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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, that has not been well explored for developing countries. Here, we study the average annual growth rate of energy consumption in 12 aggregated regions in 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 the comprehensive consideration of factors such as population and economic development, to quantify the role of renewable energy, we analyzed the long time series of energy consumption for China, India, Indonesia, Myanmar and Bangladesh since the 1970s. Despite economic development and population growth accelerated energy consumption upward substantially, energy intensity made energy consumption to decrease. Coal and oil dominated the energy transition pathway in China and India, while biomass and natural gas in Indonesia, Myanmar and Bangladesh. The amount of CO_2 combustion in different countries was closely related to the amount of used energy and the type of energy. Our research results emphasize the importance of improving energy efficiency and adjusting energy structure, to reduce energy consumption and achieve sustainable development.

Keywords: Energy consumption; Decomposition analysis; LMDI; Driving forces

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 it 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, GDP per capita played an important role in the increase of global energy consumption. While according to the income levels, Omri et al. provided a detailed analysis of the drivers of renewable energy consumption for the global panel of 64 countries and the subgroups during 1990-2011 [6]. Global energy consumption of sectors, fuel varieties and their impact on the environment was studied by Bilgen [7] who suggested to improve energy efficiency and make corresponding innovations to reduce energy consumption. Based on 1980-2001 data, the relationship between energy consumption, economic growth and CO_2 emissions was studied by Ramanathan [8], and predicted the global non-fossil energy consumption in 2025 by changing carbon emissions.

Regionally, Fernández González et al. [9] decomposed the changes of total energy consumption of EU-27 during 2001-2008, and found that the reduction of energy intensity of EU-27 could not offset the demand of total energy consumption in European economic activities. Based on the 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 concentrate on regions such as the European Union and OECD, while more studies mainly analyze the energy consumption of 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 didn't include research on energy types. Besides, compared with the analysis of energy consumption in developed countries, the researches in developing countries mainly focus 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 United States, Wang et al. [13] found that in China and India, a driving factor to increase energy consumption was the coal intensity, while the incomes and oil intensity were the leading drivers in US. Besides, many scholars made a detailed analysis 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 includes multi-countries' energy consumption is rare.

In this paper, the driving factors of energy consumption change of different regions or countries are analyzed by using the Logarithm Mean Divisia Index (LMDI) method from 2001-2017. 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 multiple countries or regions in energy consumption. The results will help countries, especially developing countries, formulate energy conservation 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 the basic mathematical expression, the Kaya identity can decompose energy consumption into population scale, economic level, energy intensity, 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:

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

Where E is the total energy consumption, E_i is the type of energy, G is the gross domestic product (GDP), and P is the total domestic population.

2.2.LMDI decomposition

The commonly used methods to study energy consumption include SDA, IDA and econometric models based on panel data [19-21]. Panel data includes two dimensions: time series and cross-section. In the study of drivers of energy consumption change, Decomposition Analysis (DA) is often used, including Structural Decomposition Analysis (SDA) and Index Decomposition Analysis (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]. While IDA has the characteristics of relatively low data requirements and flexibility. Because there is no need to use the input-output table (input-output table is 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; On the contrary, 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 input-output table [27], this study uses Index decomposition analysis (IDA) to analyze and compare the time series by using the aggregate data of various energy types [28].

IDA is mainly applicable to the analysis of driving factors of carbon emission change [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 method of logarithmic mean division index (LMDI) method is used [38]. LMDI method has the advantages of complete decomposition, simple structure and no residual [39, 40]. Therefore, the expression of the contribution value of each decomposition factor is

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

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

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 consumed per unit 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 other in the total energy consumption.

Equation (3) describes the contribution rate of each factor relative to 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 the million tons of oil equivalent (Mtoe). CO_2 data are also from the International Energy Agency, in which CO_2 unit is million tons (Mt). Renewable energy is equal to the sum of biomass, hydro and other, among which biomass includes Municipal waste (renewable), Primary solid biofuels, Biogases, Biogasoline, Biodiesels, Other liquid biofuels, Non-specified primary biofuels and waste, Charcoal. Other includes Geothermal, Solar photovoltaics, Solar thermal, Tide, wave and ocean, 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 trend 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 Asia and Central Asia, Middle East, Northern Africa, Latin America and the Caribbean, Sub-Saharan Africa, United States, 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 [43], 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 other) 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. As developing countries or regions experiencing rapid urbanization and industrialization, the roles of population growth and economic development in driving energy consumption were more obvious than that of developed countries or regions. Furthermore, the top three regions with the highest average annual growth rates were all located in Asia. Except the Middle East and Northern Africa, the decline of energy consumption could owe to the contribution of energy intensity in countries or regions. The change in energy structure and the contribution are different across countries or regions. The share of coal in most countries or regions was a factor to decrease 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 showed a role to promote energy consumption 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.

