9.5	8.7	26.0	25.7	5.6	3.5
	Non-energy-intensive	9.0	6.8	2.7	3.0	0.6	0.5
	Electricity	2.7	1.8	51.4	54.2	39.7	36.8
	Services	50.8	63.3	10.6	6.5	0.4	0.1
Russia	Non-manufacturing	15.6	13.8	10.2	8.5	2.9	0.8
	Energy-intensive	11.8	11.3	19.0	26.7	7.2	3.1
	Non-energy-intensive	5.6	3.7	0.8	0.6	0.7	0.2
	Electricity	4.5	3.2	58.1	50.6	57.4	20.8
	Services	62.4	68.0	11.9	13.6	0.9	0.3
Japan	Non-manufacturing	2.0	1.5	4.1	3.7	0.4	0.5
	Energy-intensive	12.7	10.7	34.5	29.0	0.5	0.5
	Non-energy-intensive	9.9	6.6	3.7	2.1	0.1	0.1
	Electricity	2.6	2.3	23.6	33.8	1.8	2.9
	Services	72.8	78.9	34.1	31.3	0.1	0.1
United States	Non-manufacturing	2.3	2.7	4.3	3.8	1.1	0.4
	Energy-intensive	8.7	6.7	18.4	15.7	1.2	0.7
	Non-energy-intensive	6.8	4.7	2.5	1.8	0.2	0.1
	Electricity	2.2	1.9	42.3	48.5	11.1	7.7
	Services	80.0	84.1	32.5	30.1	0.2	0.1
European Union	Non-manufacturing	3.9	2.4	5.1	4.5	1.3	0.4
	Energy-intensive	11.2	8.3	30.4	25.3	2.7	0.7
	Non-energy-intensive	8.8	6.4	3.5	2.4	0.4	0.1
	Electricity	2.7	2.4	39.8	39.7	14.6	3.5
	Services	73.3	80.4	21.2	28.1	0.3	0.1

Source: Prepared by the author from WIOD (Release 2013)
Note: Europe includes Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, the United Kingdom, Greece, Hungary, Ireland, Italy, Japan, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden

Japan, the electricity industry is the single largest source of CO_2 emissions. This is mainly due to the burning of fossil fuels (primarily coal) for generating electricity in the electricity industry. It is noteworthy that the value-added share of CO_2 emissions from the energy-intensive sector is larger in developing countries.

11.3 Results

Table 11.2 summarizes our decomposition of observed changes in CO_2 emissions in China, India, Russia, Japan, the United States, and Europe. Effects are aggregated into the five categories used in the structural decomposition analysis (SDA): emissions intensity, technology change, sourcing (intermediate and final demand), consumer preferences, and consumption level. All results in the table are expressed in Mt of CO_2 over 1995–2001 and 2002–2009. These periods coincide with distinct phases of growth of the Chinese economy.

Global CO_2 emissions increased 5953 Mt over 1995–2009. While China and India increased their levels of CO_2 emissions over 1995–2009, Russia, Japan, the United States, and Europe decreased their levels of CO_2 emissions. Increases in CO_2

Table 11.2 SDA results: decomposition of changes in CO_2 emissions (in Mt) between 1995 and 2009

Countries	Emissions intensity	Industrial structure	Sourcing	Consumer preferences	Consumption level	Total emissions
1995–2001						
China	–1229	–125	185	50	1247	128
India	–57	–23	31	–11	248	187
Russia	–66	–108	–78	–88	301	–39
Japan	45	–12	–53	–21	70	29
United States	–774	385	–214	–146	1147	399
Europe	–533	37	–76	–53	645	21
Rest of the world	–1227	389	518	182	951	813
Total	–3841	544	313	–87	4609	1537
Total (%)	–250	35	20	–5	300	100
2002–2009						
China	–2012	1074	1458	–15	2872	3377
India	–123	–32	42	66	641	595
Russia	–201	–164	–53	–75	530	37
Japan	–41	–54	–59	–16	71	–99
United States	288	–1174	–168	–161	662	–552
Europe	–603	–54	–56	–55	530	–237
Rest of the world	–1762	838	130	115	1975	1296
Total	–4454	434	1294	–140	7282	4416
Total (%)	–101	10	29	–3	165	100

Source: Calculated by the authors

Note: Europe includes Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, the United Kingdom, Greece, Hungary, Ireland, Italy, Japan, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden emissions in China, India, and the United States accounted for 42.55% of the global emissions growth over 1995–2001, while only China was responsible for the 76.45% increase in global CO_2 emissions over 2002–2009.

