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Determinants of global CO_2 emissions growth

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HIGHLIGHTS

- The share of fossil fuel in global primary energy consumption has remained steady since 1990.
- CO_2 emissions from coal use increased the most (by 3.76 Gt) in developing countries.
- CO_2 emissions from natural gas use increased the most in developed countries.
- Infrastructure built was the dominant emission driving forces in developing countries.

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ABSTRACT

This paper analyzes global CO_2 emissions growth by fossil fuel type (coal, oil or gas), demand type (consumption or investment), country group (developed or developing country) and industry group. The results indicate that, among the three fossil fuels, CO_2 emissions from coal use grew the most rapidly in developing countries, by 3.76 Gt in the period 1995–2009. By contrast, CO_2 emissions from natural gas use grew the most rapidly in developed countries, by 470 Mt in the period 1995–2009. Further decompositions show that, despite improvements in energy efficiency, the upgrades in infrastructures and changes in electricity requirements in developing countries have led to significant CO_2 emissions growth from coal use. Among these countries, China accounts for a high contribution, causing a coal-use-related CO_2 emissions growth of up to 2.79 Gt in the period 1995–2009. By contrast, consumption by the public and social services as well as chemical products is the dominant force driving CO_2 emission growth from gas in developed countries; the US accounts for a very high contribution, causing a gas-use-related CO_2 emissions growth of up to 100 Mt.

1. Introduction

Global CO_2 emissions from fossil-fuel burning and industrial processes have doubled over the past 40 years, increasing from 16.9 gigatonnes (Gt) in 1974 to 35.5 Gt in 2014, with an annual growth rate of 1.8% [1]. Against the backdrop of the extensive discussions on global climate change mitigation, in recent years the growth rate of CO_2 emissions have accelerated from 1.0% per year for the period 1990–1999 to 2.4% per year for the period 2000–2014 (see also [2,3]). Both developed countries and developing countries have witnessed continuous growth in their production-based CO_2 emissions, with developing countries having an annual rate of 3.2% for the period 1990–2014, larger than that of developed countries, 0.4% [1].

According to the Kaya identity, the growth in global CO_2 emissions is driven by four factors, that is, $Ca = \frac{Ca}{E} \cdot \frac{E}{GDP} \cdot \frac{GDP}{P} \cdot P$, where Ca is CO_2 emissions, P is population, $\frac{GDP}{P}$ is gross domestic product (GDP) per capita, $\frac{E}{GDP}$ is the energy intensity of GDP, and $\frac{Ca}{E}$ is the carbon intensity of energy (emissions/energy). Gerland et al. [4] project that the world population will continue to rise within this century, with a 95% chance that it will grow from 6.1 billion in 2000 to 9.0–13.2 billion by the year 2100. On a century-long basis, Baksi and Green [5] find that the long-term average annual decline in global energy intensity is unlikely to substantially exceed 1.1%. Given an increase in GDP per capita is very crucial for improving living standards in developing countries, one of the most important ways to curb the growth of CO_2 emissions in developing countries

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is to decrease the carbon intensity of energy, i.e., the de-carbonization of energy consumption (see also, [6–11]).[1]

However, the share of renewable energies in global primary energy consumption as a total does not show any signs of increasing, especially in developing countries. On the contrary, it has remained more or less stable at approximately 13% since 1990 (Fig. 1a). This stability may also be why we observe the acceleration in global CO_2 emissions growth (see also [2,3]). Although the share of solar, wind and bio-renewable energies rose from 0.35% in 1990 to 2.45% in 2014, that rise has been largely offset by a 1.1 percentage point decline in the share contributed by nuclear energy – also a low-carbon energy source (see also [13]). In terms of countries, the performance of developed countries with regard to renewable energy usage is slightly better than that of developing countries. The share of carbon-free renewable energy in total primary energy consumption in developing countries has remained steady at 9% during the period 1990–2010 and, in 2014, increased to 10% (Fig. 1c), whereas that of developed countries slowly increased from 13.3% in 1990 to 15.6% in 2000 and 17.9% in 2014 (Fig. 1b).

The stable share of carbon-free renewable energies implies that the total share of fossil fuels in global energy consumption has remained relatively steady. Note that this stability does not necessarily mean fixed carbon energy intensity. Indeed, there is an internal structural change by fossil fuel (Fig. 1). Developed countries have witnessed an increase in the share of natural gas by 5.0 percentage points from 1990 to 2014 and drops in the shares of coal and oil by 5.5 and 4.1 percentage points, respectively (Fig. 1b). Meanwhile, developing countries have witnessed a drop in the share of oil by 9.2 percentage points and increases in the shares of coal and gas by 3.4 and 4.2 percentage points, respectively (Fig. 1c). On average, coal and oil have higher carbon contents than gas when generating the same amount of heat.[2] The change in the relative share of different fossil fuels may lead to changes in the total CO_2 emissions for an economy, even when its total primary energy consumption remains the same. As suggested by Fig. 2, CO_2 emissions from gas use increased significantly over time in developed countries, whereas CO_2 emissions from coal use increased significantly in developing countries.

