Driving factor analysis of global carbon emissions and reduction strategies based on the Dynamic Time Warping

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ABSTRACT

The identification of driving factors of the carbon emission is fundamental for the policy makings of carbon reductions, especially at national level. In this study, the structural decomposition analysis (SDA) is applied for 112 countries in the world from 1990 to 2014. This method can not only provide a straightforward link between carbon and energy in social economic systems but also give a comprehensive perspective to probe the driving forces of carbon emission from both production and consumption sides. In this study, the carbon dioxide emission is decomposed into six driving factors: population, fuel mix, energy intensity, production structure, consumption patterns and consumption volume. Then the contributions of five final consumers and the six driving factors to the total carbon dioxide emissions are quantified. Based on three indicators (emission volume, emission structure and driving factor growth rate) and Dynamic Time Warping, the study countries are classified into five groups: 1. the USA. 2. China and India. 3. The developed country in Europe. 4: Developing countries with decreasing trend of emission. 5: Developing countries with increasing trend of emission. Meanwhile, the results showed that the developed country in Europe, which is group 3, has successfully reduced the carbon emissions by the promotion of energy intensity. However, the developing countries, still have a long way to go to reduce their carbon emissions based on the historical emission patterns of all the developed countries in group 3. The investigation of the driving forces for different consumers shows that the production structure change (that prosperity in the real estate industry and other related industries) and the growth of gross fixed capital investments would negatively affect the carbon reductions in developing countries.

Keywords: Carbon emission; structural decomposition analysis; input-output analysis; energy consumption

1. Introduction

Carbon emissions as the major contributor of global warming, have arisen global attentions to collaborate to slow down the progress of climate change[1-4]. Carbon emissions, primarily derived by the combustion of fossil fuels, have increased dramatically since the start of the industrial revolution of developed countries, such as the UK and the USA. Over the past decade (2004-2014), global CO_2 emissions from fossil fuel combustion and cement production have continued to grow by 2.5% per year, driven mostly by growth in the developing countries like China and India[5]. Meanwhile, to take the global responsibilities of climate change, all those developing countries have promised to cut down domestic carbon emissions for the benefit of all the world, i.e. China has proposed several strategies and plans to achieve the reduction goals and alleviate the strong dependency on fossil fuels, such as, the promotion of energy saving technology and regulations for energy reduction, the reduction of the total coal consumption to 4.2 billion tones by 2020, and promotion of the substitution of natural gas to coal in household heating and to petroleum in transportation, and increase of the proportion of natural gas consumptions to 20% (13th Five-Year Plan to Control Greenhouse Gas Emissions, 2016). However, carbon emission is not only an environmental issue which is directly caused by the combustion of fossil fuels, but also a society development consequence which is driven by some indirect factors, e.g. regional economy, production structure, life style and corresponding household consumption patterns, which are regarded as the inner drivers of the growth of carbon emissions[6, 7]. Thus, the investigation of driving factors of the carbon emission is fundamental for the policy makings of carbon reductions, especially at country level. Finally, the variation of the driving factors may provide an answer for the question: will the developing countries avoid or inevitably follow the same history of developed country?