Increases in consumption level were the primary proximate cause of increases in global CO_2 emissions in both periods. A decrease in emissions intensity played a major role in reducing the global CO_2 emissions. Consumer preferences had relatively little impact on emissions changes. While changes in industrial structure contributed to the increase in global emissions, the relative magnitude of its effect varied without discernable pattern between countries.

The sourcing effect, which captures CO_2 emissions embodied in international trade, has led to an increase of 1607 Mt in global CO_2 emissions (27% of global emissions). Increases in levels of international trade appear to correspond with increases in CO_2 emissions, as the shift in sourcing pattern moves from lower- to higher-emission countries. This result is the same as reported in Hoekstra et al. (2016), who analyzed emission cost of international sourcing for low-wage, medium-wage, and high-wage country groups.

For the period over 2002–2009, change in sourcing led to increased emissions of 1458 Mt of CO2 in China. At the same time, other regions, with the exception of India, reduced emissions due to the sourcing effect. This is likely to be the result of greater integration into international trade by the Chinese. This integration coincides with intensification of fragmentation in global production. With such fragmentation, countries send part of their production to countries abroad with lower wage costs. Accordingly, the activities sent abroad tend to be more emission intensive. Developed countries thus outsource parts of their production process to developing countries mainly due to low production cost and moderate environmental regulations Zhang et al. (2017b). Consequently, the developed countries transfer part of the responsibility for emissions to countries with lower wage costs, such as China and India. The evidence presented in Arto and Dietzenbacher (2014), Hoekstra et al. (2016), Vale et al. (2018), and Araújo et al. (2018) reinforces this result.

Decomposition results for global emissions are illustrated on an annual basis in Fig. 11.6. Change in CO_2 emissions is shown in three groups: technology (emissions intensity and industrial structure), sourcing (intermediate trade and final demand), and consumption (consumer preferences and consumption level). The black line depicts total CO_2 emissions. In all years except 1999, 2000, and 2009, China's emissions increased due to changes in sourcing patterns – this increase has been growing since 2001. For illustration, changes in sourcing patterns might involve purchasing intermediate goods used in production from the United States and the rest of the world, instead of relying on domestic production or purchases from former Soviet countries. The sourcing effect contributes to reducing emissions in almost every year for the United States and Europe. For all countries, the technology component has tended to reduce CO_2 emissions; however, its effect was not large enough to compensate for changes in emissions due to increased consumption. Note that China and India are countries less affected by the great recession in terms of

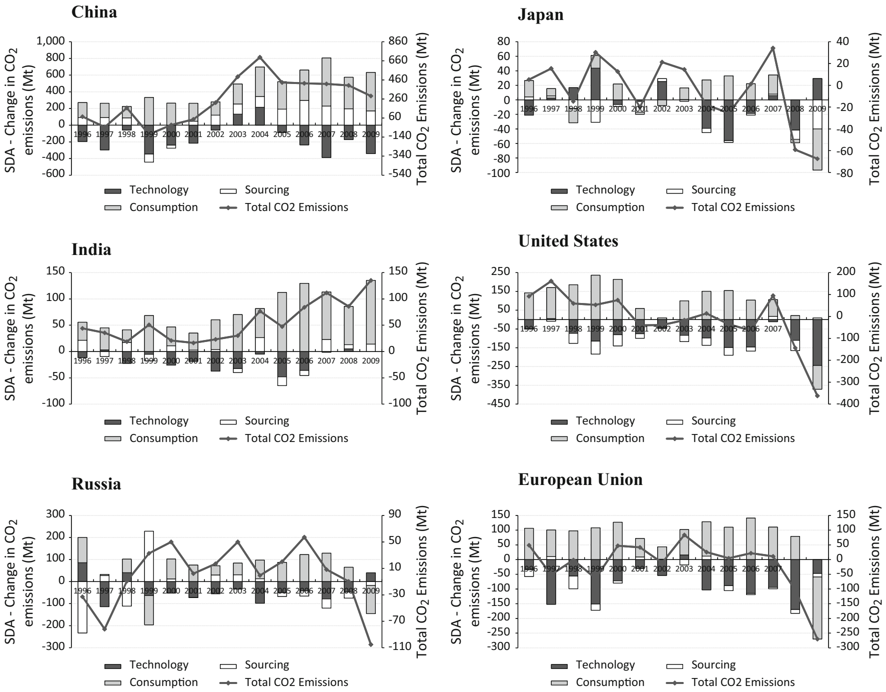

Fig. 11.6 SDA Results: The effects of change in technology, sourcing, and consumption in CO_2 emissions (in Mt), 1995–2007
Note: Europe includes Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, the United Kingdom, Greece, Hungary, Ireland, Italy, Japan, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden
Source: Calculated by the authors

