AGU100 ADVANCING EARTH AND SPACE SCIENCE

Earth's Future

RESEARCH ARTICLE
10.1029/2018EF000840

Key Points:
- This study aims to explore the pattern shift in China's energy consumption growth in the new development phase
- During the period of the global financial crisis, the energy consumption generated by China's exports dropped
- The strongest factors offsetting China's energy consumption have been shifting from efficiency gains to structural changes

Supporting Information:
- Supporting Information S1

Correspondence to:
J. Meng, Y. Shan, and D. Guan,
jm2218@cam.ac.uk;
y.shan@uea.ac.uk;
dabo.guan@uea.ac.uk

Citation:
Mi, Z., Zheng, J., Meng, J., Shan, Y., Zheng, H., Ou, J., et al. (2018). China's energy consumption in the new normal. *Earth's Future*, *6*. https://doi.org/10.1029/2018EF000840

Received 12 FEB 2018
Accepted 6 JUN 2018
Accepted article online 15 JUN 2018

China's Energy Consumption in the New Normal

Zhifu Mi[1], Jiali Zheng[2,3], Jing Meng[4,5], Yuli Shan[6], Heran Zheng[6], Jiamin Ou[6], Dabo Guan[6], and Yi-Ming Wei[7,8]

[1]The Bartlett School of Construction and Project Management, University College London, London, UK, [2]Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, China, [3]School of Economics and Management, University of Chinese Academy of Sciences, Beijing, China, [4]Department of Politics and International Studies, University of Cambridge, Cambridge, UK, [5]Cambridge Centre for Environment, Energy and Natural Resource Governance (C-EENRG), Department of Land Economy, University of Cambridge, Cambridge, UK, [6]Water Security Research Centre, School of International Development, University of East Anglia, Norwich, UK, [7]Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing, China, [8]School of Management and Economics, Beijing Institute of Technology, Beijing, China

Abstract Energy consumption is one of main reasons for global warming and highly correlated with economic development. As the largest energy consumer worldwide, China has entered a new economic development model—the "new normal." This study aims to explore the pattern shift in China's energy consumption growth in this new development phase. We use structural decomposition analysis and environmentally extended input-output analysis to decompose China's energy consumption changes during 2005–2012 into five factors: population, efficiency, production structure, consumption patterns, and consumption volume. During the period of the global financial crisis, the energy consumption generated by China's exports dropped, while the energy consumption generated by capital formation grew rapidly. Over three quarters of China's energy consumption growth was caused by capital formation during 2007–2010. This growth is mainly because of China's economic stimulus measures in response to the global recession, with a focus on infrastructure construction. In the new normal, the strongest factors offsetting China's energy consumption have been shifting from efficiency gains to structural changes. Efficiency gains were the strongest factor offsetting China's energy consumption in traditional development model and offset 42% of energy consumption between 2005 and 2010 by keeping other driving forces constant. Since 2010, however, their effects offsetting energy have become weak. The production structure and consumption patterns both drove China's energy consumption growth in the traditional development model and drove energy consumption growth by 31% and 12% between 2005 and 2010, respectively. Since 2010, however, both factors have started to offset China's energy consumption.

1. Introduction

Energy consumption is one of the main reasons for global warming and has been causally linked to economic development in China (Wang et al., 2016). China's economy has enjoyed rapid development during recent decades. As a result, its energy consumption also quickly increased, with an average annual growth rate of over 7% since 2000. In 2016, total primary energy consumption was 3.1 billion tonnes oil equivalent, which accounted for 23% of global energy consumption (BP, 2017). This high energy consumption exerts large pressures on the energy supply and energy security and results in many challenges such as environmental pollution and climate change (Mi, Meng, Guan, Shan, Song, et al., 2017; Shan et al., 2017). Therefore, it is important to quantify China's energy consumption changes.

China's economy was greatly damaged by the 2008 global financial crisis. Average annual gross domestic product (GDP) declined from 14% in 2007 to 10% in 2008 and continued declining to less than 7% in 2016. International trade was also affected, with China's export volume declining by 38% between 2008 and 2009 (Mi, Meng, Guan, Shan, Liu, et al., 2017). To counter the adverse effects of the international financial crisis and to stabilize the economy of the domestic market, the Chinese government proposed a "package plan" to further expand domestic demand and promote steady and rapid economic growth, with a focus on livelihood projects, infrastructure, and postdisaster reconstruction. As a result of this series of economic stimulus measures, the Chinese economy started to slowly recover. However, the Chinese economy could not return to the rapid growth before the financial crisis, which has maintained a steady downward trend, entering the "new normal." In this study, the "new normal" is China's new economic development model which embodies a focus on achieving better quality growth that is more economically and environmentally sustainable and achieves better social outcomes for the Chinese people (Green & Stern, 2015, 2017). With the rapid growth in energy consumption in China, the drivers of change in China's energy consumption and greenhouse gas emissions have become critical in the context of both global climate change and environmental health (Lan & Malik, 2013; Yu et al., 2016).

Here we use structural decomposition analysis (SDA) to quantify China's energy consumption changes. SDA is an analytic method based on the input-output model, which has been widely used in the energy and environmental fields (Lan et al., 2016). This method is used to evaluate the drivers of energy consumption changes in a country. For example, SDA has been used to estimate the drivers of energy consumption changes in Japan during 1970–1985 (Okushima & Tamura, 2010), in the U.S. during 1997–2002 (Weber, 2009), in Brazil during 1970–1996 (Wachsmann et al., 2009), and in India during 1973–1991 (Mukhopadhyay & Chakraborty, 1999). SDA is also often used to evaluate the drivers of greenhouse gas emission changes caused by energy consumption. For example, SDA has been used to estimate the drivers of emission changes in the U.S. during 2007–2013 (Feng et al., 2015; Kotchen & Mansur, 2016), in Norway during 1990–2002 (Yamakawa & Peters, 2011), in the UK during 1992–2004 (Baiocchi & Minx, 2010), in Brazil during 1970–2008 (Lenzen et al., 2013), in Australia during 1976–2005 (Wood, 2009), in Turkey during 1980–2003 (Lise, 2006), and in Greece during 1990–2002 (Diakoulaki et al., 2006). In addition, a summary of the drivers of energy consumption and carbon emissions can be found in Lenzen (2016) and Su and Ang (2012).