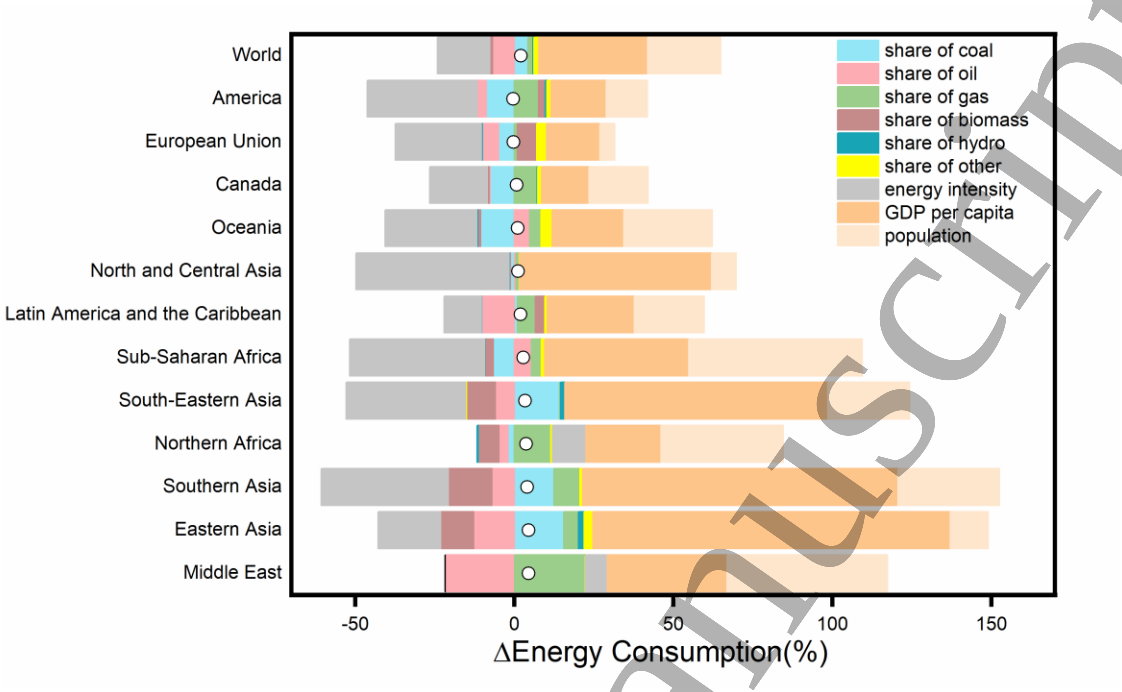


Figure 1 Average annual percentage changes in energy consumption and contributions of the drivers behind that from 2001 to 2017. The drivers of changes in energy consumption into factors - energy structure (the share of coal, oil, natural gas, biomass, hydro and other), energy intensity (energy consumption 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.

In contrast, the average annual growth rate of energy consumption was 0.7% in Canada during 2001-2017, and -0.4% and -0.2% for the United States and the European Union. The increase in energy consumption contributed by economic growth in the United States, the European Union, and Canada was 17.3%, 16.8% and 15%, respectively. Changes in the share of natural gas promoting energy consumption growth in the United States and Canada showed 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 demonstrated 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 United States 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 (see **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, a trend that 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 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 [44]. Looking to Eastern Asia, China as a developing country has 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 in Southern Asia, India and Bangladesh, which had a population of 1.3 billion and 159.7 million in 2017, respectively, have a large demand for energy consumption [45]. 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 2d**), while China grew the most, by more than 7.6 times with an increase from 391.1 Mtoe (million tons of oil equivalent) in 1971 to 2994.4 Mtoe in 2017 (**Figure 2a**).

India and China are two major energy 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 2a**). Up to 2017, China's coal and oil accounted for 1953.3 Mtoe (65.2%) and 568.1 Mtoe (19%), respectively (**Figure 2a** and **Figure A.1a**); India's coal and oil accounted for 390.9 Mtoe (44.8%) and 223.3 Mtoe (25.6%) of energy consumption, respectively **(Figure 2b** and **Figure A.1b**). However, since 2011, the role of coal in China's energy structure has been changing, showing a trend of year-on-year decline; while coal in India's energy structure has shown an upward trend in 2011-2014, and little change 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 [46]. Notably, they 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 was declining from 63.2% in 1971 to 21.4% in 2017 (**Figure A.1b**), 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 [47], 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 [48]. The energy consumption of Indonesia, Myanmar and Bangladesh (**Figure 2c-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.1c**). 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%. With 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.

