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The driving forces behind the change in energy consumption in developing countries

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Abstract

Economic growth is principally powered by energy fuels. While the potential energy transition pathways in developed countries are clear, they have not been well explored for developing countries. Here, we study the average annual growth rate of energy consumption in 12 aggregated regions during 2001–2017 and the driving factors behind that growth. The countries with high energy consumption growth rates were concentrated in Asia and North Africa and four of the top five regions were in Asia, while the energy consumption in developed countries was stable or even declined in that period. Therefore, based on a comprehensive consideration of factors such as population and economic development, to quantify the role of renewable energy, we analyze the long time series of energy consumption for China, India, Indonesia, Myanmar and Bangladesh since the 1970s. Despite economic development and population growth accelerating energy consumption substantially upward, energy intensity made energy consumption decrease. Coal and oil dominated the energy transition pathway in China and India, while biomass and natural gas dominated in Indonesia, Myanmar and Bangladesh. The amount of CO_2 emissions in different countries was closely related to the amount and type of the energy they used. Our research results emphasize the importance of improving energy efficiency and adjusting energy structure to reduce energy consumption and achieve sustainable development.

1. Introduction

Energy is an indispensable part of economic development [1]. At the same time, energy consumption is also the major source of greenhouse gas emissions, which is a driver of climate change [2, 3]. How to achieve energy sustainability, climate change mitigation and economic development at the same time is one of the biggest challenges of the next few years. Therefore, it is especially important to understand the driving factors of increasing energy consumption and decouple them from economic development [4].

The drivers of energy consumption have been explored at different spatial and temporal scales. Globally, Lan *et al* used structural decomposition analysis (SDA) to decompose the global energy footprint from 1990 to 2010 [5] and found that, during this period, gross domestic product (GDP) per capita played an important role in the increase of global energy consumption. According to income levels, Omri *et al* provided a detailed analysis of the drivers of renewable energy consumption for a global panel of 64 countries and subgroups during 1990–2011 [6]. The global energy consumption of different sectors, fuel varieties and their impact on the environment was studied by Bilgen [7], who suggested improving energy efficiency and making corresponding innovations to reduce energy consumption. Based on the data from 1980 to 2001, the relationship between energy consumption, economic growth and CO_2 emissions was studied by Ramanathan [8], who predicted the relationship between non-fossil energy consumption and CO_2 emissions on the premise of fixed GDP in 2025.

Regionally, Fernández González *et al* [9] decomposed the changes in total energy consumption of the EU-27 countries during 2001–2008 and found that the reduction of energy intensity of EU-27 could not offset the demand of total energy consumption from European economic activities. Based on panel data, Gozgor *et al* [10] researched the influencing factors of renewable energy consumption in OECD (Organization for Economic Co-operation and Development) countries during 1970–2015 and put forward economic globalization as promoting the consumption of renewable energy. Some studies center on regions such as the European Union and OECD countries, but more studies analyze the energy consumption in a single country. Baležentis *et al* [11] analyzed the changing trend of energy intensity that affected the whole and different sectors of Lithuania from 1995 to 2000. The contribution of energy savings in the service and household sectors had the greatest impact on energy intensity decrease. Nevertheless, this study only focused on sectors and did not include research on energy types. Besides, compared with the analysis of energy consumption in developed countries, research in developing countries mainly focuses on China and India. A comparative analysis made by Wang and Li [12] demonstrated the driving factors of energy consumption change between China and India in 1970–2012. Analyzing China, India and the US, Wang *et al* [13] found that in China and India, a driving factor increasing energy consumption was coal intensity, while income and oil intensity were the leading drivers in the US. Many scholars have made detailed analyses of the driving factors of energy consumption of certain industries in China, including nonferrous metals [14], logistics [15] and transportation [16]. However, a comprehensive analysis that covers multi-countries' energy consumption is rare.

In this paper, the driving factors of energy consumption change in different regions or countries from 2001 to 2017 are analyzed with the method of logarithmic mean Divisia index (LMDI). Moreover, we further analyzed the evolution of energy consumption in selected developing countries from 1971 to 2017. Therefore, our paper fills the research gap on the driving factors behind the long-term changes in energy consumption in multiple countries or regions. The results will help countries, especially developing countries, formulate energy saving measures and policies.

2. Material and methods

2.1. Kaya identity

The Kaya identity was originally put forward by the Japanese scholar Yoichi Kaya [17]. Using a basic mathematical expression, the Kaya identity can decompose energy consumption into population scale, economic level, energy intensity and energy structure and quantitatively study the change of energy consumption in countries [18]. In this study, we write the mathematical expression of the Kaya identity as follows:

$$E = \sum E_i = \sum P \times \frac{G}{P} \times \frac{E}{G} \times \frac{E_i}{E}, \qquad (1)$$

where E is the total energy consumption, E_i is the type of energy, G is the GDP and P is the total domestic population.

2.2. LMDI decomposition

The commonly used methods to study energy consumption include structural decomposition analysis (SDA), index decomposition analysis (IDA) and econometric models based on panel data [19–21]. Panel data include two dimensions: time series and cross-section. In the study of the drivers of energy consumption change, decomposition analysis (DA) is often used, including SDA and IDA. Mathematically, DA is used to evaluate the influence of the driving factors behind the change of target variable and find which factors have the least influence and which factors have the greatest influence [22]. The change of the target variable can be assigned to relevant factors. SDA is based on an input–output table, which requires more detailed data, so it can analyze more information including indirect effect and direct effect [23, 24]. IDA has the characteristics of relatively low data requirements and flexibility. Because there is no need to use an input–output table (input–output tables are not published every year in most countries), IDA can analyze long-term dimensions and adjacent years. To provide ideas for policymakers, IDA is used to decompose the concerning factors and calculate the contribution rate of each influencing factor [25, 26]. If a certain factor in the decomposition result is positive, it shows that this factor can promote the growth of the target variable. In contrast, if it is negative, it shows that this factor has an obvious effect on the decline of the target variable. Correspondingly, compared with SDA, which is based on the input–output table [27], this study uses IDA to analyze and compare energy consumption on using the aggregate data of various energy types [28].

IDA is mainly applicable to the analysis of driving factors of CO_2 emissions [29, 30], as well as the research of energy consumption [31] in a country or region, some of which involve energy consumption changes or greenhouse gas emissions in an industry or sector [32, 33]. In IDA, Laspeyres [34] and Divisia [35, 36] are two commonly used methods, both of which include addition decomposition and multiplication decomposition [37]. In this study, the addition decomposition of the LMDI method is used [38]. The LMDI method has the advantages of complete decomposition, simple structure and no residual [39, 40]. Therefore, the expressions of the contribution values of each decomposition factor are:

$$\begin{aligned}\Delta E &= E_t - E_{t-1} \\ &= \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{P^t}{P^{t-1}}\right) + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{Y^t}{Y^{t-1}}\right) + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{I^t}{I^{t-1}}\right) \\ &\quad + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{M_1^t}{M_1^{t-1}}\right) + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{M_2^t}{M_2^{t-1}}\right) + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{M_3^t}{M_3^{t-1}}\right) \\ &\quad + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{M_4^t}{M_4^{t-1}}\right) + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{M_5^t}{M_5^{t-1}}\right) + \sum L(E_i^t, E_i^{t-1}) \ln\left(\frac{M_6^t}{M_6^{t-1}}\right) \\ &= \Delta E_P + \Delta E_Y + \Delta E_I + \Delta E_{\text{coal}} + \Delta E_{\text{oil}} + \Delta E_{\text{gas}} + \Delta E_{\text{biomass}} + \Delta E_{\text{hydro}} + \Delta E_{\text{other}}\end{aligned} \tag{2}$$

$$\frac{\Delta E}{E_{t-1}} \times 100\% = \left(\frac{\Delta E_P}{E_{t-1}} + \frac{\Delta E_Y}{E_{t-1}} + \frac{\Delta E_I}{E_{t-1}} + \frac{\Delta E_{\text{coal}}}{E_{t-1}} + \frac{\Delta E_{\text{oil}}}{E_{t-1}} + \frac{\Delta E_{\text{gas}}}{E_{t-1}} + \frac{\Delta E_{\text{biomass}}}{E_{t-1}} + \frac{\Delta E_{\text{hydro}}}{E_{t-1}} + \frac{\Delta E_{\text{other}}}{E_{t-1}}\right) \times 100\% \tag{3}$$

Here, E_{t-1} is the energy consumption of countries in the $t-1$ year, E_t is the energy consumption of countries in the t year and ΔE is the change in energy consumption of countries from the $t-1$ year to the t year.

