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A comparison of trends and magnitudes of household carbon emissions between China, Canada and UK

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ABSTRACT

Household carbon emissions (HCEs) contribute a large proportion of global carbon emissions. For several reasons there are large differences in HCEs between countries. Using governments' annual data, this study aims to compare the trends and magnitudes of HCEs between China, Canada and the UK and pinpoint where these countries are heading and what lessons they can learn from others. In the years when HCEs were first reported (1995 in China, 1990 in Canada and 1997 in UK), per person HCEs in China, Canada and the UK were 0.54 tCO_2, 13.54 tCO_2 and 9.63 tCO_2, respectively. These values had changed to 1.77 tCO_2, 13.14 tCO_2, 8.20 tCO_2 by the end of reporting (2011 in China and UK and 2007 in Canada), representing an increase of 7.7%/yr in China and a decrease of 0.18%/yr in Canada and 1.14%/yr in the UK. Although the rate of increase in China was high, in absolute terms China's per person HCE remained many times lower than that of Canada and the UK. The reasons why China may not follow Canada and UK's emissions pathways are discussed. In comparison with several other studies, China's average HCEs were found to be much lower than that of developed countries. Among the developed world, Sweden and Norway had much lower HCEs, probably due to the production of electricity by hydro and nuclear power generation and the use of

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centralised heating systems in Sweden, and production of electricity by hydropower in Norway. Where possible, countries all around the world can learn lessons from these two countries.

1. Introduction

Despite a growing number of national, bilateral, multilateral and global greenhouse gas (GHG) emissions reduction policies and programs, anthropogenic GHG emissions from 2000 to 2010 grew more quickly (2.2%/yr) than in the previous three decades (1.3%/yr) (IPCC (Intergovernmental Panel on Climate Change), 2014). In 2010, about 50.1 $GtCO_2e$ GHGs were emitted into the atmosphere from anthropogenic sources, which is already about 14% higher than the median estimated emission level (44 $GtCO_2e$/yr) required to meet the 2 °C climate stabilising target by 2020 (UNEP (United Nations Environment Program), 2013). If the current trend continues, the earth will be 3.7 to 4.8 °C warmer compared to preindustrial levels by 2100, potentially resulting in a range of catastrophic effects on social, economic and environmental sectors (UNEP (United Nations Environment Program), 2013). Realising these threats, 99 countries covering over 80% of global emissions have set 2020 emissions reduction goals through a range of policies such as renewable energy, energy efficiency, demand side management, emissions trading schemes and emissions taxes (Australian Government Climate Change Authority, 2014). However, the current annual decarbonisation rate of 0.7% is not enough to revoke the climate change threat; it is estimated that an aggressive rate of 6% is necessary (PWC (PricewaterhouseCoopers International Limited), 2013).

Being a public good and therefore subject to the 'free rider' problem, the issue of 'who should bear the burden of emission reduction' has been one of contention between the developed and developing world in every climate change negotiation. When climate change policy was being negotiated in 1990, developed and developing countries shared 60% and 40% of the total global emissions, respectively; now the proportions are the opposite and both developed and developing countries are responsible for equal shares of cumulative emissions for the period from 1850 to 2010 (UNEP (United Nations Environment Program), 2013). While asking developing countries to share the emissions reduction burden would violate principles of fairness and equality, the overarching target of global emissions reduction cannot be achieved without involving them (Maraseni et al., 2009).

Setting aside this issue, this study focusses on HCEs which is a major contributor of global emissions. For example, the proportion of household emissions to the national emissions is 20% in Australia (EPA Victoria, 2013), 74% in the UK (Baiocchi et al., 2010) and over 80% in the USA (Bin and Dowlatabadi, 2005; Jones and Kammen, 2011). At the global scale, the building sector alone contributes about 19% of total emissions and the proportion rises to 25% if emissions from Agriculture, Forestry and Other Land Use sectors are excluded (IPCC (Intergovernmental Panel on Climate Change), 2014). In fact, from 1970 to 2010, total emissions increased by only 61% whereas building sector emissions increased by over 200% (IPCC (Intergovernmental Panel on Climate Change), 2014). These rapid increments were largely due to increasing population and household incomes (Liu et al., 2011; Liao and Cao, 2013; Qu et al., 2013; Wang and Yang, 2014). Therefore, the global climate stabilisation mission cannot be accomplished without combating household emissions.