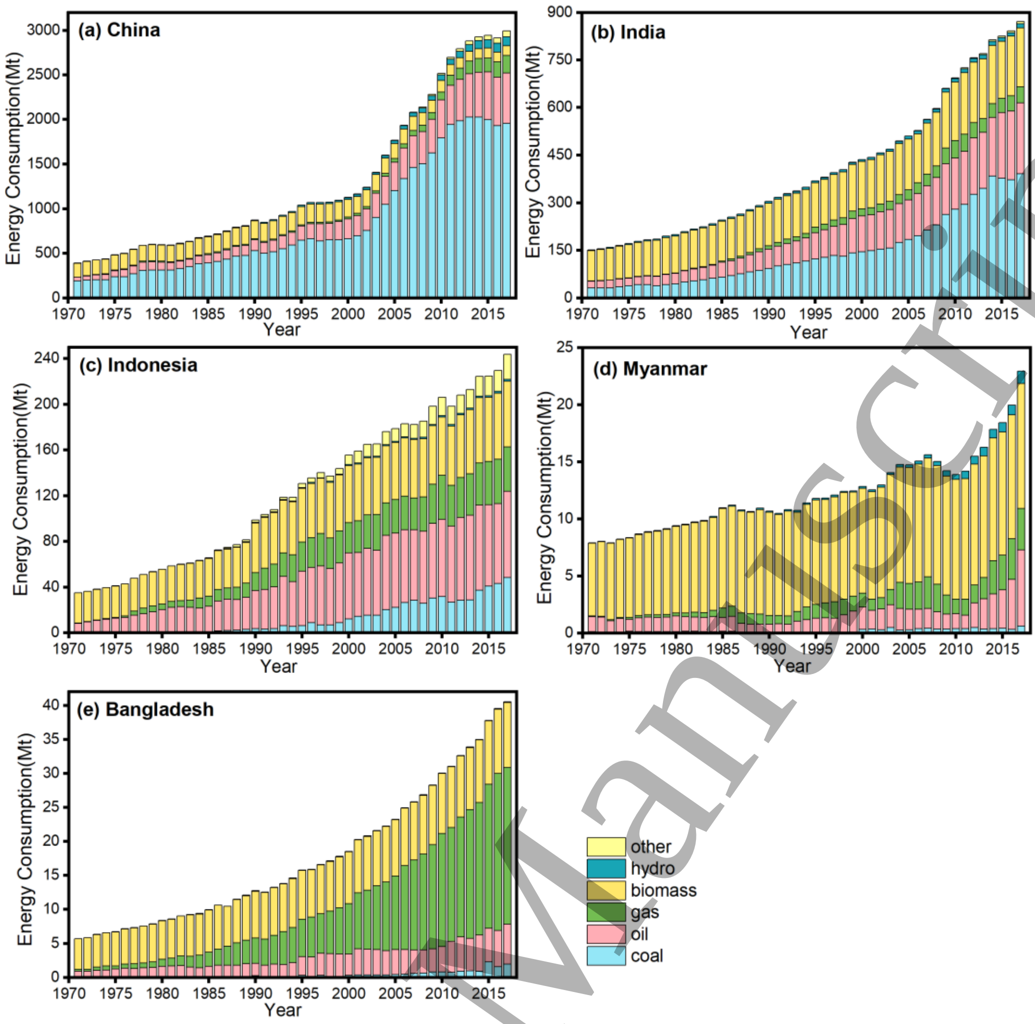


Figure 2 Energy consumption in developing countries (1971-2017). (a) China (b) India (c) Indonesia (d) Myanmar (e) Bangladesh. Mt means million tons of oil equivalent.

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 (see **Figure 3**). The driving forces of energy consumption change were different in different countries at different times.