Garbaccio et al. (1999) used SDA to decompose energy intensity changes into energy consumption, imports and exports, showing the reasons for the energy intensity decline in China during 1978–1995. Kagawa and Inamura (2004) used spatial SDA to analyze the energy demand changes in China during 1985–1990. Chai et al. (2009) used SDA to decompose energy intensity changes into the technical level and final demand structure, investigating the energy intensity fluctuation in China during 1992–2004. Fan and Xia (2012) used the input-output and SDA methods to decompose the factors of China's energy consumption changes into the energy intensity, energy structure, and consumption structure during 1987–2007. Zhang and Lahr (2014) used a multiregional SDA method to estimate the regional driving factors of energy consumption changes during 1987–2007. Mi, Meng, Guan, Shan, Song, et al. (2017) used the SDA approach to estimate the drivers of carbon emission flows within China during 2007–2012. Guan et al. used the SDA approach to estimate the drivers of energy consumption and carbon emissions in China in the 1949–2002 (Feng et al., 2009), 1992–2002 (Peters et al., 2007), and 2002–2005 (Guan et al., 2009) periods.

Two main conclusions may be drawn by summarizing the existing research on the drivers of energy consumption and carbon emission changes in China. First, efficiency played a critical role in offsetting energy consumption and carbon emissions in China. For example, Xiao et al. (2016) used SDA to decompose carbon emissions in China into nine drivers, showing that the efficiency improvement and decrease in energy intensity reduced carbon emissions in China by 77% between 1997 and 2010 with other factors remaining constant. Chang and Lahr (2016) used SDA to decompose the production-based carbon emission changes in China into six drivers. Their results showed that the efficiency improvement reduced carbon emissions in China by 38% from 2005 to 2010 with other factors remaining constant. Second, exports had greatly stimulated the energy consumption and carbon emissions growth in China before the financial crisis. Minx et al. (2011) found that carbon emissions from China's exports increased by 325% during 1992–2007. Guan et al. (2009) noted that exports caused 50% of China's carbon emission growth during 2002–2005. Third, economic growth is one of main drivers to increase China's energy consumption. For example, Wang et al. (2016) used Granger causality tests to estimate the relationships between economic growth, energy consumption, and CO_2 emissions based on the data for the period 1990–2012. They found that GDP did Granger-cause energy consumption for China.

Based on the most recently released energy data and input-output tables, this paper uses SDA and environmentally extended input-output analysis (EEIOA) to evaluate the driving factors of China's energy consumption changes during 2005–2012. Special attention is paid to the effects of the global financial crisis on energy consumption and the new features of the energy growth patterns in the new normal.

2. Materials and Methods

2.1. Environmentally Extended Input-Output Analysis

Environmentally extended input-output analysis is a life cycle assessment approach based on the input-output model, developed by economist Wassily Leontief (Leontief, 1936). Its main purpose is to establish

10.1029/2018EF000840

input-output tables and linear equation systems. Input-output tables reflect the monetary or physical transfers among economic sectors and their interdependence during a given period, where the row describes the distribution of a sector's output in the economic system and the column describes the inputs of sectors in a sector (Meng et al., 2016; Mi et al., 2015). The basic linear equation of the input-output model of n sectors in the economic system is

$$X = (I - A)^{-1}Y \tag{1}$$

where X is the total output column vector and its elements x_j are the total output of sector j; Y is the final use column vector and its elements y_j are the final use of sector j; I is the unit matrix; and A is the direct consumption coefficient matrix of $n \times n$ dimensions and its elements a_{ij} are the need for sector i by the output of per unit of sector j, with a_{ij} being defined as

$$a_{ij} = x_{ij}/x_j \quad (i, j = 1, 2, \ldots, n) \tag{2}$$

where x_{ij} is the transfer amount from sector i to sector j. EEIOA can be mathematically expressed as (Meng et al., 2017; Mi et al., 2016)

$$E = F(I - A)^{-1}Y \tag{3}$$

where E is the total energy consumption, F is the direct energy intensity line vector (total energy consumption per unit of output), and its elements f_j are the direct energy intensity of sector j. EEIOA can be used to transfer energy consumption from the production side to the consumption side to assess the driven impacts on energy consumption by different final uses, including rural consumption, urban consumption, government consumption, capital formation, and exports.

Energy consumption embodied in China's imports is estimated based on Global Trade and Analysis Project (GTAP) database (Aguiar et al., 2016). GTAP provides global multiregional input-output tables and have been widely used in energy and environmental analysis (Meng et al., 2018; Shan et al., 2018; Zhang et al., 2017). Some studies calculated energy consumption embodied in imports via assuming that import commodities were produced with domestic technology. This approach may introduce a significant bias because energy intensity of imports is greatly different from that of domestic products. Therefore, we link the China input-output table and the GTAP database to estimate energy consumption embodied in China's imports.

2.2. Structural Decomposition Analysis

Based on EEIOA, this paper uses SDA to decompose the energy consumption changes in China into five driving forces: population, efficiency, production structure, consumption patterns, and consumption volume. SDA can be expressed as

$$\Delta \mathrm{E} = \Delta pFLY_sY_v + \mathrm{p}\Delta FLY_sY_v + \mathrm{pF}\Delta LY_sY_v + pFL\Delta Y_sY_v + pFLY_s\Delta Y_v \tag{4}$$

where Δ represents the changes in a factor, P is a scalar representing the population, F is a line vector representing the direct energy intensity of each sector, L is the Leontief inverse matrix $L = (I - A)^{-1}$, Y_s is a column vector representing the proportion of the consumption of each sector in total consumption, and Y_v is a scalar representing the consumption per capita.

Each part of equation (4) represents the contribution of one driver to the energy consumption changes with other factors remaining constant. There are several different ways to conduct SDA because it is possible to use the start or end point of the investigated time period. We follow previous studies (Dietzenbacher & Los, 1998; Hoekstra & Van Den Bergh, 2002) and take the average of all possible first-order decompositions to address this issue. There are 120 different decomposition forms with five factors in SDA analysis. It needs to be noted that there are uncertainties in SDA analyses because of interaction terms (Lenzen, 2006; Wood & Lenzen, 2006) and sector aggregation (Lenzen, 2011; Lenzen et al., 2004; Su & Ang, 2010).