State-of-the-art studies of the driving factors of carbon emission have been conducted by two main approaches: Index Decomposition Analysis (IDA)[8-10] and Structural decomposition analysis (SDA)[11]. Hoekstra and van den Bergh (2003) have compared these two methods and the application studies (before 1999), and found that the applications of IDA have increased substantially over the years, and developed into various branches (e.g., the Log Mean Divisia Index, Arithmetic Mean Divisia Index, and Modified Fisher Ideal Index) covering multiple areas (e.g., carbon emission, water consumption, greenhouse gas emissions, etc.)[11]. Su and Ang (2012) has conducted a literature review (2000-2010) and a case study of China to compare these two methods, and the results showed that IDA has the advantages of a lower data requirement and simplicity of the methodology, which allows considerable flexibility in problem formulation [12]. However, by aggregating sectors to investigate the impacts of industry structure changes, IDA method will lose some details in the results [13]. Thus, to keep the integrity of sectoral information in one economy, SDA is therefore introduced to unveil the impacts of driving factors of carbon emission, such as detailed industry structures or energy consumption patterns. All of the above review studies has comprehensively summarized the features and methodology development of SDA before 2010, Thus, one of the objective of this study is to replenish the literature review with the SDA studies after 2010 and highlight some highly relative studies. In recent years, SDA has been widely used to unveil the driving forces of energy consumption[13-18], water consumption[19-24], environment pollution[15], as well as carbon[25-28]. Peter et al. (2007) used SDA to figure out the driving factors of China's carbon emissions from 1992 to 2002, showing that the urbanization and lifestyle change, especially the construction industry and household consumption, exerted great influences on the carbon emissions[29]. Then, Guan et al. (2008) studied carbon emissions in China from 1980 to 2002, which is decomposed into five driving factors and five scenarios are designed to predict the emissions in 2030, demonstrating that household consumption, capital investment and growth of exports are the main drivers in the consumption perspective[30]. Guan et al. (2009) continued to probe into the driving factors of carbon emissions in China from 2002 to 2005, and found that the export activity accounts for almost half of the carbon emission increment, while the increase of efficiency has a limited effect on the deceleration of carbon emission[31]. Feng et al. (2012) investigated the multi-regional carbon emissions in China from 2002 to 2007, which covers all the provinces in China, and five factors including population, technology, economic structure, urbanization, and household consumption patterns are considered, with the results implying that lifestyle changes is the most important driving factor of the growth of carbon emissions in all provinces, and the improvement of technology and energy efficiency are not sufficient enough to curb emissions[32].

In this study, SDA method is applied to analyze the changes of carbon emission driven by different final consumers of 112 countries from 1990 to 2014 and the results of several typical countries are illustrated in detail. In Section 2, the total carbon emissions driven by different domestic final consumers are quantified and demonstrated. In Section 3, the relationship between economic development and carbon emission has been investigated. Then, all the country has been classified into 5 groups and they are featured by specific emission patterns which is derived by different final consumers. In Section 4, the contributions of six driving factors: emission intensity, energy intensity, production structure, consumption structure, per capita consumption volume and population, are computed for all study countries to unveil the main driving factors of different groups. Finally, policy suggestions are proposed to reduce the carbon emission at national and global level in the future.

2. Material and methods

2.1 Structural decomposition analysis

Based on input–output analysis, the CO_2 emissions can be expressed mathematically as:

$$C = k(I - A)^{-1} Y = kLY \tag{1}$$

where $\mathbf{O} = \begin{bmatrix} o_1 & o_2 & \cdots & o_n \end{bmatrix}^T$ is the total output vector of all sectors in one region; $\mathbf{A}$ is the direct requirement coefficient matrix, and each column of A shows input requirement from each sector to produce one unit output of this column sector (the sum is 1); $\mathbf{Y} = \begin{bmatrix} y_1 & y_2 & \cdots & y_n \end{bmatrix}^T$ is the final demand vector; $\mathbf{k} = \begin{bmatrix} k_1 & k_2 & \cdots & k_n \end{bmatrix}^T$ is the carbon emission intensity vector (emissions per unit of economic output) in each economic sector, referring to sectoral carbon emission per monetary unit; and $\mathbf{C}$ is total carbon emission driven by the final demand Y. We consider the production structure through L, which is the renowned Leontief inversion matrix. The values in L represent the total outputs caused by one unit of consumption by final consumers, thus, the changes in the production structure, in other words, refers to industry sectors using more or less intermediate inputs from each other to meet the changes in final consumptions. Also, it has been widely discussed that the emission intensity of an economy emissions is the product of per unit of energy consumption (fuel mix) and energy intensity (energy consumption per unit of economic output), both are vital factors that impact the carbon emission. Hence, in SDA, the emission coefficients matrix $\mathbf{k}$ has been decomposed into emission intensity f (emissions per unit of energy consumption, a row vector) and energy intensity $\hat{E}$ (energy consumption per unit of output, a diagonal matrix). To distinguish the contributions of different final demand components, we further decompose Y into three components: average consumption structure y_s, per capita consumption volume y_v and population p: $Y = \frac{Y}{Ysum} \bullet \frac{Ysum}{p} \bullet p = y_s y_v p$. Therefore, the total carbon emission in IOA can be transformed to:

$$C = k(I - A)^{-1} Y = f\hat{E}Ly_s y_v p \tag{2}$$

Over the given period of time 1990 to 2014, any changes in carbon emissions in a country can be represented by equation above, in which the six factors of population, fuel mix, energy intensity, production structure, consumption patterns and consumption volume, all contribute to the changes in carbon emissions. Total difference of every factor composes the total carbon emission change:

$$\Delta C = \Delta f\hat{E}Ly_s y_v p + f\Delta\hat{E}Ly_s y_v p + f\hat{E}\Delta Ly_s y_v p + f\hat{E}L\Delta y_s y_v p + f\hat{E}Ly_s\Delta y_v p + f\hat{E}Ly_s y_v\Delta p$$