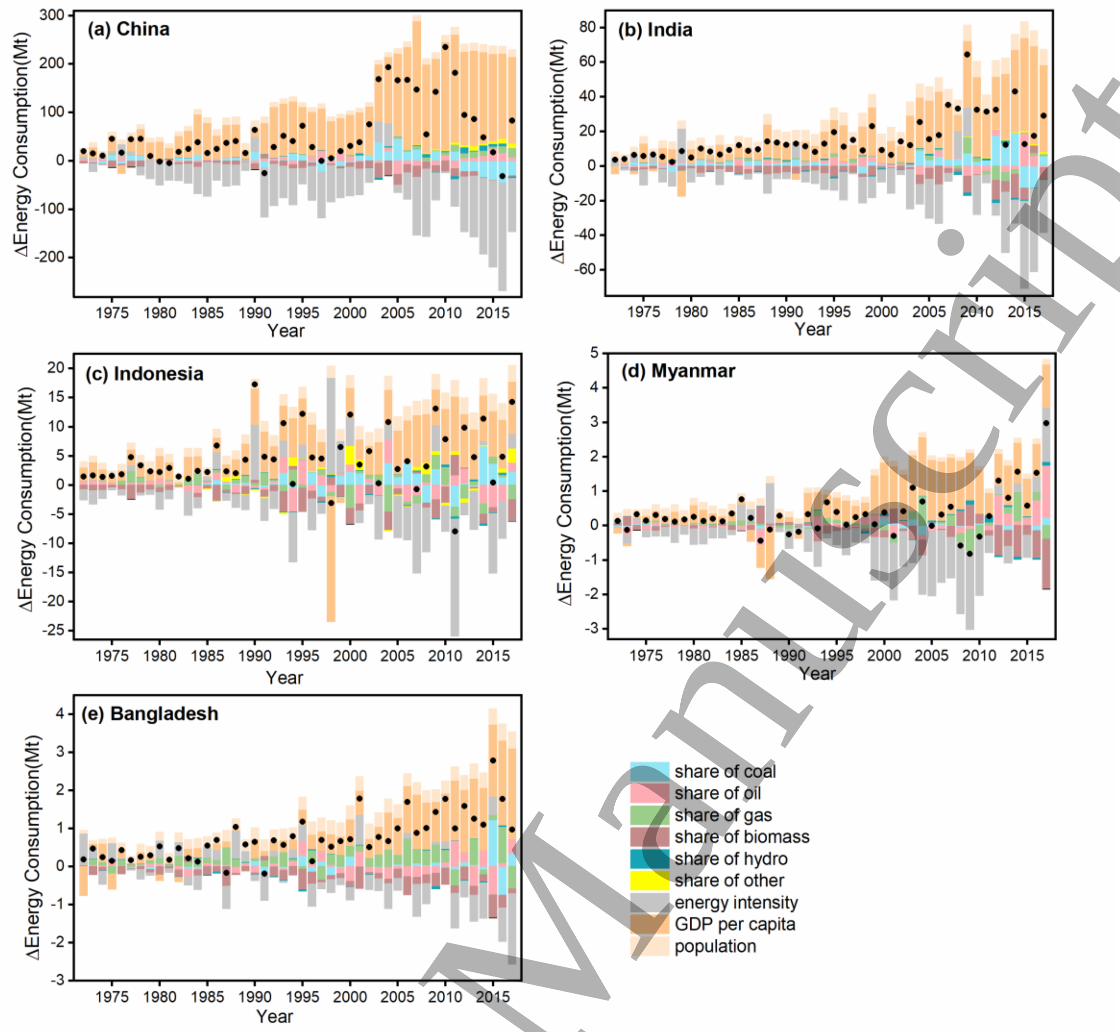


Figure 3 Decomposition of energy consumption drivers in (a) China (b) India (c) Indonesia (d) Myanmar (e) Bangladesh. Mt means million tons of oil equivalent. The black dots show the total energy consumption changes.

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 3a**) compared with the previous year. Notably, although China's energy consumption has been declining 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 3b**). Indonesia's total energy consumption increased by 1.4 Mtoe (4.1%) to 14.2 Mtoe (6.2%) during 1971–2017 (black dots in **Figure 3c**) and 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 3d**) 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 improved in the future. In addition to economic growth, the population became another driving factor for the increase in energy consumption, but the 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 3a**) on the decline of energy consumption gradually increased, indicating that China's energy consumption efficiency was steadily improving. After India's energy intensity has 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 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 needed attention is that the energy intensity effect has gradually weakened its role in decreasing energy consumption 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 has 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 share of coal in China has contributed to energy consumption growth in most years. Since 2012, the share of coal (light blue bar in **Figure 3a** and **Figure A.2a**) 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 in India increased energy consumption by 19.3 Mtoe or 2.5% during 2013-2014 (light blue bar in **Figure 3b** and **Figure A.2b**). The contribution of the share of oil to energy consumption in India has become increasingly obvious and is closely related to the changing role of oil in India's energy structure. The contribution of the share of oil to energy consumption growth was 2.4% in 2014-2015, though 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. In addition to population and economic growth, the share of oil (pink bar in **Figure 3d** and **Figure A.2d**) 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 **Figure 3e** and **Figure A.2e**) 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 bar in **Figure 3a**).

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, the share of 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 **Figure 3e** and **Figure A.2e**) in Bangladesh except for five of the 47 years. Indonesia's share of other energy (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 has declined rapidly for several decades, 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 per capita energy consumption was 6.6 toe of energy in the United States 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 per capita energy consumption 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 see the total amount, but also the energy consumption per capita and energy efficiency. That is to say, a comprehensive analysis from multiple dimensions for policymakers is crucial.

Due to the significant climate impacts, 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 need to be paid attention to. In 2017, China produced the most CO_2 emissions through coal combustion (7469.9Mt) among these ten countries (blue bar in **Figure 5**); similarly, the United States produced the most CO_2 emissions by oil and gas combustion (light blue and green bar 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 (yellow bar in **Figure 5**). At the same time, CO_2 emissions produced by coal in China and Korea accounted for 76.6% and 52.8%, respectively. Although there was heterogeneity in CO_2 emissions caused by related energy type in different countries, the goal of the development of renewable energy and reducing CO_2 emissions is consistent from the perspective of saving energy and mitigating climate change [49].

