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Balancing Carbon Emission Reductions and Social Economic Development for Sustainable Development: Experience from 24 Countries

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Abstract: The impact of human carbon emissions on climate has generated widespread global concern. We selected 24 countries as research objects and analysed the changes in carbon emissions in different countries between the establishment of emission reduction actions in 1990 and 2014. Then, we selected 19 factors representing four categories (economy, population, technology and energy) to explore the key factors that led to changes in carbon dioxide (CO_2) emissions in different countries. Emission reduction actions since 1990 did not lead to marked improvements, and only five countries (Russia, Germany, the United Kingdom, Italy and France) achieved reductions in carbon emissions. The factors that influenced CO_2 emissions varied among countries. In most developing countries, reductions in CO_2 emissions were caused by reductions in poverty and inherent natural conditions. Moreover, the extent of influence of a given factor on CO_2 emissions differed among countries. The global economic crisis may cause similar fluctuations in CO_2 emissions in many countries. Adjustments to energy and industrial structures are the main reason for the reduction in carbon emissions, whereas economic growth and urbanization are the two major contributors to the growth of carbon emissions. According to historical carbon emissions data, a green energy revolution must be implemented to address global climate change and ensure the sustainable development of human societies.

Keywords: carbon dioxide (CO_2) emissions; climate change; economic growth; sustainable development

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1 Introduction

Climate change is a global issue. The Sustainable Development Goal 13 is 'Climate Action'. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the average temperature of the Earth's surface rose by approximately 0.85 degrees from 1880 to 2012. In the Northern Hemisphere, 1983–2012 was the hottest period in nearly 1400 years. Since the 1950s, human activities have contributed to more than half of global warming (Qin and Stocker, 2014). Identifying a method of reducing carbon dioxide (CO_2) that can be implemented along with social development has become a focus of the international community. In the first World Climate Conference held in Geneva in 1979, climate change was included in the agenda as a matter of concern of the international community. Subsequently, various governments have carried out negotiations and cooperated to reduce CO_2 emissions and address global climate change since the

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first IPCC evaluation report in 1990 and the ‘Framework Convention on Climate Change’ in 1992. However, the implementation of emission reduction plans and the promotion of low-carbon economies have encountered many difficulties. The attitudes and policies of individual countries regarding emission reductions differ because their interests and national conditions differ. Carbon rights negotiations affect the right of countries to development..Therefore, it is necessary to strengthen cooperation between countries when addressing global climate change, which is emphasized in Sustainable Development Goal 17. Some politicians assert that mitigation actions will limit economic growth and employment and that action to reduce emissions are not conducive to social stability. Therefore, they resist emissions reduction through political decision-making. It is undeniable that some emission reduction actions can be expected to negatively impact the social economy. Determining ways to reduce carbon emissions while achieving economic growth and maintaining social stability has become a challenge for humanity.

According to statistics published by the World Bank, world carbon emissions showed an increasing trend from 1990 to 2014. In 1990, the world’s CO_2 emissions were 22.15 billion t, and by 2014, this number had grown to 36.14 billion t. The impacts of global climate change on ecosystems and human societies are becoming increasingly apparent. In December 2015, leaders in Pairs committed to achieving global net decarbonization of human activities before 2100. However, the Paris documents contain few specific prescriptions for emissions mitigation, thus leaving various countries to pursue their own agendas. Anthropogenic emissions need to peak within the next 10 years to maintain realistic pathways towards meeting the CO_2 emission and warming targets, barring unforeseen and transformative technological advancements (Walsh et al., 2017). In December 2018 at the 24th UN Climate Conference in Poland, representatives from more than 200 countries and organizations negotiated the implementation rules of the Paris Agreement. One of the core objectives of the conference is to establish a uniform and transparent set of guidelines for countries to report greenhouse gas emissions and emission reduction efforts. A preliminary consensus regarding that goal was reached in the latter part of the negotiations. Although rules are important, documents do not reduce carbon emissions, and actions must be implemented. Thus, research on CO_2 emission dynamics and the key influencing factors are urgently required to address global climate change and achieve the goal of reducing CO_2 emissions.

The CO_2 emissions of a given country are affected by many factors. The drivers of carbon emissions include economic, population, technological, and energy drivers. However, significant uncertainties exist regarding the degrees of influence and the direction of action. Regarding economic factors, researchers are committed to determining whether ‘economic growth’ and ‘CO_2 emissions’ follow the ‘environmental Kuznets curve’ (EKC). Along an EKC, the emissions of CO_2 and other pollutants increase with economic growth at the initial stage of economic development but decrease with economic growth after the economy reaches a certain level (Grossman and Krueger, 1991). While the bulk of early studies evaluated time series models of environmental degradation and economic growth, recent empirical frameworks have begun to entertain panel data regression models (Friedl and Getzner, 2003; Dinda and Coondoo, 2006; Liao and Cao, 2013; Dogan and Turkekul, 2016). Some scholars have also discussed the trade-off between economic growth and carbon emissions by building models, such as generalized method of moment estimators and autoregressive distributed lag models (Mi et al., 2017). Subsequent studies found that the industrial structure, international trade and other economic factors also have important impacts on CO_2 emissions (Li et al., 2016; Peters et al., 2011). Cities with higher economic levels play an important role in the process of climate change, are home to half of the world’s population and produce 75% of the world’s CO_2 (Mi et al., 2019). Urbanization and carbon emissions can also be studied by EKCs, although the EKC does not apply to all areas (Xu et al., 2016; Xu and Lin, 2016; He et al., 2017; Katircioğlu and Katircioğlu, 2018). The EKC reflects the complexity of the economic role of carbon emissions (Xu et al., 2016). Many scholars have attempted to determine the elasticity coefficient between population and CO_2 emissions. The extent and direction of the impact of the population on CO_2 emissions may differ among economic levels (York et al., 2003; Shi, 2003). Population growth has been identified as a potentially important driving force in future carbon emissions. However, as the population grows, additional researchers may become engaged in research on clean technologies and thereby help mitigate climate change (Li and Yuan, 2014). In addition, the effects of technological progress on the environment remain unclear. Clean technology may have a positive impact on the environment, whereas the progression of dirty technology will further accelerate CO_2 emissions (Acemoglu et al., 2012). The development of renewable energy technologies can facilitate the realization of a low-carbon economy (Lin and Zhu, 2019). Comprehensive research on economic growth, energy use and CO_2 emissions is a hot topic (Lean and Smyth, 2010; Wang et al., 2015; 2017; Dong et al., 2018). Economic growth may reduce climate vulnerability, whereas the associated increased per capita use of fossil fuels will increase national CO_2 emissions (Grecequet et al. 2019). Previous research has shown that energy efficiency plays a leading role in reducing CO_2 emissions in China and Turkey (Zhang et al., 2017; Köne and Büke, 2019). The impact of the energy structure on the reduction of China's emissions is greater than its impact on industrialization (Xu and Lin, 2016).

There is much uncertainty regarding the impacts of various factors on the world's CO_2 emissions. Many studies have conducted quantitative and qualitative analyses of the causal relationships between single-factor or two-factor influences and area-specific CO_2 emissions (Narayan et al., 2016). However, comparative analyses of the impacts of carbon emissions in different countries and the driving influences of various factors are few. A comprehensive evaluation is required to analyse the factors influencing carbon emissions in various countries. Moreover, differences among countries in the dominant factors should be determined to identify key measures for reducing emissions. Understanding the changing trends of CO_2 emissions in different countries is of great significance for formulating appropriate policy responses to global climate change. In addition, such understanding can help individual countries identify international partners and implement emission reduction measures. Such understanding is also necessary to develop new models for the sustainable development of green and low-carbon emissions. This study uses multi-year CO_2 emission data from major countries throughout the world to analyse the changes in CO_2 emissions over the last 20 years. Using 19 factors associated with the realms of economy, population, technology and energy, an evaluation system is constructed to analyse the leading factors driving carbon emission changes in different countries. The research objectives are to 1) analyse the dynamics of CO_2 emissions in different countries to identify the key factors affecting carbon emissions in each country, 2) analyse the similarities and differences in impact factors among these countries to determine the main forces driving CO_2 emissions reduction worldwide and 3) provide scientific support for building a green low-carbon social development model. The findings of this study may contribute to the realization of sustainable human development goals by the UN.