(3)

where, Δ is the difference operator. Meanwhile, the order of these six factors in $f\hat{E}Ly_{is}y_{iv}\Delta p$ is not unique, which implies the contribution of population changes to the total carbon emission. $\Delta p = p_t - p_0$ is the change of the population from the base year to the target year, where p_t represents the population in the target year, and p_0 represents the population in the base year. Dietzenbacher and Los [33] found that in patterns of repetition of different orders. There are 720 (6!) kinds of order that result in the exactly the same results of carbon emission change. For example, $f_0\hat{E}_0L_0y_{s0}y_{v0}\Delta p$ appears 120 times, $f_t\hat{E}_0L_0y_{s0}y_{v0}\Delta p$ appears 24 times, et al. Since the direct observation method could be difficult in 720 decomposition equations. Finally, the contribution of population to the total carbon emission change can be represented as:

$$f\hat{E}Ly_s y_v\Delta p = \frac{1}{720}(120 \bullet f_0\hat{E}_0L_0y_{s0}y_{v0}\Delta p + 24 f_t\hat{E}_0L_0y_{s0}y_{v0}\Delta p + \cdots + 120 \bullet f_t\hat{E}_tL_ty_{st}y_{vt}\Delta p)$$

(4)

Similarly, we can calculate the changes derived emission intensity f, energy intensity $\hat{E}$, production structure L, consumption structure y_s, per capita consumption volume y_v and population p.

2.2 Study site and data

In this study, we use SDA to estimate the driving factors of carbon emissions in 112 countries in the world. The input-output tables from 1990 to 2014 are collected from the EORA database, which is a input–output table database that provides a time series of high-resolution input–output (IO) tables with matching environmental and social satellite at national and global level[34]. The IO tables from EORA include the intermediate transactions of different sectors and final consumptions of six final consumers (households, government, non-profit institutions serving household, fixed gross capital formation, changes in inventory, and acquisitions less disposals of valuables). Table 1 shows the study countries. The database also provides sectoral energy supply data and carbon emission data which are collected from the International Energy Agency database (https://www.iea.org/)[35]. Thus, the uncertainty in this study mainly comes from the various second-hand data sources[34].

[place Table 1 here]

3. Results

3.1 Changes of total carbon dioxide emissions derived by final consumers at national level

To better illustrate the historical CO_2 emission trend of different countries, all study countries are classified into three groups based on their total CO_2 emissions from 1990 to 2014 driven by domestic final consumers (except export): 1. More than 500,000 kt per year; 2. Between 5,000 kt and 500,000 kt per year; 3. Less than 5000 kt per year. Fig. 1 shows the carbon dioxide emissions of countries in group 1, which only includes the USA, China and India. For the first subfigure in Fig. 1, the CO_2 emission of the USA keeps relatively stable from 1990 to 2014, the total emission ranges from 3.9 Gt to 4.2 Gt. In the early 1900s, the USA has finished its secondary industrial revolution, that could be a reason why its emission driven by domestic final consumers keeps stable after 1990. China catches up the USA and becomes the greatest emission country after 2008, its emission increase from 1.5Gt in 1990 to 6.9 Gt in 2014, which is almost fivefold increment. Especially from 1999 to 2007, the government has put forward several economic strategies such as "The Great Development of the Western Region", "Revitalizing the Old Industrial Base in Northeast China" and "Accelerating the Development of the Central Region". As another emerging economy, the emission of India also increases from 0.5 Gt to 2.0 Gt from 1990 to 2014. Looking deep into the contributions of different final consumers. In the USA, the household are always the main consumers, the emission derived by household accounts for about 60% all over the study years. China and India are in the same development stage but the emission features differ from each other. In China, the gross fixed capital formation is the main reason of the increase of emissions, which accounts for 39% in 1990 to 50% in 2014. In India, the household is the main consumers, which causes 53% of emission in 1990 to 54% in 2014.