HCEs have been estimated for countries such as Australia (EPA Victoria, 2013), the USA (Bin and Dowlatabadi, 2005; Jones and Kammen, 2011, 2014; Weber, 2008; Weber and Matthews, 2008), the Netherland (Kerkhof et al., 2009), the UK (Druckman and Jackson, 2009; Kerkhof et al., 2009; Büchs and Schnepf, 2013), Sweden (Kerkhof et al., 2009; Statistics Sweden, 2006), Norway (Kerkhof et al., 2009; Peters and Hertwich, 2006), Canada (Statistics Canada, 2011), China (Liu et al., 2011) and the Philippines (Seriño, 2010). Large differences in average HCEs amounts between countries are apparent. However, only three governments/countries in the world (China, Canada and UK) have published nationwide annual HCE data. Therefore, we decided to compare the trends and magnitudes of HCEs between these three countries. We are aware that US and China share 15.50% and 22.95% of the global emissions, respectively (Burck et al., 2013). Therefore, collectively they share >38% of global emissions. We valiantly tried to obtain time series data for the US as well but could not.

As noted, there are some studies from individual countries, however, they are based on consumer expenditure surveys but not at the national level of their respective countries. Moreover, these studies are limited to a given point in time and thus they have not conducted time series data analysis. For these reasons, we decided not to include them in our manuscript. However, for the sake of comparison, we did compare China, Canada and the UK's HCEs with these countries' single point (year) HCEs data.

In the case of China, HCEs data are available for 1995–2011; for the UK and Canada, data are available for 1997–2011 and 1990–2007, respectively. Using this data, this study aims to compare the trends and magnitudes of HCEs between these three countries and to pinpoint where these countries are heading and what lessons they can learn from others. Finally, the outcomes of this study are compared with the results from several single year studies for various countries.

HCEs are emissions related to the use of two categories of household goods and services: (1) Direct household goods and services, which include the use of different types of coals (such as raw coal, washed coal, moulded coal, cooking coal), gases, gasoline, kerosene, diesel, liquid petroleum gas and electric power; and (2) indirect household goods and services, which include food, clothing, reside (residential), household equipment, transportation and communication, cultural & educational entertainment, and medical care.

2. A brief snapshot of China, Canada and the UK's emissions reduction policies

China, Canada and the UK collectively share 25.85% of global emissions, 19.31% of global GDP and 20.82% of the global population (Table 1). All these countries have set emission reduction targets for 2020: China aims to reduce carbon intensity by 40–45% from 2005 levels; Canada aims to reduce emissions by 17% from 2005 levels and the UK by 20% from 1990 levels (Australian Government Climate Change Authority, 2014). As shown by their annual average change in carbon intensity, to some extent, these countries appear to be progressing well. From 2006 to 2010, China reduced its energy intensity by 19.1% (Network for Climate and Energy Information, 2012), and replaced ~500 small and inefficient power plants with more efficient ones (Australian Government Climate Change

Table 1
Share of global GDP, population and emissions by three research countries.

Country	Share of global GDP*	Share of world population*	Share of global emission*	Per capita emissions national (tCO_2e/yr)**	Emissions reduction targets for 2020**	Annual avg. change in C intensity (2007–12)***	Climate change performance index rank 2014***
China	14.63%	19.42%	22.95%	7.1	Decrease C intensity by 40–45% from 2005 level	−1.9%	46
Canada	1.75%	0.50%	1.58%	19.9	Decrease emissions by 17% from 2005 level	−1.8%	58
UK	2.93%	0.90%	1.32%	9.3	Decrease emissions by 20% from 1990 level	−1.7%	5
Total	19.31%	20.82%	25.85%	NA	NA	NA	NA

* Adopted from Burck et al. (2013).
** Australian Government Climate Change Authority (2014) and
*** From PWC (PricewaterhouseCoopers International Limited) (2013); Climate change performance index rank is calculated on the basis of five indicators: emissions level (30% weight), emissions development (30% weight), renewable energy (10% weight), energy efficiency and climate policy (20% weight).