2.3. Data Sources

This article requires two sets of data: the time series of input-output tables and the corresponding energy consumption. The input-output tables are obtained from the National Bureau of Statistics (National Bureau of

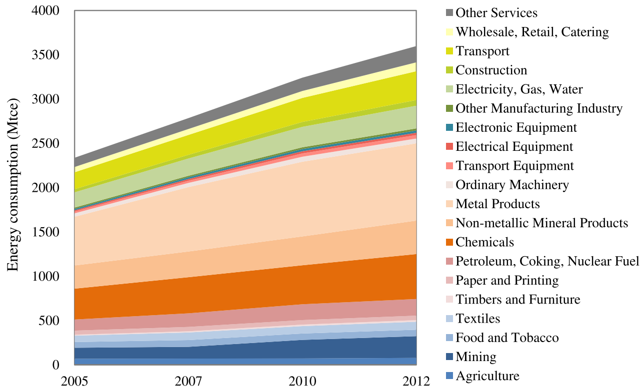

Figure 1. Energy consumption for each sector in China between 2005 and 2012.

Statistics, 2016), including the most recent 2012 national input-output table. China's National Bureau of Statistics compiles an input-output table based on national surveys every 5 years, during which an input-output is extended. The input-output tables for 2007 and 2012 are survey based with 135 and 139 sectors, respectively, while the input-output tables for 2005 and 2010 are extended with 42 sectors. This paper aggregates all tables into 20 sectors. See Table S1 in the supporting information for sector classification. The double deflation method is used to deflate all tables to 2012 constant prices (UNSD, 1999). The price index of China's input-output tables is obtained from the National Statistical Yearbook (National Bureau of Statistics, 2015a), and the price index for China's imports and for the imports of the rest of the world is obtained from the National Accounts Main Aggregates Database (UNSD, 2016). See Table S2 for price deflators. The energy consumption data are obtained from the National Energy Statistical Yearbook (National Bureau of Statistics, 2015b). It is necessary to indicate that this paper is limited to the energy consumption of economic sectors without the direct energy consumption of residents. Direct energy consumption by Chinese residents accounts for approximately 10% of national energy consumption. In addition, global multiregional input-output tables are obtained from the version 9 of the GTAP database (Aguiar et al., 2016).

3. Results

3.1. Energy Consumption Before the Financial Crisis

From 2005 to 2007, China's energy consumption increased from 2,338 million tonnes of coal equivalent (Mtce) to 2,786 Mtce, with a growth rate of 19% (Figure 1). Efficiency was the strongest factor offsetting energy consumption growth. Efficiency improvement could reduce energy consumption by 23% with other factors remaining constant (Figure 2). During the same period, the other four factors (i.e., population, production structure, consumption patterns, and consumption volume) each contributed to the increase in energy consumption. The production structure made the largest contribution and increased energy consumption by 18% with other factors remaining constant. The effects of consumption per capita and consumption patterns were similar in driving energy consumption (13% and 10%, respectively). In addition, population growth led to a 1% growth in energy consumption.

China's energy intensity declined faster than that in developed countries. During 2005–2007, the direct energy intensity (total energy output per unit of output) dropped from 28 grams of coal equivalent (gce) per yuan to 26 gce/yuan, with a negative growth rate of 7%. The average direct energy intensity of the industry and agriculture sectors decreased by 21% and 9%, respectively. Consequently, efficiency improvement played a decisive role in curbing the growth in energy consumption.

3.2. Energy Consumption During the Period of the Financial Crisis

From 2007 to 2010, China's energy consumption increased from 2,786 to 3,242 Mtce, with a growth rate of 16% (Figure 1). Efficiency was still the most important factor among the five offsetting energy consumption. Efficiency improvement reduced energy consumption by 16% with other factors remaining constant (Figure 2). Per capita consumption became the strongest factor driving energy consumption growth and increased China's energy consumption by 19%. The driving effects of the production structure, consumption patterns, and population were 11%, 2%, and 2%, respectively.

As a result of the global financial crisis in 2008, the average annual growth rate of China's energy consumption sharply dropped to 5% during 2007–2010, significantly lower than that during 2005–2007 (i.e., 9%). The financial crisis in 2008 delivered an enormous blow to China's and the global economy. The average annual growth rate of China's GDP dropped from 12% in 2002–2007 to 10% in 2007–2010. Energy is the material basis for economic development, and its consumption is largely determined by economic development (e.g., Wang et al., 2016).

Another significant impact of the financial crisis on China's energy consumption was the drop in energy consumption generated by exports during 2007–2010 (Table 1). Investment, consumption, and exports are the

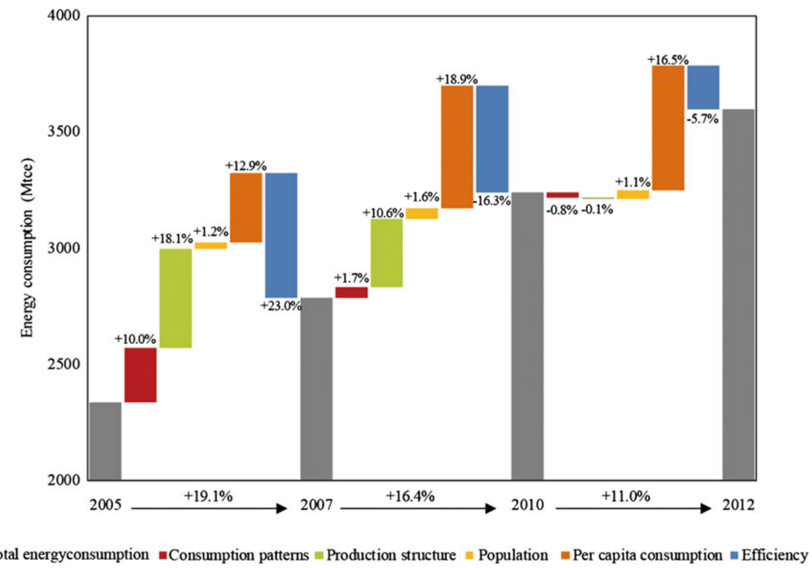

Figure 2. Contributions of different drivers to energy consumption changes in China between 2005 and 2012. The production structure and consumption patterns drove energy consumption growth between 2005 and 2010 but offset energy consumption between 2010 and 2012.