[place Fig. 1 here]

Fig. 2 shows the carbon dioxide emissions of countries in group 2, which includes most of the European countries (i.e. Germany, Italy, France, Poland and the UK) and several fast-growing developing countries (i.e. Mexico, Indonesia, Turkey). For the developed countries, the main trend of carbon emission is decreasing, which is represented by Germany with a decrease from 678702 kt in 1990 to 394115 kt in 2014. On the contrary, Mexico, Indonesia and Turkey have dramatically increases all over the years. For Germany, the household is always the main contributor of carbon emissions, which contribute 74% in 1990 to 77% in 2014. For the UK, which is the first country of the global industrial revolution, the contribution of household also takes the largest part, which is 79% in 1990 to 85% in 2014. For Indonesia and Mexico, the household are also the main reason that drives the total carbon dioxide emission.

[place Fig. 2 here]

Fig. 3 shows the carbon dioxide emissions of countries in group 3, which includes several developed countries (i.e. Bulgaria) and most of the developing (i.e. Viet Nam, Philippines). For the developed countries, the trend of carbon emission is decreasing, which shows a similar picture with the previous developed countries. On the contrary, Viet Nam and Philippines have dramatically increases all over the years. For Viet Nam, the household is always the main contributor of carbon emissions, which contribute 83% in 1990 to 76% in 2014. For Philippines, the contribution of household also takes the largest part, which is 64% in 1990 to 74% in 2014.

[place Fig. 3 here]

3.2 Carbon emissions and economic development: classification of all countries

To better identify the current key emission sources and future potential emission sources, the total emission in 2014 and the emission growth rate from 1990 to 2014 of all countries has been depicted in Fig 4. Thus, the countries can be classified into 4 groups (shown in Fig. 4):

Group 1: The developed countries in quadrant I (total emission is more than 1Gt and the growth rate is more than 0), which only implies the USA.

Group 2: The developing countries in quadrant I, which includes China and India.

Group 3: The developed country in quadrant III (total emission is less than 1Gt and the growth rate is less than 0), which are mainly located in Europe, such as Greece, Slovenia, Finland, Belgium, France, Italy, Poland, UK, Sweden and Germany.

Group 4: For the developing countries in quadrant III (total emission is less than 1Gt and the growth rate is less than 0), such as Kazakhstan, Ukraine.

Group 5: For the developing countries in quadrant IV (total emission is less than 1Gt and the growth rate is more than 0), such as Viet Nam, Angola, Bolivia, Indonesia, Cote dIvoire, Congo, Thailand, Turkey, Philippines, Kenya, Egypt, Cameroon, and Mexico.

[place Fig. 4 here]

In group 1, the USA is the only one developed country. Carbon emissions of the USA maintain steady increase from 1990 to 2014 (0.3%) and its total carbon emission is much higher than the others. In group 2, China and India as two largest developing countries have the largest total carbon emissions in the world and their emission growth rate are 14% and 10% per year respectively. In group 3, represented by Germany, Italy, France and the UK, the carbon emissions of all the countries are decreasing all over the years. In group 4, the countries are still under developing and the emissions are still in a relatively low level. In group 5, there are emerging economies with dramatically high emissions growth rate all over years, especially Viet Nam (31%), Tanzania (19%), Nepal (17%).

The relationship between economy level and carbon emission is vital for the prediction of the development path for all countries, especially for the developing. Thus, Fig. 9 demonstrate the relationship between GDP and carbon intensity in different groups, which has been defined above. Most of the countries in group 4 will be concentratedly located at the left bottom corner of Fig. 9, thus only Ukraine has been displayed in this figure. From Fig.9, it is obvious that group 3, especially for the UK, Germany and Greece, which have high GDP and low carbon intensity, show a pathway to low-carbon development for all the other countries. Meanwhile, group 1 is much higher than group 3, which implies that to create same amount of GDP, group 1 will emit more carbon than group 3. However, based on the GDP that group 1 has made, which is much greater than group 3. In this figure, there is no future pathways that group 1 can refer to. Finally, if we assume that group 2, group 4 and group 5 will follow the same path that group 3 walk along, how to adjust all the driving factors to make them on the right track will be the next important question.