Authority, 2014). China is also the world leader in renewable energy. In 2012 alone, it invested over US $67 billion in renewable energy, which is over 25% of the world total (REN21, 2013).

In Canada, energy efficiency regulations are in place. Because of these, fuel efficiency of the average car fleet increased by 15% and the heating energy intensity of new residential buildings by 25% between 1990 and 2010 (SDSN (Sustainable Development Solutions Network), IDDRI (the Institute for Sustainable Development and International Relations), 2014). However, in absolute terms both China and Canada's emissions have been increasing while the UK's emissions in 2010 had fallen by 22% from 1990 levels, mainly due to: (1) moving away from carbon intensive coal and large-scale take-up of gas for power generation; (2) economic restructuring, with large reductions in emissions from industrial energy use; and (3) efficiency gains in end-use sectors such as transport and buildings (SDSN (Sustainable Development Solutions Network), IDDRI (the Institute for Sustainable Development and International Relations), 2014). Consequently, among these three countries, the climate change performance of the UK is ranked much higher than that of either China or Canada (Table 1).

3. Data collection

HCEs and related data were collected from Canadian, UK and Chinese government websites:

- For Canada, the number of households and average household sizes for different years were taken from Statistics Canada (2012); total, direct and indirect annual HCEs data were taken from Statistics Canada (2011); and annual national emissions data were taken from Government of Canada (2012).
- For the UK, national emissions and total, direct and indirect HCEs data for different years were taken from DEFRA (Department for Environment, Food & Rural Affairs) (2014); and household numbers and average household sizes for various years were taken from Office of National Statistics (2013).
- For China, average household sizes and household consumption of different types of direct and indirect goods and services for different years were obtained from 17 volumes of: (1) China Statistical Yearbook (National Bureau of Statistics of China (NBSC), 1996–2012b); (2) China Energy Statistics Yearbooks (National Bureau of Statistics of China (NBSC), 1996–2012a,b); and (3) China Population Statistical Yearbook (National Bureau of Statistics of China (NBSC), 1996–2012a). Household numbers, as a ratio of total population and household size, was obtained from China Statistical Yearbook (National Bureau of Statistics of China (NBSC), 1996–2012b). Consumed direct and indirect goods and services amounts were converted into HCEs amounts using their emission factors. Similarly, total national emissions data for different years were taken from World Bank (2014c) and CDIAC (2014).
- For all three countries, GDP per capita (hereafter referred as per capita income) and population density (people per square km of land area) were taken from World Bank (2014a), (2014b), respectively.

All three countries use input–output accounts/models that link the flow of goods and services described in monetary terms and their emissions intensities during the production process (China Statistical Yearbook, 2010 (NBSC, 2010); DEFRA (Department for Environment, Food & Rural Affairs), 2014; Statistics Canada, 2011). Each country divides household emissions into two types: (1) direct household emissions which include emissions due to the use of heat and energy; and (2) indirect household emissions which include emissions due to the consumption of goods and services such as food, clothing, household equipment, communication, cultural and educational entertainment, medical care etc. However, there are some inconsistencies in categorising goods and services between these countries. For example, in Canada, private motor vehicle related emissions are categorised under direct emissions and electricity [purchase] related emissions are categorised under indirect emissions whereas in China the opposite is the case (Qu et al., 2013; Statistics Canada, 2011). Therefore, while in the earlier sections we have discussed both direct and indirect HCEs, in order to draw concluding remarks, we only compare total HCEs between the countries.

4. Results and discussions

4.1. Comparison of household carbon related attributes between China, Canada and the UK

Data for different HCEs related attributes are not available for the same period of time for the three countries included in this study. Data for China, Canada and the UK are available for periods of 17 years (1995–2011), 18 years (1990–2007) and 15 years (1997–2011), respectively (Tables 2–4). During these periods, the numbers of households, average per capita incomes and population densities increased in all countries whereas average household sizes decreased. In general, these trends were most apparent in China, followed by Canada and the UK.