2 Materials and Methods

2.1 Study area

The following twenty-four countries were selected as research subjects: China (mainland), the United States, India, Russia, Japan, Germany, Iran, Saudi Arabia, South Korea, Canada, Brazil, South Africa, Mexico, Indonesia, the United Kingdom, Australia, Turkey, Italy, Thailand, France, Pakistan, Philippines, Nigeria and Bangladesh. These countries had the top 20 carbon emissions in the world in 2014 or had populations greater than 100 million in 2014. Moreover, these countries were selected because the attitudes and actions of the major and most populous countries that are facing climate change are crucial to the global reduction of carbon emissions. The reduction of carbon emissions is related to the survival and development of mankind. Therefore, this study included countries with populations greater than 100 million in 2014. Thus, 24 countries were ultimately studied. The sum of the CO_2 emissions from the 24 countries in 2014 accounted for more than 80% of the world's combined CO_2 emissions. Countries with high human development indices, high per capita gross national product, high levels of industrialization, and high quality of life can be called developed countries. According to the certification of the developed economies in the World Economic Outlook issued by the International Monetary Fund (IMF, https://www.imf.org/zh/Publications/WEO/Issues/2019/07/18/WEOupdateJuly2019), nine of the 24 countries are developed countries: the United States, Japan, Germany, South Korea, Canada, the United Kingdom, Australia, Italy and France. The remaining 15 are developing countries (Fig. 1).

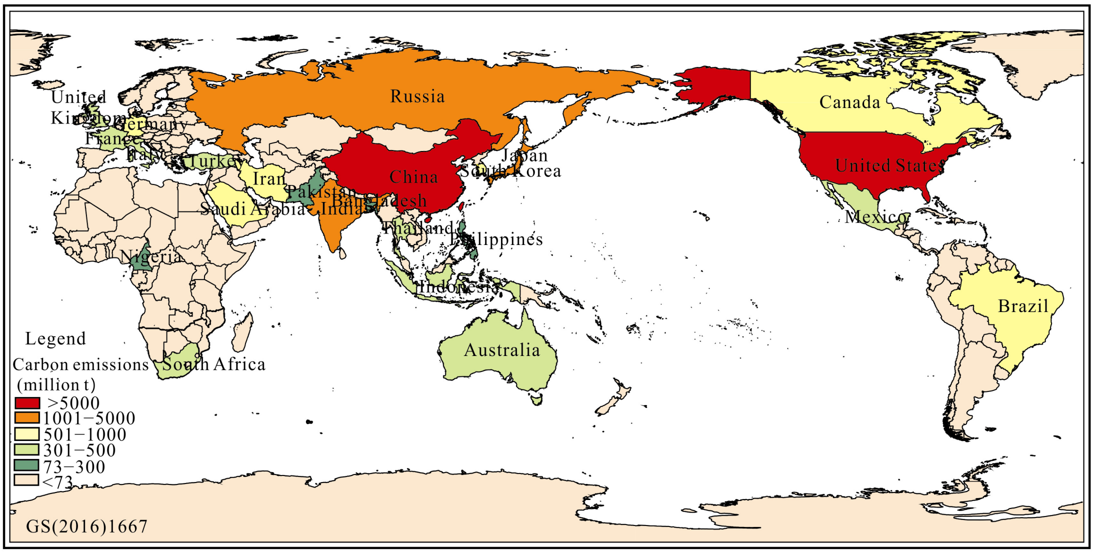

Fig. 1 CO_2 emissions for the world major countries in 2014

2.2 Data and methods

The CO_2 and socioeconomic data used in this study are from the World Bank (https://data.worldbank.org/). The annual average carbon emissions and annual average carbon emissions per unit area of the world's major countries from 1960 to 2014 were selected as important indicators. Because the cumulative global CO_2 emission statistics were based on data from 1990, and the Kyoto protocol in 1990 was also used as a baseline for carbon emissions. Therefore, the period 1990–2014 was selected to analyse the changes in carbon emissions and the influencing factors in different countries.

Nineteen factors were selected, representing economic, population, technological management and energy factors, and their influences on country-level and per capita CO_2 emissions were analysed. GDP, per capita GDP, the annual rate of change in per capita GDP and the proportional contribution of the three major industries to the GDP were used to represent the economic aspects. The total population, Percentage of the total population living in urban areas with over one million people and the proportions of the total population living in rural and urban areas were used to represent the population factors. 'GDP unit energy consumption' represents the GDP unit generated by the value of GDP (2011 constant US dollars/kg oil equivalent), whereas forest area and forest share of land area represent the technological management factors. In addition, the percentage of the total energy use represented by alternative energy and nuclear energy, the proportional contribution of fossil fuel energy consumption to the total energy consumption, and per capita energy use were used to represent the energy factors.

Statistical methods were applied to analyse the national CO_2 emission data. Charts were constructed to illustrate trends, accumulation, rates of change and other information. Principal component analysis of the 19 impact factors was implemented in SPSS software, and the principal components with eigenvalues greater than 1 were extracted. Correlation analysis was used to test the correlations between the extracted principal components and both national carbon emissions and per capita carbon emissions. Then, the compositions of the principal components with strong correlations were analysed to obtain the key factors affecting the change in CO_2 emissions in various countries.

3 Results

3.1 Changes in carbon emissions

3.1.1 Changes in total carbon emissions

From 1990 to 2014, all the studied countries showed fluctuating CO_2 emissions (Table 1), and the fluctuations from 2008 to 2010 were the most pronounced. Before 2008, five countries had declining CO_2 emission trends. Twenty countries showed substantial reductions in their CO_2 emissions from 2008 to 2010 and then sharp increases thereafter. Throughout the study period, CO_2 emissions in most countries showed upward trends, and only five countries showed reductions in CO_2 emissions: Russia, Germany, the United Kingdom, Italy and France. All of these countries are located in Europe. Except for Russia, all countries are developed countries. The country with the largest average annual reduction was Russia. During the study period, Russia's carbon emissions decreased by an average of 16.97 million t per year. The three countries with the largest annual average increases were China (327.06 million t), India (67.47 million t) and Iran (18.29 million t). The average annual carbon emissions growth was much higher in developing countries (32.20 million t) than in developed countries (2.61 million t). The countries with more than 300% growth in CO_2 emissions were Bangladesh and China. The countries with growth rates between 100% and 300% were India, Iran, Saudi Arabia, South Korea, Brazil, Indonesia, Turkey, Thailand, Pakistan, Philippines and Nigeria. Countries with growth rates of less than 100% included the United States, Japan, Canada, South Africa, Mexico and Australia.

3.1.2 Changes in per capita carbon emissions

The per capita CO_2 emissions fluctuated over time in all the studied countries (Table 2). Seven countries exhibited reductions in per capita CO_2 emissions: the United States, Russia, Germany, the United Kingdom, Australia, Italy, and France. Among these seven, six are developed countries. In addition, the per capita CO_2 emissions of the six developed countries showed continuous declines in different periods. The country with the greatest average annual per capita CO_2 emission reduction, 0.134 t, was the United Kingdom. The per capita CO_2 emissions of the remaining 17 countries generally increased over time. Among them, the country with the largest annual average increase, 0.340 t, was Saudi Arabia. The countries with per capita growth rates of CO_2 emissions exceeding 200% were China and Bangladesh. Five countries had growth rates of 100%–200%, namely, India, Iran, South Korea, Indonesia and Thailand. Ten countries had per capita emissions of less than 100%: Japan, Saudi Arabia, Canada, Brazil, South Africa, Mexico, Turkey, Pakistan, Philippines and Nigeria.

