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Driving Forces of CO_2 Emissions in Emerging Countries: LMDI Decomposition Analysis on China and India's Residential Sector

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Abstract: The main objective of this paper is to identify and analyze the key drivers behind changes of CO_2 emissions in the residential sectors of the emerging economies, China and India. For the analysis, we investigate to what extent changes in residential emissions are due to changes in energy emissions coefficients, energy consumption structure, energy intensity, household income, and population size. We decompose the changes in residential CO_2 emissions in China and India into these five contributing factors from 1990 to 2011 by applying the Logarithmic Mean Divisia Index (LMDI) method. Our results show that the increase in per capita income level was the biggest contributor to the increase of residential CO_2 emissions, while the energy intensity effect had the largest effect on CO_2 emissions reduction in residential sectors in both countries. This implies that investments for energy savings, technological improvements, and energy efficiency policies were effective in mitigating CO_2 emissions. Our results also depict that the change in CO_2 emission coefficients for fuels which include both direct and indirect emission coefficients slowed down the increase of residential emissions. Finally, our results demonstrate that changes in the population and energy consumption structure drove the increase in CO_2 emissions.

Keywords: CO_2 emissions; emerging economy; residential sector; Logarithmic Mean Divisia Index (LMDI) method

1. Introduction

Global warming has been regarded as one of the most important environmental problems of our age. The ever-increasing amount of CO_2 emissions, which are partly to blame for the greenhouse effect, is aggravating climate change. In an effort to mitigate climate change, the international society has been undertaking numerous efforts to reduce CO_2 emissions at the national level. Given their high growth potential, emerging economies significantly affect future emission levels. Indeed, among the world's emerging economies, China and India are the largest CO_2 emitters, accounting for almost one-third of the world's CO_2 emissions [1,2]. Accordingly, in recent years, rapid economic growth accompanied by increasing CO_2 emissions has focused the world's attention on China and India in the context of emissions reduction.

The rapid economic growth experienced by China and India in recent years has led to an exponential increase in the countries' energy consumption [3]. Over the last few years, China and India have been ranked significantly high in terms of energy demand; China was ranked the largest global energy consumer in 2011, followed by the United States, Russia, and India [4–8]. As the energy consumption structures of both countries are heavily dependent on coal, it is highly likely that the spurt in economic growth will cause their CO_2 emissions levels to rise even further in the coming years [9]. Furthermore, more than three-quarters of the world's energy-related CO_2 emissions growth is expected to come from China and India [10], while it is predicted that the share of the other industrialized countries will fall continuously.

The recent impressive economic growth in China and India have intensified their demand for energy across all sectors, including the residential sector. The residential sector in China accounts for 23% of total energy consumption, the second largest share in its economy. India's residential sector consumes 36% of its total final energy and constitutes the largest sector in this respect. More importantly, with increasing household income and rapid electrification in these countries, the residential sector is recognized as being key toward mitigating CO_2 emissions at the national level. Trends in CO_2 emissions are closely tied to economic growth and energy consumption. Therefore, the main objective of this paper is to identify and understand the drivers behind CO2 emissions from the residential sector in China and India, so as to draw implications in terms of challenges and opportunities with regard to their countries' energy policies.

To address this objective, we use the Logarithmic Mean Divisia Index (LMDI) decomposition technique to analyze how socio-economic factors contribute to changes of CO_2 emissions in the residential sector over time (from 1990 to 2011). The LMDI approach has been used previously to analyze the determinants of CO_2 emissions in the residential sector [11–15]. However, these studies are limited to a single country and do not conduct a comparative analysis between countries. By comparing the factors affecting the trends of CO_2 emissions in these countries, we discuss possible energy policy implications for other developing countries.

The rest of this paper is organized as follows. Section 2 introduces the LMDI methodology and datasets used for the decomposition analysis. Section 3 presents the main results from the decomposition analysis on residential CO_2 emissions in China and India. Section 4 concludes and draws policy implications from the analysis.

2. Methods and Data

2.1. The Logarithmic Mean Divisia Index (LMDI) Method

Index decomposition analysis (IDA) has been widely applied to studies that focus on analyzing the driving factors of energy consumption and greenhouse gas (GHG) emission trends. Index decomposition starts by defining the various factors associated with the aggregate variable (e.g., industrial energy consumption and industrial energy-related carbon emissions). Using these defined factors, different methods can be formulated to quantify the impacts of changes in the factors on the aggregate variable [14,15]. The IDA approach can be divided into two groups: methods linked to the Laspeyres index and methods linked to the Divisia index. Since 2000, the LMDI method, classified as a Divisia index approach, has been the most popular IDA approach [15,16]. The LMDI approach has advantages in terms of practical implementation; it does not contain an unexplained residual term and is consistent in aggregation [17–19]. Furthermore, the literature notes that the LMDI method can be used to investigate changes in GHG emissions both in the theoretical and practical contexts [15,19,20]

This paper investigates the evolving patterns of CO_2 emissions in the residential sectors of China and India from 1990 to 2011 using the LMDI approach. Given their rapid rates of economic growth, these countries have been experiencing a sharp increase in energy demand. Rampant urbanization has triggered high construction activity in the world's top two populous nations. Therefore, household share of total CO_2 emissions will continue to grow as these emerging economies are expected to make transitions to higher industrialization and higher income levels [21]. Given the strong prospects for continued rapid economic growth and higher future CO_2 emissions, a number of studies have explored key factors influencing changes of CO_2 emissions in the residential sector, with a special focus on China and India [11–13,22,23].

In the case of China, Wang *et al.* [22] decomposed China's CO_2 emissions at the regional level (focusing on Tianjin city) and concluded that income and population effects were the dominant positive factors affecting the growth in CO_2 emissions for all sectors. Zhao *et al.* [13] concluded that price effects resulting from price deregulation in the energy sector contributed to reduction of energy consumption, and thus slowed down CO_2 emissions. Zha *et al.* [11] estimated and compared CO_2 emissions trends and key factors influencing these trends for the urban and rural residential sectors. They found that energy intensity and income effects, respectively, contributed the most to the decline and the increase of residential CO_2 emissions in both urban and rural areas. Xu *et al.* [23] also reported that an increase in per capita energy usage contributed to rising emissions in the residential sector, while the effects of the shifts in the energy mix and emission coefficients on the change in CO_2 emissions were marginal. For the Indian residential sector, Das *et al.* [24] identified that income level, energy consumption expenditure level, and population size were the main factors responsible for increasing CO_2 emissions at the household level. Pachauri [25] analyzed the variations in the pattern of household energy consumption using micro level survey data. The econometric analysis showed that income level and age of the household head were important explanatory variables for variation in energy requirements across households. As one of the analysis tools, the LMDI approach has been employed in a number of practical applications pertaining to the analysis of the determinants associated with the change of CO_2 emissions in the residential sector.

2.2. Model Construction

The LMDI method can be either additive or multiplicative form [14,15]. In our analysis, we use the additive form of the LMDI approach to analyze the driving forces contributing to changes in CO_2 emissions from the residential sectors in China and India. Annual aggregate residential CO_2 emissions can be decomposed into five factors as follows (Equation (1)):

$$CO2^t = \sum_i^n CO2_i^t = \sum_i^n \frac{CO2_i^t}{ENE_i^t}\frac{ENE_i^t}{ENE^t}\frac{ENE^t}{GDP^t}\frac{GDP^t}{POP^t}POP^t \tag{1}$$

As shown in the Equation (1), $CO2^t$ refers to each country's aggregate CO_2 emissions from the residential sector, and $CO2_i^t$ represents the CO_2 emissions arising from consumption of fuel type i (e.g., coal, oil, gas, and electricity). In calculating those values, both direct CO_2 emissions from residential fuel use and indirect CO_2 emissions arising from the electricity and heat consumption are considered. In addition, we define the following variables for year t: ENE_i^t, the residential energy consumption level for fuel i; ENE^t, total energy consumption in the residential sector; GDP^t, Gross Domestic Product (GDP) level; POP^t, population size in each country. Hence, the Equation (1) can be expressed as an Equation (2):

$$CO2^t = \sum_i^n CO2_i^t = \sum_i^n COEFF_i^t \cdot ES_i^t \cdot EIN^t \cdot INC^t \cdot POP^t \tag{2}$$

In the Equation (2), $COEFF_i^t$ ($= \frac{CO2_i^t}{ENE_i^t}$) term is the emission factor of each fuel in the residential sector, which is CO_2 emission coefficient effect. This effect evaluates the fuel quality [11], and this covers both direct emission coefficients and indirect emission coefficients. ES_i^t ($= \frac{ENE_i^t}{ENE^t}$) captures the energy consumption share of fuel i relative to the total energy consumption, which indicates the energy substitution effect. In addition, EIN^t ($= \frac{ENE^t}{GDP^t}$) term presents energy intensity of the residential sector, which is related to investments for energy savings, technological improvements, and energy efficiency policies. INC^t ($= \frac{GDP^t}{POP^t}$), and POP^t are, respectively, per capita income, and population effect associated with the change in the residential CO_2 emissions.