In the initial years (1995 in China, 1990 in Canada and 1997 in the UK), total national emissions in China, Canada and the UK were 3320.26 $mtCO_2$, 571.46 $mtCO_2$, 727,874 $mtCO_2$, respectively, and in the final years (2011 in China and the UK and 2007 in Canada), these values changed to 9093.49 $mtCO_2$, 723 $mtCO_2$, 650.16 $mtCO_2$, respectively, representing an increase of 173.88% in China and 26.52% in Canada, and a decrease of 10.68% in the UK. Similarly, in the initial years, total HCEs in China, Canada and the UK were 652.57 $mtCO_2$, 375 $mtCO_2$ and 554.04 $mtCO_2$, respectively, while by the final years these values changed to 2380.97 $mtCO_2$, 432 $mtCO_2$ and 505.86 $mtCO_2$, respectively, representing an increase of 264.86% and 15.2% in China and Canada, respectively, and a decrease of 8.7% in the UK. These results show that HCEs in China increased much faster than those of Canada and also much faster than national total emissions, possibly due to the low starting base as well as rapidly increasing

Table 2
Households CO_2 emissions and other statistics in China, 1995–2011.
Source:

Year	Total national emissions ($ktCO_2$)	Total HH emissions ($ktCO_2$)[c]	Number of household (thousand)[d]	Average household size[e]	Ave per capita income (US$)[f]	Direct HH emissions ($ktCO_2$)[c]	Indirect HH emission ($ktCO_2$)[c]	Population density (No/km^2 land area)[g]
1995	3320,285[a]	652,570	327,354	3.70	604	362,570	290,000	129.17
1996	3463,089[a]	634,890	330,781	3.70	703	313,890	321,000	130.53
1997	3469,510[a]	664,430	339,632	3.64	774	319,430	345,000	131.88
1998	3324,345[a]	690,130	343,694	3.63	821	323,130	367,000	133.15
1999	3318,056[a]	728,100	351,358	3.58	865	324,100	404,000	134.31
2000	3405,180[a]	794,390	368,439	3.44	949	328,390	466,000	135.37
2001	3487,566[a]	844,970	368,864	3.46	1042	343,970	501,000	136.36
2002	4525,177[a]	939,250	378,917	3.39	1135	362,250	577,000	137.27
2003	4694,242[a]	1038,100	382,328	3.38	1274	406,100	632,000	138.13
2004	5288,166[a]	1158,420	386,869	3.36	1490	461,420	697,000	138.95
2005	5790,017[a]	1310,740	417,751	3.13	1731	517,740	793,000	139.77
2006	6414,463[a]	1459,170	414,662	3.17	2069	570,170	889,000	140.55
2007	6791,805[a]	1654,570	416,811	3.17	2651	644,570	1010,000	141.29
2008	7035,444[a]	1763,670	420,259	3.16	3414	665,670	1098,000	142.02
2009	7692,211[a]	1974,790	423,651	3.15	3749	716,790	1258,000	142.72
2010	8286,892[a]	2154,790	432,552	3.10	4433	748,790	1406,000	143.42
2011	9093,489[b]	2380,970	446,142	3.02	5447	808,970	1572,000	144.10
Change in % (1995–2011)	173.88	264.86	36.29	– 18.38	801.82	123.12	442.07	11.56
Annual change (%/yr)	6.50	8.43	1.95	– 1.26	14.73	5.14	11.14	0.69

[a] World Bank (2014c).
[b] CDIAC (2014).
[c] Calculated on the data from *China Statistics Yearbooks* (National Bureau of Statistics of China (NBSC), 1996–2012b).
[d] Calculated on the data from *China Statistics Yearbooks* from 1996 to 2012 (National Bureau of Statistics of China (NBSC), 1996–2012b).
[e] National Bureau of Statistics of China (NBSC) (1996–2012a,b).
[f] World Bank (2014a).
[g] World Bank (2014b).