3.1.3 Changes in carbon intensity

Among 24 countries, the developing countries of Iran, Saudi Arabia, Bangladesh, Thailand, Brazil and Indonesia exhibited increases in the intensity of carbon emissions, whereas the remaining countries exhibited decreases (Fig. 2). Among the 10 countries with the highest carbon emission reduction rates, nine are developed countries, and one is a developing country: China. Additionally, China was the country with the highest reduction in carbon intensity ratio (58.1%). However,

Table 1 Changes in CO_2 emissions in the major countries of the world

Country	Change rate* (%)	Average annual change (million t)	Country	Change rate (%)	Average annual change (million t)
China	321.38	327.06	Mexico	50.83	6.74
United States	8.93	17.95	Indonesia	210.35	13.11
India	261.52	67.47	United Kingdom	–24.48	–5.67
Russia**	–17.96	–16.97	Australia	36.99	4.06
Japan	10.75	4.91	Turkey	137.20	8.34
Germany***	–22.59	–9.13	Italy	–23.26	–4.05
Iran	208.59	18.29	Thailand	248.23	9.39
Saudi Arabia	223.49	17.30	France	–19.28	–3.02
South Korea	137.77	14.18	Pakistan	142.54	4.07
Canada	23.44	4.25	Philippines	152.98	2.66
Brazil	153.63	13.37	Nigeria	145.64	2.38
South Africa	56.32	7.35	Bangladesh	371.18	2.40

Notes: *Ratio of changes in the total CO_2 emissions compared to the 1990 CO_2 emissions between 1990 and 2014. **The total volume of CO_2 emissions from the Russian Federation was considered starting from 1992 due to a lack of data, ***The total volume of CO_2 emissions from Germany was considered starting from 1991 due to a lack of data

Table 2 Changes in per capita CO_2 emissions in the major countries of the world

Country	Change rate* (%)	Average annual change (t)	Country	Change rate (%)	Average annual change (t)
China	250.62	0.225	Mexico	3.64	0.006
United States	–14.66	–0.118	Indonesia	120.71	0.041
India	143.13	0.042	United Kingdom	–33.09	–0.134
Russia**	–15.18	–0.096	Australia	–0.54	–0.003
Japan	7.50	0.028	Turkey	66.04	0.074
Germany***	–23.52	–0.130	Italy	–28.40	–0.087
Iran	121.28	0.189	Thailand	188.00	0.126
Saudi Arabia	71.61	0.340	France	–28.77	–0.077
South Korea	100.86	0.242	Pakistan	40.75	0.011
Canada	3.46	0.023	Philippines	56.55	0.016
Brazil	85.50	0.050	Nigeria	32.62	0.006
South Africa	7.66	0.027	Bangladesh	213.88	0.013

Notes: *Ratio of the 2014 per capita CO_2 emissions to the 1990 per capita CO_2 emissions, **The total volume of CO_2 emissions from the Russian Federation was considered starting from 1992 due to a lack of data, ***The total volume of CO_2 emissions from Germany was considered starting from 1991 due to a lack of data.

China's 2014 emission intensity was 10 times that of France and four times that of the United States. The world's overall mitigation actions have made limited progress in reducing carbon intensity. Developed countries have made significant contributions to reducing carbon intensity. China is also investing substantial effort to implement emission reduction policies; however, there remains substantial opportunity for further reducing China's carbon intensity. The international community must pay attention to limiting the growing carbon intensities of Iran and Saudi Arabia (the main fossil energy-consuming countries). The growing carbon intensities of Iran and Saudi Arabia, major fossil-energy countries, need to be restricted.

Efforts to reduce emissions have had limited success. The global reduction in carbon emissions between 1990 and 2014 was small. However, carbon intensity in most countries has fallen sharply, especially in developed countries. Carbon emissions and per capita carbon emissions are rising in most countries. In the years when the global economic crisis erupted, the fluctuations in carbon emissions were similar among many countries. From 1998 to 2000, the carbon emissions of 10 countries experienced similar trends, with initial reductions and then sharp increases. From 2008 to 2010, the carbon emissions of 18 countries exhibited almost simultaneous changes. Among the 24 countries, five countries exhibited reductions in total and per capita carbon emissions. Russia exhibited significant reductions in CO_2 emissions due to the extensive social reforms that have been underway since 1992. Historical factors, such as low energy demand, are inextricably linked. Since Russia's carbon dioxide emissions have been increasing since 2002, only four of the 24 countries studied (Germany, the United Kingdom, Italy and France) have successfully completed the 'Sustainable Emissions Reduction Action'. In terms of emission-reduction efforts, some developed countries in the European Union have set an example for the rest of the world.