emissions, with India actually increasing its CO_2 emission in 2009. All other countries have a significant decrease in emissions levels during these years.

Figure 11.7 shows detailed decomposition results for emissions changes in five groups of sectors (non-manufacturing, energy-intensive manufacturing, non-energy-intensive manufacturing, electricity, and services). All results in the figure are expressed in percent of the change in emissions over 1995–2009 for each country. This analysis is presented by components of the SDA. The complete results for 35 sectors are provided in Tables 11.4, 11.5, 11.6, 11.7, 11.8, and 11.9 in the Appendix.

The decomposition results reveal a very substantial decrease in global CO_2 emissions due to emission intensity (−8295 Mt). In China this reduction is concentrated mainly in the energy-intensive sectors (–38%) and electricity (–47%). Japan is

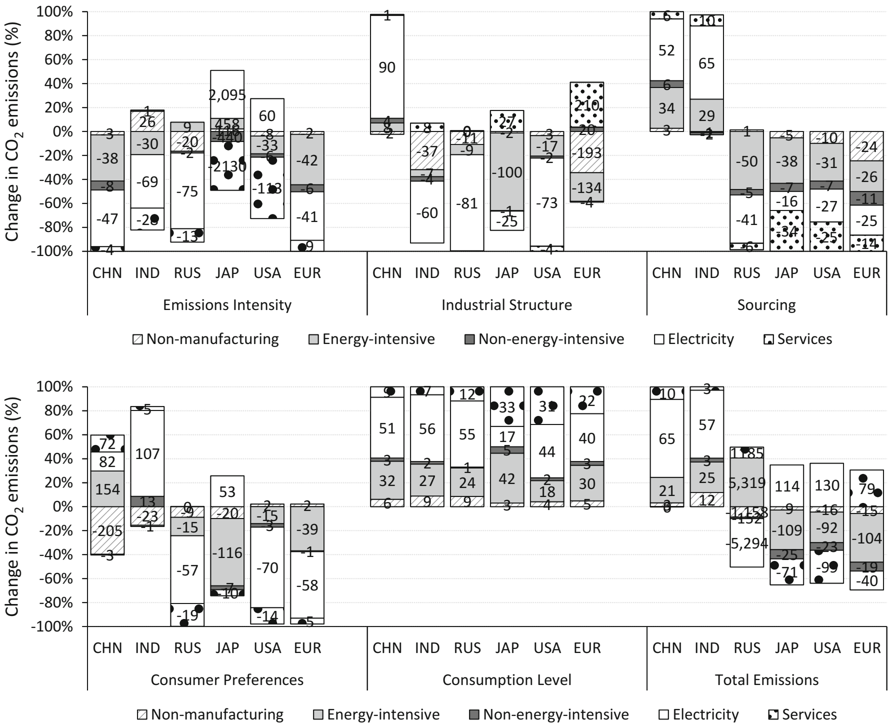

Fig. 11.7 SDA Results: Decomposition of changes in CO_2 emissions (in Mt) by group of sectors between 1995 and 2007
Note: CHN (China), IND (India), RUS (Russia), JAP (Japan), USA (United States), and EUR (Europe)
Source: Calculated by the authors

the only country the effect of emission intensity is positive (3 Mt) – this is caused by the increase in emissions of the non-manufacturing sector (12%) and electricity (2095%).[2] Emissions changes driven by the industrial structure effect are concentrated in the electricity sector – with a positive effect only in China.