Table 3
Households CO_2 emissions and other statistics in Canada, 1990–2007.
Source:

Year	Total national emissions ($ktCO_2$)[a]	Total HH Emissions ($ktCO_2$)[b]	Number of household (thousand)[c]	Average household size[c]	Per capita income (US$)[d]	Direct HH emissions ($ktCO_2$)[b]	Indirect HH emission ($ktCO_2$)[b]	Population density (No/ km^2 land area)[e]
1990	571,464	375,000	9,854	2.81	21,302	95,000	280,000	3.06
1991	558,826	370,000	10,013	2.80	21,591	92,000	278,000	3.10
1992	580,145	392,000	10,169	2.79	20,693	95,000	297,000	3.14
1993	581,403	386,000	10,318	2.78	19,936	99,000	287,000	3.17
1994	601,208	389,000	10,507	2.76	19,786	102,000	287,000	3.20
1995	620,353	387,000	10,655	2.75	20,509	101,000	286,000	3.23
1996	637,644	394,000	10,807	2.74	21,129	106,000	288,000	3.26
1997	649,244	403,000	10,955	2.73	21,709	104,000	299,000	3.30
1998	655,384	410,000	11,086	2.72	20,875	100,000	310,000	3.33
1999	668,907	412,000	11,260	2.70	22,110	103,000	309,000	3.35
2000	693,268	411,000	11,407	2.69	24,032	105,000	306,000	3.38
2001	684,524	410,000	11,575	2.68	23,574	103,000	307,000	3.42
2002	689,050	424,000	11,745	2.67	23,995	108,000	316,000	3.45
2003	711,551	433,000	11,895	2.66	28,026	111,000	322,000	3.48
2004	712,426	423,000	12,098	2.64	31,830	110,000	313,000	3.52
2005	705,493	416,000	12,259	2.63	36,029	111,000	305,000	3.55
2006	689,346	412,000	12,431	2.62	40,245	109,000	303,000	3.58
2007	723,002	432,000	12,601	2.61	44,329	115,000	317,000	3.62
Change in % (1990–2007)	26.52	15.20	27.88	−7.12	108.10	21.05	13.21	18.30
Annual change (%/yr)	1.39	0.84	1.46	−0.43	4.41	1.13	0.73	0.99

[a] Government of Canada (2012).
[b] Statistics Canada (2011).
[c] Statistics Canada (2012).
[d] WHO [World Health Organisation] (2014).
[e] WHO [World Health Organisation] (2014).

household incomes and affordability (Golley and Meng, 2012; Liu et al., 2012, 2013; Zhang et al., 2012; Cai and Zhang, 2014; Ren et al., 2014).

HCEs were further divided into direct and indirect HCEs. Tables 2–4 provide absolute values for these emission sources. In 1995, direct HCEs in China (362.57 $mtCO_2$) were much higher than indirect HCEs (290.00 $mtCO_2$), but by 2011, indirect HCEs had increased more rapidly (442.07%) than direct HCEs (123.12%); as a result, in 2011, indirect emissions were almost two times of direct emissions (808.97 $mtCO_2$ vs 1572 $mtCO_2$). The rapid increase in indirect HCEs in China highlights two things: (1) with rapid economic growth, people's priority moves toward quality lifestyles with more attention to medical care and health, housing, education, transportation, electrical appliances etc. (Qu et al., 2013); and (2) direct HCEs alone do not provide a complete picture, hence consideration of both direct and indirect HCEs is necessary. By the final year of reporting (2007), both direct and indirect HCEs also increased in Canada; however, unlike China, direct emissions represented the higher proportion of HCEs. On the other hand, despite evidence of rising incomes in the UK, both direct and indirect emissions have decreased, potentially due to large-scale uptake of gas for power generation, economic restructuring and efficiency gains in end-use sectors (SDSN (Sustainable Development Solutions Network), IDDRI (the Institute for Sustainable Development and International Relations), 2014). As a result of these decarbonising activities, the UK is ranked relatively high in terms of its climate change performance index (PWC (PricewaterhouseCoopers International Limited), 2013).