Based on this structure, we can decompose the observed changes in CO_2 emissions ($\Delta CO2^t$) from the residential sector from a base year (t-1) to a target year (t) into five different factors as mentioned above: the change in emission factors in energy consumption $\Delta CO2_{COEFF}$: CO_2 emission coefficient effect), the change in energy consumption structure ($\Delta CO2_{ES}$: energy substitution effect), the change in residential energy intensity ($\Delta CO2_{EIN}$: energy intensity effect), the change in the income of residents ($\Delta CO2_{INC}$: income effect), and the change in population size ($\Delta CO2_{POP}$: population effect). Hence, the changes of aggregate residential CO_2 emissions between year (t-1) and year (t) can be expressed as the following equation (Equation (3)).

$$\Delta\ CO2^t = \Delta CO2_{COEFF} + \Delta CO2_{ES} + \Delta CO2_{EIN} + \Delta CO2_{INC} + \Delta CO2_{POP} \tag{3}$$

In addition, those five contributing factors can be derived from Equation (4) to Equation (8). Those factors give information upon relative contributions to changes in residential CO_2 emissions. Each of those five effects is isolated by measuring changes in residential CO_2 emissions associated with the change in the corresponding variable, while fixing the other variables constant with respective values in base year [26,27].

$$\Delta CO2_{COEFF} = \sum_i \left[\frac{\left(CO2_i^t - CO2_i^{t-1} \right)}{\left(\ln CO2_i^t - \ln CO2_i^{t-1} \right)} \right] \cdot \ln \left(\frac{COEFF_i^t}{COEFF_i^{t-1}} \right) \tag{4}$$

$$\Delta CO2_{ES} = \sum_i \left[\frac{\left(CO2_i^t - CO2_i^{t-1} \right)}{\left(\ln CO2_i^t - \ln CO2_i^{t-1} \right)} \right] \cdot \ln \left(\frac{ES_i^t}{ES_i^{t-1}} \right) \tag{5}$$

$$\Delta CO2_{EIN} = \sum_i \left[\frac{\left(CO2_i^t - CO2_i^{t-1} \right)}{\left(\ln CO2_i^t - \ln CO2_i^{t-1} \right)} \right] \cdot \ln \left(\frac{EIN^t}{EIN^{t-1}} \right) \tag{6}$$

$$\Delta CO2_{INC} = \sum_i \left[\frac{\left(CO2_i^t - CO2_i^{t-1} \right)}{\left(\ln CO2_i^t - \ln CO2_i^{t-1} \right)} \right] \cdot \ln \left(\frac{INC^t}{INC^{t-1}} \right) \tag{7}$$

$$\Delta CO2_{POP} = \sum_i \left[\frac{\left(CO2_i^t - CO2_i^{t-1} \right)}{\left(\ln CO2_i^t - \ln CO2_i^{t-1} \right)} \right] \cdot \ln \left(\frac{POP^t}{POP^{t-1}} \right) \tag{8}$$

where $\Delta CO2_{COEFF}$, $\Delta CO2_{ES}$, $\Delta CO2_{EIN}$, $\Delta CO2_{INC}$, and $\Delta CO2_{POP}$ denote the changes in CO_2 emissions from the residential sector arising from the CO_2 emission coefficient effect, energy substitution effect, energy intensity effect, income effect, and population effect, respectively.

2.3. Data Collection

In order to apply above mentioned additive form of the LMDI approach, we collect the data related to the energy consumption and CO_2 emissions from the residential sectors in China and India. Data for the residential CO_2 emissions levels from 1990 to 2011 in both countries are collected from the International Energy Agency's (IEA) datasets [1,2,28]. The values of energy consumption in the residential sectors from 1990 to 2011 are sourced from other IEA datasets [6,7].

For China, we divide energy sources into 11 categories according to [6,7], including coal (bituminous coal, patent fuel, coke oven coke, gas works gas, and coke oven gas), oil (liquefied petroleum gases (LPG), kerosene, and gas/diesel oil), natural gas, electricity, and heat. For India, seven categories of energy sources, including coal (coking coal, bituminous coal, and brown coal briquettes (BKB)), oil (LPG, and kerosene), natural gas, electricity, and heat are considered. Furthermore, according to the accounting methodology for CO_2 emissions proposed by the

Intergovernmental Panel on Climate Change (IPCC) [28], biofuels is not considered in assessments of CO_2 emissions from fuel combustion.

By constructing datasets, both direct CO_2 emissions from fuel combustion and indirect emissions associated with the electricity and heat consumption have been considered to understand the residential CO_2 emissions. CO_2 emissions from electricity and heat generation have been allocated to residential sectors in proportion to the electricity and heat consumed. In case of direct emissions from fuel use, emission factor (coefficient) by fuel type is calculated by dividing CO_2 emissions arising from consumption of fuel i by consumption level of fuel i in the residential sector. As with direct emission factor, indirect emission factor is derived from dividing indirect CO_2 emissions by the amount of electricity and heat demand from the residential sector. The population and GDP levels during the study period are obtained from the statistics collected by the Organization for Economic Co-operation and Development (OECD) [29,30].

3. Analysis Results

3.1. Residential CO_2 Emissions and Energy Consumption Structure

The CO_2 emissions from the residential sector in China, including both direct emissions and indirect emissions) increased by 136%, from 398.9 million tonnes CO_2 equivalent ($MtCO_2e$) in 1990 to 942.1 $MtCO_2e$ in 2011, during the study period (2009–2011). India also shows a clear trend of a rapid increase between 1990 (79 $MtCO_2e$) and 2011 (278 $MtCO_2e$). When comparing the absolute emissions levels between two countries, China shows higher values, as it is the largest CO_2 emitter in the world. Moreover, residential CO_2 emissions in India show a steady increase from 1990 to 2011 (Figure 1).

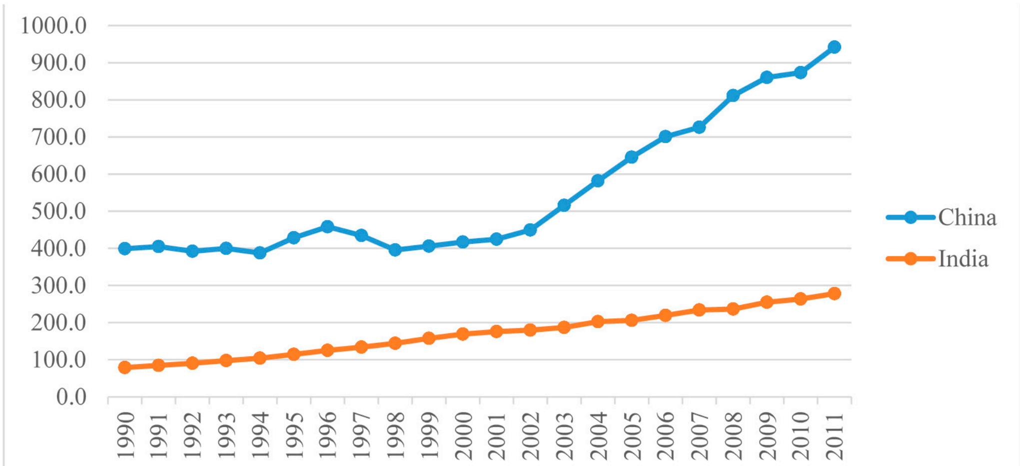

Figure 1. Residential CO_2 emissions from China and India (Unit: $MtCO_2e$).

The energy consumption structures associated with residential CO_2 emissions in both countries show the structural changes in fuel switching (Tables 1 and 2) and the quantity of energy used (Figure 2). Residential energy consumption in China is more than triple that of India in terms of the aggregate level. However, both countries experienced rapid increase in rates of energy consumption in the residential sectors from 1990 to 2011, mainly due to rapid urbanization, industrialization, and economic growth [31]. Those factors contributed to the accelerated growth of energy demand in their residential sectors.