$L(E_i^t, E_i^{t-1}) = (E_i^t - E_i^{t-1})/(\ln(E_i^t - \ln(E_i^{t-1}))$ [41]. $I = E/G$ is the energy consumption intensity, which refers to the amount of energy consumption per GDP in a country or region during a certain period. It reflects the degree of economic dependence on energy and is closely related to energy utilization, social development stage and economic structure. $Y = G/P$ is GDP per capita, which is the main tool to measure the living standard and macroeconomic operation of a country. With the development of the economy and the change of population, the level and mode of energy consumption are constantly changing. $M_i = E_i/E$ is an energy structure. M_1, M_2, M_3, M_4, M_5 and M_6 in equation (2) describe the proportion of coal, oil, natural gas, biomass, hydro and others in the total energy consumption.

Equation (3) describes the contribution rate of each factor relative to the $t-1$ year. In this study, we research the contributions of the change of population, the change of GDP per capita, the change of energy intensity and the change of six types of energy to total energy consumption.

2.3. Data

The research period in this paper selects 1971–2017. The energy consumption data are from the International Energy Agency (IEA) World Energy Balances database [42], in which the energy unit is million tons of oil equivalent (Mtoe). CO_2 data are also from the IEA [43] in which the CO_2 unit is million tons (Mt). Renewable energy is equal to the sum of biomass, hydro and others, among which biomass includes Municipal waste (renewable), primary solid biofuels, biogases, biogasoline, biodiesels, other liquid biofuels, non-specified primary biofuels and waste, and charcoal. Others include geothermal, solar photovoltaics, solar thermal, tide, wave and ocean, and wind. GDP and population data are taken from the United Nations (UN data) and GDP is in constant 2015 prices.

3. Results

3.1. Changes in energy consumption in 2001–2017

To compare the trends and drivers of energy consumption, we divide the economies into 12 regions according to geographical location and development level, namely, Eastern Asia, South-Eastern Asia, Southern Asia, North and Central Asia, Middle East, Northern Africa, Latin America and the Caribbean, Sub-Saharan Africa, US, Canada, the European Union, and Oceania. Figure 1 shows the average annual energy consumption growth in 2001–2017 and the contribution of each factor to energy consumption. Based on Kaya analysis [44], changes in energy consumption can be decomposed into changes in population growth, GDP per capita growth, energy structure (the share of coal, oil, natural gas, biomass, hydro and others) and energy intensity (energy consumption per GDP).

The top five regions with the highest average annual energy consumption growth rate (dots in figure 1) were the Middle East, Eastern Asia, Northern Africa, Southern Asia and South-Eastern Asia.

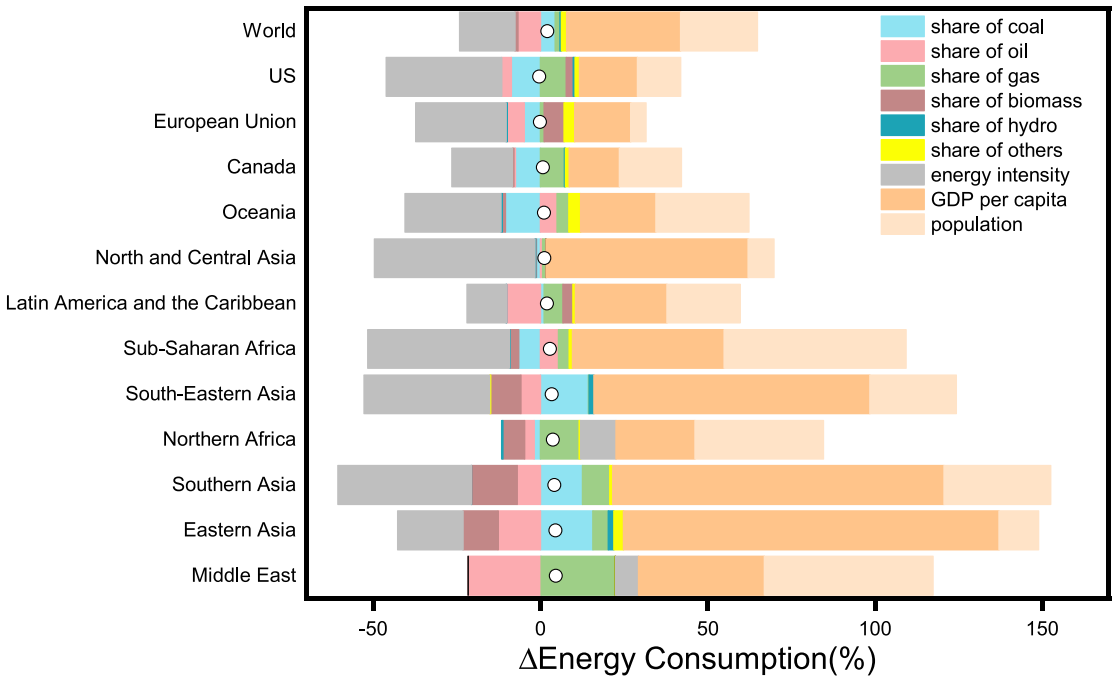

Figure 1. Average annual percentage changes in energy consumption and contributions of their drivers from 2001 to 2017. The drivers of changes in energy consumption are divided into factors: energy structure (the share of coal, oil, natural gas, biomass, hydro and others), energy intensity (energy consumption per GDP), population growth and GDP per capita. The length of each bar indicates the percentage contribution of each factor to the increasing or decreasing energy consumption. The dots show the average annual percentage changes in energy consumption.

As developing countries or regions experience rapid urbanization and industrialization, the roles of population growth and economic development in driving energy consumption were more obvious than those of developed countries or regions. Furthermore, the top three regions with the highest average annual growth rates were all located in Asia. Except for the Middle East and Northern Africa, the decline of energy consumption could be due to the contribution of energy intensity in countries or regions. The changes in energy structure and the contributions are different across countries or regions. The share of coal in most countries or regions was a factor decreasing the energy consumption, but three regions (Eastern Asia, South-Eastern Asia and Southern Asia) showed the opposite. The share of oil (pink bar in figure 1) in Sub-Saharan Africa and Oceania promoted the energy consumption growth, showing 5.4% and 4.9%, while the other countries or regions restrained the rise of energy consumption. Natural gas played a role in promoting energy consumption growth in all countries or regions. Besides, biomass energy was also an important factor in decelerating energy consumption. These trends show that it is important to understand the energy structure and drivers behind energy consumption in developing countries.