Data for these countries were for different periods, making comparison difficult. In order to compare the trends in different attributes, annual rates of change were estimated for the respective data periods. In the UK, total national emissions decreased by 0.80%/yr, whereas in China and Canada

Table 4
Households CO_2 emissions and other statistics in UK, 1997–2011.
Source:

Year	Total national emissions ($ktCO_2$)[a]	Total HH emissions ($ktCO_2$)[a]	Number of household (thousand)[b]	Average household size[b]	Per capita income (US$)[c]	Direct HH emissions ($ktCO_2$)[a]	Indirect HH emission ($ktCO_2$)[a]	Population density (No/km^2 land area)[d]
1997	727,874	554,039	23,865	2.41	23,734	147,756	406,283	241.05
1998	765,889	580,153	24,036	2.40	25,266	149,559	430,594	241.75
1999	764,215	581,749	24,209	2.39	25,871	150,489	431,260	242.56
2000	778,412	598,795	24,396	2.38	25,362	150,687	448,108	243.43
2001	786,862	608,282	24,535	2.38	25,121	154,117	454,165	244.37
2002	791,325	613,031	24,776	2.36	27,301	152,922	460,109	245.40
2003	804,744	624,860	24,878	2.36	31,437	153,164	471,696	246.55
2004	831,265	644,242	24,936	2.37	37,021	156,194	488,048	247.96
2005	817,835	634,216	25,130	2.36	38,432	151,772	482,444	249.66
2006	809,190	619,986	25,263	2.37	40,808	149,238	470,748	251.51
2007	801,292	607,307	25,457	2.36	46,591	145,529	461,778	253.47
2008	741,366	570,111	25,687	2.36	43,487	146,106	424,005	255.47
2009	675,215	532,518	25,830	2.36	35,455	139,454	393,064	257.41
2010	681,665	537,797	26,006	2.36	36,573	149,160	388,637	259.44
2011	650,160	505,859	26,135	2.36	38,927	128,197	377,662	261.48
Change in % (1997–2011)	−10.68	−8.70	9.51	−2.07	64.01	−13.24	−7.04	8.48
Annual change (%/yr)	−0.80	−0.65	0.65	−0.15	3.60	−1.01	−0.52	0.58

[a] DEFRA (Department for Environment, Food & Rural Affairs) (2014).
[b] Office of National Statistics (2013).
[c] WHO [World Health Organisation) (2014).
[d] WHO [World Health Organisation) (2014).

they increased by 6.5%/year and 1.39%/yr, respectively. Similarly, total HCEs increased in China (8.43%/yr) and Canada (0.84%/yr) and decreased in the UK (0.65%/yr). Similarly, the highest annual decreasing rate in household size was observed in China (1.26%/yr) and lowest in the UK (0.15%/yr). However, average household size in China in 2011 was still much larger than that of all other countries in the 1990s. Two things can be highlighted from the observations of household size trends in these countries: (1) all countries are moving towards nuclear family with average family sizes showing signs of levelling off at 2.30–2.35 per household (refer to Tables 2–4); and (2) the larger the current household size the greater will be the annual decreasing rate. Both increasing household number and decreasing household size could result in escalating HCEs with a reduction in the economies of scale experienced by larger households (Wang and Fede, 1996; Underwood, 2014; Qu et al., 2013; IPCC (Intergovernmental Panel on Climate Change), 2014).

4.2. Comparison of proportion of national carbon emissions shared by HCEs between China, Canada and the UK

Per person carbon emission represents a very broad figure, which is derived from the ratio of total national carbon emissions to total population, whereas per person HCEs represents the sum of both direct and indirect HCEs, derived from the ratio of total HCEs to total number of people. The gap between these two emission figures highlights emissions from non-household sources. China represents the key player in the global production of goods and services. Therefore, Chinese national carbon emissions are the highest in the world (Tables 2–4), but it's per HCEs is lower than that of Canada and UK.