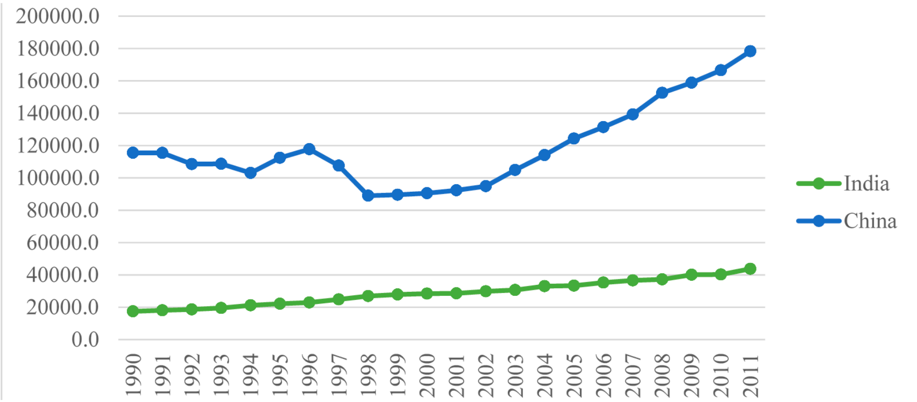

Figure 2. Trends of energy consumption level in China and India (Unit: kTOE).

The structural transitions of energy consumption by the residential sectors of both countries are reported in Tables 1 and 2. As shown in Table 1, coal and peat products accounted for the largest proportion of energy consumption during the whole study period. However, it is also pertinent to note that the residential sector in China shifted from using the most carbon-intensive energy source (coal, including bituminous coal, patent fuel, *etc.*) to oil products, natural gas, and electricity. In the case of China, the share of coal and peat products in energy consumption by the residential sector declined from 90.3% in 1990 to 34.5% in 2011. On the other hand, the shares of oil products, natural gas, and electricity grew by 13.1%, 11.1%, and 23.6%, respectively, between 1990 and 2011.

Table 1. Final energy consumption structure of China's residential sector (Unit: %).

		1990	**1995**	**2000**	**2005**	**2010**	**2011**
Coal/Peat	Bituminous Coal	89.09%	73.92%	48.82%	38.42%	31.71%	29.75%
	Patent Fuel	0.00%	4.59%	5.63%	5.48%	2.43%	2.35%
	Coke Oven Coke	0.19%	0.79%	1.02%	0.49%	0.18%	0.16%
	Gas Works Gas	0.29%	0.90%	2.54%	2.08%	1.00%	1.40%
	Coke Oven Gas	0.78%	0.92%	1.90%	1.65%	1.27%	0.85%
Oil	LPG	1.65%	5.70%	11.38%	12.82%	10.49%	10.82%
	Kerosene	0.83%	0.64%	0.86%	0.23%	0.13%	0.14%
	Gas/Diesel Oil	0.00%	0.15%	2.01%	3.33%	4.72%	5.12%
Natural Gas		1.35%	1.44%	2.99%	5.34%	11.39%	12.40%
Electricity		3.97%	8.27%	16.73%	20.22%	27.02%	27.64%
Heat		1.85%	2.68%	6.13%	9.93%	9.66%	9.38%

Table 2. Final energy consumption structure of India's residential sector (Unit: %).

		1990	**1995**	**2000**	**2005**	**2010**	**2011**
Coal/Peat	Coking Coal	2.44%	1.17%	0.86%	0.00%	0.04%	0.04%
	Bituminous Coal	16.86%	13.89%	11.27%	10.23%	9.14%	8.53%
	BKB	2.29%	1.77%	0.91%	0.65%	0.68%	0.81%
Oil	LPG	12.21%	15.56%	21.56%	33.24%	34.70%	34.38%
	Kerosene	50.27%	46.87%	41.56%	29.90%	22.66%	19.23%
Natural Gas		0.24%	0.66%	0.97%	0.19%	0.06%	3.62%
Electricity		15.69%	20.07%	22.85%	25.79%	32.72%	33.41%

For India, it is found that the residential sector in India also experienced a structural transition in terms of the relative importance of different types of energy sources (Table 2). In 1990, the majority of India's energy demand was fulfilled by coal (21.6%) and oil products (62.5%), respectively. However, shares of coal and oil products in total final energy consumption in the residential sector declined to 9.4% and 53.6%, respectively, in 2011. These declines were accompanied by increased shares of natural gas and electric power during this period. In summary, like Pachauri and Jiang [31], we find that both China and India have undergone transitions with regard to residential energy consumption, which are described by their shifting away from low efficiency solid fuels to more efficient liquid and gaseous fuels and electric power.

It is also essential to look into the electricity generation mix by fuel type for each country, as indirect emissions arising from the electricity consumption are taken into consideration when analyzing changes of residential CO_2 emissions. In China, the electricity consumption by the residential sector grew rapidly from 53.4 TWh (approximately 4.0% of final energy consumption in the residential sector) in 1990, to 573.1 TWh (27.6% of total final energy consumption) in 2011 (Table 1). In addition, as shown in Figure 3, China's electricity sector is predominantly reliant on fossil fuels, especially via coal-fired generation [32,33]. It is found that total electricity output from coal-fired power plants with high emission coefficients grew significantly, from 600.3 TWh in 1992 to 3751.0 TWh in 2012. Dominance of coal-fueled power plants in China can be attributed to its large proven coal reserves [34], firmly holding the first place among coal producing countries.

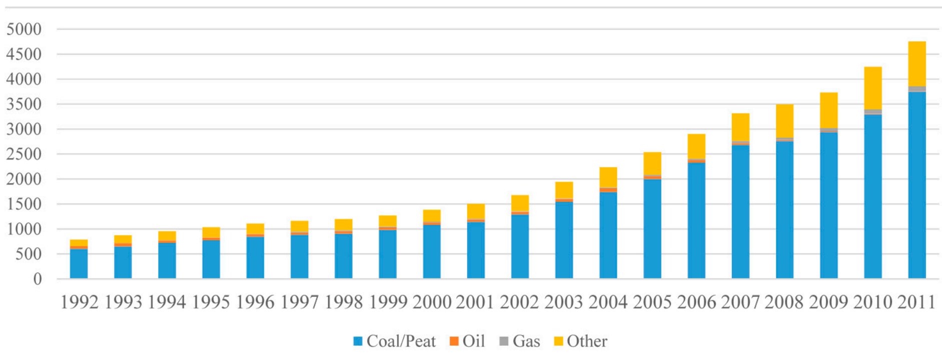

Figure 3. Generation mix by fuel type in China (Unit: TWh)

As with China, the demand for greater electricity generation is found for India's residential sector during the study period. India's residential sector also showed rapid rates of electrification, and the share of electricity in final energy consumption grew by 7.9% annually, increasing from 15.7% in 1990 to 33.4% in 2011 (Table 2). India's electricity sector is also heavily dependent on fossil fuels, especially coal, because it is the least expensive fossil fuel for power generation in the Indian economy (Figure 4). This can be understood by the India's domestic coal reserves (the third largest coal reserves in the world), and relatively easy access to affordable imported coal [34]. From 1990 to 2011, increased electricity generation was accompanied by increased coal-fired generation [32,33]. It is also found that total electricity generation output grew from 229.3 TWh in 1992 to 714.9 TWh in 2011.

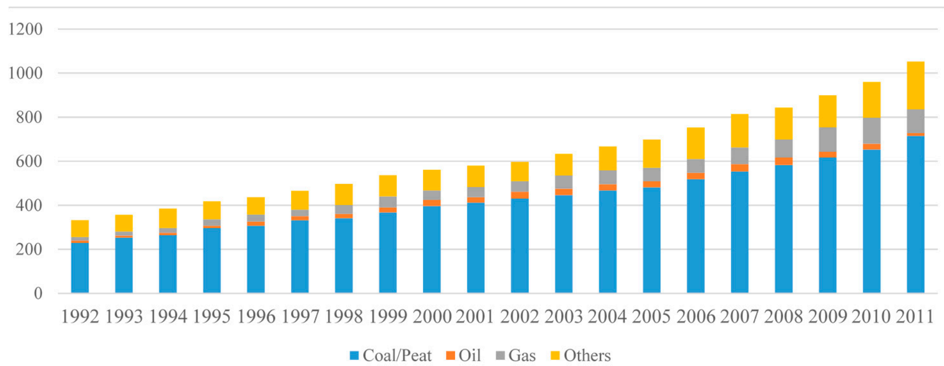

Figure 4. Generation mix by fuel type in India (Unit: TWh).

3.2. Main Results from the LMDI Methodology

This section presents the main results of the year-by-year decomposition analyses of China's and India's residential CO_2 emissions from 1990 to 2011. We use the equations and datasets mentioned in Section 2 to investigate the degree of contribution of socio-economic factors to trends in CO_2 emissions. The decomposition analyses allow us to understand the impact of those factors driving these trends in each country. Furthermore, we find common features in the identified contributing factors and accordingly draw policy implications for major CO_2 emitting countries such as, China and India.