In contrast, the average annual growth rate of energy consumption was 0.7% in Canada during 2001–2017 and that in the US and the European Union was −0.4% and −0.2%, respectively. The increases in energy consumption contributed by economic growth in the US, the European Union and Canada were 17.3%, 16.8% and 15%, respectively. Changes in the share of natural gas promoting energy consumption growth in the US and Canada were stronger than that in the European Union, and the effect of the share of coal in driving energy consumption down performed stronger than that in the European Union. Meanwhile, the downward influence of the share of oil in energy consumption was weaker than that in the European Union. Compared with the effect of Canada's energy intensity of −18.1%, the decline of energy consumption caused by energy intensity in the US and the European Union was revealed to be stronger than that of Canada.

In summary, four of the top five regions with the fastest average growth rate were in Asia from 2001 to 2017. At the same time, the impact of the share of coal on energy consumption was particularly prominent in Eastern Asia, South-Eastern Asia and Southern Asia, i.e. 15.6%, 14.3% and 12.6%, respectively (figure 1). In other words, the increase in energy consumption pushed by the share of coal in these three regions was significantly stronger than other countries or regions, so this trend needs more attention. In addition, compared with developed countries or regions, economic growth and population played a more prominent role in increasing energy consumption in developing regions. For example, the increase of energy consumption driven by economic growth in Eastern Asia, Southern Asia and South-Eastern Asia

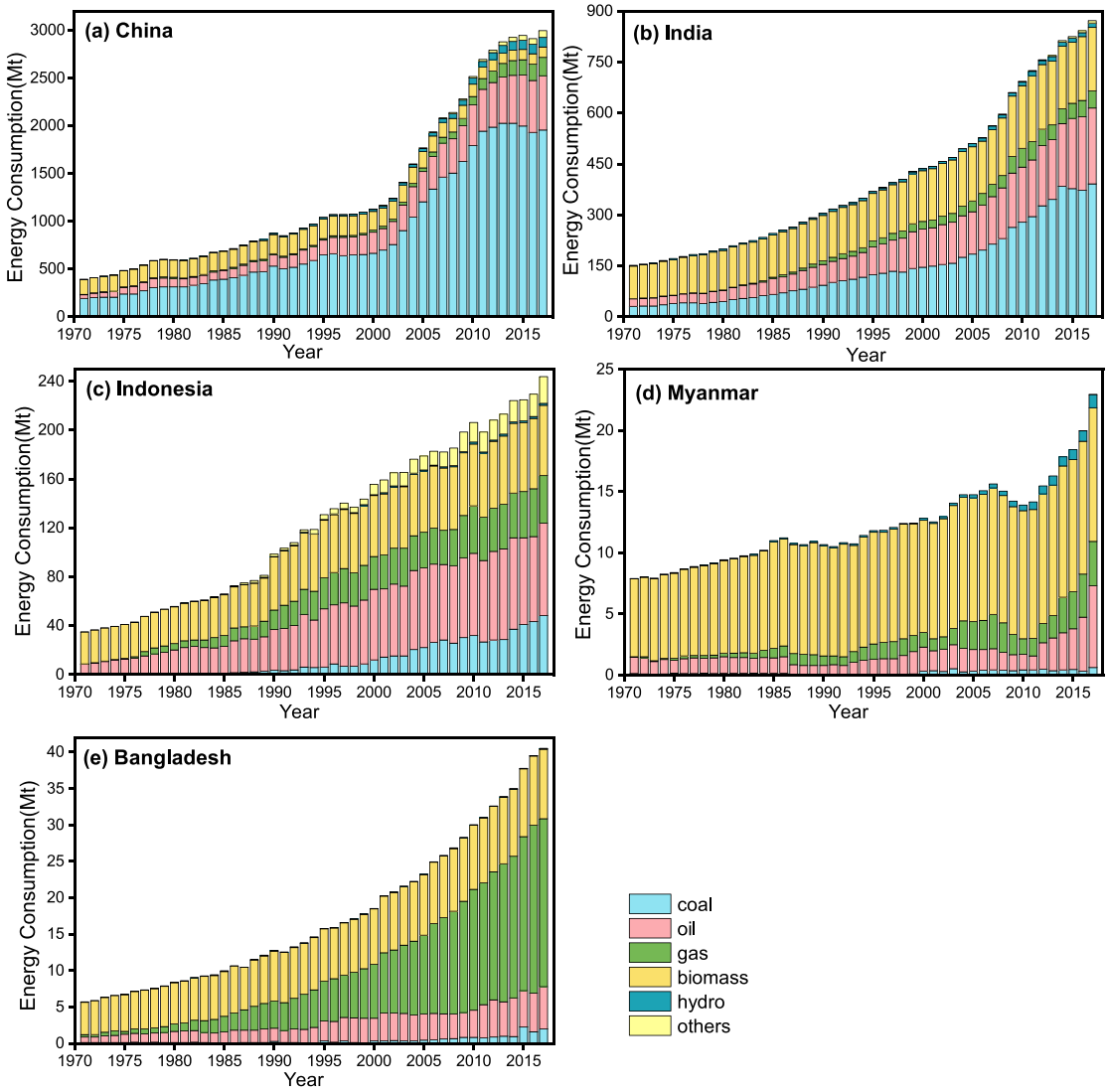

Figure 2. Energy consumption in developing countries (1971–2017). (a) China. (b) India. (c) Indonesia. (d) Myanmar. (e) Bangladesh. Mt means million tons of oil equivalent.

was as high as 112.3%, 99.1% and 82.6%, respectively. South-Eastern Asia is a region where nearly one-tenth of the world's population lives, and the growing demand for fuel, especially for oil, far exceeds the output of the region [45]. Looking to Eastern Asia, China as a developing country has a large economic volume and energy consumption. Simultaneously, Southern Asia is a densely populated region. As an important node in the 'one belt and one way' strategy, India and Bangladesh in Southern Asia, which had a population of 1.3 billion and 159.7 million in 2017, respectively, have a large demand for energy consumption [46]. Therefore, based on the consideration of large population size, demand for energy consumption and economic development, Indonesia and Myanmar (South-Eastern Asia), Bangladesh and India (Southern Asia) and China (Eastern Asia) are selected as the main research focus for developing countries, which will become an important part of the global energy consumption market in the future.

3.2. Energy consumption in developing countries

From the perspective of total energy consumption, developing countries showed an increasing trend, but the growth of energy consumption was different in five developing countries. Among them, Myanmar had the least growth, although that still more than doubled during the study period (figure 2(d)), while China grew the most, by more than 7.6 times with an increase from 391.1 Mtoe in 1971 to 2994.4 Mtoe in 2017 (figure 2(a)).

India and China are two major consumers with energy consumption that primarily depends on coal and oil. After China joined the World Trade Organization (WTO) in 2001, the rapid growth of its energy consumption was mainly due to the increase in coal consumption (figure 2(a)). Up to 2017, China's coal and oil accounted for 1953.3 Mtoe (65.2%) and 568.1 Mtoe (19%), respectively (figures 2(a) and A.1(a)); India's coal and oil accounted for 390.9 Mtoe (44.8%) and 223.3 Mtoe (25.6%) of

energy consumption, respectively (figures 2(b) and A.1(b)). Notably, since 2011, the role of coal in China's energy structure has been changing, showing a trend of year-on-year decline. However, coal in India's energy structure showed an upward trend in 2011–2014 and changed little in 2015–2017 (figure A.1). This change in China's energy structure was closely related to a series of policies such as the 12th Five-Year Plan, Energy Development '12th Five-Year' Plan released by the Chinese government and has achieved significant results [47]. Government in China emphasized the decline of the proportion of coal in primary energy consumption and the increase in the proportion of natural gas consumption, which was consistent with our results. Although the proportion of biomass energy in India declined from 63.2% in 1971 to 21.4% in 2017 (figure A.1(b)), India's energy structure was still more dependent on biomass energy than China. Specifically, biomass energy is mainly used as fuel in household energy consumption, which has low efficiency, produces air pollution and endangers health. As Mani discussed [48], especially in rural areas, crops, crop waste, wood and firewood are easier to obtain. Correspondingly, easy access to biomass energy makes its consumption relatively high in India and may delay the transformation of household energy consumption.