[place Fig. 5 here]

To better unveil the features of different groups, the emissions ratio of main final consumers (household, gross fixed capital formation, and government) and their growth rates are described in Fig. 6. In Fig. 6, all the emissions from three main final consumers in group 1 are in the middle compared with other groups. Group 2 obviously owns higher level carbon emissions from gross fixed capital formation and growth rate from 1990 to 2014. The household causes less emission than all the other groups. For group 3, which have the most developed countries, have relatively higher emission derived from household final consumptions and lower emission derived from gross fixed capital formation. Especially Germany, the UK and Greece. Group 4 includes the developing countries with a decreasing trend of carbon emission and has ambiguous pattern of carbon emissions. The various industry structure and social environment maybe the main reason that causes the huge difference among the countries in group 4. In the group 5, most of the countries have high emissions driven by the household, and the growth rate is also greater than group 1, 2, 3. At the same time, the emission derived by the government is lower than other groups.

[place Fig. 6 here]

3.3 Driving factors of carbon dioxide emissions

[place Fig. 7 here]

As the largest emitter of carbon dioxide in the group 2 and in the world, China deserves more attention on its driving factors, which is crucial for the implementation of global carbon reduction goals. Fig. 4 shows the contributions of six driving factors on carbon emissions derived by five final consumers in China from 1990 to 2014. From the consumption perspective, the carbon dioxide emission derived by gross fixed capital formation has taken the largest part of the total carbon dioxide emissions from 1990 to 2014. It accounts for 28.8% of total carbon dioxide emission in 1990 to 38.6% in 2014, and the increase also implies the rapid increasing expenditure on fixed assets like residential buildings, infrastructure in China. As one of the consequences of expanded expenditure on fixed assets, the total economic output of construction industry in China has dramatically increased almost 136 times (including inflation). The second largest consumer is household, which implies the carbon dioxide emissions driven by the household consumptions on goods or services for people's daily life are dramatic. This part has also increased in the whole study period (1.6 Gt in 1990 to 2.5 Gt in 2014), but the proportion of it has decreased from 34.6% in 1990 to 27.5% in 2014. The proportion of carbon dioxide emission driven by government consumption has kept stable in these years, which is around 6.0%-8.0%. The emission derived by non-profit institutions serving household and changes in inventories account for 1%-2% of the total carbon dioxide emissions in China, and their contributions keep stable in the whole study period.

The total carbon dioxide emission driven by household increases from 0.7Gt in 1990 to 2.5Gt in 2014. The most significant driving factor of carbon dioxide emission in household is the growth of consumption volumes, which implies the significant growth in per capita consumption of goods and services in China. The increases in consumption volume correspond to 57.11% of carbon dioxide emission growth in 1991 and 480% in 2014. Meanwhile, the production structure is another important factor that contributes to the increase of carbon dioxide emissions by household. The production structure represents the sectoral transactions in the society. The contributions of production structure have fluctuated all over these years, while it is still increasing from 69% in 2003 to 126% in 2014. The contribution of fuel mix decreases from 101% in 1990 to 62% in 2014, demonstrating that the carbon dioxide emission per energy consumption in China is decreasing, which has positive effects on carbon dioxide reduction. Energy intensity, which is energy consumption per outputs, is the most important driving factors for carbon dioxide reduction, the contribution of which is negative over the years from -230% to -600%. In addition, the population also has an important contribution, which increases from 15% in 1991 to 49% in 2000, then slightly decreases to 42% in 2014. However, the population grows from 1.13 in 1990 billion to 1.36 billion in 2014. Compared with the rapidly increase of the total carbon dioxide emissions caused by household, the influence of population growth is negligible. Thus, from household perspective, the population control strategy would not be quite effective for carbon reduction in recent years.

Then, the total carbon dioxide emission driven by non-profit institutions serving households has increased from 0.02 Gt in 1990 to 0.07 Gt in 2014, which shows a similar trend as the contribution of household. The largest contributor is consumption volume because the increase of consumption volume corresponds to 57% of increase in 1991 to a 480% of increase in 2014 compared with the base year 1990. Meanwhile, energy intensity as the energy consumption per outputs has negative contributions ranging from -238% to -597% to the carbon dioxide emission over the years, which implies that the increase of energy efficiency plays an important role in China. Meanwhile, the production structure is the third factors that contributes to the increase of carbon dioxide emissions by no-profit institutions. The contribution of production structure fluctuates over these years, with the recent trend is declining: from 138% in 2008 to 105% in 2014. Fuel mix shows a similar trend with the production structure, the contribution of which decreases from 101% in 2008 to 62% in 2014.