Figures 5 and 6 present the LMDI decomposition results from 1990 (the base year) to 2011 (the target year) for China and India, respectively. In the case of China (Figure 5), the emission coefficient effect ($\Delta CO2_{COEFF}$) and the energy substitution effect ($\Delta CO2_{ES}$) accounted for a decrease of 43.0 MtCO_2e and an increase of 234.5 MtCO_2e, respectively, in CO_2 emissions from the residential sector. Furthermore, the intensity effect ($\Delta CO2_{EIN}$) contributed to a decrease of 697.6 MtCO_2e, whereas the income effect ($\Delta CO2_{INC}$) and population effect ($\Delta CO2_{POP}$) caused increases of 965.5 MtCO_2e and 83.7 MtCO_2e, respectively.

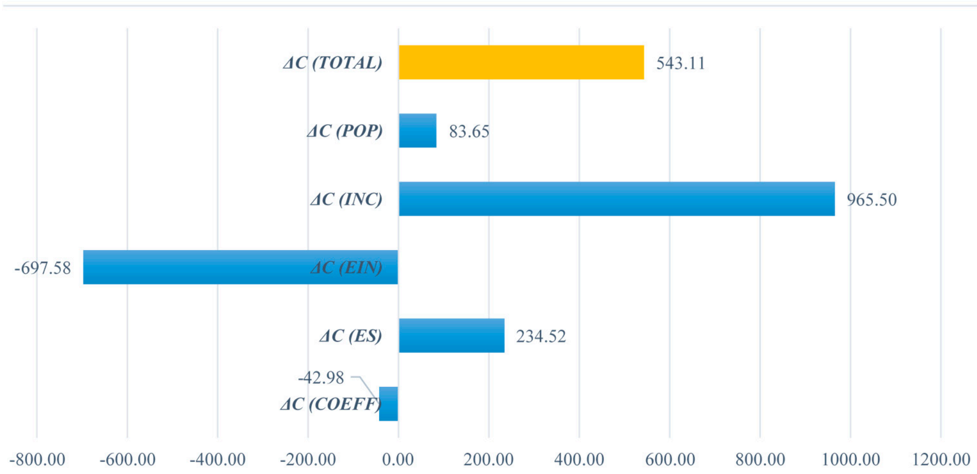

Figure 5. Results of LMDI decomposition from 1990 to 2011 in China (Unit: MtCO_2e).

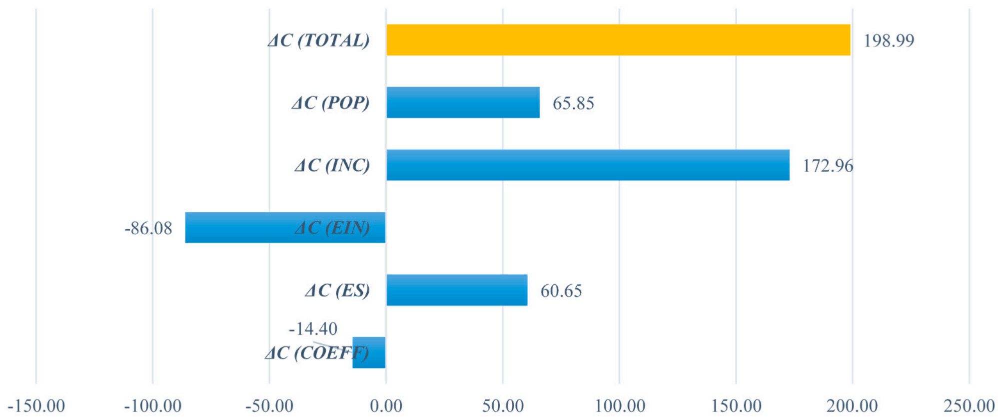

Figure 6. Results of LMDI decomposition from 1990 to 2011 in India (Unit: MtCO_2e).

When analyzing the corresponding factors for India (Figure 6), similar trends are observed from 1990 to 2011. The CO_2 emission coefficient effect was responsible for a decrease of 14.4 MtCO_2e in residential CO_2 emissions, while changes in the fuel mix pertaining to the energy consumption structure accounted for an increase of 60.7 $MtCO_2e$. In addition, the change in the population drove increases in CO_2 emissions by 65.9 $MtCO_2e$. The income effect was the main contributory factor raising CO_2 emissions from India's residential sector, as it drove an increase of 173.0 $MtCO_2e$. On the other hand, it is found that the change in energy intensity was mainly responsible for slowing down residential CO_2 emissions, causing a decrease of 86.1 $MtCO_2e$ between 1990 and 2011.

Accordingly, it can be stated that the income effect was the major contributory factor leading to increased CO_2 emissions in both countries during the study period. The changes in energy consumption structure and population also drove increase both countries' CO_2 emissions from their residential sectors, while CO_2 emission coefficient effect slowed down the residential CO_2 emissions. In addition, the energy intensity effect was mainly responsible for the CO_2 emissions reduction in the residential sectors of China and India from 1990 to 2011.

Besides analyzing the overall trends from the decomposition analysis, it is essential to analyze year-by-year trends of factors contributing to residential CO_2 emissions. Figures 7 and 8 highlight several characteristics of the decomposition analysis of residential CO_2 emissions since 1991. It is worthwhile to identify the forces responsible for residential CO_2 emissions and the differences between the two countries in terms of policy interventions associated with this issue. We discuss each of the five contributing factors in the following sub-sections.

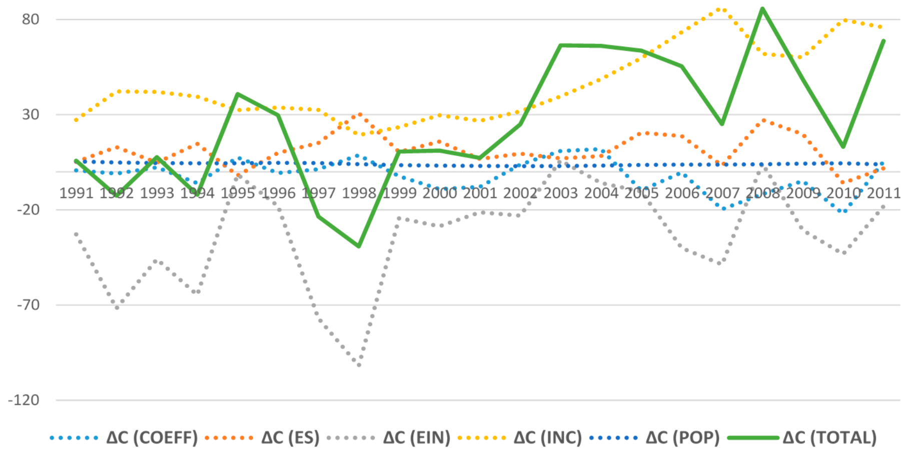

Figure 7. Year-by-year decomposition analysis for China (Unit: $MtCO_2e$)

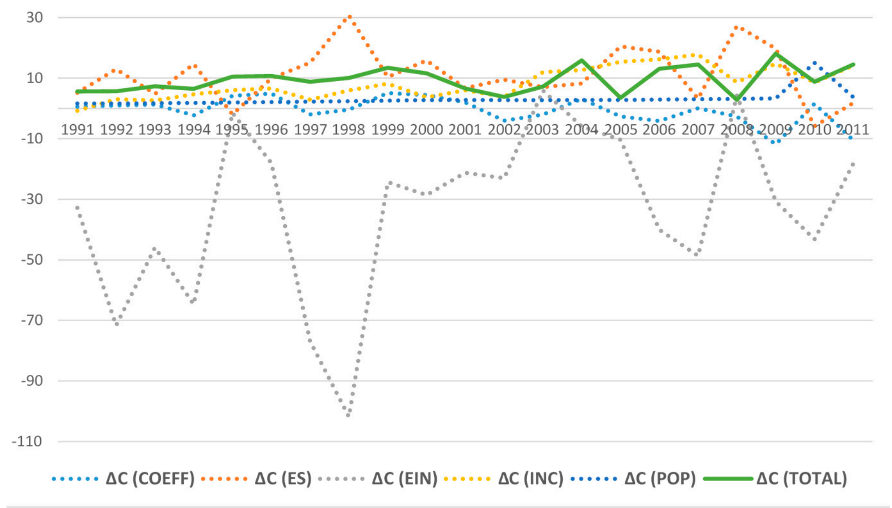

Figure 8. Year-by-year decomposition analysis for India (Unit: $MtCO_2e$).