The changes in the sourcing pattern caused an increase in emissions embodied in the trade only in China and India. The intensification of international outsourcing, with the production processes distributed globally, has provided economic growth in these countries. However, this has also brought production fragmentation and a corresponding negative externality caused by the increase of emissions incorporated

[2]The reason the electricity value (2095%) is so out of line with all of the other values may be that "The Liberal Democratic Party, which governed Japan almost continuously from 1955 to 2009 and returned to power in December, wasn't proactive in cleaning up the country's air and water." https://latitude.blogs.nytimes.com/2013/02/15/japans-pollution-diet/ (last accessed on 5/6/2019).

in the trade, largely through transportation. This increase is concentrated in the recipient countries to which the most energy-intensive production stages are transferred. Zhang et al. (2017b) showed that the share of emissions in developing countries induced by the global value chain-related trade is increasing gradually.

Consumer preferences reduced the global emissions by 228 Mt of CO_2. Consumption growth was mainly responsible for the increase in global emissions (11,890 Mt CO_2 over 1995–2009). This increase was concentrated in the electricity sector in China (50%), India (56%), and Russia (55%). While in the United States and Europe, the services sector accounted for an important part of the increase in emissions caused by the consumption growth. In Japan, the energy-intensive manufacturing and services sectors together accounted for 69% of the increase in emissions due to variations in consumption.

11.4 Discussion and Conclusion

In this research we used structural decomposition analysis to estimate the proximate causes of change in CO_2 emissions for six worldwide mega-regions. Our objective was to determine whether observed changes in CO_2 emissions from 1995 to 2009 were attributable to the adoption of new energy technology or to changes in trade relationships, final demand structures, or other elements of these six mega-regional economic structures. In achieving this objective, it became evident that the causal structure of change in CO_2 emissions is multifaceted and nuanced from region to region.

A substantial percentage of the increase in CO_2 emissions (27%) over this time period was attributable to increases in levels of international trade associated with changes in where intermediate goods were purchased. Sourcing patterns apparently moved from lower- to higher-emission countries as production moved from high-wage to medium-wage to low-wage countries.

In China, total emissions growth from 1995 to 2009 was slowed greatly by decreases in emissions intensity (probably attributable in large measure to the adoption of new and advanced energy technologies in its electricity industry). Over this same period, however, increased emissions attributable to all other factors, particularly change in industrial structure, sourcing, and consumption (largely of electricity), combined to make China's total emissions growth greater than the total from the rest of the world combined. Fortunately, the Chinese have subsequently made major strides toward reducing the rate of growth of their greenhouse gas emissions, largely through a combination of reduced growth in coal use, widespread deployment of renewable energy sources, decreases in energy intensity, increased use of electric vehicles, proposals for new forms of urbanization, development of carbon capture and storage capacity, and the recent creation of a national-level emission trading market (Xu et al. 2014; Mi et al. 2017).

In contrast, during this same period, both Russia and the United States improved across all factors other than emissions attributable to consumption. Europe is similar with the exception that changes in its industrial structure over the period 1995–2001 led to increases in its CO_2 emissions (though these were more than offset by improvements made between 2002 and 2009). In all three of these regions, the improvements reflect a combination of the adoption of new energy technologies as well as changes in trade relationships, final demand structures, and other economic factors. In India, the adoption of new energy technology decreased CO_2 emissions vis-à-vis improvements in emissions intensity and industrial structure: but these improvements were nevertheless considerably outweighed by increases attributable to final demand sourcing, consumer preferences, and levels of consumption. While Japan's growth in CO_2 emissions attributable to consumption was the smallest of any of the six countries or mega-regions, total emissions attributable to increased consumption grew there as well.

In terms of policy implications, the largest single contributing factor to increases in total CO_2 emissions in all of the observed regions from 1995 to 2009 was consumption levels. These increases occurred along with an increase of just under 50% in gross world product, according to World Bank estimates.[3] As levels of production increased, incomes grew, consumption increased, and more CO_2 was produced. Thus, the policy implications go to possible mechanisms for reversing trends toward greater consumption. These could include widespread reductions in working hours, restrictions on the quantity and nature of marketing messages (e.g., bans on advertising and sponsorship from all public spaces, restrictions on advertising time on television and radio, and tax laws in which the costs of advertising are not deductible business expenses), and education aimed not as much toward consumer capitalism as toward self-understanding and greater knowledge about the world in which we live.