The total carbon dioxide emission driven by government increases from 0.1 Gt in 1990 to 0.7 Gt in 2014. The increases of consumption volume correspond to 94% of carbon dioxide emission increase in emissions in 1991 to 470% in 2014 compared with the emissions in 1990. Another important factor that influences the carbon dioxide emissions is energy intensity, whose contributions to the carbon dioxide emission are negative, from -56% to -535% to the increase of carbon dioxide emission compared with 1990, implying that the energy intensity is the most important contributor to the carbon dioxide reduction. Meanwhile, the production structure is the third factors that contributes to the carbon dioxide emissions growth driven by government. The production structure is influenced by government planning and economic market. The contributions of production structure have fluctuated, with the main trend being decreased: from 106% in 2003 to 93% in 2014. Fuel mix is another contributor to the carbon dioxide emission changes, contribution of which increases from 21% in 1990 to 49% in 2014, representing that the carbon dioxide emission per energy consumption has a growing contribution to carbon dioxide emission derived from government. Thus, the carbon dioxide emission reduction caused by government part relies on the shrinkage of consumption volumes and energy intensity, rather than production structure.

The total carbon dioxide emission driven by gross fixed capital formation increases from 0.6 Gt in 1990 to 3.5 Gt in 2014. Consumption volume, as the largest contributor to carbon dioxide emission increase, is caused by the growth in per capita consumption of goods and services in China. The increase in such consumption volume corresponds to 60% of increase of emissions in 1991 to 432% in 2014. The second important factor is energy intensity, with contribution being negative, from -147% in 1990 to -536% in 2014 compared with the emissions in 1990. Meanwhile, the production structure is the third factor that contributes to the carbon dioxide emissions by household. The contributions of production structure remain stable in recent years, just slightly increase from 116% in 2008 to 130% in 2014. Fuel mix fluctuates from 30% to 60%. The contribution of population derived by gross fixed capital format steadily increases from 9% in 1990 to 37% in 2014. From the perspective of gross fixed capital, the population control is workable for carbon dioxide reduction.

The total carbon dioxide emission driven by changes in inventory decreases from 0.06 Gt in 1990 to 0.02 Gt in 2002, then keeps increasing to 0.19 Gt in 2014. The total carbon dioxide emission derived by changes of inventory is found to be increasing. The largest contributors are still consumption volumes and production structure. Energy intensity is the most vital factor that boosts the carbon dioxide emission mitigation.

[place Fig. 8 here]

India is the second largest emitter in group 2. Fig. 8 shows the contributions of six driving factors on carbon emissions derived by five final consumers in India from 1990 to 2014. All driving factors contribute to the increase of carbon emissions except energy intensity. The same as China, energy intensity is the main driving factor that shows positive effects on carbon reduction.

[place Fig. 9 here]

Group 3, leading the future pathways for the other countries, is represented by Germany and Greece. Thus, Fig. 9 shows the contributions of six driving factors on carbon emissions derived by five final consumers in Germany from 1990 to 2014, which will be instructive for the adjustment of driving factors in other countries. The contributions of all driving factors show a different picture with China and India. In Germany, the same with previous countries, the energy intensity are the main drivers of the decrease of carbon emission. However, the fuel mix and the production structure are secondary important factors that can lead to the decrease of carbon emission. The changes of production structure only can significantly contribute to the carbon reduction of government.

[place Fig. 10 here]

Group 1 is special in all the countries as we explained previous. Thus, the analysis of the USA is also necessary for the further explanation about its peculiarity. Fig. 10 shows the contributions of six driving factors on carbon emissions derived by five final consumers in the USA from 1990 to 2014. The main driving factors for the increase of carbon emissions are consumption volume and population. The same as China, energy intensity is main driving factors that show positive effects on carbon reduction. However, for different final consumers, the situations have some differences, for example, the production structure only significantly contributes to the government. The reason is the carbon emissions of government has a slightly increase from 1990 to 2014, as opposed to all the other final consumers.