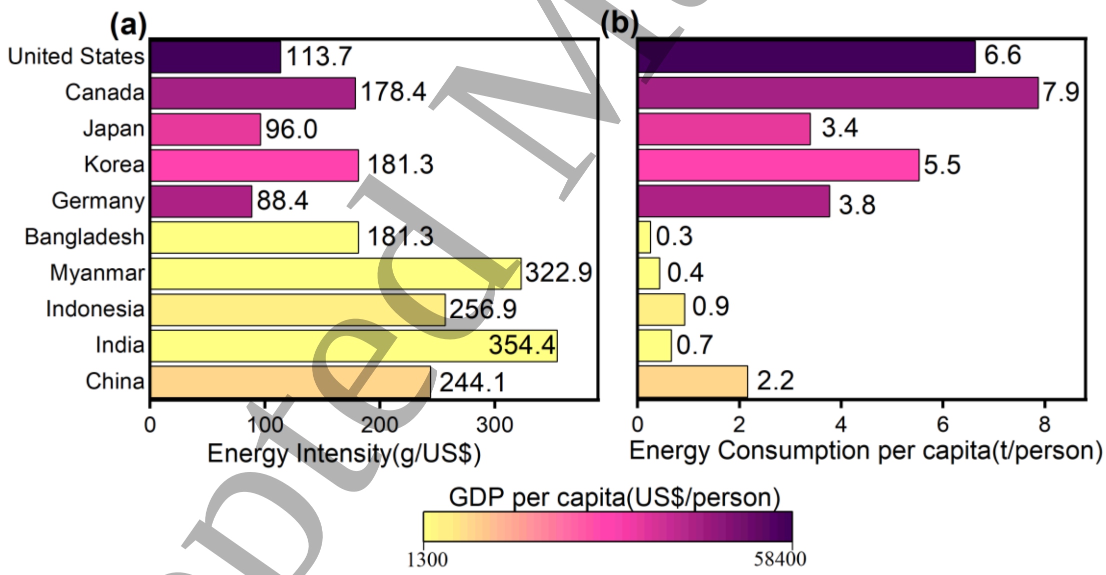


Figure 4 Compare Energy consumption between five developing countries and five developed countries in 2017. The colour represents GDP per capita in different countries. Figure shows the (a) energy intensity (b) energy consumption per capita of 10 countries in 2017. See **Figure A.3** for energy intensity and energy consumption per capita of 10 countries during 1971-2017. g means gram of oil equivalent, t means ton of oil equivalent.

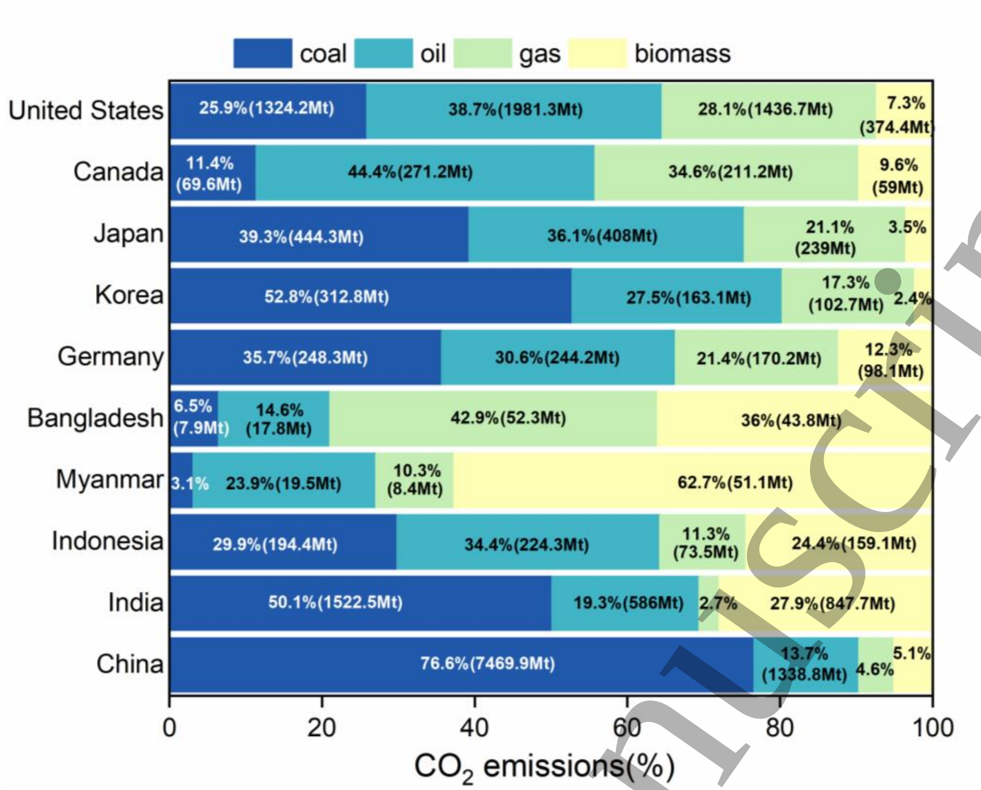


Figure 5 The share of CO_2 emissions by fuel combustion including coal, oil, gas, biomass between five developing countries and five developed countries in 2017.