When comparing the 1995–2001 period with the 2002–2009 period, total emissions increased in China, India, and Russia, while at the same time, they decreased in Japan, the United States, and Europe. China, India, and Russia are, of course, all members of the trilateral relationship known as Russia-India-China Triangle, and all are members of the BRICS (short for Brazil, Russia, India, China, South Africa) economic trade block. All three are large developing countries with similar development paths. Probably more importantly, however, is that Japan, the United States, and Europe are all characteristically more advanced technologically and have considerably fewer problems with functioning democratically than the other three. So their citizens and local governments are more likely to accept greater responsibility for taking the sorts of local policy and other actions necessary to minimize CO_2 emissions.

[3] http://statisticstimes.com/economy/gross-world-product.php (last accessed on 4/25/2019).

Past this, the dominant view among scholars and policy makers has been that the governance of climate change should be based on international agreements. The variegation in causal structures found in this research implies that policy makers should not attempt to take a "one-size-fits-all" approach to these agreements. Generally, when the causal structures of two or more problems in two or more regions, locations, or levels are invariant, this would imply invariant solutions to the problems that arise within them. But when the causal structures vary from one region, location or level to the next, as they do throughout these mega-regions, they warrant consideration of correspondingly different policy solutions. The only consistent contributing factor to increased CO_2 emissions found throughout this time period in these regions is consumption. Past this, the policy implications of this research for China differ from those for other countries and regions. International agreements that recognize and respect regional, national, and perhaps local institutional diversity and corresponding approaches for reducing emissions are thus critical.

Appendix

Table 11.3 Industrial composition used in the structural decomposition analysis (SDA)

Industrial sector energy consumption	Industry	Description
Non-manufacturing	Agriculture	Agriculture, hunting, forestry, and fishing
Non-manufacturing	Mining	Mining and quarrying
Energy-intensive	Food	Food, beverages, and tobacco
Non-energy-intensive	Textiles	Textiles and textile products
Non-energy-intensive	Leather	Leather and footwear
Non-energy-intensive	Wood	Wood and products of wood and cork
Energy-intensive	Paper	Pulp, paper, paper, printing, and publishing
Energy-intensive	Ref. petroleum	Coke, refined petroleum, and nuclear fuel
Energy-intensive	Chemicals	Chemicals and chemical products
Energy-intensive	Rubber	Rubber and plastics
Energy-intensive	Non-metallic	Other non-metallic mineral
Energy-intensive	Metals	Basic metals and fabricated metal
Non-energy-intensive	Machinery	Machinery, Nec
Non-energy-intensive	Electrical	Electrical and optical equipment
Non-energy-intensive	Transport	Transport equipment

(continued)

Table 11.3 (continued)

Industrial sector energy consumption	Industry	Description
Non-energy-intensive	Manufacturing	Manufacturing, Nec; recycling
Electricity	Electricity	Electricity, gas, and water supply
Services	Construction	Construction
Services	Maintenance	Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel
Services	Wholesale trade	Wholesale trade and commission trade, except of motor vehicles and motorcycles
Services	Retail trade	Retail trade, except of motor vehicles and motorcycles; repair of household goods
Services	Hotels	Hotels and restaurants
Services	Inland transport	Inland transport
Services	Water transport	Water transport
Services	Air transport	Air transport
Services	Other transport	Other supporting and auxiliary transport activities; activities of travel agencies
Services	Telecommunications	Post and telecommunications
Services	Financial intermediation	Financial intermediation
Services	Real estate activities	Real estate activities
Services	Renting M & Eq	Renting of M & Eq and other business activities
Services	Public admin	Public Admin and Defense; compulsory social security
Services	Education	Education
Services	Health	Health and social work
Services	Personal services	Other community, social, and personal services
Services	Private HH	Private households with employed persons

Source: Industrial composition of the World Input-Output Tables of the WIOD, 2013 Release. Industrial sector energy consumption from the US Energy Information Administration, International Energy Outlook

Table 11.4 Decomposition of change in CO_2 emissions (in Mt) between 1995 and 2009 by industry: China