Among the three countries, the UK had the highest 'proportion of national carbon emissions shared by HCEs' followed by Canada and China (Fig. 1). For example, in 2007, about 76% of the national carbon emission was derived from HCEs in the UK, whereas these proportions were 60% in Canada and 24% in China. During the study periods, these proportions increased in China and the UK and decreased in Canada. For example, in China, the proportion was 19.65% in 1995 and increased to 26.22% in 2011, an increase of 33.22%. Similarly, from 1997 to 2007, the proportion for the UK increased from 76.12% to 77.81%, an increase of 2.22%, whereas in case of Canada the proportion decreased by 8.95%, from 65.62% in 1990 to 59.75% in 2007.

The higher proportional share of HCEs in Canada and UK were due to their consumption-based economies, while the lower share attributed from China, the world's largest manufacturer and trading economy, was potentially the result of its production-based economy (Morrison, 2013). Moreover, the relative development of a country can also determine the proportion of national emissions contributed by HCEs; i.e., the more developed the country, the higher the proportion is likely to be. Predictably, the proportion of national emissions shared by HCEs in China will continue to increase, mainly due to: (1) rapidly changing lifestyles and consumption patterns catalysed by increasing household incomes; and (2) heavy reliance on carbon intensive coal and its derivatives in rural China (Golley and Meng, 2012; Liu et al., 2012, 2013; Zhang et al., 2012; Cai and Zhang, 2014; Ren et al., 2014).

The international environment for GHG emissions reductions, as well as China's current energy and climate policy, means that China does not reach the levels of GHG emissions reductions of either the UK or Canada. However, China has: (1) a very aggressive carbon intensity reduction target and is on the track to achieve these (Network for Climate and Energy Information, 2012); (2) a policy of replacing small and inefficient power plants with efficient ones (Australian Government Climate Change Authority, 2014); (3) seven regional emissions trading schemes (ETSs) are in place (Australian Government Climate Change Authority, 2014); (4) made significant progress and is leading the world in implementing renewable energy options (REN21, 2013); and (5) a strategy for phasing in fuel economy standards for passenger vehicles, currently in place in Shanghai, Guangzhou and Beijing (Australian Government Climate Change Authority, 2014).

Developed countries' citizens currently enjoy high welfare levels and living standards while also contributing higher levels of HCEs. While this may violate principle of fairness and equity, developing countries such as China cannot sustain the emissions associated with the development pathways of developed countries but must begin to curb emissions growth. In fact, there may be additional benefits in doing so. For example, cutting emissions could have huge health benefits; it is estimated that the US Government's plan to reduce carbon emissions from power plants by 30% will deliver up to $7 of health benefits for every dollar of investment (EPA, 2014). In recognition of this, at the 15th APEC meeting then Chinese president Hu Jintao stressed the importance of reducing ecological footprints for sustainable development.

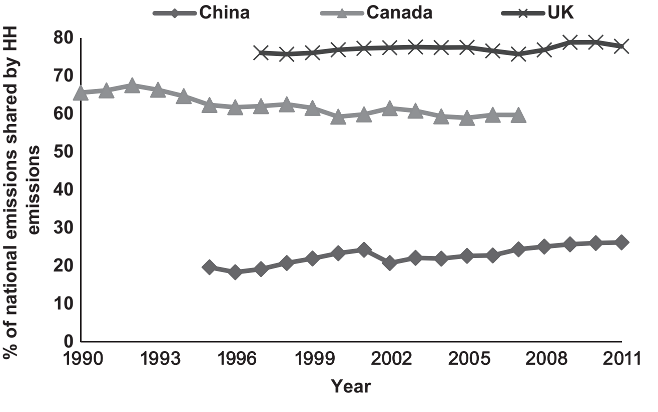

Fig. 1. Proportion of national carbon emissions shared by HCEs.