4.Discussion and Conclusion

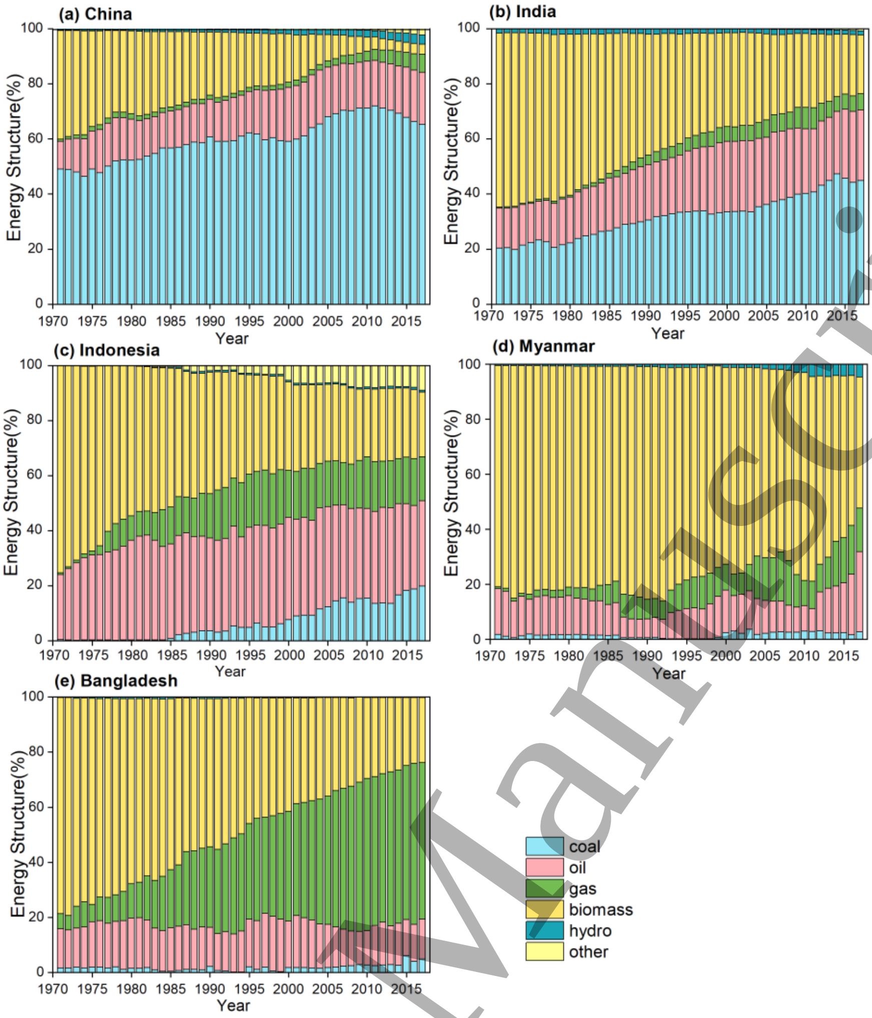
Energy consumption is one of the main sources of climate change. Countries are at the intersection of energy sustainability and economic growth. Renewable energy is an important factor in sustainable development. which is also confirmed in previous studies [50, 51]. For this reason, it is urgent to develop renewable energy to achieve emissions 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 has mainly consumed fossil energy 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 [52] and natural gas instead of fossil energy [53]. The energy policy of the Chinese government emphasizes the leading role of renewable energy policy as well as the standardization of management and formulates 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 wind and solar hybrid. For Bangladesh, Myanmar and Indonesia with agricultural and population countries, which mainly depended on traditional biomass energy [54], the energy consumption in rural areas is still facing severe challenges. In the rural areas of these countries, the best choice is to improve the efficiency of the use of abundant biomass energy and make full use of renewable energy such as solar energy to solve the energy consumption issue. Many studies in the past have also realized the importance of adjusting energy structure and improving energy efficiency [55]. 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 [56].

And the energy consumption gap between countries should be faced squarely, especially the gap between developing countries and developed countries [57]. Although the energy consumption of developing countries has increased rapidly in recent years, the developed countries will still occupy a large share in 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 the 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 shows driving energy consumption up or down in various countries, there is still a great space for the adjustment of energy structure to change its influence on energy consumption. For energy intensity, its effect on the decline of energy consumption is still very obvious [46], and attention should be paid to improving energy efficiency in future development.

1 **Appendix A.**



2

3 **Figure A.1** The tendency of developing countries' energy structure over 1971-2017.

4 (a) China (b) India (c) Indonesia (d) Myanmar (e) Bangladesh.