Sector	Emissions intensity	Industrial structure	Industrial sourcing	Consumer preferences	Final demand sourcing	Consumption level	Total emissions
Agriculture	−54	−13	5	−68	11	133	13
Mining	−38	−10	8	−2	21	120	99
Food	−95	20	4	−10	6	68	−8
Textiles	−76	12	14	−11	22	32	−8
Leather	−5	0	1	−1	1	3	−1
Wood	−13	4	3	0	2	9	3
Paper	−48	9	11	−2	5	37	12
Ref. petroleum	−46	−7	21	0	12	72	51
Chemicals	−298	40	71	−16	40	203	39
Rubber	−44	7	8	0	6	18	−5
Non-metallic	−279	−71	67	41	46	527	332
Metals	−437	74	161	40	101	385	324
Machinery	−65	7	7	1	14	32	−3
Electrical	−35	8	7	4	7	11	3
Transport	−33	7	5	5	4	19	8
Manufacturing	−18	0	1	0	5	5	−7
Electricity	−1532	855	473	28	373	2089	2286
Construction	−9	0	0	13	0	51	55

Maintenance	0	0	0	0	0	0	0
Wholesale trade	−20	−5	4	0	2	12	−8
Retail trade	−5	−2	1	0	2	7	2
Hotels	2	1	1	−1	1	11	15
Inland transport	−30	−14	11	−2	11	79	55
Water transport	−27	13	22	3	12	59	83
Air transport	20	−4	12	1	8	26	63
Other transport	−1	9	1	1	1	17	27
Telecommunications	−3	1	0	2	0	4	5
Financial intermediation	−3	−1	0	0	0	3	0
Real estate activities	−10	−1	0	0	0	6	−5
Renting M & Eq	−5	3	4	0	2	14	18
Public admin	−3	0	0	0	0	17	15
Education	−20	1	0	3	0	18	1
Health	4	1	0	2	0	10	17
Personal services	−17	6	2	3	1	26	22
Private HH	0	0	0	0	0	0	0
Total	−3241	949	926	34	717	4120	3505

Source: Calculated by the authors

Table 11.5 Decomposition of change in CO_2 emissions (in Mt) between 1995 and 2009 by industry: India

Sector	Emissions intensity	Industrial structure	Industrial sourcing	Consumer preferences	Final demand sourcing	Consumption level	Total emissions
Agriculture	4	−7	0	−16	0	36	16
Mining	43	−14	−5	4	4	43	76
Food	27	2	−2	−11	0	38	54
Textiles	−11	−1	0	0	3	8	−1
Leather	−1	0	0	0	0	0	0
Wood	9	−1	0	7	−7	3	11
Paper	−3	−1	0	−2	0	6	2
Ref. petroleum	−8	3	7	0	3	28	33
Chemicals	−36	2	4	1	3	34	8
Rubber	0	0	0	0	0	1	2
Non-metallic	−31	−2	−6	6	0	66	33
Metals	−4	−8	2	6	8	63	68
Machinery	1	0	0	0	0	2	4
Electrical	0	0	0	1	1	2	3
Transport	4	0	0	0	1	3	9
Manufacturing	−1	0	0	0	0	1	0
Electricity	−125	−33	12	59	35	495	443
Construction	−5	1	0	2	0	9	6

Maintenance	0	0	0	0	0	0	0
Wholesale trade	0	0	0	0	0	1	0
Retail trade	−2	0	0	0	0	3	1
Hotels	−10	1	1	1	1	9	2
Inland transport	−21	3	1	2	1	21	7
Water transport	1	0	0	−1	0	3	4
Air transport	−6	−1	0	−1	0	4	−3
Other transport	−1	0	0	−1	0	2	1
Telecommunications	−4	2	0	1	0	1	1
Financial intermediation	0	0	0	0	0	0	0
Real estate activities	0	0	0	0	0	0	0
Renting M & Eq	1	0	0	1	0	1	3
Public admin	−1	0	0	0	0	1	0
Education	0	0	0	0	0	1	1
Health	0	0	0	0	0	0	0
Personal services	−1	−1	0	−1	0	2	0
Private HH	0	0	0	0	0	0	0
Total	−180	−55	18	55	55	889	781

Source: Calculated by the authors

Table 11.6 Decomposition of change in CO_2 emissions (in Mt) between 1995 and 2009 by industry: Russia