troika that drives China's economic development. As the factory of the world, China greatly relied on export growth to boost its economic development. From 2005 to 2007, energy consumption generated by China's exports increased by 110 Mtce, accounting for 24% of the total growth of energy consumption during the same period. However, the financial crisis damaged China's exports. The average annual growth rate of China's exports plunged from 10% in 2005–2007 to 2% in 2007–2010. The energy consumption caused by China's exports decreased by 6% during 2007–2010 with the improvement in efficiency and upgrade of the energy structure. This phenomenon is even more pronounced in industries with higher export dependency. The energy consumption caused by exports of metal products dropped by 30% from 170 Mtce in 2007 to 120 Mtce in 2010. In the same period, energy consumption caused by textile exports dropped by 17% (Table 1). From the perspective of final use, the energy consumption generated by exports accounted for 27% of China's total energy consumption, lower than the 35% in 2005 and 33% in 2007.

In contrast, China's energy consumption generated by capital formation increased rapidly during 2007–2010. To counter the adverse effects of the global financial crisis and to stabilize the domestic economy, the Chinese government proposed a "package plan" to further expand domestic demand and promote economic growth, with a focus on livelihood projects, infrastructure, and postdisaster reconstruction (Central Government of China, 2008; The Economist, 2008). As a result of these economic stimulus measures, 76% of China's energy consumption growth was caused by capital formation during 2007–2010, considerably higher than 59% in 2005–2007 and 49% in 2010–2012. From a sectoral perspective, the energy consumption caused by capital formation in the construction sector increased by 24% from 710 Mtce in 2007 to 870 Mtce in 2010 (Table 1). In addition, the transportation field was the investment focus in the "package plan," which included the construction of passenger-dedicated lines, coal transportation corridors, the railways in western China, and the improvement of the expressway networks. As a result, energy consumption caused by capital formation in the transport equipment manufacturing sector increased by 70 Mtce or 80% in 2007–2010, higher than 20 Mtce in 2005–2007 and 3 Mtce in 2007–2012.

3.3. Energy Consumption in the New Normal

In China's traditional development mode, the production structure and consumption patterns drove the growth in energy consumption, while efficiency was the most important factor driving the decline in energy consumption (Guan et al., 2009; Peters et al., 2007). During 2005–2010, the production structure and consumption patterns drove China's energy consumption by 31% and 12%, respectively, while efficiency drove a 42% decrease in China's energy consumption. In the new normal, however, structural changes became the

Table 1
Changes in Energy Consumption Caused by Final Use for Each Sector in China During 2005–2012 (Unit: Mtce)

No.	Sectors	2005–2007						2007–2010						2010–2012					
		R	U	G	C	E	Total	R	U	G	C	E	Total	R	U	G	C	E	Total
1	Agriculture	−3.3	−1.6	0.1	−0.7	−0.2	−5.8	−4.3	−5.8	0.1	3.4	−0.2	−6.7	3.4	14.0	0.0	6.3	−0.7	23.1
2	Mining	0.0	−1.2	0.0	8.9	−3.3	4.4	−0.1	−0.1	0.0	4.7	−1.8	2.7	0.0	0.0	0.0	−3.1	−0.8	−3.8
3	Food and tobacco	4.1	31.1	0.0	−22.0	0.6	13.8	8.0	15.3	0.0	−0.2	−2.2	20.8	0.9	2.7	0.0	0.5	−0.4	3.8
4	Textiles	2.7	4.7	0.0	−4.5	21.7	24.6	1.6	4.9	0.0	2.4	−20.2	−11.3	1.1	4.7	0.0	−2.5	−5.7	−2.4
5	Timbers and furniture	0.0	−0.3	0.0	9.8	2.6	12.1	0.2	0.9	0.0	−0.2	0.1	1.0	0.4	1.1	0.0	−0.1	2.2	3.6
6	Paper and printing	−0.2	−1.4	0.0	−0.4	−2.0	−4.0	0.0	2.0	0.0	1.3	−4.5	−1.2	1.7	4.6	0.0	3.5	20.9	30.8
7	Petroleum, coking, nuclear fuel	−0.3	6.0	0.0	−15.2	−6.1	−15.5	0.2	4.6	0.0	0.3	−1.4	3.7	0.5	6.3	0.0	4.4	2.4	13.6
8	Chemicals	−1.1	4.6	0.0	28.3	13.8	45.7	−0.1	3.3	0.0	5.5	−1.4	7.3	2.4	20.8	0.0	−9.8	−5.0	8.4
9	Nonmetallic mineral products	−1.7	−8.9	0.0	−2.3	6.2	−6.8	−0.6	−0.5	0.0	5.5	−2.2	2.1	1.8	1.0	0.0	−7.6	11.0	6.2
10	Metal products	−1.3	−2.5	0.0	45.3	36.0	77.5	0.0	0.2	0.0	−5.6	−50.6	−56.1	−0.1	−1.1	0.0	15.0	5.7	19.6
11	Ordinary machinery	−0.1	−0.6	0.0	−14.1	12.0	−2.8	0.0	0.1	0.0	62.1	5.6	67.8	0.3	0.8	0.0	12.4	12.2	25.8
12	Transport equipment	−0.7	9.6	0.0	18.1	9.7	36.8	0.7	10.2	0.0	69.0	7.6	87.5	0.1	9.0	0.0	2.8	−0.6	11.3
13	Electrical equipment	0.0	−2.4	0.0	24.8	18.1	40.4	1.7	7.2	0.0	41.6	11.8	62.4	0.5	−2.0	0.0	−23.2	0.3	−24.4
14	Electronic equipment	0.5	0.0	0.0	−2.7	4.8	2.6	0.3	2.2	0.0	11.5	8.6	22.6	0.2	0.1	0.0	−9.8	−8.0	−17.5
15	Other manufacturing industry	0.4	2.3	0.0	1.4	−13.7	−9.6	0.8	2.3	0.0	3.8	−0.8	6.1	−1.3	−6.9	0.0	−7.5	−16.7	−32.4
16	Electricity, gas, water	4.1	3.8	0.0	0.1	0.0	7.9	0.5	11.7	0.0	0.1	0.0	12.3	0.1	1.8	0.0	0.5	0.0	2.3
17	Construction	0.0	11.2	0.0	210.9	2.3	224.4	0.0	0.1	0.0	167.6	4.0	171.7	0.0	−11.3	0.0	162.3	−2.7	148.3
18	Transport	−4.8	−15.7	11.2	−17.6	5.1	−21.7	−0.7	2.9	−7.5	−0.1	−12.1	−17.6	5.2	22.2	6.3	16.7	17.4	67.9
19	Wholesale, retail, catering	8.0	16.4	0.0	0.1	−4.0	20.5	−3.4	−6.8	0.0	0.1	2.2	−7.9	−1.5	6.8	0.0	4.2	6.0	15.6
20	Other services	−1.1	3.9	−0.8	−2.8	3.8	3.0	0.9	40.1	27.8	19.3	0.9	89.0	8.6	9.4	29.2	12.2	−2.4	56.9
Total		5.1	58.9	10.4	265.7	107.5	447.5	5.8	94.6	20.4	392.0	−56.4	456.3	24.4	84.1	35.5	177.4	35.0	356.5