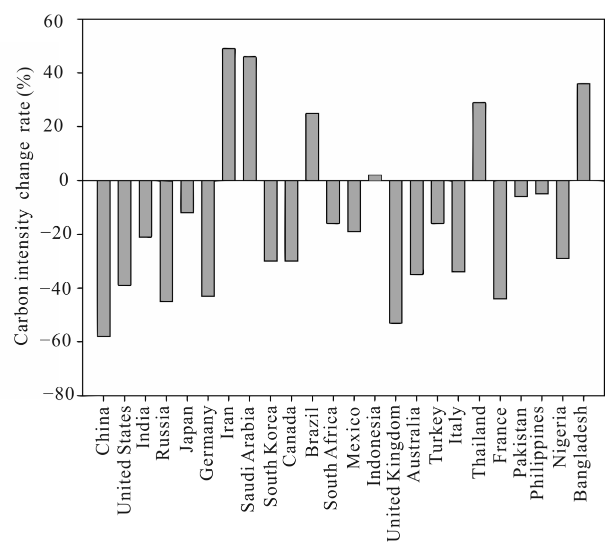

Fig. 2 Carbon intensity change rate from 1990 to 2014

Table 3 Main factors affecting carbon emissions in various countries

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
China	F_1	0.970	–0.115	0.972	0.017	0.981	0.997	–0.972	–0.999	1.000	0.999	–0.952	0.250	0.961	0.965	0.959	0.967	0.971	0.994	0.994
	F_2	0.110	0.946	–0.104	0.960	0.067	–0.006	0.088	0.011	–0.013	–0.011	–0.210	0.740	–0.045	–0.032	–0.053	–0.133	0.123	0.055	0.055
United States	F_1	0.949	–0.595	0.871	–0.538	0.992	0.972	–0.394	–0.990	0.993	0.99	0.092	–0.897	0.878	0.988	–0.903	0.934	–0.909	0.969	0.964
	F_2	0.004	0.706	–0.060	0.736	0.048	0.163	–0.012	–0.017	0.048	0.017	0.835	0.211	–0.295	0.085	–0.181	0.143	–0.289	0.154	0.156
	F_3	0.196	0.306	0.337	0.332	0.034	0.139	–0.782	–0.113	0.046	0.113	–0.329	–0.023	0.057	0.011	0.335	–0.124	0.181	–0.159	–0.188
India	F_1	0.975	0.463	0.977	0.559	0.994	0.992	0.985	–0.995	0.996	0.995	–0.955	0.494	0.941	0.997	0.961	0.830	0.980	0.991	0.991
	F_2	–0.141	0.846	–0.131	0.789	–0.041	–0.093	–0.014	0.084	–0.074	–0.084	–0.069	0.520	–0.124	–0.024	–0.164	–0.097	–0.033	–0.045	–0.045
Russia	F_1	0.784	0.555	0.810	0.541	–0.958	0.990	–0.989	–0.850	–0.921	0.850	–0.745	–0.837	0.832	0.954	0.031	0.891	–0.878	0.843	0.860
	F_2	0.570	–0.543	0.537	–0.567	0.098	0.127	–0.064	–0.443	0.183	0.443	0.428	0.468	–0.470	0.236	0.899	–0.421	0.407	0.392	0.348
	F_3	0.228	0.568	0.220	0.564	–0.155	–0.004	–0.059	0.186	–0.202	–0.186	0.422	0.164	–0.267	0.108	0.393	–0.035	0.021	–0.252	–0.267
Japan	F_1	0.915	–0.147	0.911	–0.068	0.760	0.987	–0.990	–0.990	0.986	0.990	–0.908	–0.965	0.966	0.938	–0.726	–0.760	0.744	0.907	0.918
	F_2	0.131	0.954	0.180	0.963	–0.221	0.039	0.029	0.034	–0.053	–0.034	0.110	0.125	–0.124	0.089	0.040	–0.319	0.316	0.020	–0.011
	F_3	0.277	0.239	0.228	0.237	0.548	–0.081	–0.074	–0.087	0.135	0.087	–0.370	–0.057	0.086	–0.301	0.669	0.522	–0.533	–0.046	0.004
Germany	F_1	0.971	–0.215	0.960	–0.076	0.052	0.574	–0.974	–0.994	0.887	0.994	–0.838	–0.806	0.826	0.962	–0.827	–0.065	–0.983	0.995	0.993
	F_2	–0.097	–0.420	–0.195	–0.397	0.954	–0.763	0.200	0.034	0.422	–0.034	–0.032	–0.552	0.532	–0.237	0.234	0.912	–0.019	–0.015	0.001
	F_3	0.147	0.876	0.122	0.902	0.216	–0.244	–0.031	–0.069	0.163	0.069	0.044	0.028	–0.029	–0.012	0.345	0.287	–0.078	0.063	0.074
Iran	F_1	0.977	–0.342	0.951	–0.287	0.980	0.946	–0.97	–0.985	0.981	0.985	–0.837	0.744	–0.579	–0.893	0.988	–0.077	0.288	0.966	0.966
	F_2	0.107	0.638	0.169	0.664	–0.018	0.109	–0.044	0.033	–0.009	–0.033	0.049	0.154	–0.261	0.274	0.007	0.740	–0.792	0.201	0.201
	F_3	0.021	0.654	0.057	0.663	–0.012	–0.132	0.082	–0.003	–0.021	0.003	–0.338	0.140	0.005	0.044	–0.038	–0.642	0.513	0.034	0.034
	F_4	0.125	0.201	0.070	0.167	0.158	0.198	–0.191	–0.125	0.163	0.125	0.311	–0.634	0.747	–0.009	0.115	0.081	0.085	0.010	0.010
Saudi Arabia	F_1	0.967	–0.068	0.540	–0.081	0.990	0.965	0.987	–0.983	0.991	0.983	–0.953	0.832	–0.766	–0.907	0.967	0.730	0.597	0.967	–0.068
	F_2	0.142	0.952	0.486	0.942	0.018	–0.218	0.053	0.123	0.014	–0.123	–0.228	0.290	–0.300	0.325	–0.028	–0.467	0.137	0.142	0.952
	F_3	0.198	–0.153	0.506	–0.160	0.057	–0.072	0.053	0.059	0.057	–0.059	0.100	–0.354	0.421	0.135	0.113	–0.220	0.704	0.198	–0.153
Korea	F_1	–0.968	0.581	–0.971	0.540	–0.986	0.956	0.935	0.972	–0.991	–0.972	0.990	0.640	–0.934	–0.825	–0.972	0.731	–0.629	0.980	0.961
	F_2	0.173	0.047	0.162	0.030	0.139	–0.247	–0.011	–0.065	0.114	0.065	–0.051	0.543	–0.202	–0.043	0.195	0.597	–0.726	–0.149	–0.180
	F_3	0.101	0.808	0.107	0.837	0.050	–0.001	–0.027	–0.031	0.046	0.031	–0.026	–0.013	0.023	0.149	0.094	–0.108	0.100	–0.062	–0.068

Continued Table

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
Canada	F_1	0.932	0.436	0.656	0.415	0.995	0.971	0.935	–0.949	0.994	0.949	0.436	–0.357	0.302	0.987	–0.689	–0.865	0.842	–0.992	–0.992
	F_2	0.321	0.659	0.710	0.671	–0.060	–0.130	0.092	0.189	–0.074	–0.189	0.350	0.918	–0.931	0.013	0.662	–0.213	0.105	0.087	0.087
	F_3	–0.068	0.594	–0.144	0.597	0.013	0.126	–0.177	–0.170	0.031	0.170	–0.369	–0.092	0.129	–0.004	–0.138	0.389	–0.504	–0.044	–0.044
Brazil	F_1	0.940	0.320	0.906	0.420	0.986	0.989	–0.990	–0.991	0.988	0.991	–0.811	–0.810	0.827	–0.415	0.930	0.368	0.431	–0.982	–0.982
	F_2	0.099	0.722	0.120	0.711	0.067	0.007	0.008	–0.023	0.057	0.023	0.216	0.369	–0.347	0.667	0.017	–0.673	0.393	–0.103	–0.103
	F_3	–0.291	0.517	–0.334	0.467	–0.132	–0.110	0.010	0.003	–0.115	–0.003	–0.223	–0.311	0.300	–0.298	–0.288	0.370	0.315	0.114	0.114
	F_4	0.106	0.326	0.135	0.312	0.011	0.046	0.011	0.019	0.008	–0.019	0.227	0.198	–0.208	–0.212	0.175	0.389	–0.696	0.026	0.026
South Africa	F_1	0.973	0.457	0.927	0.572	0.987	0.988	0.688	–0.987	0.986	0.987	–0.951	–0.929	0.948	0.822	0.795	0.618	–0.328	0.973	0.457
	F_2	–0.190	0.664	–0.329	0.635	0.037	–0.014	0.655	0.063	–0.031	–0.063	0.000	–0.305	0.250	–0.268	–0.298	–0.575	0.617	–0.190	0.664
	F_3	–0.091	0.545	–0.031	0.490	–0.138	–0.136	–0.036	0.134	–0.145	–0.134	0.108	0.042	–0.056	–0.218	0.197	0.491	–0.626	–0.091	0.545
Mexico	F_1	0.990	–0.198	0.953	–0.139	0.983	0.929	0.975	–0.987	0.981	0.987	–0.909	0.575	–0.219	0.807	0.68	–0.586	0.859	–0.995	–0.995
	F_2	–0.039	0.426	0.110	0.446	–0.101	0.128	0.133	0.086	–0.111	–0.086	–0.269	0.742	–0.884	0.326	–0.177	0.598	–0.414	0.045	0.045
	F_3	0.098	0.881	0.142	0.881	0.043	–0.096	–0.074	–0.024	0.048	0.024	0.236	–0.280	0.243	0.116	0.109	–0.334	0.185	0.002	0.002
Indonesia	F_1	0.949	0.019	0.933	0.056	0.996	0.967	–0.960	–0.996	0.996	0.996	–0.907	0.519	0.316	0.631	0.988	0.952	0.930	–0.968	–0.968
	F_2	0.208	0.823	0.244	0.820	0.013	0.109	0.153	0.069	0.000	–0.069	–0.082	–0.643	0.772	0.502	–0.035	–0.094	–0.130	0.195	0.195
	F_3	–0.178	0.563	–0.186	0.566	–0.045	–0.088	–0.047	–0.006	–0.038	0.006	–0.149	0.484	–0.377	–0.382	0.057	0.179	0.086	–0.041	–0.041
The United Kingdom	F_1	0.962	–0.163	0.913	–0.266	0.989	0.946	–0.954	–0.982	0.986	0.982	–0.876	–0.955	0.952	0.993	–0.857	–0.115	–0.580	0.976	0.976
	F_2	0.041	0.901	0.063	0.895	–0.013	0.093	0.114	0.064	–0.028	–0.064	–0.043	–0.046	0.046	–0.009	0.154	0.807	–0.596	0.121	0.121
	F_3	0.264	0.266	0.391	0.233	–0.120	–0.280	0.196	0.131	–0.132	–0.131	–0.401	–0.235	0.249	–0.025	0.441	–0.411	0.531	0.156	0.156
Australia	F_1	0.993	–0.073	0.987	–0.195	0.988	–0.615	0.963	–0.183	0.982	0.183	–0.837	–0.391	0.666	0.960	0.734	0.267	0.424	–0.896	–0.896
	F_2	–0.005	0.582	0.112	0.607	–0.067	–0.669	0.238	0.958	–0.117	–0.958	0.238	–0.804	0.622	–0.063	0.500	–0.609	–0.110	0.380	0.380
	F_3	0.078	0.424	0.025	0.443	0.123	0.225	0.075	–0.117	0.130	0.117	0.079	–0.204	0.151	0.184	–0.278	0.678	–0.797	0.079	0.079
	F_4	0.022	0.682	0.033	0.620	0.004	0.209	–0.042	–0.146	0.012	0.146	–0.106	0.358	–0.277	–0.088	0.273	–0.236	0.310	–0.150	–0.150
Turkey	F_1	0.980	0.177	0.97	0.194	0.995	0.994	–0.867	–0.996	0.997	0.996	–0.911	–0.690	0.856	0.779	0.969	0.504	0.934	0.996	0.996
	F_2	0.109	0.866	0.149	0.853	–0.058	–0.021	–0.174	0.059	–0.042	–0.059	0.314	0.390	–0.364	0.279	0.080	0.596	–0.214	–0.006	–0.006
	F_3	0.136	–0.464	0.141	–0.480	–0.003	0.040	–0.297	0.002	0.018	–0.002	0.138	0.544	–0.330	0.273	0.055	0.377	–0.215	0.063	0.063