Due to the separation of emissions caused by international trade, the increasing attention to global CO_2 emissions has shifted from a production-based perspective to a consumption-based perspective (see, e.g., [14–18]). That is, concern has shifted from answering the question "Who emits?" to answering the question "For whom is it emitted?". For example, Arto and Dietzenbacher [18] used WIOD and found that the changes in the levels of consumption per capita and population growth have dominated global CO_2 emissions growth for the period 1995–2008. However, there are scarce studies that discuss the reasons behind the CO_2 emissions growths by fossil fuel type from the consumption-based perspective. One of the pioneer studies might be from Malik et al. [12]. Based on Eora, they decomposed the global CO_2 emission growth by fuel type for the period 1990–2010, and demonstrate that affluence (per-capita consumption) and population growth are outpacing any improvements in carbon efficiency in driving up emissions worldwide. In this paper, based on the WIOD, we further distinguish the final demand into consumption and investment, and employ a structural decomposition model (SDA) to explore the driving forces behind global CO_2 emissions growth by demand type (consumption or investment), country group (developed or developing country), fossil fuel type (coal, oil or gas) and industry group. By such a decomposition, we hope to understand the global CO_2 emissions growth at a more detailed level. For example, for whom gas-use-related CO_2 has been emitted in developed countries or for whom coal-use-related CO_2 has been emitted in developing countries? Is there a difference in the demand structures and consumption bundles between developed and developing countries that have led to different oil, coal, and gas requirements? It is hoped that doing so may illuminate the questions noted above.

2. Methodology and data

In this paper, we employed a structural decomposition model (SDA) based on a global multi-regional input-output (GMRIO) framework to explore the reasons behind global CO_2 emissions growth by fossil fuel type and region. The GMRIO framework has been widely accepted to analyze the global energy consumption and CO_2 emissions growth (see, [18–23]). Table 1 presents the GMRIO framework employed in this paper. The diagonal matrices of intermediate use give the intra-regional intermediate deliveries. For example, the elements z_{ij}^{rr} of matrix $\mathbf{Z^{rr}}$ give the intermediate deliveries from industry i in region r to industry j in region r, with $i, j = 1, \ldots, m$, where m is the number of industries, and $r = 1, \ldots, n$, where n is the number of regions. The non-diagonal matrices indicate inter-regional intermediate deliveries. For example, the elements z_{ij}^{rs} of matrix $\mathbf{Z^{rs}}$ indicate the deliveries of products from industry i (=1, …, m) in country r (=1, …, n) for input use in industry j (=1, …, m) in country s (=1, …, n; $\neq r$). The matrices of final demand have a similar structure; they are divided by consumption (including consumption by households, governments and non-government organizations), $\mathbf{F_c^{rs}}$ (r, $s = 1, \ldots, n$), and investment (for fixed capital formation), $\mathbf{F_i^{rs}}$ (r, $s = 1, \ldots, n$).

According to Table 1, we have row equilibrium in matrix notation as follows:

$$\begin{bmatrix} \mathbf{Z}^{11} & \cdots & \mathbf{Z}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{Z}^{n1} & \cdots & \mathbf{Z}^{nn} \end{bmatrix} + \begin{bmatrix} \mathbf{F}_c^{11} + \cdots + \mathbf{F}_c^{1n} + \mathbf{F}_i^{11} + \cdots + \mathbf{F}_i^{1n} \\ \cdots \\ \mathbf{F}_c^{n1} + \cdots + \mathbf{F}_c^{nn} + \mathbf{F}_i^{nn} + \cdots + \mathbf{F}_i^{nn} \end{bmatrix} = \begin{bmatrix} \mathbf{X}^1 \\ \vdots \\ \mathbf{X}^n \end{bmatrix} \tag{1}$$

The direct input coefficients can then be obtained by normalizing the columns in the IO table; that is:

$$\mathbf{A^{rs}} = \mathbf{Z^{rs}}(\widehat{\mathbf{X^s}})^{-1} \tag{2}$$

where r, $s = 1, \ldots, n$, and $(\widehat{\mathbf{X^s}})^{-1}$ denotes the inverse of a diagonal matrix of total outputs in region s.

Define the input coefficients matrix $\mathbf{A} = \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{A}^{n1} & \cdots & \mathbf{A}^{nn} \end{bmatrix}$ where $\mathbf{A^s}$ is the input coefficient from region r to region s. Then, the Leontief inverse can be calculated as $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$; that is, $\mathbf{B} = \begin{bmatrix} \boldsymbol{B}^{11} & \cdots & \boldsymbol{B}^{1n} \\ \vdots & \ddots & \vdots \\ \boldsymbol{B}^{n1} & \cdots & \boldsymbol{B}^{nn} \end{bmatrix} = \begin{bmatrix} \boldsymbol{I} - \boldsymbol{A}^{11} & \cdots & -\boldsymbol{A}^{1n} \\ \vdots & \ddots & \vdots \\ -\boldsymbol{A}^{n1} & \cdots & \boldsymbol{I} - \boldsymbol{A}^{nn} \end{bmatrix}^{-1}$, where $\mathbf{I}$ is the identity matrix with diagonal elements as ones and non-diagonal elements as zeros. The Leontief inverse describes both the direct and indirect linkages across countries and sectors.

Using $\mathbf{E_o^r}$ to denote CO_2 emissions linked to fossil fuel type o (=coal, oil and gas) in region r and $\mathbf{CA_o^r} = \mathbf{E_o^r}(\widehat{\mathbf{X^r}})^{-1}$ to denote the carbon emissions intensity per unit of output linked to fossil

[1] Note that an increase in GDP per capita does not necessarily bring an improvement of quality of life or subjective well-being in developing countries. Therefore, the intervention in unsustainable lifestyles has been highly encouraged to achieve global emission reductions [12].

[2] On average, coal has the highest carbon contents, with 3.96 tons of CO_2 per ton of oil equivalent (toe), followed by oil (2.35 tons of CO_2 per toe) and natural gas (3.07tons of CO_2 per toe) [1].

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