Note. R, U, G, C, and E represent the energy consumption generated by rural consumption, urban consumption, government consumption, capital formation, and export, respectively. The energy use generated by export declined between 2007 and 2010, mostly because of the global financial crisis.

main factors offsetting China's energy consumption. As the strongest factor driving the decline in energy consumption by 2010, efficiency drove a decrease of only 6% in 2010–2012, which was much lower than 23% in 2005–2007 and 16% in 2007–2010 (Figure 2). Although efficiency remains the most important factor driving the decline in China's energy consumption, its effect is far lower than that before 2010, showing that the space for energy efficiency in China is gradually shrinking.

The production structure and consumption patterns drove China's energy consumption by 0.8% and 0.1%, respectively, in 2010–2012 (Figure 2). In the traditional development mode, these two factors were the main factors driving the growth in China's energy consumption. In the new normal, structural upgrades in China drove a decline in energy consumption from both the production and consumption sides.

From the production-based perspective, the production structure drove the decline in energy consumption because the proportions of energy-intensive products in total inputs, such as inputs from the mining, transportation, and electricity sectors, declined. Mining was a sector with a high direct energy intensity, and its proportion in total inputs decreased from 8.3% in 2010 to 7.3% in 2012 (Figure S1 in the supporting information). For example, the share of the mining sector in the inputs of the paper and printing sector dropped from 1.4% to 1.2%. In addition, the proportion of transportation in total inputs dropped from 5.6% to 4.6% during the same period. For example, the share of the transportation sector in the inputs of the wholesale and retail sector declined from 12.7% to 5.6%. In contrast, the proportions of less energy-intensive sectors in total inputs, such as the electronic equipment sector, increased.

From the consumption-based perspective, consumption patterns drove a decline in energy consumption because the proportions of energy-insensitive products in final use (i.e., the products that are ultimately consumed rather than used in the production of other products), such as the construction and chemicals sectors, declined. The share of the construction sector in final use dropped from 21.2% in 2010 to 19.7% in 2012, and the share of chemicals sector in final use also dropped from 2.6% to 2.4% (Figure S2).

In the new normal, the proportions of energy use generated by consumption in China began to increase. Consumption can be divided into rural, urban, and government consumptions. The share of consumption-induced energy use in China had been declining by 2010; however, it increased by 0.2% during 2010–2012 (Figure 3). Although the growth rate is not large, it shows the progress that China has made in stimulating consumption and expanding domestic demand. This shift is mainly caused by changes in China's consumption and investment structure. China's consumption rate (final consumption as a share of GDP) has continued to decline after 2000 and

10.1029/2018EF000840

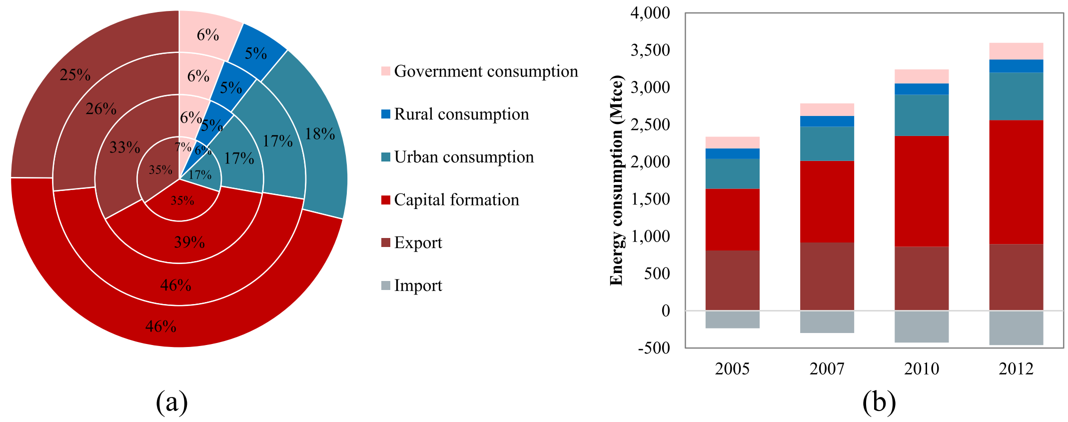

Figure 3. The proportions of energy consumption caused by different final use categories between 2005 and 2012. The proportions of energy consumption generated by export have been declining, while the proportions of energy consumption generated by capital formation have been increasing. The proportions of energy consumption generated by consumption (including rural, urban, and government consumption) declined during 2005–2010 but increased during 2010–2012.

reached a minimum of 48.5% by 2010; meanwhile, the investment rate (capital formation as a share of GDP) reached the highest level. Subsequently, the consumption rate gradually rose to 51.6% in 2015, while the investment rate gradually dropped to 44.9% (Table S3). The State Information Center predicted that the consumption rate in China will continue to grow. Consumption demands will gradually replace investment demands and become the most important force promoting national economic growth.