3.2.1. CO_2 Emission Coefficient Effect

Figure 7 shows that the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) contributed the least toward changes in residential CO_2 emissions in China. In fact, during the entire period under study, the CO_2 emission coefficient effect on the changes of residential CO_2 emissions is found to be negative. In addition, the results from the annual decomposition analysis show that this effect on residential CO_2 emissions tends to fluctuate. Given that we consider both the direct emissions from fuel combustion and the indirect emissions from the consumption of electricity and heat, the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) is associated with direct emission factors (which is calculated by dividing direct CO_2 emissions by fuel use), and indirect emission factors (which is defined as indirect emissions from the electricity consumed per unit of electricity consumed). In this context, the impact of emission coefficients on residential CO_2 emissions is mainly determined by the fluctuation of indirect emission coefficients, while the direct emission coefficient is fuel specific, and relatively constant over the study period [35]. The electricity emission coefficient, and the indirect emission coefficient could vary depending on the fuel mix used to generate the electricity, and electricity generation efficiency.

In the case of China, it is evident that, barring the period from 2003 to 2005, these changes slowed down residential CO_2 emissions since 1999. As shown in Figure 3, China's electricity sector is predominantly reliant on fossil fuels, especially via coal-fired generation, and total electricity output from coal-fired power plants with high emission coefficients grew significantly. Therefore, it can be inferred that the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) on reducing China's residential CO_2 emissions could be attributed to increased electricity production and transmission efficiency. These efficiency gains reduced the indirect emission coefficients, partly offsetting the increased electricity generation from coal-fired power plants. As shown in the Figure 9, the indirect emission coefficient for China's residential sector showed a decreasing trend with the exception of the period from 2003 to 2005, which implies a strong relationship between the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) and the indirect emission coefficient. Furthermore, it is also found that CO_2 intensity of coal-fired generation (CO_2 emissions per KWh from electricity generation using coal) in China decreased from 1102 in 1990 to 950 in 2011 [32]. Efficiency improvements in the power sector can be understood by retracing the relevant policy implementation during this period. As mentioned above, the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) had contributed to the decrease of residential CO_2 emissions since 1999 in China. Therefore, it is worthwhile to look into relevant policies to improve the overall efficiency in the electricity power generation which were implemented at that time (around 1999).

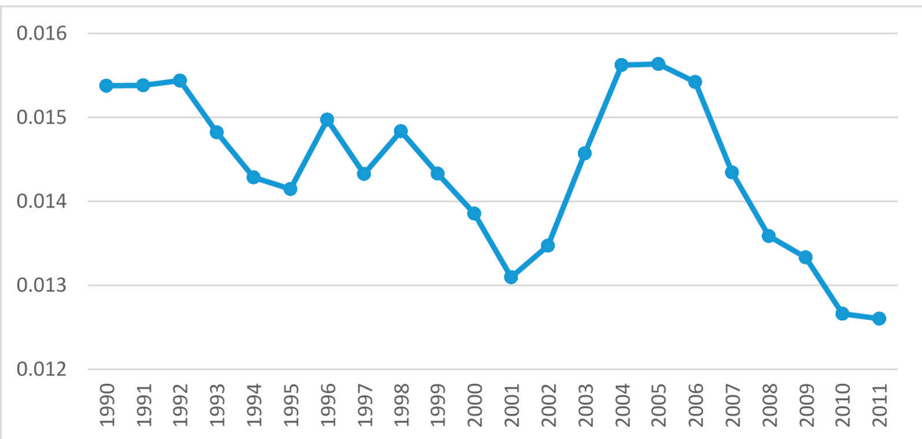

Figure 9. Trends of indirect emission coefficients in China (Unit: $MtCO_2e/GWh$).

A scrutiny of the regulation based on policy implementation shows that China's government has made substantial efforts to increase the efficiency of the electricity production and transmission process by transforming power sector's market structure. In fact, the Electric Power Law legislated in 1996 was brought into force, which aimed to regulate the generation, distribution, and consumption of electricity [36]. For instance, small-scale power plants were prohibited, and small coal-fired power plants with inefficient facilities had been continuously closed down through 2002. However, closure of small and inefficient power plants stopped completely from 2003 to 2004, due to the power supply shortages experienced in China at that time [37]. In addition, closing of small plants with outdated capacity was again accelerated from 2005, showing the average growth rate of closure capacity of 115% from 2005 to 2008, as reported by [37]. Therefore, it can be inferred that the annual fluctuations in the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) were partly driven by the small plant closures which had been implemented since 1999.

In addition, in 1997 the Chinese government took steps to reform the electricity sector by establishing the State Power Corporation. This action involved separating business operations and management from government authorities in order to resolve the power industry's structural problem [36]. Starting with this action, the Chinese government accelerated market reforms in the electricity sector by transforming the monopoly system of the country's planned economy to a market-based economy. In 2002, Chinese government dismantled the State Power Corporation legislated by the Scheme of the Reform for Power Industry, and set up 11 new companies in a move to end the corporation's monopoly of the power industry, which was expected to improve efficiency and lower costs. Thus, the restructuring process with breaking up the monopoly in the industry and introducing the concept of competition helped improve the overall electricity production (including, the fuel use efficiency) and transmission efficiency in China's power sector. Xu and Chen [36] estimated that the coal consumption for power supply was reduced with improvements of fuel use in the power generation process after the market reforms in 2002. In addition, Zha *et al.* [38] also reported that transmission losses in China's power sector declined from 7% in 1990 to 6.5% in 2004.

Figure 8 shows that the emission coefficient factor generally drove the increase in CO_2 emissions from India's residential sector until 2004. Conversely, this factor drove CO_2 emissions reduction in the residential sector since 2004. India's electricity sector is also heavily dependent on fossil fuels, especially coal, as shown in the Figure 4. From 1990 to 2011, increased electricity generation was accompanied by increased coal-fired generation with high emission coefficients. Similar to China's case, the CO_2 emissions coefficient effect ($\Delta CO2_{COEFF}$) on reducing India's residential CO_2 emissions from 2004 onwards could be attributed to gradual improvements in power generation and transmission efficiencies. As shown in the Figure 10, the indirect emission coefficient for India's residential sector showed an increasing trend from 1990 to 2002, while it showed a decreasing trend over the period from 2002 to 2011. It is also confirmed that there is a strong relationship between the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) and the indirect emission coefficient.

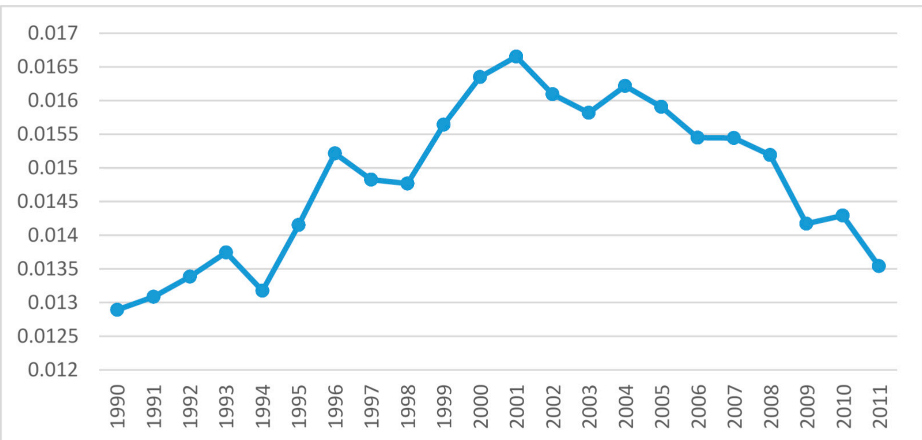

Figure 10. Trends of indirect emission coefficients in India (Unit: $MTCO_2e/GWh$).

Indeed, India's government implemented the Electricity Act of 2003 to create a market-based regime in the electricity sector to ensure a stable supply of electricity [38–40]. This legislation entailed open access to the transmission and distribution system, introduction of competition in the power generation sector, and facilitating an electricity trading market [41]. In particular, this Act aimed to improve efficiency and customer service standards by promoting competition among various players within the electricity sector [38]. Furthermore, India's short-term energy policies were executed based on Five-Year Plans [41]. During the 9th and 10th Five-Year Plans (1996–2001 and 2002–2007, respectively), approximately 138 units at 29 power stations were taken up for renovation and modernization in order to improve their technological performance and efficiency [4]. Thus, its efforts to enhance efficiency in power generation helped India's power sector take steps for promoting positive technology changes related to energy conversion efficiency [42,43].