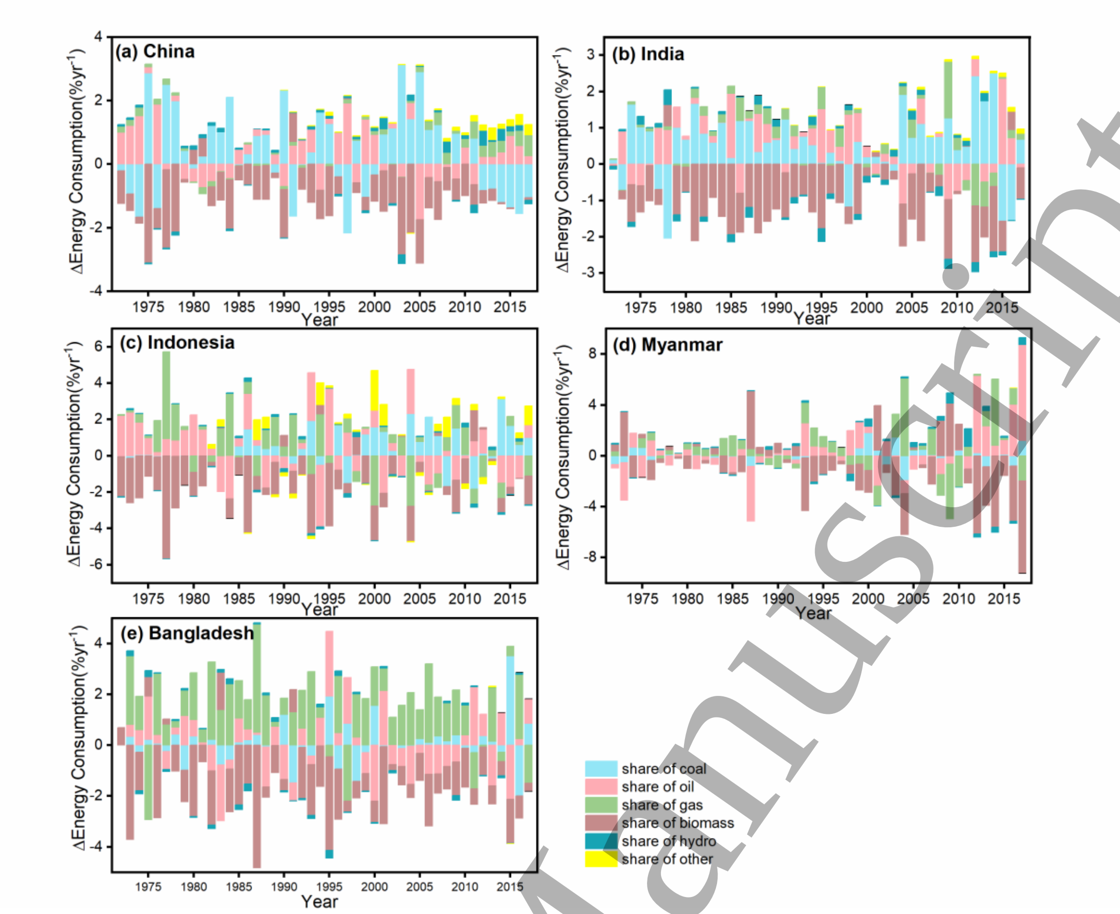


Figure A.2 Decomposition of energy structure drivers. (a) China (b) India (c)Indonesia (d) Myanmar (e) Bangladesh.

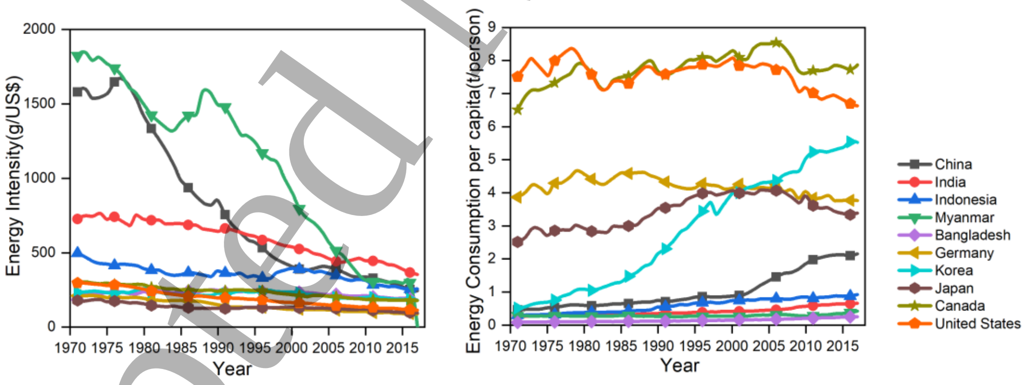


Figure A.3 Energy intensity and energy consumption per capita of five developing countries and five developed countries during 1971-2017.