Since the energy use caused by per unit of capital formation is much higher than that caused by per unit of consumption, increasing the consumption rate is helpful for China to control its energy consumption. In 2012, the embodied energy intensity of capital formation was 67 gce/yuan in China, which was much higher than that of consumption (i.e., 38 gce/yuan). The implication is that 29 gce will be saved if 1 yuan GDP for capital formation is transferred to consumption. In the new normal, China's economy has begun to move away from the traditional investment-driven growth mode and is gradually shifting to a path that places greater emphasis on quality, pays more attention to ecological civilization construction, and focuses more on people's livelihood improvement. Consumption-induced energy use will continue to grow, and China's energy consumption growth mode is shifting from investment-driven to consumer-driven.

In addition, the gap in energy consumption embodied in China's exports and imports has been narrowing. In 2005, the energy consumption embodied in China's exports was 809 Mtce, 3.4 times of that in its imports (Figure 3). This is largely because China relied largely on heavy industries and exported large volumes of low value-added but energy-intensive products, such as textile and metallurgy products (Mi, Meng, Guan, Shan, Song, et al., 2017; Mi et al., 2018). This gap has narrowed largely because of structural changes and energy efficiency improvements. In 2012, energy consumption embodied in China's exports was 1.9 times of that in its imports.

4. Conclusions

The global financial crisis had an enormous impact on China's energy consumption. First, the average annual growth rate of China's energy consumption sharply dropped during the period of the financial crisis. The average annual growth rate of China's energy consumption was 5% in 2007–2010, which was much lower than the precrisis level. The main reason for this slowdown is that China's economic growth rate declined as a result of the global financial crisis. Second, the energy consumption generated by China's exports declined during the same period. Export growth has always been a critical factor driving China's economic development. However, China's export growth rate dropped rapidly because of the decline in demand from foreign countries. This drop in the export growth rate resulted in a decline in the energy consumption generated by China's exports during 2007–2010, especially for the sectors with higher export dependency, such as the metal and textile product sectors. The energy consumption caused by China's exports in the metal and textile product sectors declined by 30% and 17%, respectively, during 2007–2010. From the perspective of final use, China's energy consumption caused by exports in 2010 accounted for 27% of total energy consumption, significantly lower than the precrisis level. Third, the energy consumption generated by China's capital formation increased rapidly during the financial crisis. The Chinese government proposed a package plan to withstand the impact of the financial crisis. Approximately 76% of China's energy consumption growth was caused by capital formation in 2007–2010, a much higher proportion than that in other periods. From the sectoral perspective, the energy consumption generated by capital formation in the construction and transportation equipment manufacturing sectors increased by 24% and 80%, respectively, during 2007–2010.

In the new normal, the factors offsetting China's energy consumption growth began to shift from efficiency gains to structural upgrade. In China's traditional development model, efficiency was the only factor among the five driving factors driving the decline in energy consumption. In 2010–2012, however, efficiency drove an energy consumption decline of only 6%, which was much lower than 23% in 2005–2007 and 19% in 2007–2010. The space of China's energy efficiency improvement is gradually shrinking. The structural upgrade is expected to be the main factor driving down China's energy consumption. In the new normal, the production structure and consumption patterns began to inhibit China's energy consumption growth. In China's traditional development mode, the production structure and consumption pattern originally existed as factors that stimulated growth in energy consumption, but both of these factors reduced the energy consumption in China by 0.8% and 0.1%, respectively, in 2010–2012. This result reflects the initial success of China's structure upgrade from both the production and consumption sides. From the production-based perspective, the production structure drove a decline in China's energy consumption because the proportions of energy-intensive products in total inputs, such as inputs from the mining, transportation, and electricity sectors, declined. From the consumption-based perspective, the consumption patterns drove a decline in China's energy consumption because the proportions of energy-insensitive products in final use, such as the electrical equipment, electricity, and chemicals sectors, declined.

In the new normal, China's energy consumption growth mode is shifting from investment-driven to consumption-driven. The share of consumption-driven energy use had been declining by 2010 but increased by 0.2% between 2010 and 2012. Although the growth rate is not large, it shows the effect of the measures taken by China to stimulate consumption and expand domestic demand. In the new normal, China's economy has begun to abandon the traditional mode of investment-driven growth and is gradually shifting to a path that places greater emphasis on quality, pays more attention to ecological civilization construction, and focuses more on people's livelihood improvement. The share of consumption-driven energy use is expected to continue growing, and the pattern of China's energy consumption growth is shifting from investment-driven to consumption-driven.

In the near future, China's energy consumption growth rate will decline as a result of changes in its economic development model. In the new normal, China focuses on achieving better quality growth that is more economically and environmentally sustainable. The production and consumption structure is expected to be cleaner with lower proportions of coal in total energy use. China's total energy consumption increased by 1.9% annually between 2013 and 2017, which was much lower than the average level during the past decade. As a result, China's carbon emissions have been in a downward trend since 2013.

Acknowledgments
This study was supported by the National Key R&D Program of China (2016YFA0602604 and 2016YFA0602603), the Natural Science Foundation of China (41629501 and 71761137001), the UK Economic and Social Research Council (ES/L016028/1), and the Natural Environment Research Council (NE/N00714X/1). The data of Chinese energy can be downloaded from China Emission Accounts and Datasets (http://www.ceads.net/) and Shan et al. (2018).

References

Aguiar, A., Narayanan, B., & McDougall, R. (2016). An overview of the GTAP 9 data base. *Journal of Global Economic Analysis*, *1*(1), 181–208. https://doi.org/10.21642/JGEA.010103AF

Baiocchi, G., & Minx, J. C. (2010). Understanding changes in the UK's CO_2 emissions: A global perspective. *Environmental Science & Technology*, *44*(4), 1177–1184. https://doi.org/10.1021/es902662h

BP (2017). Statistical review of world energy 2017. Retrieved from https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Central Government of China (2008). Measures to expand domestic demand and promote economic growth. Retrieved from http://www.gov.cn/ldhd/2008–11/09/content_1143689.htm

Chai, J., Guo, J.-E., Wang, S.-Y., & Lai, K. K. (2009). Why does energy intensity fluctuate in China? *Energy Policy*, *37*(12), 5717–5731. https://doi.org/10.1016/j.enpol.2009.08.037

Chang, N., & Lahr, M. L. (2016). Changes in China's production-source CO_2 emissions: Insights from structural decomposition analysis and linkage analysis. *Economic Systems Research*, *28*(2), 224–242. https://doi.org/10.1080/09535314.2016.1172476