Developing countries in Asia account for over half of the global growth in generation from renewables, which may challenge coal consumption in Asia's power sector [49]. The energy consumption of Indonesia, Myanmar and Bangladesh (figures 2(c)–(e)) mainly relied on traditional biomass energy, which was highly dependent in Myanmar. In Indonesia, though the share of biomass decreased from 75.1% in 1971 to 23.5% in 2017, biomass also accounted for the second main energy type of total energy consumption (figure A.1(c)). After 1990, energy consumption, such as wind energy and geothermal energy, increased significantly in Indonesia. In 1971, biomass energy in Myanmar accounted for 80.4% of the total energy consumption. However, until 2017, biomass energy in Myanmar still occupied nearly half of total energy consumption, up to 10.9 Mtoe, and consumption of oil and natural gas in Myanmar also reached 6.7 Mtoe and 3.6 Mtoe, respectively. At the same time, Bangladesh's energy consumption was mainly related to natural gas 56.9%, biomass energy 23.5% and oil 14.4%. In both Myanmar and Bangladesh, coal accounted for a small proportion of energy consumption, i.e. 0.6 Mtoe (2.8%) and 2 Mtoe (4.9%), respectively.

3.3. Drivers of energy consumption in developing countries

Figure 3 shows the contribution of each factor. The GDP per capita and population growth were both important driving forces for the increase of energy consumption in five developing countries, while the energy intensity and the share of biomass were the main important factors for the decrease of energy consumption (figure 3). The driving forces of energy consumption change were different in different countries at different times.

Economic growth has always been the main driving force of energy consumption growth. After China joined the WTO, the promotion of economic growth to energy consumption reached a new high, up to 13.2% from 2006 to 2007 in China. At the same time, energy consumption in 2004 increased by 13.7% (black dots in figure 3(a)) compared with the previous year. Notably, although China's energy consumption declined during 2010–2016, it rebounded slightly in 2017. India's economic development started later. After the economic crisis, India's energy consumption has increased with the rapid economic growth (figure 3(b)). Indonesia's total energy consumption increased by 1.4 Mtoe (4.1%) during 1971-1972 and 14.2 Mtoe (6.2%) during 2016–2017 (black dots in figure 3(c)). The effect of GDP per capita growth of Indonesia increased energy consumption except for its effect on the decline of energy consumption in 1981–1982, 1997–1998 and 1998–1999 (−0.1%, −15.3% and −0.6%, respectively). Meanwhile, Myanmar's energy consumption (figure 3(d)) grew rapidly after 2015, from 0.58 Mtoe (3.2%) in 2015 to 2.98 Mtoe (14.9%) in 2017 and since 1992, the upward impact of GDP per capita in Myanmar on energy consumption has become increasingly significant. As for Bangladesh, the contribution rate of economic growth to energy consumption increased rapidly from 1971 to 2017, reaching 7.7% at the highest, which has been the main factor affecting energy consumption growth. As a developing country, Bangladesh's economic development potential is huge, and it is expected that the contribution of the effect of GDP per capita growth to energy consumption will be further increased in the future. In addition to economic growth, population became another driving factor for the increase in energy consumption, but its effect has been decreasing in recent years.

Energy intensity was the main factor in the decline of energy consumption. Compared with other countries, China's energy intensity improvement was more obvious. In particular, from 2010 to 2016, China's energy consumption showed a downward trend compared with the previous year, in which energy intensity played a major role. During this period, the effect of energy intensity (gray bar in figure 3(a)) on the decline of energy consumption gradually increased, indicating that China's energy consumption efficiency was steadily improving. After India's energy intensity changed from the increase of energy consumption (16.8 Mtoe or 2.8%) in 2008–2009 to the decrease of energy consumption (−22.7 Mtoe or −3.4%) during 2009–2010, it has always been shown

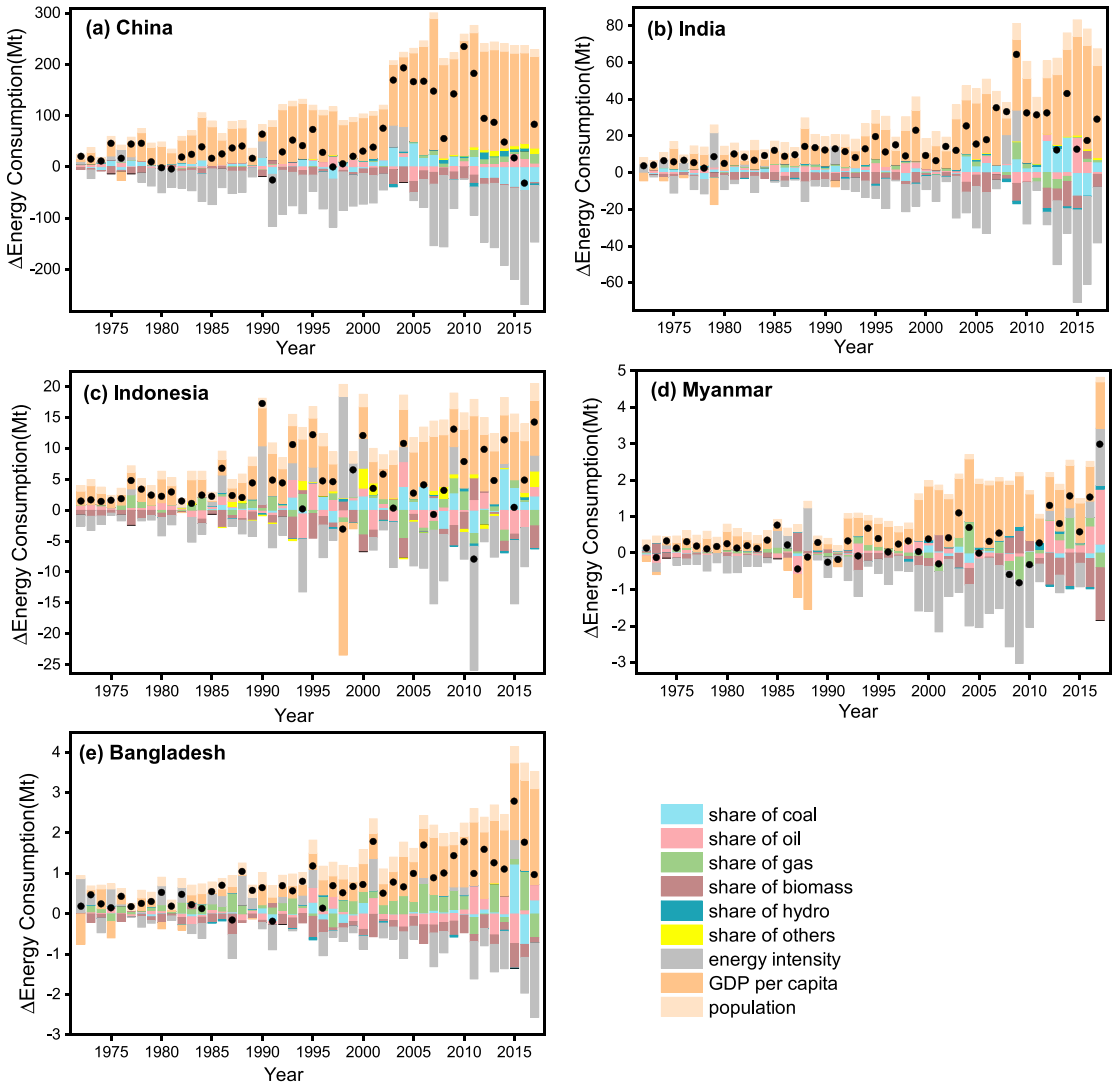

Figure 3. Decomposition of energy consumption drivers in: (a) China; (b) India; (c) Indonesia; (d) Myanmar; (e) Bangladesh. Mt means million tons of oil equivalent. The black dots show the total energy consumption changes.