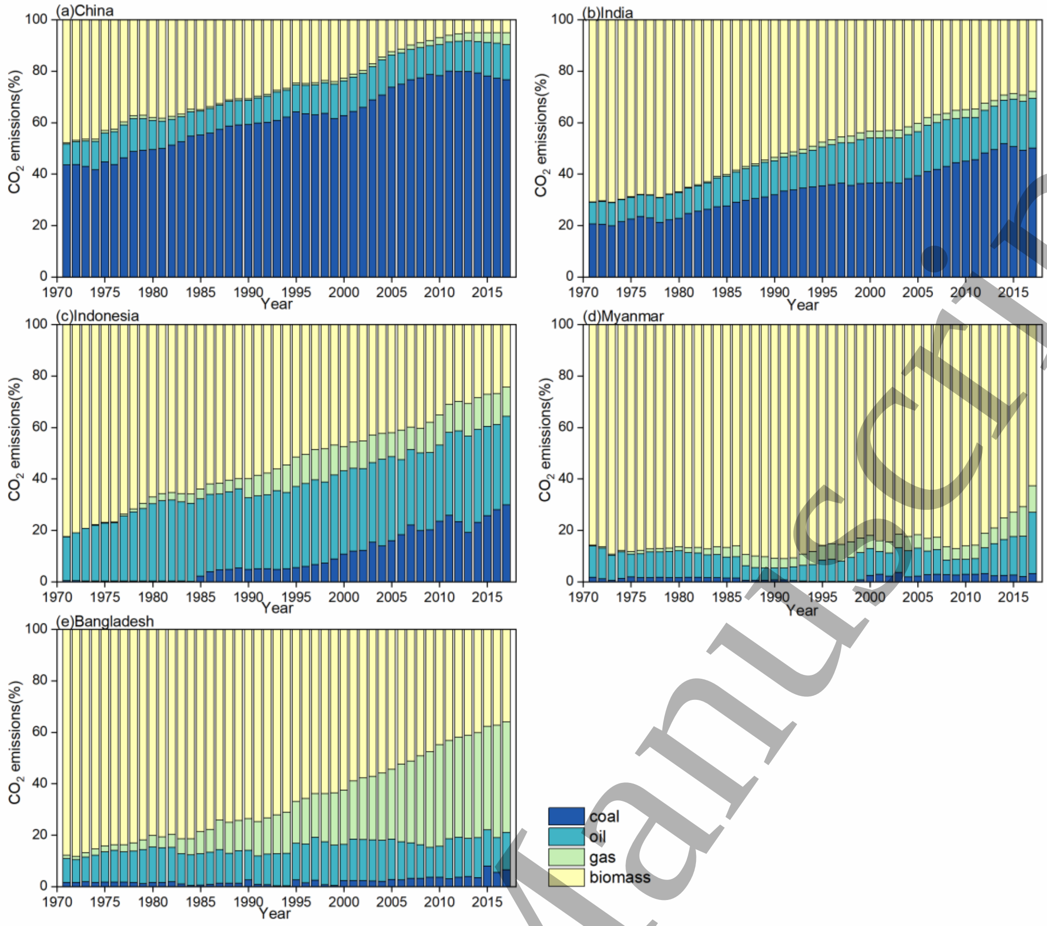


Figure A.4 The tendency of the share of CO_2 emissions by fuel combustion including coal, oil, gas, biomass in five developing countries from 1971 to 2017.

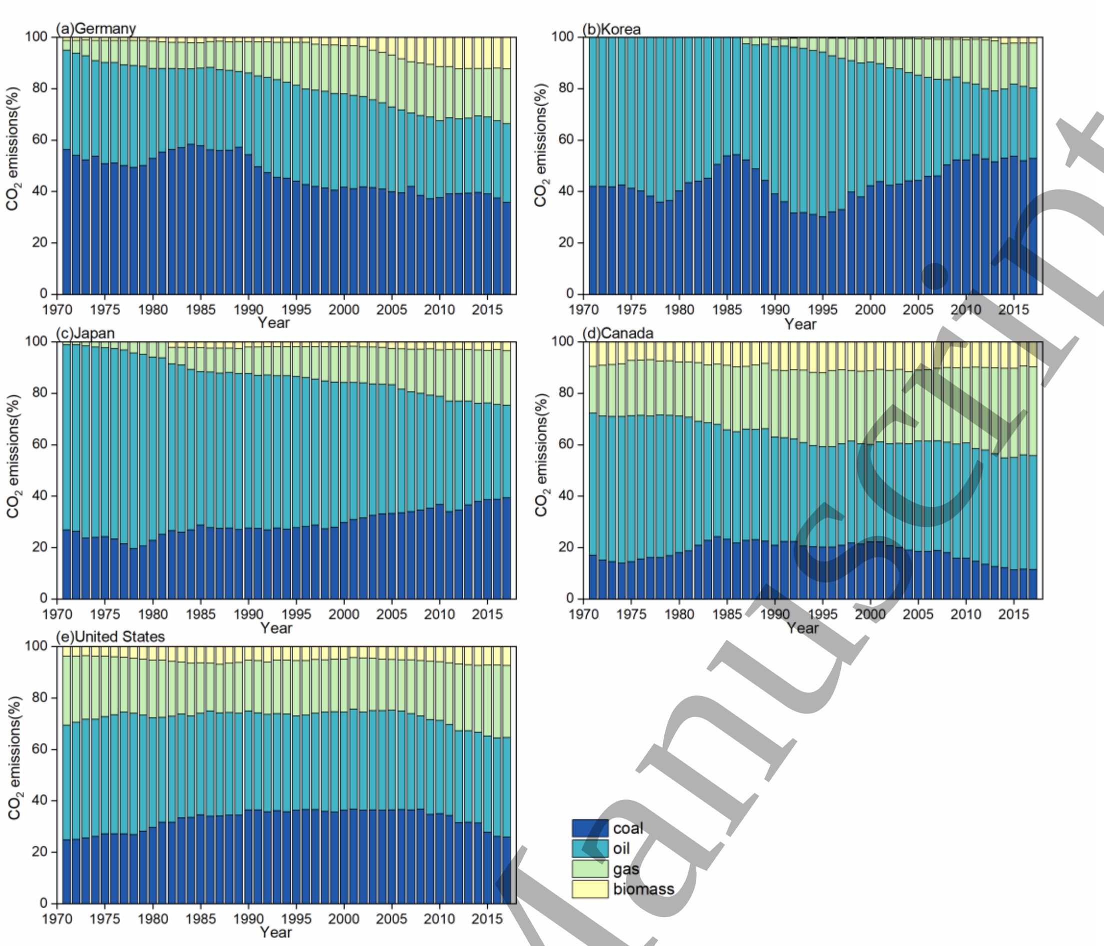


Figure A.5 The tendency of the share of CO_2 emissions by fuel combustion including coal, oil, gas, biomass in five developed countries from 1971 to 2017.

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Author Contributions

J.M. and D.G. designed the study. S.L. collected and analysed the data. S.L. and J.M.

prepared the manuscript and Supplementary Information. H.Z., N.Z. and Y.L. participated in the writing of the manuscript. J.M. and D.G. supervised and revised the manuscript.

Declaration of Interests

The authors declare no competing interests.