4. Discussion

In this study, we analyzed 1. the contributions of five final consumers to the carbon dioxide emissions in 120 countries from 1990 to 2014; and 2. All the countries are classified into 5 groups based on their economic development level, the volumes of carbon emission, and emissions patterns. 3. the driving forces of the carbon dioxide emissions of five final consumers in typical country of 5 groups are analyzed.

In this study, the carbon dioxide emission is decomposed with six driving factors: population, fuel mix, energy intensity, production structure, consumption patterns and consumption volume. Then the contributions of five final consumers and the six driving factors to the total carbon dioxide emissions are quantified. The results lead to the classification of all countries into 5 groups. And we made an assumption that the country development endpoint is group 3. However, the pathways of the other groups to the endpoint could be totally different. The developed countries in group 3 successfully decrease the carbon emissions by the great promotion of the energy intensity, and its emissions are mainly come from household. Group 2, that is China and India, showed that the proportions of gross fixed capital formation keep increasing all over the years, which implies that the emission proportion of gross fixed capital will decrease in the future. The USA, as one of the developed country, its future is difficult to predict because of its higher GDP per capita and stable carbon emissions. Maybe it is in the transitional period of carbon emission and would follow the same decreasing trend of European countries in the future. However, the developing countries in group 4 and 5 still have a long way to go to reduce their carbon emissions based on the emission patterns of group 1, 2 and 3.

Overall, from the driving factors' perspective, the driving forces of the energy intensity, consumption pattern and production structure show potential positive effects on reducing carbon emission, especially the energy intensity factor. On the contrary, the driving factors of the consumption volume per capita result in the increase of the carbon emission, but the effects of the driving factors in different countries are diverse. The population is not the main driving force of carbon emissions all over the world.

5. Conclusion

The traditional structural decomposition analysis is applied for 112 countries in this study. This method can not only provide a straightforward link between carbon and energy in social economic systems but can also give a comprehensive perspective from which to probe the driving forces of carbon emission from both production and consumption sides. Meanwhile, it offers meaningful references for examining the influences of past policies (e.g., industry transitions, energy structure changes, population control, etc.) and supporting the formulation of future policies for addressing global carbon reduction pressures and mitigation of climate change.

There is no doubt that, the developing countries with large amount of carbon emissions are vital for the global carbon reduction. Thus, we take China as an example to propose several suggestions. From consumers' aspect, gross fixed capital formation leads the growth of carbon dioxide emission in China compared with other final consumers including household and government, etc. Along with the economic development and household/government income gains, more and more residential buildings are built to fulfill the requirements from household and government, both making the rapid growth of fixed capital be the largest emitter, which accounts for 39% of total carbon dioxide emission in 2014. The carbon dioxide emission derived by expenditure on fixed assets is also highly related to household consumption habit in China. As for the carbon dioxide emission driven by household, through the decomposition of carbon dioxide emission changes, the results showed that the carbon dioxide consumption volumes have the most positive impacts on the increase of carbon dioxide emission, which implies the increasing purchasing power of household is the most notable obstacle of carbon dioxide mitigation. Although the decrease of energy intensity has a huge contribution to carbon dioxide reduction, it's still not enough to cut down the total emission. The same situation happens in emissions derived from all the other final consumers. The increase of energy efficiency is the most important tool to reduce carbon emission in China. Meanwhile, production structure, as the ratio of different industries and their connections, is the second largest contributor of the total emission. The contribution of fuel mix is decreasing due to the promotion of cleaner production technology and more government regulations. However, the influence of the decrease of fuel mix on carbon emission mitigation is limited compared with the compelling increase of consumption volumes. Finally, the contribution from population growth is small to affect the increasing carbon emission. The consumption pattern, which implies the expenditure structure of final consumers, also has little influence on the total carbon emission. Thus, the industrial transformation is urgent, and more regulations and restrictions aiming to slow down the rapid growth of real estate should be implemented. Meanwhile, population is not a major driving factor for carbon emission, but its purchasing power is. Thus, the race between people's income growth and emerging of new energy saving technologies is vital for the carbon emission mitigation in China. And the same situation also happened in India, and perhaps it will happen in all the countries in group 4, which are in rapid expansion in the current and in the future.

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