as a factor for the decrease of energy consumption. From 1971 to 2017, Indonesia's energy intensity effect changed unsteadily, sometimes as a factor of energy growth and sometimes as a factor of energy decline. What should be highlighted is that the effect of energy intensity on the decline of energy consumption has gradually weakened since 2011, and changed from negative to positive (−2.8% to 1.1%) during 2016–2017, which may need some guidance from the government. From 1989 to 2011, Myanmar's energy intensity has been a negative influence on the growth of energy consumption. In 2009, the energy intensity contributed 15.2% to the decrease in energy consumption; nevertheless, it changed to increase energy consumption (2.4%) after 2016.

The change in energy structure has exerted various effects on energy consumption across countries. Different types of energy played different roles in energy consumption. In the past, the use of coal in China contributed to energy consumption growth in most years. Since 2012, the share of coal (light blue bar in figures 3(a) and A.2(a)) in China is the factor that exerted the decline of energy consumption, while other countries have shown either increasing or decreasing influence on energy consumption during this period with uncertain changes. In contrast to China, the share of coal in most years contributed to the upward influence of India's energy consumption, of which the share of coal increased energy consumption by 19.3 Mtoe or 2.5% during 2013–2014 (light blue bar in figures 3(b) and A.2(b)). The contribution of the share of oil to energy consumption in India has become increasingly obvious and was closely related to the changing role of oil in India's energy structure. Although the contribution of the share of oil to energy consumption growth was 2.4% in 2014–2015, the contribution to energy consumption in India was not stable. Sometimes the share of oil showed the effect of the decline of energy consumption and sometimes showed the effect of the rise of energy consumption.

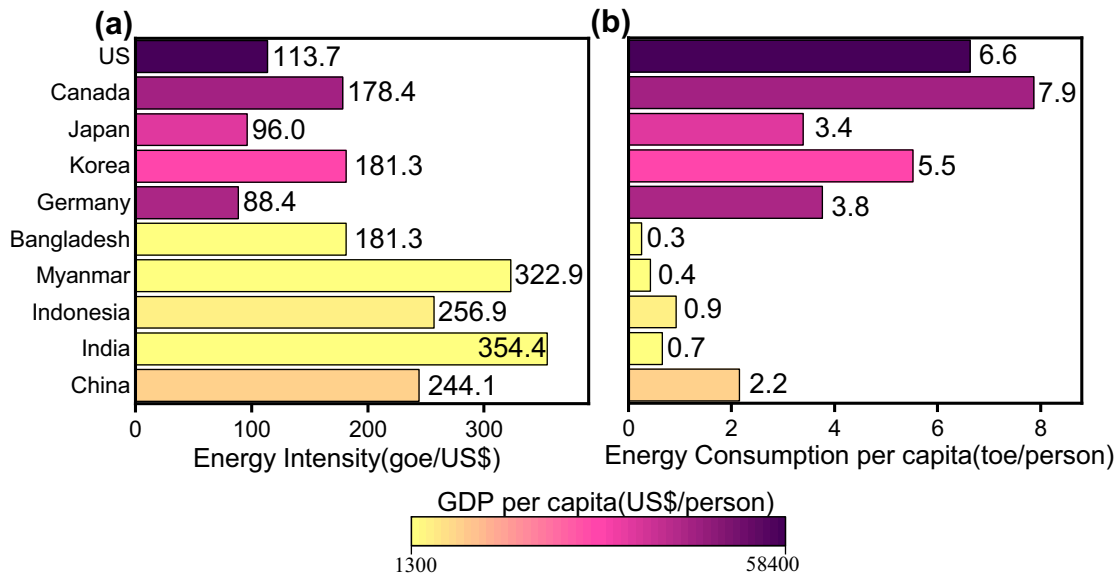

Figure 4. Energy consumption in five developing countries and five developed countries in 2017. The color represents GDP per capita in different countries. The figure shows the (a) energy intensity (b) energy consumption per capita of ten countries in 2017. See figure A.3 for energy intensity and energy consumption per capita of ten countries during 1971–2017. g means gram of oil equivalent, t means ton of oil equivalent.

In addition to population and economic growth, the share of oil (pink bar in figures 3(d) and A.2(d)) has gradually become another driving factor for the increase of energy consumption in Myanmar since 2012. The contribution of the share of natural gas to energy consumption was more prominent in Indonesia, Myanmar and Bangladesh. The effect of natural gas (green bar in figures 3(e) and A.2(e)) for the increase or decrease of Bangladesh's energy consumption was significant, reaching 0.96 Mtoe (2.5%) in 2015–2016, which was related to the increasing proportion of natural gas in Bangladesh's energy structure. By comparison, the contributions of the share of oil and natural gas in China to energy consumption were minimal (pink and green bars in figure 3(a)).

Furthermore, in addition to energy intensity, the share of biomass for the decrease of energy consumption was prominent. In Indonesia, the share of biomass contributed to the decrease of energy consumption, except in eight of the years covered. What is also apparent is that in recent years, biomass played a decisive role in the decrease of Myanmar's energy consumption. Changes in the share of biomass in Myanmar's energy consumption accounted for a large decreasing force in 2016–2017 (−7.3%). In the absence of other factors, the decrease of energy consumption was triggered by the share of biomass (brown bar in figures 3(e) and A.2(e)) in Bangladesh except for 5 of the 47 years. Indonesia's share of others (wind, geothermal) contributed more to the increase in energy consumption than the other four countries. All in all, the energy structure caused small changes in energy consumption during 1971–2017.

3.4. High energy intensity and CO_2 emissions

The energy intensity in developing countries declined rapidly for several decades (figure A.3), but a large gap still existed between developing countries and developed countries. In 2017, India's energy intensity was about four times that of Germany, which has the lowest energy intensity, as shown in figure 4. Bangladesh has the lowest energy intensity of the five developing countries. So, compared with the developed countries with stable energy intensity, there was still room for further improvement of energy efficiency in India, Myanmar and Indonesia.

On the other hand, the energy consumption per capita in developed countries was far higher than that of developing countries. The energy consumption per capita was 6.6 toe in the US, which was almost three times that of China (2.2 toe), and that in Canada was 7.9 toe in 2017. From another point of view, the low energy consumption per capita and rapid economic growth in developing countries also indicated that there was still room for energy consumption growth. As a result, energy consumption should not only pay attention to the total amount, but also analyse the energy consumption per capita and energy efficiency. That is to say, a comprehensive analysis from multiple dimensions is crucial for policymakers.