As discussed above, we can figure out that both countries' power sector reforms had promoted competition within these sectors, and improved the overall efficiency in electricity production and transmission process. Furthermore, the annual fluctuations in the CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$) can be partly understood by each country's relevant policy implementations as mentioned above. In this context, differences of annual $\Delta CO2_{COEFF}$'s trends between China and India, and those fluctuations can be liked with timing of relevant policies implemented, as shown in Figure 11.

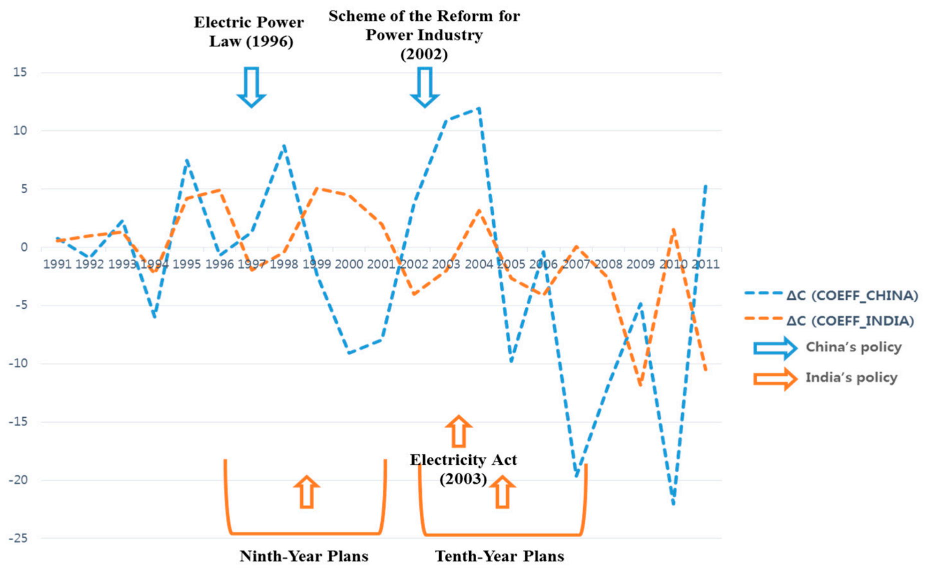

Figure 11. Annual trends of $\Delta CO2_{COEFF}$ and relevent policies in China and India.

3.2.2. Energy Substitution Effect

The energy substitution effect ($\Delta CO2_{ES}$) contributed to increases in CO_2 emissions for most of the study period for both China (234.52 $MtCO_2e$) and India (60.65 $MtCO_2e$). This energy substitution effect ($\Delta CO2_{ES}$) captures to what extent changes in residential emissions are due to changes in the share of energy consumption by fuel type. Investigating the trend of the energy substitution effect requires an analysis of the energy consumption structure, as discussed in Section 3.1. For China, the proportion of coal products in residential energy consumption decreased substantially from 1990 to 2011, as shown in the Table 1. On the other hand, the share of the electricity and heat, both of which have high emission coefficients, increased from 5.8% in 1990 to 37.0% in 2011. Therefore, it can be understood that even though there was a reduction in the direct emissions from most carbon-intensive energy sources, the indirect emissions from electricity and heat consumption increased. Accordingly, it can be inferred that the increased share of electricity largely based on the coal-fired generation substituted for other fuels, resulted in the increase of residential CO_2 emissions.

A similar trend in energy consumption structure of the residential sector, is also detected for India (Table 2). In 1990, oil products (e.g., LPG and kerosene) accounted for the largest share of energy consumption associated with emissions from the residential sector, followed by coal products (e.g., coking coal and bituminous coal). However, in 2011, while oil products continued to dominate other fuels, electricity took the second largest share (33.41%) in the final energy consumption. In other words, the share of coal in the energy consumption structure of India's residential sector was relatively reduced while that of electricity rose. Accordingly, it can be understood that electricity consumption which has high emission coefficients, substituted demands for other energy sources, resulting in increases of residential CO_2 emissions in both countries.

In 2000, India alone accounted for more than 35% of the world's population without electricity access, which was the largest contributor in the world [44,45]. To counter this, the Indian government launched several programs to provide households access to electricity in India. In 2000, the Prime Minister's Village Development Program was launched with a focus on providing basic services, including the rural electricity supply, to villages with investments in new generation capacity [46,47]. In addition, the Rajiv Gandhi Grameen Vidyutikran Yojana (RGGVY), funded by the Rural Electrification Corporation (REC), was launched in 2005, which aimed to electrify all villages and habitations in India. The REC designed a couple of policy programs to provide free supply of electricity to households below the poverty line and invested in fundamental infrastructure, such as electricity distribution transformers and distribution lines, to fulfill this goal [45,48].

China's central government had also undertaken many initiatives to expand citizens' access to electricity. From 1990 to 2002, over 900 million rural residents had benefitted from these initiatives, and the country had achieved an electricity access rate of as high as 98% in 2002 [49,50]. In 1996, the Chinese government launched the Brightness Program and Developing Rural Power through Wind to improve the living conditions of populations in remote areas by providing electricity from decentralized sources [51]. In fact, the institutional management of rural electricity was operated by a multi-level administrative system until the late 1990s. From 1998 to 2002, China implemented and launched a series of policy instruments aimed at "reforming rural electricity management, renovating rural power grid and leveling rural and urban electricity tariffs" [50]. Moreover, the central government facilitated commercial operations in the utility market by letting the local electricity supply free from the control of local governments. Furthermore, the rural and urban electricity systems have been merged to form a uniform and integrated nationwide system after 2002.

As described above, China and India's governments made efforts to expand households' access to electricity in order to stimulate economic and social development, and decrease disparities between rural and urban residents. However, contrary to India's relatively low level of the electricity access (62.3% of population), China showed higher level of the electricity access (98.0% of population) in 2000. In this context, in the early 2000s India's government mainly took into consideration promoting access to electricity nation wide with investments in new generation capacity and fundamental infrastructure by implementing various programs as mentioned above. On the other hand, the Chinese government focused on renovating rural power grids, and improving the existing systems to facilitate efficient delivery of electricity to remote areas. Accordingly, we can figure out different approaches between China and India to expand households' access to electricity during the study period. Furthermore, we can infer that those programs implemented by each country's government to promote electricity consumption partially drove changes of $\Delta CO2_{ES}$, as shown in Figure 12.

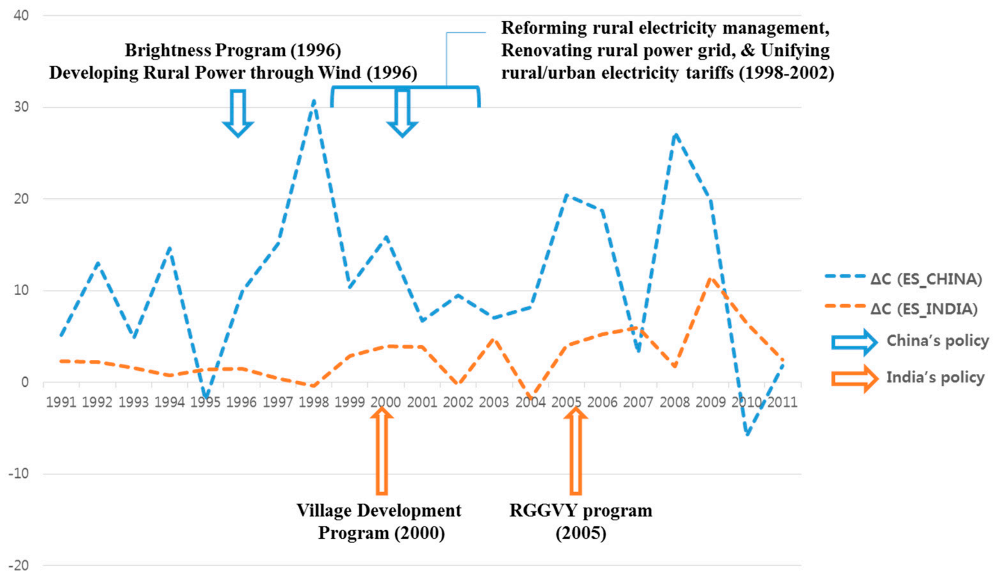

Figure 12. Annual trends of $\Delta CO2_{ES}$ and relevant policies in China and India.