Continued Table

		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
Italy	F_1	0.770	–0.549	0.578	–0.622	0.938	–0.951	–0.584	–0.982	0.956	0.982	–0.933	–0.980	0.983	0.679	0.143	0.786	–0.934	0.986	0.986
	F_2	0.622	0.379	0.804	0.367	–0.283	–0.231	–0.541	0.140	–0.241	–0.140	–0.262	–0.076	0.115	–0.606	0.969	–0.540	0.341	0.158	0.158
	F_3	–0.026	0.730	–0.045	0.679	0.062	–0.064	–0.193	–0.087	0.074	0.087	0.089	–0.016	–0.005	0.309	–0.180	0.242	–0.068	0.015	0.015
Thailand	F_1	0.980	–0.400	0.97	–0.335	0.988	0.966	–0.654	–0.952	0.971	0.952	0.024	0.320	–0.198	–0.859	0.987	–0.731	0.758	0.675	0.675
	F_2	0.125	0.524	0.132	0.542	–0.066	0.224	–0.665	–0.284	0.219	0.284	0.784	0.550	–0.870	0.292	0.077	0.064	–0.559	–0.683	–0.683
	F_3	0.054	0.721	0.062	0.743	0.085	–0.021	0.160	0.019	–0.003	–0.019	–0.471	0.269	0.183	–0.011	0.049	–0.113	0.224	0.114	0.114
France	F_1	0.965	–0.359	0.927	–0.399	0.994	0.573	–0.991	–0.996	0.995	0.996	–0.938	–0.981	0.982	0.967	–0.224	0.855	–0.948	0.997	0.997
	F_2	0.202	0.803	0.304	0.749	0.017	–0.442	0.030	–0.02	0.010	0.020	–0.068	–0.112	0.105	–0.018	0.634	0.202	0.021	0.027	0.027
	F_3	–0.105	0.472	–0.161	0.524	–0.008	0.562	–0.101	–0.017	0.008	0.017	0.277	0.047	–0.089	0.172	–0.676	0.081	–0.153	0.017	0.017
Pakistan	F_1	0.995	–0.085	0.987	0.047	0.993	0.994	0.993	–0.989	0.993	0.989	–0.072	–0.484	0.535	0.851	0.899	0.546	0.839	–0.994	–0.994
	F_2	0.000	0.933	0.045	0.945	–0.022	–0.032	–0.02	0.026	–0.025	–0.026	–0.728	0.522	0.113	–0.003	0.092	0.419	0.005	0.017	0.017
	F_3	0.036	0.101	0.050	0.045	–0.052	–0.016	–0.062	0.109	–0.039	–0.109	0.184	–0.522	0.353	0.417	–0.318	0.594	–0.464	0.064	0.064
	F_4	0.063	0.165	–0.001	0.142	0.082	0.091	0.077	–0.063	0.088	0.063	0.546	0.295	–0.756	0.198	–0.187	0.174	–0.186	–0.067	–0.067
Philippines	F_1	0.958	0.630	0.928	0.711	0.996	–0.628	0.996	0.885	0.995	–0.885	–0.911	–0.413	0.977	0.901	–0.429	0.583	0.861	0.803	0.803
	F_2	0.175	0.351	0.229	0.315	0.002	0.661	–0.018	–0.335	0.029	0.335	0.331	–0.752	–0.109	0.142	0.152	–0.726	0.225	0.270	0.270
	F_3	–0.121	0.212	–0.157	0.172	–0.042	0.026	–0.053	–0.121	–0.028	0.121	–0.204	0.378	0.090	–0.364	0.850	0.203	0.197	0.403	0.403
	F_4	–0.144	0.635	–0.155	0.585	–0.064	–0.006	–0.05	0.173	–0.082	–0.173	0.096	0.085	–0.114	–0.102	–0.089	0.054	0.088	–0.291	–0.291
Nigeria	F_1	0.982	0.250	0.958	0.240	0.995	0.975	0.975	–0.996	0.996	0.996	–0.481	–0.908	0.936	0.947	0.856	–0.856	–0.355	–0.986	–0.986
	F_2	–0.031	0.931	0.016	0.934	–0.020	0.036	0.018	0.015	–0.038	–0.015	0.232	–0.017	–0.089	0.000	0.177	0.263	0.462	–0.006	–0.006
	F_3	0.115	–0.084	0.161	–0.087	–0.049	–0.139	–0.153	0.035	0.001	–0.035	–0.700	0.263	0.099	0.117	0.332	–0.055	0.647	0.114	0.114
Bangladesh	F_1	0.979	0.684	0.971	0.848	0.991	0.995	0.922	–0.991	0.994	0.991	–0.959	0.897	0.876	0.935	0.975	–0.838	0.987	–0.997	–0.997

Notes: X_1: GDP (Constant 2010 US $); X_2: GDP growth rate; X_3: Per capita GDP (Constant 2010 US $); X_4: Per capita GDP growth rate; X_5: Total population; X_6: Percentage of the total population living in urban areas with over one million people; X_7: Rural population; X_8: Percentage of the total population living in rural areas; X_9: Urban population; X_{10}: Proportion of the urban population to the rural population; X_{11}: Percentage of agricultural added value; X_{12}: Percentage of industrial added value; X_{13}: Percentage of services and other added value; X_{14}: GDP unit energy consumption (2011 constant US dollars/kg oil equivalent); X_{15}: Per capita energy use; X_{16}: Alternative energy and nuclear energy as a percentage of the total energy use; X_{17}: Fossil fuel energy consumption as a percentage of total energy consumption; X_{18}: Forest area; and X_{19}: Forest area as a percentage of total land area. F_1: Factor 1; F_2: Factor 2; F_3: Factor 3; F_4: Factor 4.