Sector	Emissions intensity	Industrial structure	Industrial sourcing	Consumer preferences	Final demand sourcing	Consumption level	Total emissions
Agriculture	−28	−2	−1	−5	−4	19	−22
Mining	−24	−27	9	−9	−2	52	−2
Food	−10	0	0	0	−1	4	−6
Textiles	−1	0	0	0	−1	0	−1
Leather	0	0	0	0	0	0	0
Wood	0	−1	0	0	0	1	0
Paper	−1	0	0	0	0	1	0
Ref. petroleum	20	−7	4	−9	4	31	41
Chemicals	23	4	−9	−1	−10	24	32
Rubber	0	0	0	0	0	0	0
Non-metallic	24	−42	−6	−7	−1	43	12
Metals	−32	20	−22	−9	−23	94	28
Machinery	−4	1	0	0	−2	2	−3
Electrical	−2	0	0	0	−1	1	−1
Transport	2	0	−1	0	−1	1	1
Manufacturing	0	0	0	0	0	0	0
Electricity	−200	−220	−8	−92	−46	458	−108

Construction	−12	1	0	−1	0	5	−7
Maintenance	−1	0	0	0	0	1	1
Wholesale trade	−1	1	0	0	0	3	3
Retail trade	−1	0	0	0	0	2	2
Hotels	−1	0	0	0	0	1	0
Inland transport	−11	−6	−8	−18	0	50	7
Water transport	0	−1	0	−1	0	2	−1
Air transport	7	4	0	2	0	6	19
Other transport	−4	1	0	0	0	3	0
Telecommunications	−2	1	0	0	0	1	1
Financial intermediation	−2	0	0	0	0	1	−1
Real estate activities	−8	1	0	1	0	3	−2
Renting M & Eq	−2	0	0	0	0	1	0
Public admin	−1	0	0	−1	0	3	1
Education	0	0	0	−3	0	2	0
Health	0	0	0	−1	0	2	0
Personal services	5	−4	0	−10	0	10	1
Private HH	0	0	0	0	0	0	0
Total	−268	−272	−41	−163	−90	831	−2

Source: Calculated by the authors

Table 11.7 Decomposition of change in CO_2 emissions (in Mt) between 1995 and 2009 by industry: Japan

Sector	Emissions intensity	Industrial structure	Industrial sourcing	Consumer preferences	Final demand sourcing	Consumption level	Total emissions
Agriculture	−11	−1	0	−3	0	2	−13
Mining	15	0	−2	−5	−4	3	6
Food	−3	0	0	−2	0	1	−4
Textiles	2	−1	−1	−2	−2	1	−3
Leather	0	0	0	0	0	0	0
Wood	1	−1	0	−1	0	0	−2
Paper	−3	−5	−1	0	0	2	−7
Ref. petroleum	2	−7	−2	−1	−1	3	−5
Chemicals	−3	−6	−5	1	−3	11	−6
Rubber	−2	0	0	0	0	1	−2
Non-metallic	4	−19	−6	−20	−2	11	−31
Metals	20	−28	−14	−21	−7	30	−21
Machinery	−5	0	0	0	0	1	−5
Electrical	−10	3	−1	2	−1	2	−6
Transport	−2	0	−1	0	0	3	0
Manufacturing	0	−1	0	−1	−1	1	−2
Electricity	71	−16	−10	20	−7	24	81

Construction	1	0	0	−15	0	2	−13
Maintenance	0	0	0	0	0	0	−1
Wholesale trade	−7	−3	0	−2	0	3	−10
Retail trade	−5	−2	0	−4	0	1	−10
Hotels	−1	−2	0	0	0	1	−2
Inland transport	−1	−6	−1	−2	0	4	−8
Water transport	−8	27	−24	3	−7	24	15
Air transport	−19	−3	−1	0	0	4	−19
Other transport	1	0	0	0	0	0	0
Telecommunications	−2	1	0	1	0	0	0
Financial intermediation	−2	−1	0	0	0	0	−2
Real estate activities	−1	0	0	1	0	0	−1
Renting M & Eq	−9	7	0	3	0	1	2
Public admin	−5	0	0	8	0	1	4
Education	−2	0	0	−1	0	0	−2
Health	−6	0	0	3	0	1	−2
Personal services	−5	−1	−1	2	−1	2	−3
Private HH	0	0	0	0	0	0	0
Total	3	−65	−72	−37	−41	141	−71

Source: Calculated by the authors

Table 11.8 Decomposition of change in CO_2 emissions (in Mt) between 1995 and 2009 by industry: United States