3.2.3. Energy Intensity Effect

The energy intensity effect ($\Delta CO2_{EIN}$) contributed to emissions reductions over 1990 to 2011 in both China and India. It was the main driving factor responsible for slowing down residential CO_2 emissions, as it cancelled out the positive effects arising from the other factors. This energy intensity effect ($\Delta CO2_{EIN}$) captures the effectiveness of investments for energy savings, technological improvements, and energy efficiency policies. Figure 5 shows that about 697.58 $MtCO_2e$ of CO_2 emissions reduction were associated with the change in energy intensity of China's residential sector over the whole study period. In addition, we detected that $\Delta CO2_{EIN}$ had the largest impact in 1998, driving a decline of 101.86 $MtCO_2e$ in CO_2 emissions. For India, about 86.08 $MtCO_2e$ of CO_2 emissions reduction was driven by the energy intensity effect throughout the study period (Figure 6), while it had the largest impact in 2010, contributing to emissions reductions of 22.83 $MtCO_2e$. Impacts of the energy intensity effects on residential emissions reductions in both countries can be attributed to each country's efforts to improve energy efficiency by promoting technological progress and regulating standards for product energy efficiency levels. Therefore, the energy intensity effect can be interpreted as the decrease in energy consumption from energy efficiency gains, partly offsetting the increase energy consumption from economic growth [11].

China has undertaken wide-ranging efforts toward improving energy efficiency. Since the 1990s, it has been encouraging citizens to replace their old energy-inefficient home appliances [52]. In 1990, the Chinese government unveiled its first program on energy efficiency standards for appliances such as air conditioners and washing machines [53–55]. After modernizing the energy efficiency standard system in mid 1990s, the Energy Conservation Law was formulated in 1998 to introduce mandatory minimum efficiency standards and energy efficiency labeling [53]. Accordingly, new standards and labeling requirements (such as voluntary energy efficiency labeling) were implemented in 1999, inducing appliance manufacturers to invest in technological progress [53,56]. Furthermore, the energy efficiency labeling system was formally established in China in 2005 in order to help consumers make more informed choices while buying appliances [11,57].

India also recognized the importance of energy efficiency. The government passed the Energy Conservation Act in 2001 in order to reduce the energy intensity of the economy [58]. In addition, the Bureau of Energy Efficiency (BEE), established in 2002 under the Ministry of Power [58,59], initiated a number of energy efficiency initiatives in the areas of household lighting, standards, labeling of appliances, and so on. The establishment of the BEE was a turning point for articulating national initiatives for energy efficiency. In 2006, the BEE launched the Standards and Labeling Program for residential and commercial appliances/equipment, including 19 categories of products such as air conditioners, refrigerators, color TVs, washing machines, and so on. Furthermore, in 2008, India announced the National Action Plan on Climate Change, which emphasized climate change mitigation. India's government included the National Mission for Enhanced Energy Efficiency (NMEEE) as one of the missions under this Plan. Based on this initiative, India is making efforts to accelerate the shift to more energy efficient products and is using fiscal instruments to promote their development [60,61].

In summary, China and India have long perceived the importance of energy efficiency and adopted energy efficiency standards and labeling systems. However, these policies were initiated at different times, from the 1990s for China and from the 2000s for India. Therefore, we can infer that this difference in the timing of policy implementation between two countries shows up in the observed trends in their energy intensity effects (Figure 13).

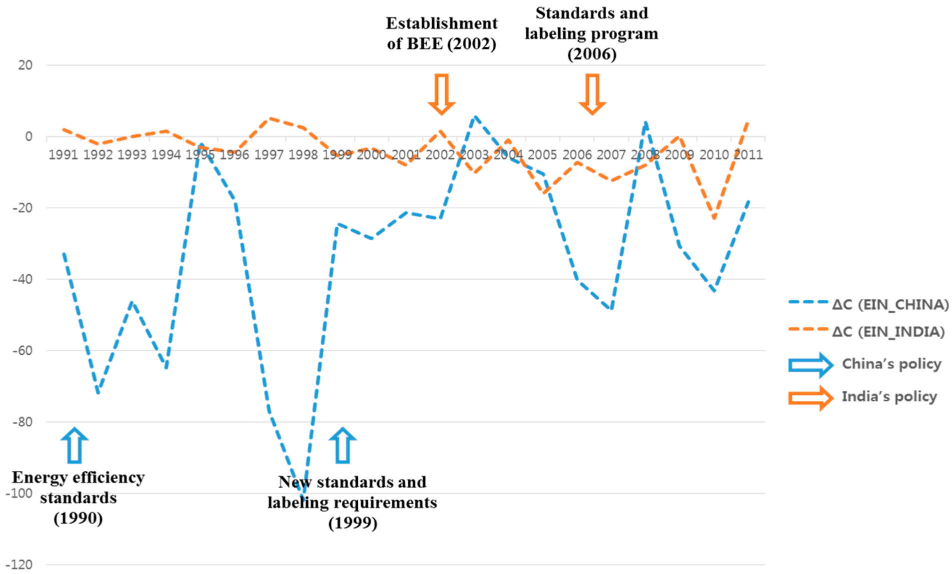

Figure 13. Annual trends of $\Delta CO2_{EIN}$ and relevent policies in China and India.

3.2.4. Income Effect

The income effect ($\Delta CO2_{INC}$) had the largest effect on increases of CO_2 emissions from the residential sectors in China and India. Figure 5 shows that an increase of 965.50 $MtCO_2e$ of emissions was attributed to the change in the income level in China during the whole study period, while the corresponding value for India was 172.96 $MtCO_2e$ (Figure 6). In addition, the trends for this factor show a pronounced increase from 1990 to 2011 in both countries. China and India are the world's fastest expanding large economies. From 1990 to 2011, China and India experienced rapid economic growth by means of privatization and trade liberalization, as evidenced by their average GDP growth rates of 9.1% and 6.2%, respectively. In addition, it is found that in China, the proportion of expense on food to total consumption expenditure decreased from 54.2% in 1990 to 36.3% in 2011, while the share of expense on transport and communications rose from 3.2% in 1990 to 14.2% in 2011 [62]. For India, the share of food expenditure had also steadily fallen from 60%–70% in 1990 to 40%–50% in 2011 [63]. We can infer that the rapid growth of energy demand is associated with high and stable economic expansion evidenced in both countries, higher household income levels, and improved access to electricity encouraged households to use more electric home appliances.

In fact, the electrification rates of China and India increased from 94.2% and 50.9% in 1990 to 100% and 78.7% in 2012, respectively, [64]. Bearing in mind that access to energy is essential for economic development and a better quality of life, the Chinese and Indian governments launched a variety of programs to support household electrification in their countries. In the 1990s, China made great strides in enhancing rural electrification. Chinese power companies owned by the public sector enacted several programs to spur rural electrification using renewable energy such as solar and wind energy [65,66] (e.g., Serving Agriculture & Serving Peasants, Serving Rural Economic Development, and Project for Reducing Poverty and Simultaneously Enriching Rural and Urban Households by Electrification). In addition, in 1998 the Chinese government launched the Rural Network Development and Upgrade Program, which involved reforms in rural electricity systems, including leveling tariffs across networks and promoting technological advances in the electricity supply system [67].

India also executed a variety of programs to fulfill the energy and electricity demand of its rural population from the early 1990s by covering a wide range of technology and fuel options [45,66]. For example, India's government initiated the Rural Electricity Supply Technology Mission (REST) in 2002 in order to provide decentralized electricity generation options in all villages using local renewable energy sources instead of depending on the centralized electricity supply system. This initiative included identifying and adopting technological solutions and providing financial support to rural areas [68,69].

Consequently, the electrification rates in both countries improved between 1990 and 2011. With better access to the electricity, the number of home appliances owned by the residential sector with higher income level increased drastically in China and India [12,70]. Therefore, it shows that people with better access to electricity experienced significant improvements in living standards, which led to consuming more energy to sustain their comfortable lives.

3.2.5. Population Effect

The population effect ($\Delta CO2_{POP}$) contributed to increasing CO_2 emissions in China (83.65 $MtCO_2e$) and India (65.85 $MtCO_2e$) during the whole study period. From 1990 to 2011, population grew steadily, with average annual growth rate of 0.77% in China and 1.74% in India. The significant population size and its expanding growth rate drove rapid energy consumption in the residential sectors of both countries. Furthermore, the urbanization rate (which refers to the share of population living in urban areas) increased from 26% in 1990 to 51% and 31% in 2011 in China and India, respectively [71]. With rapid rates of urbanization, China now has the largest urban population (758 million), followed by India (410 million). In fact, as a part of family planning policy, China had implemented the one child policy for last two decades to control the population. However, from the decomposition analysis it is found that the population effect in China was relatively constant over the study period. Hence, it can be inferred that, while one child policy had somewhat slowed down China's population growth, rapid rates of urbanization had made rural residents move to urban areas with higher living standards, resulting in higher demands for energy sources. Therefore, it can be understood that the process of urbanization, along with the already large population size, drove the increase of CO_2 emissions in the residential sectors of both countries [72].