Due to its significant climate impact, this study also focuses on CO_2 emissions. Saving energy and reducing greenhouse gas emissions, especially CO_2 emissions, is the way to achieve sustainable development. In this process, the differences between countries needs attention. In 2017, China produced the most CO_2 emissions through coal combustion

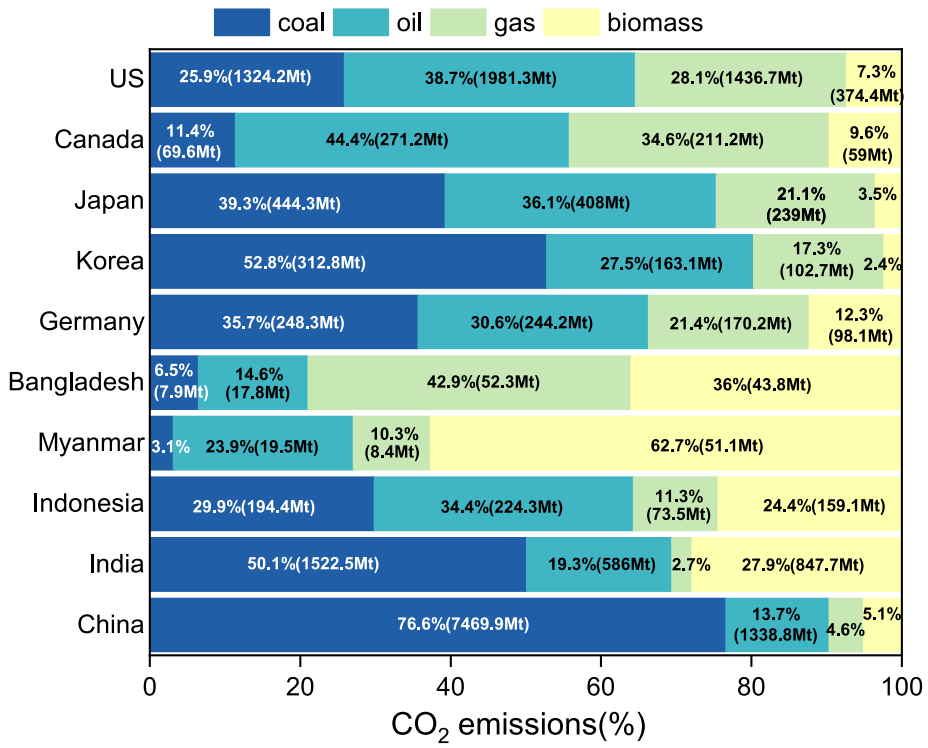

Figure 5. The share of CO_2 emissions by fuel combustion including coal, oil, gas and biomass between five developing countries and five developed countries in 2017.

(7469.9 Mt) among these ten countries (blue bar in figure 5); similarly, the US produced the most CO_2 emissions by oil and gas combustion (light blue and green bars in figure 5); India produced the most CO_2 emissions by biomass combustion (847.7 Mt). From the perspective of the share of CO_2 emissions by fuel type, biomass energy in Myanmar, Bangladesh and India still accounted for a large proportion of domestic CO_2 emissions, which was closely related to the energy structure and different from the situation in developed countries (yellow bar in figures A.4 and A.5). At the same time, CO_2 emissions produced by coal in China and Korea accounted for 76.6% and 52.8% in 2017, respectively. Although there was heterogeneity in CO_2 emissions caused by related energy type in different countries, the goal of developing renewable energy is consistent with the goal of reducing CO_2 emissions from the perspective of saving energy and mitigating climate change [50].

4. Discussion and conclusion

Energy consumption is one of the main sources of climate change. Countries are at the intersection of energy sustainability and economic growth. Renewable energy is an important factor in sustainable development, which was also confirmed in previous studies [51, 52]. For this reason, it is urgent to develop renewable energy to achieve emission mitigation and deal with climate change.

Great differences and imbalances have been displayed in the utilization of renewable energy among countries and various countries have issued corresponding policies to guide the development of renewable energy. Therefore, for China and India, which mainly consumed fossil fuels such as traditional coal [13] and oil in the past, the market share of renewable energy and natural gas should be increased significantly in the future to improve their energy consumption structure and encourage the use of renewable energy [53] and natural gas instead of fossil energy [54]. The energy policy of the Chinese Government emphasizes the leading role of renewable energy policy as well as the standardization of management and formulating a plan to vigorously develop the smart photovoltaic industry. India steadily promotes the development of renewable energy and has opened up a new model of hybrid projects such as a wind and solar hybrid. Bangladesh, Myanmar and Indonesia, as agricultural countries with large population, mainly depend on traditional biomass energy [55], and their energy consumption in rural areas still faces severe challenges. In the rural areas of these countries, the best choice is to improve the efficiency of the use of the abundant biomass energy and make full use of renewable energy such as solar power to solve the energy consumption issue. Many studies in the past have also realized the importance of adjusting energy structure and improving energy efficiency [56]. With these analyses and studies, countries should take measures, such as

plans formulated by the government, to carry out structural adjustment of energy to reduce greenhouse gas emissions (CO_2, CH_4, N_2O) and achieve sustainable development [57].

The energy consumption gap between countries should be faced squarely, especially the gap between developing countries and developed countries [58]. Although the energy consumption of developing countries has increased rapidly in recent years, developed countries will still occupy a large share of future energy consumption. Whereas the space for improving energy efficiency in developed countries is smaller than that in developing countries, it is still necessary to improve technology to reduce energy intensity. Accordingly, to reduce energy consumption, improving energy efficiency and optimizing energy structure are two key choices. Countries should accelerate the transformation and upgrading of energy, match the supply and demand for energy, and rely on technological progress.

Countries need to strengthen the adjustment of economic structure in the future and take into account the changes in energy consumption in the process of ensuring the smooth operation of the economy. Moreover, different contributions of the same energy variety on energy consumption reflect the heterogeneity among countries. Put another way, although the contribution of energy structure drives energy consumption up or down in various countries, there is still a great space for the adjustment of the energy structure to change its influence on energy consumption. For energy intensity, its effect on the decline of energy consumption is still very obvious [47], and attention should be paid to improving energy efficiency in the future.

Data availability statement

The energy consumption and CO_2 data are from the International Energy Agency (IEA) World Energy Balances [42] and CO_2 emissions from fuel combustion [43] database. The code that supports the findings of this study are available upon reasonable request from the authors.

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Conflict of interest

The authors declare no competing interests.

Author contributions

J M, Y L and D G designed the study. S L collected and analysed the data. S L and J M prepared the manuscript and supplementary information. All authors (S L, J M, H Z, N Z, J H, Y L and D G) participated in the writing of the manuscript. J M and D G supervised and revised the manuscript.