Table 4 Coefficients of the correlations between each of total carbon dioxide emissions and per capita carbon dioxide emissions and primary factors

Country	CO_2 emissions				Per capita CO_2 emissions			
	F_1	F_2	F_3	F_4	F_1	F_2	F3	F_4
China	0.958**	–0.044	–	–	0.953**	–0.038	–	–
United States	–0.518*	–0.380	0.579*	–	–0.914**	–0.213	0.283	–
India	0.967**	–0.168	–	–	0.957**	–0.178	–	–
Russia**	0.032	0.789**	–0.170	–	0.220	0.824**	–0.079	–
Japan	0.177	0.607**	0.322	–	–0.004	0.686**	0.199	–
Germany***	–0.972**	0.078	0.102	–	–0.977**	–0.051	0.072	–
Iran	0.978**	0.016	–0.017	0.178	0.979**	0.000	0.019	0.146
Saudi Arabia	0.935**	0.133	0.154	–	0.687**	0.212	0.168	–
South Korea	–0.947**	0.280	0.105	–	–0.933**	0.300	0.114	–
Canada	–0.760*	0.430	–0.058	–	–0.932**	0.280	–0.048	–
Brazil	0.945**	–0.107	–0.201	0.211	0.917**	–0.196	–0.161	0.267
South Africa	0.948**	–0.104	–0.005	–	0.646**	–0.247	0.204	–
Mexico	0.974**	–0.097	0.051	–	0.708**	–0.050	0.064	–
Indonesia	0.913**	0.177	–0.067	–	0.884**	0.190	–0.034	–
United Kingdom	–0.857**	–0.114	0.456*	–	–0.932**	–0.072	0.326	–
Australia	0.916**	0.167	–0.136	0.132	0.602**	0.544**	–0.460*	0.281
Turkey	0.985**	0.042	0.069	–	0.965**	0.067	0.055	–
Italy	–0.409*	0.878**	–0.185	–	–0.537**	0.817**	–0.164	–
Thailand	0.987**	–0.020	0.087	–	0.979**	–0.055	0.099	–
France	–0.544**	0.397*	–0.612**	–	–0.848**	0.241	–0.390	–
Pakistan	0.991**	0.012	–0.078	–0.033	0.943**	0.056	–0.186	–0.172
Philippines	0.929**	0.197	0.206	–0.146	0.630**	0.348	0.541**	–0.150
Nigeria	0.796**	0.356	–0.014	–	0.495*	0.529**	–0.005	–
Bangladesh	0.975**	–	–	–	0.973**	–	–	–

Notes: * indicates a significant correlation at the 0.05 level (bilateral). ** indicates a significant correlation at the 0.01 level

3.2 Factors affecting carbon emissions

We performed a principal component analysis (Table 3) and correlation analysis (Table 4) to analyse the key factors affecting carbon emissions in each country. Principal components that had strong correlations (positive or negative) with national carbon emissions were selected. The loadings of the factors on the principal components were analysed to determine the dominant factors affecting CO_2 emissions. The key factors affecting carbon emissions differed among countries. In addition, some factors were shared among countries but with different effects (Table 5).

The population category was the most influential category affecting the increase of carbon emissions, and total population and urban population were the most influential factors. In 18 of the 24 countries, carbon emissions were strongly and positively correlated with these two factors. These countries include both typical populous countries, such as China, India, Indonesia, Pakistan and Bangladesh, and countries with extremely high urban populations, such as Japan, Brazil and Australia. In 2014, the urban population in each of these countries exceeded 85% of the total. Furthermore, the impact of economic factors on carbon emissions was significant. The GDP indicator was positively correlated with carbon emissions in more than half of the countries. In considering the global economic background, we noticed that the Asian financial crisis in 1998 and the United States subprime mortgage crisis in 2008 led to economic trauma in the corresponding countries. The CO_2 emissions in these years exhibited strong reductions. Since these crises occurred, the demand for revitalizing the economy has increased. After the economic crises, CO_2 emissions underwent apace increases. Thus,

Table 5 Main factors affecting carbon emissions in various countries.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}
China					+	+		–	+	+						+	+	+	+
United States		–		–							–								
India	+		+		+	+	+	–	+	+				+				+	+
Russia	+		+	–								+	–		+				
Japan	+	–	+	+											+				
Germany	–	+	–											–			+	–	
Iran					+			–	+	+					+				
South Korea					+				+		–							–	
Saudi Arabia					+		+		+										
Brazil					+	+	–	–	+	+								–	–
Mexico	+				+			–	+	+								–	–
Indonesia					+			–	+	+					+			–	–
Canada	+	+				+		–	+	+								–	–
South Africa	+				+	+		–	+	+									
United Kingdom	–		–		–	–		+	–	–				–		–			
Australia	+		+		+			–	+	+									
Italy	+		+				–							–	+	–			
France	–	–		–		–								–	+	–			
Turkey	+				+	+		–	+	+								+	+
Thailand	+														+				
Pakistan	+		+		+	+		–	+	+								–	–
Philippines	+				+		+		+				+						
Nigeria	+				+			–	+	+									
Bangladesh	+		+		+	+		–	+	+							+	–	–

Notes: "+": Positive correlation; "–": Negative correlation; X_1: GDP (Constant 2010 US $); X_2: GDP growth rate; X_3: Per capita GDP (Constant 2010 US $); X_4: Per capita GDP growth rate; X_5: Total population; X_6: Percentage of the total population living in urban areas with over one million people; X_7: Rural population; X_8: Percentage of the total population living in rural areas; X_9: Urban population; X_{10}: Proportion of the urban population to the rural population; X_{11}: Percentage of agricultural added value; X_{12}: Percentage of industrial added value; X_{13}: Percentage of services and other added value; X_{14}: GDP unit energy consumption ($/kg of oil equivalent); X_{15}: Per capita energy use; X_{16}: Alternative energy and nuclear energy as a percentage of the total energy use; X_{17}: Fossil fuel energy consumption as a percentage of total energy consumption; X_{18}: Forest area; and X_{19}: Forest area as a percentage of total land area.

global economic crises led to changes in carbon emissions in the affected countries. Technological management factors showed strong correlations with carbon emissions in the countries with reduced carbon emissions. GDP unit energy consumption (2011 constant US dollars/kg oil equivalent) showed a negative correlation with emissions in the United Kingdom, France, Germany, and Italy, which indicates that increases in energy efficiency can reduce CO_2 emissions. The use of clean energy was significantly negatively correlated with emissions in France and Italy, and increases in the proportion of clean energy were associated with reduced emissions. These findings indicate that population factors and economic factors are positively correlated with carbon emissions and that technical factors are negatively correlated with energy factors and carbon emissions. Increases in the urban population and rapid economic development are the main factors leading to increased carbon emissions in most countries. Clean energy development is the main factor driving reductions in carbon emissions.

4 Discussion

4.1 Leading factors driving changes in carbon emissions in different countries

This study shows that global carbon reduction actions have achieved limited results. Carbon intensity has decreased in many countries. However, the reduction in carbon emissions is small. This outcome reflects the attitudes of different countries towards carbon emission reductions and the objective status quo of social development in these countries. Climate change governance and reduction of carbon emissions are not only issues of the natural sciences but also political, economic, social, ethical issues. There is a large gap between the social development stage and the life quality of people of the developed and developing countries. Attitudes towards balancing carbon emission reduction and social economic development also differ between developed and developing countries. In this study, Russia was the only developing country found to achieve both total and per capita carbon emissions reductions. Germany, Britain, France and Italy also achieved total and per capita emission reductions; are all developed countries. These developed countries have succeeded in transforming into low-carbon societies and have achieved a balance between reducing carbon emissions and economic development. However, the poorest countries face greater threats from climate change. How to achieve fairness and justice in the international community and the environment represents a key issue in international climate negotiations. In addition, the dominant factors influencing carbon emissions differ among countries. However, some common characteristics are observed, and new ideas are needed to implement emission reduction actions.