4. Conclusions and Discussions

Emerging economies can significantly influence future emission levels on a global scale, given their present emission levels and high growth potentials. Trends and changes in CO_2 emissions in such countries are closely associated with their economic growth and changes in energy consumption. Among the emerging economies, China and India are the world's largest CO_2 emitting countries, together accounting for almost one-third of global CO_2 emissions. Moreover, their recent impressive economic growth has intensified their energy demand in all sectors, including the residential sector. The residential sector in China accounts for 23% of the country's total final energy consumption, comprising the second largest share in its economy. India's residential sector is responsible for 36% of the nation's total final energy consumption, which is the largest sector in its economy. More importantly, increasing households' income and rapid rates of electrification in these countries point to enhanced focus on the residential sector as an important segment in mitigating CO_2 emissions at the national level.

Therefore, it is essential to analyze trends of residential CO_2 emissions in those countries, and investigate key contributing factors behind them. After identifying these determinants, we can investigate the challenges and opportunities pertaining to those countries' existing energy policies. In this paper, we analyzed changes of residential CO_2 emissions in China and India using LMDI decomposition analysis. Five socio-economic factors were considered as key contributing factors affecting changes of residential CO_2 emissions: CO_2 emission coefficient effect ($\Delta CO2_{COEFF}$), energy substitution effect ($\Delta CO2_{ES}$), energy intensity effect ($\Delta CO2_{EIN}$), income effect ($\Delta CO2_{INC}$), and population effect ($\Delta CO2_{POP}$). Along with analyzing relative contributions of each factor, we investigated relevant policies implemented by those countries, which were related to changes of five factors ($\Delta CO2_{COEFF}$, $\Delta CO2_{ES}$, $\Delta CO2_{EIN}$, $\Delta CO2_{INC}$, and $\Delta CO2_{POP}$).

We found that during the period 1990-2011, the increase in per capita income level contributed to the most to the increase in CO_2 emissions. This implies that rapid growth of energy demand is associated with high and stable economic expansion evidenced in both countries. In addition, we found that the energy intensity effect had the largest effect on CO_2 emissions reduction in both countries' residential sectors, which implies that investments for energy savings, technological improvements, and energy efficiency policies were effective in mitigating CO_2 emissions. It is also found that the change in CO_2 emission coefficients for fuels which is the CO_2 emissions per unit of fuel uses slowed down the increase of residential emissions. This can be understood by both countries' power sector reforms which promoted competition within power sectors, and improved the overall efficiency in electricity production and transmission process. Furthermore, our results demonstrate that changes in the population and energy consumption structure drove the increase in CO_2 emissions. Those results are largely associated with rapid rates of electrification and better access to electricity experienced by those countries' residential sectors, resulting in increases of indirect emissions from the higher levels of electricity consumption.

The increased population, household income level, and urbanization indicate that the residential sectors of both countries must receive greater attention when planning CO_2 emissions mitigation efforts at the national level. Environmental sustainability is challenged by rapid urbanization and consumption patterns that prevail in urban settings. Owing in part to their higher incomes, urban populations tend to consume more energy resources than rural populations [73,74]. Yet many governments are not well prepared to cope with the speed at which their urban populations are growing. Therefore, it is essential for governments, including China and India who are experiencing rapid urbanization, to be well equipped with skillful planning and management to handle residential CO_2 emissions [75]. Furthermore, policies which aim to mitigate residential CO_2 emissions should be prepared from various perspectives. Based on the results of our research, national level strategies and policies for low carbon economy in China and India are presented as follows:

(1) Technology policy

Despite prior policy implementation to enhance the overall efficiency in electricity sectors (as discussed in Section 3.2), the energy efficiency of thermal power generation in China and India is consistently poor compared to that of other countries (e.g., the United States, Japan, Australia, Germany, and Italy) [76]. Thus, there is considerable potential to reduce CO_2 emissions via energy efficiency improvements in the electricity sector. The analysis shows that the electricity emission coefficients and indirect emission coefficient decreased recently for both countries. Therefore, both China and India need to further reduce the CO_2 emission intensity of electricity by adopting advanced technologies to enhance energy efficiency in their existing power generation systems to cope with further increases in electricity demand.

To be specific, China and India's electricity sectors are predominantly reliant on fossil fuels, especially via coal-fired generation due to large proven coal reserves. It is also found that total electricity output from coal-fired power plants with high emission coefficients grew significantly. Therefore, it is essential for both countries to reduce the CO_2 intensity of electricity and improve efficiency by applying mature and advanced technologies and enhancing the overall coal-fired power generation technology.

In addition, hybrid power systems which combine coal-fired power plants with renewable energy power generation systems can be another option for the power sector to reduce CO_2 intensity in China and India. The introduction of wind energy, solar energy, and other renewables in electricity generation can be attractive options to reduce the dependence on fossil fuel power generation. However, electricity production from these sources is largely intermittent and unstable, which are strongly influenced by seasonal and regional characteristics. Therefore, it could be an attractive option for China and India's power sectors to develop hybrid power systems which integrate renewables with stable coal-fired power plants. However, this approach poses substantial developmental and operational challenges. Hence, there should be higher level of investments in research and development on related technologies, supported by governments.

(2) Industry policy

China and India's governments made great efforts to make power sector reforms by introducing competition in the power sector and phasing out small plants with inefficient facilities. Those approaches aimed to increase the overall efficiency in the power generation and transmission process, implement effective incentive mechanisms, and deliver electricity with lower costs. Price *et al.* [37] estimated that China's power market reforms with closures of small plants and outdated generation capacities resulted in significant amounts of savings from final energy and primary energy consumption. In addition, Xu and Chen [36] estimated that the coal consumption for power supply in China was reduced with improvements of fuel use in the power generation process after the market reforms in 2002. Furthermore, Thakur *et al.* [38] also reported that transmission losses in China's power sector declined from 7% in 1990 to 6.5% in 2004, after the market reforms.

As mentioned above, it can be inferred that structural changes in China and India' electricity sectors enhanced efficiency in power generation and transmission process, and reduced the carbon intensity of the power sectors. However, these measures are not enough to complete the desired structural shift away from carbon intensive and low efficiency systems. As mentioned by Price *et al.* [37], additional measures are needed, such as adoption of international practices in energy management and technologies to encourage efficiency gains, and energy pricing reform (including, energy or carbon taxes) to incentivize economic agents (electricity producers and consumers) to reduce energy consumption with efficiency gains.

Furthermore, China and India must continue their efforts toward improving the energy efficiency of home appliances. The growing population and increased household income levels led to a drastic increase in the ownership of home appliances in both countries. Fortunately, our analysis found that there was a decoupling of GDP growth from energy consumption growth, resulting in the observed effects of energy intensity on residential CO_2 emissions reduction in both countries. Therefore, efforts to reduce residential energy consumption should be continuously made with continuous and timely revisions to energy efficiency standards and labeling systems. The home appliances market is rapidly changing with the rise of the middle class and dramatic technological progress. Therefore, China and India should capture dynamic changes in the appliance market and reflect those in newly updated energy efficiency standards and labeling systems.

(3) Population policy

Population policy can be divided into direct (or explicit) policy and indirect (or implicit) policy. Direct policy refers to government actions taken for the purpose of controlling fertility rates and maintaining the size of the population. Indirect policy is associated with policy implementation indirectly influencing individual and family decisions. In terms of direct policy, China implemented the one child policy for the last two decades as a part of family planning policy. However, from the decomposition analysis it is found the population effect in China relatively constant over the study period. Hence, it can be inferred that, while the one child policy had somewhat slowed down China's population growth, rapid rates of urbanization had made rural residents move to urban areas with higher living standards, resulting in higher demands for energy sources.

As the urban population increases at a rapid rate, managing energy consumption and CO_2 emissions from urban populations will become a greater priority in China and India. Rather than direct population policy such as controlling fertility rates by governmental regulation, more attention should be given to indirect policy with education programs. Increasing awareness of the urbanization will have to include the impact of cities on the environment and their contribution to global environmental solutions [77]. In addition, government officials of both countries need to note that urban populations in China and India are now experiencing significant increases in per capita income through rapid urbanization and economic development, offering vibrant new consumer markets for businesses to serve [74]. In fact, private consumption nowadays plays a significant role in India and China's economy [75]. In this regard, population policy should pay more attention to educating citizens about purchasing environmentally friendly products, consuming less energy in daily life which would ultimately lead to residential CO_2 emissions reduction in both countries.

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