Appendix A

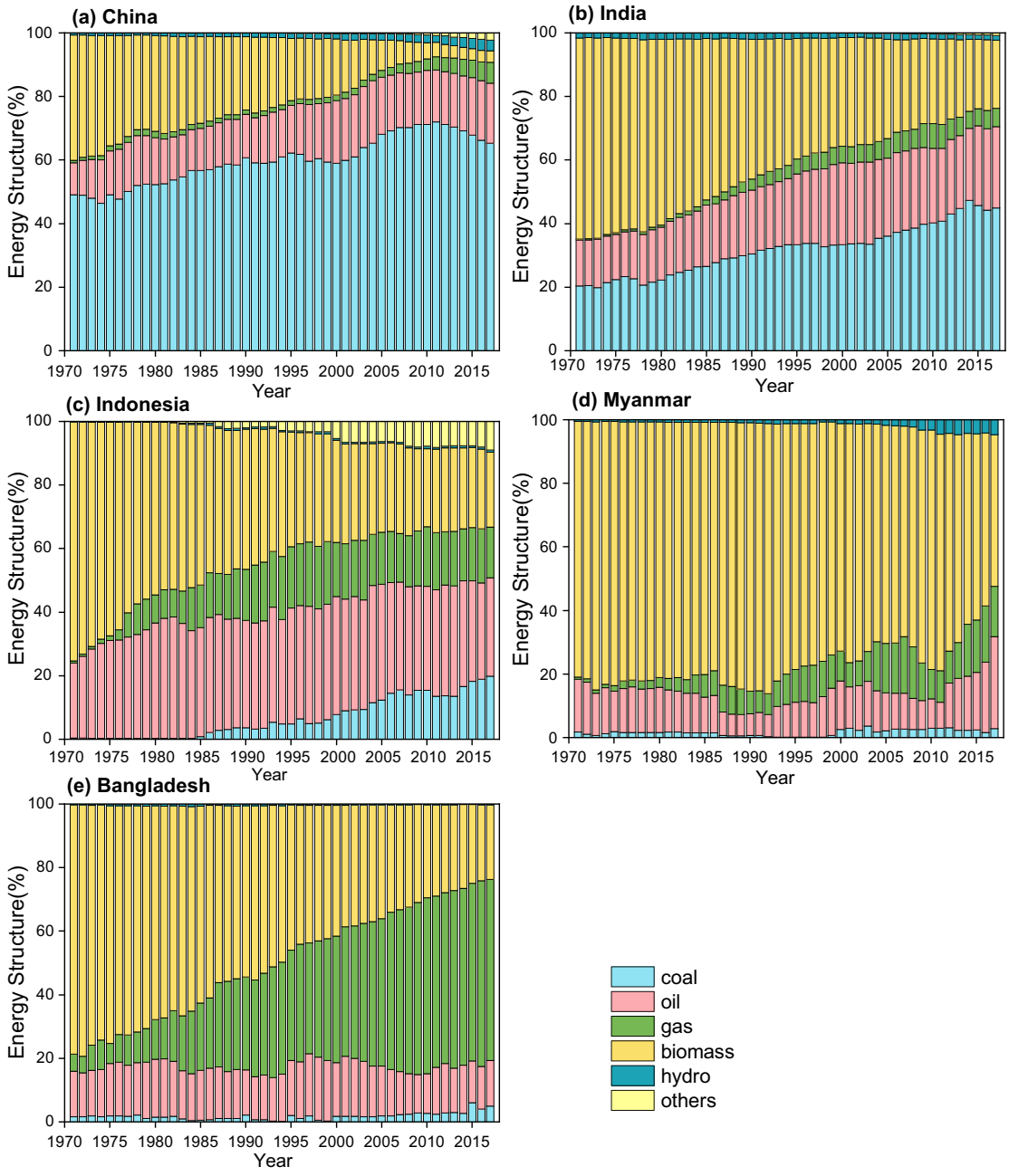

Figure A.1. The trends of developing countries' energy structures over 1971–2017. (a) China. (b) India. (c) Indonesia. (d) Myanmar. (e) Bangladesh.

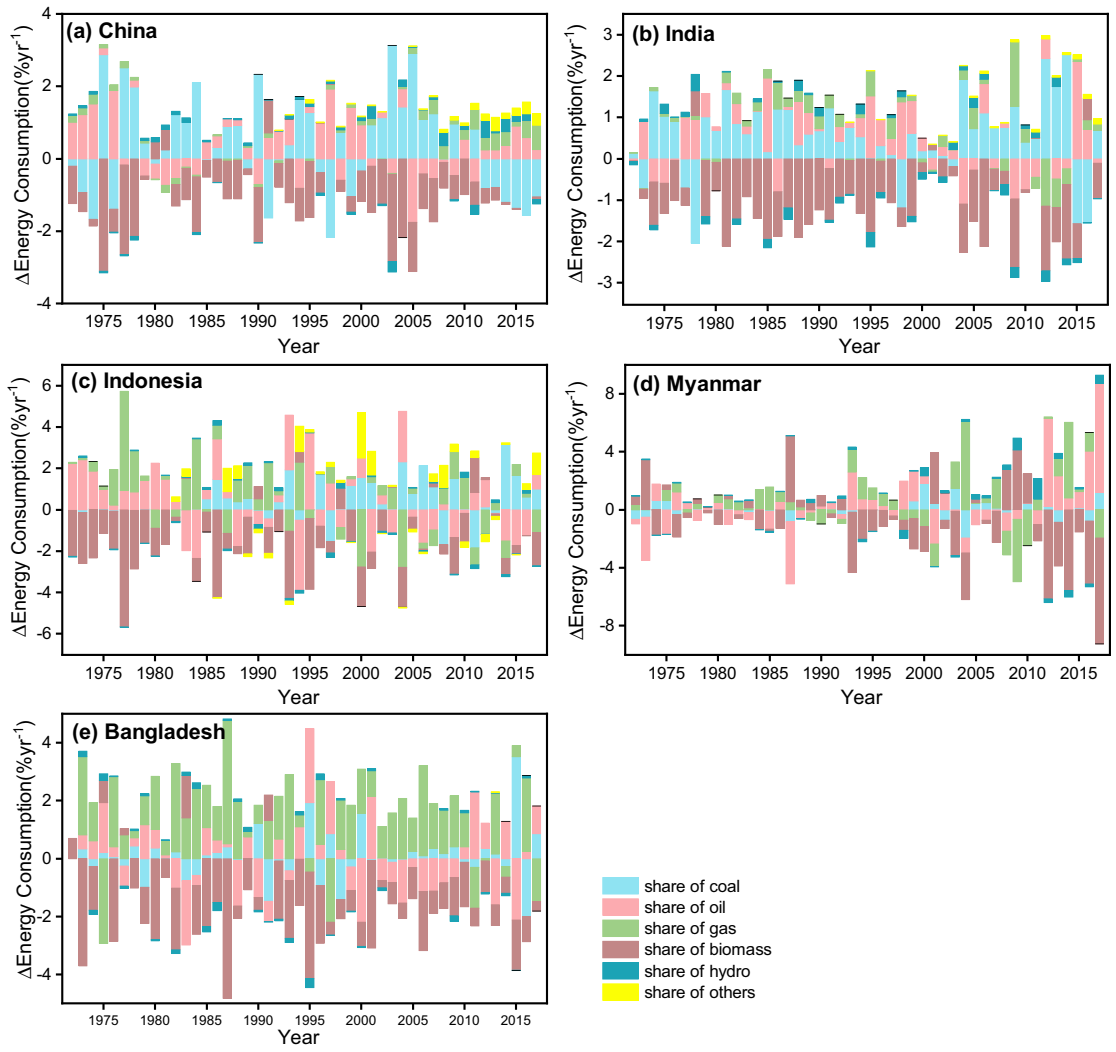

Figure A.2. Decomposition of energy structure drivers. (a) China. (b) India. (c) Indonesia. (d) Myanmar. (e) Bangladesh.