4.1.1 Factors affecting carbon emissions in developing countries

Developing countries are countries with lower human development indices, per capita gross national product, industrialization levels and quality of life than developed countries. For developing countries, improving social and economic levels and eliminating extreme poverty are the top priorities. Economic development and increases in the urban population are the main reasons for the growth of carbon emissions in most countries. For a developing country with a large population, the large population size will inevitably lead to substantial demands for resources and force the rapid development of the economy to ensure a stable life for the citizens (Wang and Zhao, 2018; Li et al., 2018). Economic development is inseparable from the support of energy, which has increased the CO_2 emissions of various countries. Taking China and India as examples, the CO_2 emissions of both countries have continued to grow almost every year. Economic development in both countries is highly dependent on fossil energy. Since the 21st century, China's economy has rapidly developed to become the second largest economy in the world. The country's urbanization has accelerated, and nationalized metropolises and urban agglomerations have emerged. As a populous country, India not only has a large population but also has undergone rapid population growth, with the population increasing by 49% during the study period. Rapidly growing populations and urban economic construction have resulted in substantial energy demands, and China and India continue to increase their CO_2 emissions. For developing countries with rapid urbanization, such as Brazil, urbanization proceeds in the absence of effective planning, and the expansion of urban land caused by urbanization leads to deforestation. From 1990 to 2014, Brazil's forest area decreased; it currently has a total area of 521 830 km^2 and accounts for 6.24% of the total land area of Brazil. Forest areas are important carbon sinks; they are important for carbon sequestration and climate regulation. The results indicate that the forest area of Brazil has a significant negative correlation with CO_2 emissions. The reduction of forest emissions is one of the most important strategies for reducing emissions worldwide (Keenan, 2017). As the forest area of Brazil is the most abundant rainforest resource in the world, the significant reduction in its area is a key factor leading to increased CO_2 emissions in the country has affects climate change throughout the world (Hamilton and Friess, 2018). China and India have dominated the global increase in vegetation over the past 20 years through afforestation and improved agricultural efficiency, thereby making important contributions to global greening (Chen et al., 2019). Despite being blamed for total carbon emissions data, the two most populous countries are making efforts to achieve global emissions reductions in various ways.

4.1.2 Factors affecting carbon emissions in developed countries

Compared with developing countries, developed countries have higher human development index values, per capita gross national product, industrialization levels and quality of life and are more likely to transition to a low-carbon society. The main factor affecting the growth of carbon emissions in developed countries is high per capita energy use. For developed countries such as the United States, Japan, and South Korea, the level of economic development, urban population proportion, quality of life, and per capita energy use are all high. Identifying a method of reducing per capita energy use and improving energy efficiency through technological and energy strategies is important for controlling carbon emissions. Among such strategies, clean energy development is the main force driving reductions in carbon emissions. After 2010, two developed countries in North America, i.e., the United States and Canada, began to focus on developing low-carbon economies, increasing the use of alternative energy and nuclear energy, improving energy efficiency, and reducing the per capita energy consumption (Cai et al., 2018). As a result, emissions growth in the United States and Canada has declined since 2010. Germany, the United Kingdom, Italy, and France are the most active developed countries with respect to promoting the development and use of alternative energy sources. In 2014, the use of alternative energy and nuclear energy accounted for more than 50% of France's energy. After 2005, Germany, the United Kingdom, Italy, and France had a unit GDP energy consumption of approximately 10 (2011 constant US dollars/kg oil equivalent) and high resource utilization efficiency. In Italy, the energy consumption per unit GDP in 2014 was 14.06 (2011 constant US dollars/kg oil equivalent), which was approximately 2.5 times that of China and 1.9 times that of the United States. The industrial structure also affects the carbon emissions of developed countries. The development process and current situation of developed countries can provide valuable information for developing countries.

4.2 Global strategy for achieving both carbon emission reductions and social development

4.2.1 Common but differentiated responsibilities

Table 1 shows that the countries with the highest growth in carbon emissions do not correspond to the countries with the largest increases in carbon emissions. Similarly, the countries with the highest carbon emissions differ from those with the highest carbon emissions per capita. For this reason, we are wary of using 'change' and 'rate of change' to measure the carbon emissions of a country and allocate emission reduction targets.

The development history of certain countries, the 'base' issue of carbon emission levels, and historical carbon emissions should all be considered when studying carbon emissions in various countries. The CO_2 emissions data from 22 countries worldwide from 1960 to 2014 released by the World Bank (Germany and Russia were not included due to a lack of data) were collected to calculate the annual average carbon emissions in each country (Fig. 3a) and the annual average carbon emissions per unit land area (Fig. 3b). The annual average carbon emissions can reflect the overall level of carbon emissions in each country for half a century. The annual average carbon emissions per unit area reflect the intensity of production in the country and represent an indicator of the level of carbon emissions per unit area.

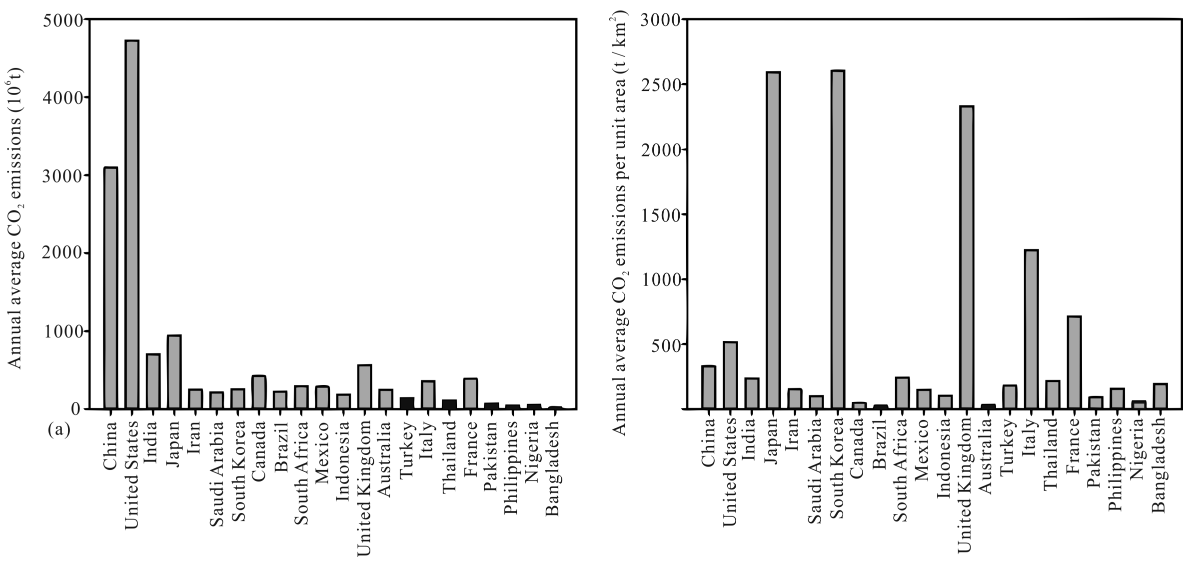

Fig. 3 Annual average carbon emissions (a) and carbon emissions per unit area (b) from 1960 to 2014

In terms of annual average CO_2 emissions, seven of the nine developed countries are in the top 10, with the United States being the country with the highest carbon emissions; this country has an average annual carbon emission amount of 4723 million t. The average carbon emissions of developing countries, such as China and India, were also high over the half-century, with China and India ranking 2nd and 4th, respectively, among the 22 countries. Regarding the annual average carbon emissions per unit of land area, Japan, South Korea, and the United Kingdom have carbon emission values of more than 2000 t, which are much higher than the values in other countries. These three countries have small land areas but high degrees of industrialization. All three countries have values that are more than four times the average for all the other countries. Of the six countries that have annual average carbon emissions per unit area of more than 500 t, all are developed countries. In terms of carbon emissions per unit area, developed countries with high development levels but small land areas have much higher levels of carbon emissions than developing countries because of their spatially intensive production activities and large amounts of CO_2 emissions.