Diakoulaki, D., Mavrotas, G., Orkopoulos, D., & Papayannakis, L. (2006). A bottom-up decomposition analysis of energy-related CO_2 emissions in Greece. *Energy*, *31*(14), 2638–2651. https://doi.org/10.1016/j.energy.2005.11.024

Dietzenbacher, E., & Los, B. (1998). Structural decomposition techniques: Sense and sensitivity. *Economic Systems Research*, *10*(4), 307–324. https://doi.org/10.1080/09535319800000023
Fan, Y., & Xia, Y. (2012). Exploring energy consumption and demand in China. *Energy*, *40*(1), 23–30. https://doi.org/10.1016/j.energy.2011.09.049
Feng, K., Davis, S. J., Sun, L., & Hubacek, K. (2015). Drivers of the US CO_2 emissions 1997–2013. *Nature Communications*, *6*, 7714. https://doi.org/10.1038/ncomms8714
Feng, K., Hubacek, K., & Guan, D. (2009). Lifestyles, technology and CO_2 emissions in China: A regional comparative analysis. *Ecological Economics*, *69*(1), 145–154. https://doi.org/10.1016/j.ecolecon.2009.08.007
Garbaccio, R. F., Ho, M. S., & Jorgenson, D. W. (1999). Why has the energy-output ratio fallen in China? *The Energy Journal*, *20*(3), 63–91.
Green, F., & Stern, N. (2015). China's "new normal": Structural change, better growth, and peak emissions, Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science. Retrieved from http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/06/Chinas_new_normal_green_stern_June_2015.pdf
Green, F., & Stern, N. (2017). China's changing economy: Implications for its carbon dioxide emissions. *Climate Policy*, *17*(4), 423–442. https://doi.org/10.1080/14693062.2016.1156515
Guan, D., Peters, G. P., Weber, C. L., & Hubacek, K. (2009). Journey to world top emitter: An analysis of the driving forces of China's recent CO_2 emissions surge. *Geophysical Research Letters*, *36*, L04709. https://doi.org/10.1029/2008GL036540
Hoekstra, R., & Van Den Bergh, J. C. (2002). Structural decomposition analysis of physical flows in the economy. *Environmental and Resource Economics*, *23*(3), 357–378. https://doi.org/10.1023/A:1021234216845
Kagawa, S., & Inamura, H. (2004). A spatial structural decomposition analysis of Chinese and Japanese energy demand: 1985–1990. *Economic Systems Research*, *16*(3), 279–299. https://doi.org/10.1080/0953531042000239374
Kotchen, M. J., & Mansur, E. T. (2016). Correspondence: Reassessing the contribution of natural gas to US CO_2 emission reductions since 2007. *Nature Communications*, *7*, 10648. https://doi.org/10.1038/ncomms10648
Lan, J., & Malik, A. (2013). Structural decomposition analysis of the energy consumption in China and Russian application of the Eora MRIO database. In J. Murray & M. Lenzen (Eds.), *The sustainability practitioner's guide to multi-regional input-output analysis* (pp. 176–185). Champaign: Common Ground Publishing.
Lan, J., Malik, A., Lenzen, M., McBain, D., & Kanemoto, K. (2016). A structural decomposition analysis of global energy footprints. *Applied Energy*, *163*, 436–451. https://doi.org/10.1016/j.apenergy.2015.10.178
Lenzen, M. (2006). Decomposition analysis and the mean-rate-of-change index. *Applied Energy*, *83*(3), 185–198. https://doi.org/10.1016/j.apenergy.2005.02.005
Lenzen, M. (2011). Aggregation versus disaggregation in input-output analysis of the environment. *Economic Systems Research*, *23*(1), 73–89. https://doi.org/10.1080/09535314.2010.548793
Lenzen, M. (2016). Structural analyses of energy use and carbon emissions—An overview. *Economic Systems Research*, *28*(2), 119–132. https://doi.org/10.1080/09535314.2016.1170991
Lenzen, M., Pade, L.-L., & Munksgaard, J. (2004). CO_2 multipliers in multi-region input-output models. *Economic Systems Research*, *16*(4), 391–412. https://doi.org/10.1080/0953531042000304272
Lenzen, M., Schaeffer, R., Karstensen, J., & Peters, G. P. (2013). Drivers of change in Brazil's carbon dioxide emissions. *Climatic Change*, *121*(4), 815–824. https://doi.org/10.1007/s10584-013-0930-1
Leontief, W. W. (1936). Quantitative input and output relations in the economic systems of the United States. *The review of economic statistics*, *18*(3), 105–125. https://doi.org/10.2307/1927837
Lise, W. (2006). Decomposition of CO_2 emissions over 1980–2003 in Turkey. *Energy Policy*, *34*(14), 1841–1852. https://doi.org/10.1016/j.enpol.2004.12.021
Meng, J., Liu, J., Xu, Y., Guan, D., Liu, Z., Huang, Y., & Tao, S. (2016). Globalization and pollution: Tele-connecting local primary $PM_{2.5}$ emissions to global consumption. *Proceedings of the Royal Society A, Mathematical, Physical, and Engineering Sciences*, *472*(2195), 1–17. https://doi.org/10.1098/rspa.2016.0380
Meng, J., Mi, Z., Yang, H., Shan, Y., Guan, D., & Liu, J. (2017). The consumption-based black carbon emissions of China's megacities. *Journal of Cleaner Production*, *161*, 1275–1282. https://doi.org/10.1016/j.jclepro.2017.02.185
Meng, J., Mi, Z., Guan, D., Li, J., Tao, S., Li, Y., et al. (2018). The rise of south-south trade and its effect on global CO_2 emissions. *Nature Communications*, *9*, 1871. https://doi.org/10.1038/s41467-018-04337-y
Mi, Z., Meng, J., Green, F., Coffman, D. M., & Guan, D. (2018). China's "exported carbon" peak: Patterns, drivers, and implications. *Geophysical Research Letters*, *45*, 4309–4318. https://doi.org/10.1029/2018GL077915
Mi, Z., Meng, J., Guan, D., Shan, Y., Liu, Z., Wang, Y., et al. (2017). Pattern changes in determinants of Chinese emissions. *Environmental Research Letters*, *12*(7), 074003. https://doi.org/10.1088/1748-9326/aa69cf
Mi, Z., Meng, J., Guan, D., Shan, Y., Song, M., Wei, Y.-M., et al. (2017). Chinese CO_2 emission flows have reversed since the global financial crisis. *Nature Communications*, *8*, 1712. https://doi.org/10.1038/s41467-017-01820-w
Mi, Z., Zhang, Y., Guan, D., Shan, Y., Liu, Z., Cong, R., et al. (2016). Consumption-based emission accounting for Chinese cities. *Applied Energy*, *184*, 1073–1081. https://doi.org/10.1016/j.apenergy.2016.06.094
Mi, Z.-F., Pan, S.-Y., Yu, H., & Wei, Y.-M. (2015). Potential impacts of industrial structure on energy consumption and CO_2 emission: A case study of Beijing. *Journal of Cleaner Production*, *103*, 455–462. https://doi.org/10.1016/j.jclepro.2014.06.011
Minx, J. C., Baiocchi, G., Peters, G. P., Weber, C. L., Guan, D., & Hubacek, K. (2011). A "carbonizing dragon": China's fast growing CO_2 emissions revisited. *Environmental Science & Technology*, *45*(21), 9144–9153. https://doi.org/10.1021/es201497m
Mukhopadhyay, K., & Chakraborty, D. (1999). India's energy consumption changes during 1973/74 to 1991/92. *Economic Systems Research*, *11*(4), 423–438. https://doi.org/10.1080/09535319900000030
National Bureau of Statistics (2015a). *China statistical yearbook 2015*. Beijing: China Statistics Press.
National Bureau of Statistics (2015b). *China energy statistical yearbook 2015*. Beijing: China Statistics Press.
National Bureau of Statistics (2016). China input-output tables, National Bureau of Statistics of China. Retrieved from http://data.stats.gov.cn/ifnormal.htm?u=/files/html/quickSearch/trcc/trcc01.html&h=740
Okushima, S., & Tamura, M. (2010). What causes the change in energy demand in the economy?: The role of technological change. *Energy Economics*, *32*, S41–S46. https://doi.org/10.1016/j.eneco.2009.03.011
Peters, G. P., Weber, C. L., Guan, D., & Hubacek, K. (2007). China's growing CO_2 emissions a race between increasing consumption and efficiency gains. *Environmental Science & Technology*, *41*(17), 5939–5944. https://doi.org/10.1021/es070108f
Shan, Y., Guan, D., Zheng, H., Ou, J., Li, Y., Meng, J., et al. (2018). China CO_2 emission accounts 1997–2015. *Science Data*, *5*, 170201. https://doi.org/10.1038/sdata.2017.201