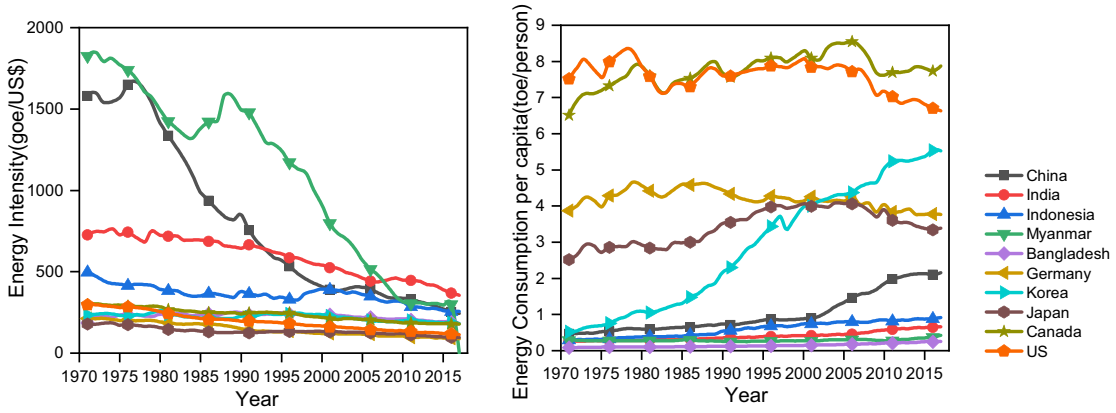

Figure A.3. Energy intensity and energy consumption per capita of five developing countries and five developed countries during 1971–2017.

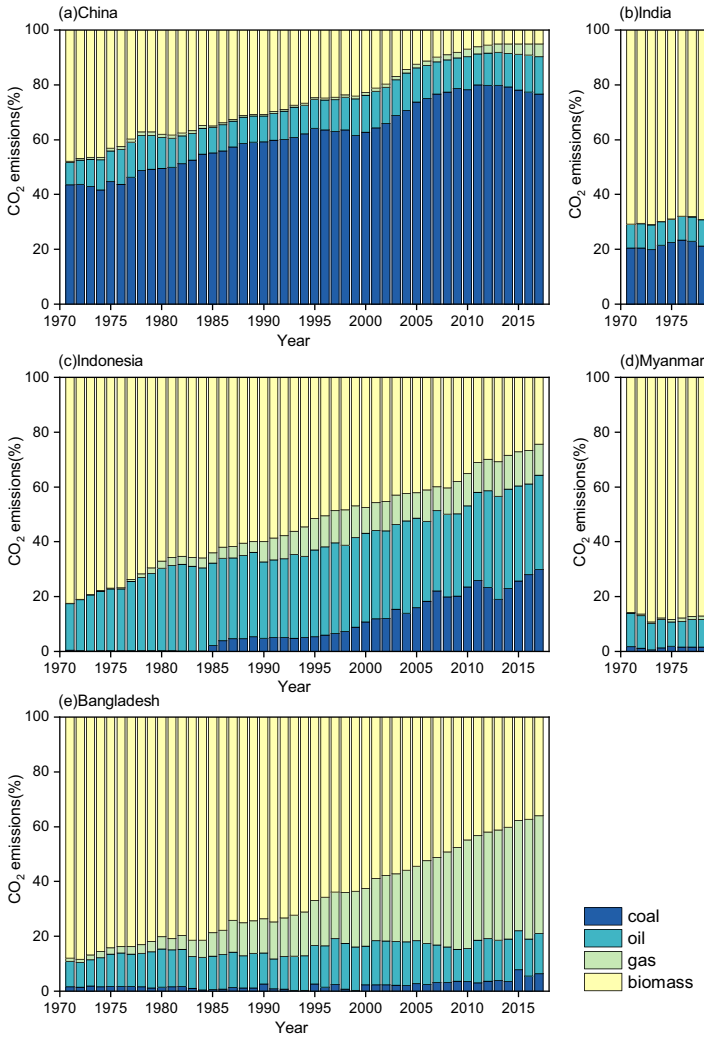

Figure A.4. The tendency of the share of CO_2 emissions by fuel combustion including coal, oil, gas and biomass in five developing countries from 1971 to 2017.

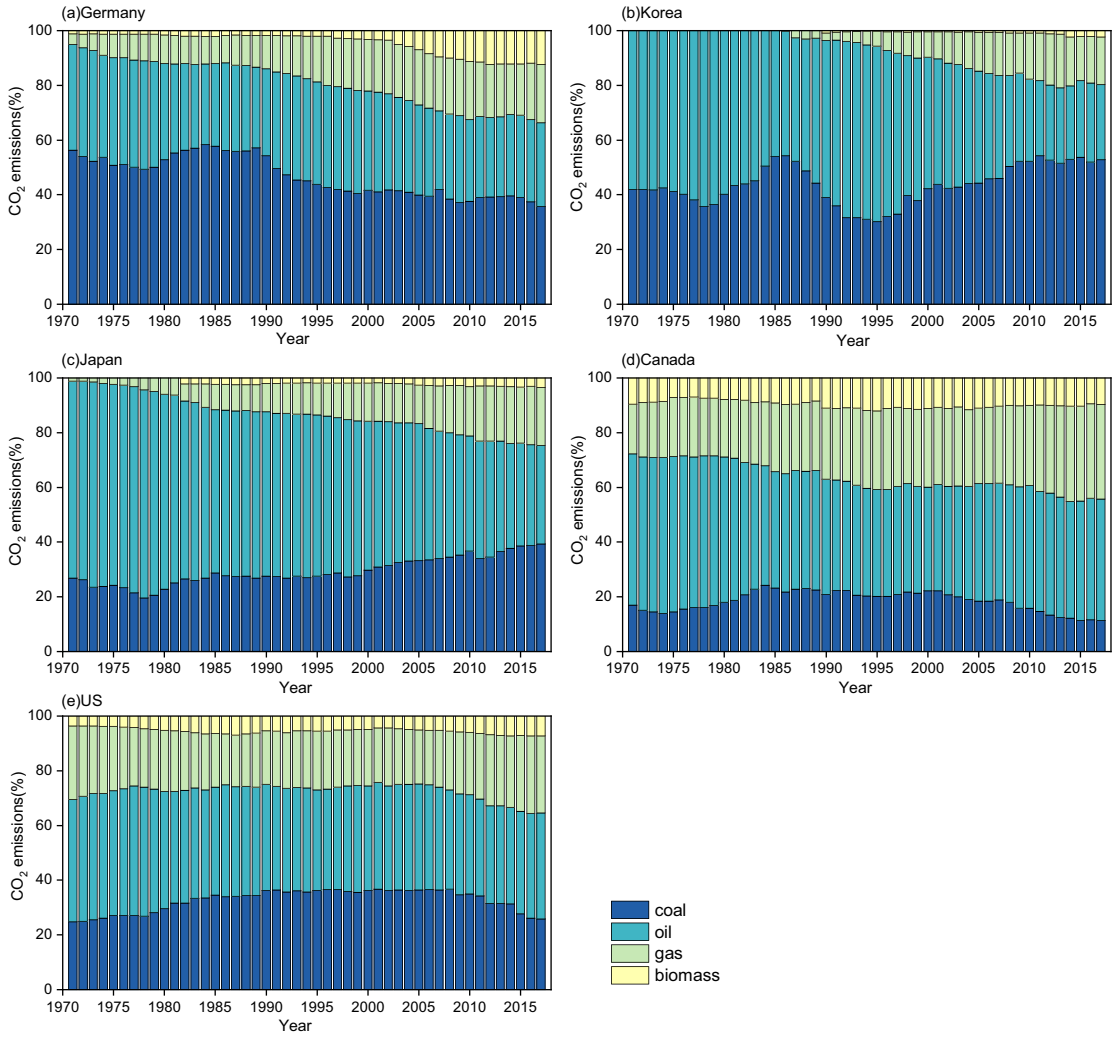

Figure A.5. The tendency of the share of CO_2 emissions by fuel combustion including coal, oil, gas and biomass in five developed countries from 1971 to 2017.

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