The carbon emissions of the eight developed countries accounted for 46.6% of the total carbon emissions in 1960 but only 24.9% of the total emissions in 2014. One reason for this significant decline is the slow growth of carbon emissions in developed countries over the past 20 years. However, a more important reason is that the political environment of the world is more stable, and a large number of developing countries have initiated industrialization and urbanization processes. During economic growth, the acceleration of industrialization is necessary for the accumulation of capital, and this stage is accompanied by energy consumption and CO_2 emissions. Developed countries have long histories of development since the United Kingdom began the industrial revolution in the 19th century. The economic development of the United Kingdom was at the forefront of the world, and its carbon emission levels were also at the forefront. Currently, most developed countries have completed the transformation of their industrial structure, and the high energy consumption and high emissions from industry have gradually been replaced by lower levels of consumption and emissions from cleaner industries. Through the accumulation of capital, some developed countries have implemented technological upgrades to develop low-carbon economies while achieving economic growth and reducing carbon emissions. Most of the industrial development in developing countries began late because of issues associated with capital, technology and other conditions, and these countries are now in high energy consumption and high emission stages. Some developing countries have higher carbon emissions than some developed countries; however, this comparison is of little significance because the historical development of different countries is different. Thus, accusing developing countries of high carbon emissions is clearly one-sided and unfair. Therefore, in seeking emission reductions, the allocation of emission reduction tasks should consider both current carbon emissions data and the historical development stage of carbon emissions in developed countries.

4.2.2 Strengthening cooperation to achieve sustainable carbon reduction

Countries differ in their attitudes towards emissions reduction according to their own conditions and interests. In the 2019 United Nations Global Climate Change Conference, the interests of various countries varied, resulting in no progress at the conference. However, global climate change threatens the survival and development of all mankind, and everyone should be held accountable. Global carbon credits belong to public pond resources, and they are both non-exclusive and competitive. To maximise the short-term benefits, individual users tend to over-explore and utilize resources, which threatens the sustainable use of resources and the overall benefits to the world (Ostrom, 2009). Therefore, all countries should adopt an attitude of fairness and actively undertake appropriate tasks to reduce emissions to contribute to the realization of the sustainable development of mankind (Peters et al., 2017). Economic development is the main force underlying the growth of carbon emissions throughout the world. The utilization of energy and the development and utilization of clean energy are the keys to reducing emissions (Fulton et al., 2017). The cost of carbon emissions is enormous, and it is impossible to rely on certain countries to complete this task; thus, all nations must unite to weather the storm (Walsh et al., 2017).

For developed countries at a mature stage of economic development, the living standards of people are good, and technical standards are high. These countries should fulfil their own emission reduction responsibilities and be consistent with Germany, the United Kingdom, Italy and France. Regarding adjustments to the industrial structure and energy structure, all countries should develop new energy, improve energy efficiency, and vigorously promote low-carbon economic development. For developing countries, economic growth and urbanization are the major drivers of carbon emissions growth. At present, the primary task of developing countries remains economic development and poverty alleviation. However, there is a gap between the rich and the poor in developing countries. The countries most severely affected by climate change are developing countries that are extremely poor. For these countries, the task of reducing emissions beyond the capacity of the country's economic development should not be included among the state's responsibilities. Otherwise, more serious climate and other environmental problems will result. Developing countries with economies that have steadily improved and that have solved extreme poverty should undertake emission reduction tasks. They should learn from the development experience of developed countries and focus on industrial restructuring and new energy development and utilization. Carbon emissions should be controlled to allow the peak to be reached quickly. At the UN Climate Conference in December 2018, developing countries led by China agreed to implement the Paris Agreement in accordance with a set of emission reduction guidelines. This agreement shows the determination of the countries to reduce international responsibility and reduce emissions. However, these countries will encounter many difficulties in their operations and will need technical support from developed countries.

The implementation of inappropriate emission reduction actions has had some negative impacts on society. While some cities have achieved their emission reduction targets, they have ordered factories to stop production, which has affected the social economy and people's lives. However, emission reduction actions and economic development are not completely mutually exclusive. People should unite in the community to complete the transition to a low-carbon society under guidance from scientists and balance emission reduction actions and socioeconomic development. Strengthening exchanges and cooperation between developing and developed countries is necessary to allow the global community to jointly address climate change and develop a sustainable low-carbon economy. Regarding technology, energy efficiency should be improved, and alternative energy sources should be developed. Regarding the economy, the issue of carbon trading markets should be discussed when promoting green low-carbon economies globally. This process can also promote exchanges and negotiations on climate issues among countries (van den Bergh, 2017) and lead to the construction of an international open and transparent carbon-emissions trading system and trading market. However, attention should be paid to the unfairness of carbon-producing countries and carbon-consuming countries in calculating carbon emissions. New energy technologies and the new carbon-emissions trading market will promote the global green energy revolution. Countries that master new energy and environmental technologies will play a greater role than other countries in the green technology revolution. The green technology revolution will generate new energy industries and cleaner production and consumption patterns after eliminating old energy use methods and production methods. The huge transfer of funds and technology will bring new employment opportunities. The highly concentrated fossil energy industry will be transformed into a much more diversified renewable energy industry including wind and solar energy sectors, which will give the economy of green technology an opportunity to grow (Gorjian et al., 2019) Regarding environmental issues, countries should jointly control the unlimited expansion of cities, discuss methods of improving the efficiency of urban land use, develop new urban planning programmes and protect forest areas and ecological functions (Fujii et al., 2017). In this regard, exchanges and cooperation should occur between European countries, such as France and Germany, and developing countries. Such exchanges between China and South Africa have been established successfully and can serve as models for bringing developed and developing countries together to jointly address climate change and reduce global CO_2 emissions. In recent years, international NGOs have gradually played an increasingly important role in global climate governance and act as coordinators and buffers between states and between states and communities. NGOs have played positive roles in international cooperation in emissions reduction and the increased prevalence of low-carbon production and lifestyles. The international community and government agencies should pay attention to and cooperate with international NGOs to achieve emission reductions. To achieve both the reduction of carbon emissions and social development, interdisciplinary and multi-sectoral exchange efforts are needed. Together, they can build a strong scientific foundation that guarantees policy implementation and ecological security (Soussana et al., 2019; Christis et al., 2019). In the low-carbon transition period of society, many new types of employment will emerge. The society will need to provide the labour force with new skills and to transform the supply side of the job market. This transformation will include the enrolment and development of new energy- and technology-related majors in universities. Providing the new labour force with high-quality training and excellent human resources will be an effective way to meet these needs. Furthermore, the popularization of science is among the tasks of researchers. While strengthening cooperation with non-governmental international organizations, scientists should promote low-carbon lifestyles, including dietary changes, and new energy technologies (Harwatt, 2019). Let the whole people participate in low-carbon life and supervise government and corporate emission reduction actions. The people worked hard with the government and enterprises to complete this 'great change unprecedented'.

5 Conclusions

The emission reduction actions of the world's countries have achieved limited success. Carbon emissions have fallen significantly in most countries. However, the total amount of carbon emissions needs to be strictly controlled. Economic and demographic factors remain important factors influencing carbon emissions in most countries. GDP growth and urban population growth are the dominant factors driving increases in carbon emissions. Energy and technology factors are the main factors driving reductions in carbon emissions. EU countries have achieved a balance between emission reduction and economic growth mainly due to the high proportion of clean energy use and high energy efficiency. With the stipulation that a fair and transparent emission-reduction system and carbon emission market be established, this paper suggests that developing countries should pay attention to adjusting the energy structure and industrial structure based on their own development capabilities, development of their economy and the elimination of extreme poverty. Countries that improve energy efficiency can effectively reduce carbon emissions. Some developed countries should abandon the idea that strict emission reduction actions are not conducive to economic development. Britain, France, Germany, and Italy have become examples of "win-win" economic development and emissions reduction. In addition, in the context of globalization, countries should be alert to the potential for global economic crises to cause fluctuations in carbon emissions and, in such events, control carbon emissions to yield a more stable, less volatile state.

All countries should actively exchange information to promote equality and objectiveness, appropriately allocate emission reduction tasks based on the country's historical background and development status, promote cooperation in technology and trade among all countries, and develop new energy. All sectors of society should abandon improper emission reduction methods, promote the development of a low-carbon economy and strive to launch the global green technology revolution. These efforts will help control and reduce global carbon emissions while ensuring socio-economic growth in response to global climate change, which will help achieve sustainable human development and improve people's health and well-being.

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