Sector	Emissions intensity	Industrial structure	Industrial sourcing	Consumer preferences	Final demand sourcing	Consumption level	Total emissions
Agriculture	−23	−7	0	−4	−2	23	−12
Mining	−18	−20	−34	11	−3	51	−13
Food	4	−7	−1	−7	−3	22	8
Textiles	2	−9	−2	−3	−9	7	−13
Leather	0	0	0	0	0	0	−1
Wood	0	−2	0	−4	0	6	−1
Paper	9	−30	−5	−4	−2	26	−5
Ref. petroleum	−58	−19	−20	−1	−7	82	−23
Chemicals	−37	−19	−19	6	−14	64	−21
Rubber	−2	−2	−1	0	0	3	−2
Non-metallic	14	−30	−14	−27	−1	50	−8
Metals	−88	−27	−21	−12	−12	71	−89
Machinery	2	−3	−2	−4	−3	8	−2
Electrical	−22	4	−2	5	−1	8	−9
Transport	−7	−2	−2	−4	−2	11	−5
Manufacturing	−4	−1	−1	0	−2	3	−4
Electricity	293	−580	−66	−215	−38	805	199

Construction	−16	−3	0	−17	0	23	−14
Maintenance	−5	0	0	0	0	3	−3
Wholesale trade	−37	1	−2	7	−1	17	−14
Retail trade	−72	−4	−1	3	0	43	−31
Hotels	−24	−3	0	−5	0	28	−5
Inland transport	33	−35	−7	−15	−3	66	39
Water transport	0	1	−34	24	−9	21	3
Air transport	−6	−16	−17	−24	−6	66	−3
Other transport	19	1	−2	1	−1	14	33
Telecommunications	−6	2	−1	6	0	11	11
Financial intermediation	−37	10	−1	4	0	16	−8
Real estate activities	−9	0	0	0	0	5	−4
Renting M & Eq	−84	19	−3	13	−2	49	−8
Public admin	−186	−4	0	−40	0	133	−98
Education	−4	−2	0	−1	0	6	0
Health	−48	−1	0	4	0	38	−7
Personal services	−66	−2	−1	−3	−1	30	−42
Private HH	0	0	0	0	0	0	0
Total	−486	−789	−260	−306	−122	1809	−153

Source: Calculated by the authors

Table 11.9 Decomposition of change in CO_2 emissions (in Mt) between 1995 and 2009 by industry: Europe

Sector	Emissions intensity	Industrial structure	Industrial sourcing	Consumer preferences	Final demand sourcing	Consumption level	Total emissions
Agriculture	−33	−11	1	−10	1	35	−17
Mining	5	−20	−21	12	−13	22	−15
Food	−30	−2	−1	−9	0	30	−12
Textiles	−11	−1	−3	−4	−5	8	−15
Leather	−1	0	0	−1	0	1	−2
Wood	−4	0	1	−1	0	3	−2
Paper	−19	−5	−1	−4	0	17	−12
Ref. petroleum	−70	14	2	−10	4	54	−6
Chemicals	−101	−6	−9	8	3	59	−46
Rubber	−12	2	−1	0	0	5	−6
Non-metallic	−85	−14	−9	−19	−1	87	−40
Metals	−161	−11	−18	−9	−2	97	−105
Machinery	−13	0	−1	0	0	7	−7
Electrical	−13	3	−2	3	−2	5	−6
Transport	−17	2	0	3	−2	8	−7
Manufacturing	−7	0	0	−1	0	5	−3
Electricity	−460	−1	−28	−63	−5	469	−88

Construction	−18	−1	0	−7	0	20	−6
Maintenance	−7	1	0	0	0	6	−1
Wholesale trade	−15	2	0	1	0	10	−3
Retail trade	−15	1	0	−1	0	9	−7
Hotels	−2	0	0	−1	0	4	1
Inland transport	−19	4	0	−6	−1	68	45
Water transport	−29	14	−3	3	1	38	24
Air transport	76	−6	−1	8	−11	39	106
Other transport	−3	3	0	−1	0	5	5
Telecommunications	−8	3	0	3	0	3	2
Financial intermediation	−6	1	0	2	0	3	−1
Real estate activities	−6	1	0	0	0	4	−2
Renting M & Eq	−17	9	0	2	0	12	5
Public admin	−14	−1	0	−3	0	10	−8
Education	−5	1	0	−5	0	7	−2
Health	−13	1	0	3	0	9	−1
Personal services	−2	3	0	−3	0	15	12
Private HH	0	0	0	0	0	0	0
Total	−1136	−16	−96	−109	−36	1175	−217

Source: Calculated by the authors

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