10.1029/2018EF000840

Shan, Y., Zheng, H., Guan, D., Li, C., Mi, Z., Meng, J., et al. (2017). Energy consumption and CO_2 emissions in Tibet and its cities in 2014. *Earth Future*, *5*(8), 854–864. https://doi.org/10.1002/2017EF000571

Su, B., & Ang, B. (2012). Structural decomposition analysis applied to energy and emissions: Some methodological developments. *Energy Economics*, *34*(1), 177–188. https://doi.org/10.1016/j.eneco.2011.10.009

Su, B., & Ang, B. W. (2010). Input-output analysis of CO_2 emissions embodied in trade: The effects of spatial aggregation. *Ecological Economics*, *70*(1), 10–18. https://doi.org/10.1016/j.ecolecon.2010.08.016

The Economist (2008). China seeks stimulation. Retrieved from https://www.economist.com/node/12585407

UNSD (1999). *Handbook of input-output table compilation and analysis*. New York: United Nations Statistical Division (UNSD). Retrieved from http://unstats.un.org/unsd/publication/SeriesF/SeriesF_74E.pdf

UNSD (2016). *National accounts main aggregates database*. New York: United Nations Statistical Division (UNSD). Retrieved from http://unstats.un.org/unsd/snaama/Introduction.asp

Wachsmann, U., Wood, R., Lenzen, M., & Schaeffer, R. (2009). Structural decomposition of energy use in Brazil from 1970 to 1996. *Applied Energy*, *86*(4), 578–587. https://doi.org/10.1016/j.apenergy.2008.08.003

Wang, S., Li, Q., Fang, C., & Zhou, C. (2016). The relationship between economic growth, energy consumption, and CO_2 emissions: Empirical evidence from China. *Science of the Total Environment*, *542*, 360–371. https://doi.org/10.1016/j.scitotenv.2015.10.027

Weber, C. L. (2009). Measuring structural change and energy use: Decomposition of the US economy from 1997 to 2002. *Energy Policy*, *37*(4), 1561–1570. https://doi.org/10.1016/j.enpol.2008.12.027

Wood, R. (2009). Structural decomposition analysis of Australia's greenhouse gas emissions. *Energy Policy*, *37*(11), 4943–4948.

Wood, R., & Lenzen, M. (2006). Zero-value problems of the logarithmic mean divisia index decomposition method. *Energy Policy*, *34*(12), 1326–1331. https://doi.org/10.1016/j.enpol.2004.11.010

Xiao, B., Niu, D., & Guo, X. (2016). The driving forces of changes in CO_2 emissions in China: A structural decomposition analysis. *Energies*, *9*(4), 259. https://doi.org/10.3390/en9040259

Yamakawa, A., & Peters, G. P. (2011). Structural decomposition analysis of greenhouse gas emissions in Norway 1990–2002. *Economic Systems Research*, *23*(3), 303–318. https://doi.org/10.1080/09535314.2010.549461

Yu, S., Zheng, S., Ba, G., & Wei, Y.-M. (2016). Can China realize its energy-savings goal by adjusting its industrial structure? *Economic Systems Research*, *28*(2), 273–293. https://doi.org/10.1080/09535314.2015.1102714

Zhang, H., & Lahr, M. L. (2014). China's energy consumption change from 1987 to 2007: A multi-regional structural decomposition analysis. *Energy Policy*, *67*, 682–693. https://doi.org/10.1016/j.enpol.2013.11.069

Zhang, Q., Jiang, X., Tong, D., Davis, S. J., Zhao, H., Geng, G., et al. (2017). Transboundary health impacts of transported global air pollution and international trade. *Nature*, *543*(7647), 705. https://doi.org/10.1038/nature21712