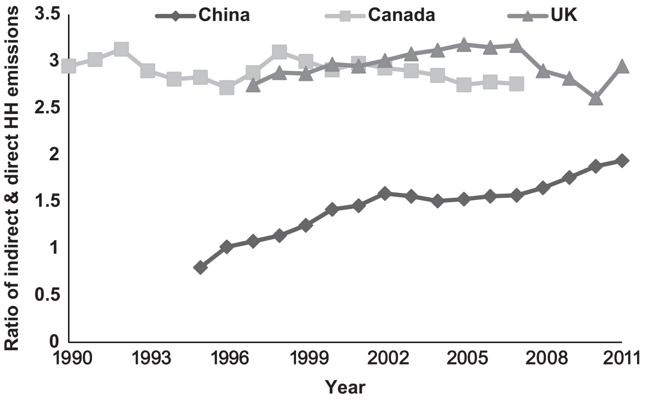

Fig. 2. Ratio of indirect and direct HCEs in China, Canada and UK.

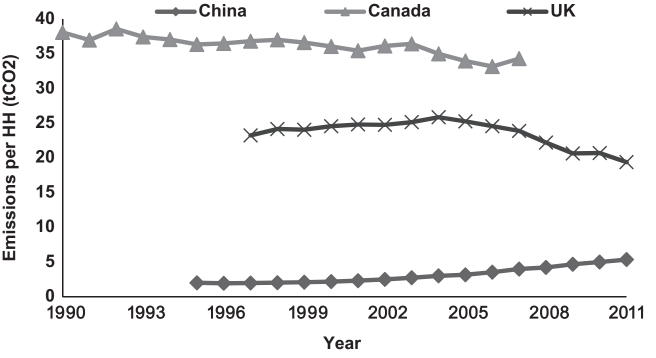

Fig. 3. Per HCEs in China, Canada and the UK.

4.3. Comparison of the proportion of indirect and direct HCEs between China, Canada and the UK

Over the periods for which data are available, the ratio of indirect to direct HCEs in China grew consistently (Fig. 2). In Canada, the ratio peaked in 1998, then started to decline, while in the UK it peaked in 2005 and then declined but increased again in 2011. In the initial years, the ratio was 0.8 in China, 2.95 in Canada and 2.75 in UK and in the end years these values were changed to 1.94, 2.76 and 2.95, respectively; an increase of 48% in China and 7.14% in UK and a decrease of 6.48% in Canada. This indicates that indirect HCEs are increasingly becoming an issue in China, potentially in association with increasing income levels as a result of which the population is moving from the provision of basic needs to the more advanced needs, with higher levels of consumption of a range of goods and services including education, transportation, electrical appliances etc. (Qu et al., 2013).

4.4. Comparison of per HCEs between China, Canada and the UK

Comparison of per HCEs is more meaningful than that of total HCEs. The latter does not tell the full story about the differences in household consumption patterns between the countries and it also does not consider population and household dynamics. In 2007, the total number of households in China was about 33 times and 16 times higher than that of Canada and the UK, respectively. Therefore, if we consider total HCEs, China has the highest followed by the UK and Canada but if we compare emissions on a household basis, the order is reversed. For example, in 2007, Canada had the highest

HCEs per household (34.28 tCO_2), followed by the UK (23.86 tCO_2) and China (3.97 tCO_2) (Fig. 3). The higher HCEs/household in Canada could be due to its: (1) longer colder winters; (2) lower population density (Wier et al., 2001); and (3) increasing transportation demand fuelled by increasing household incomes (SDSN (Sustainable Development Solutions Network), IDDRI (the Institute for Sustainable Development and International Relations), 2014).

Throughout the study periods, HCEs per household in China showed a clear positive trend but in Canada and the UK the curves varied over time but in general showed negative trends. From 1990 to 2007, per HCEs in Canada decreased from 38.06 tCO_2 to 34.28 tCO_2e, a decrease of 9.91%. Similarly, in the UK, there was an overall decrease of 16.63% from 23.22 tCO_2 in 1997 to 19.36 tCO_2 in 2011. During the study period of 17 year (1995–2011), China's HCEs per household increased by about 228%. As noted, China is a rapidly emerging economy and its initial per household HCEs amount was very low; therefore, the higher increment was to be expected; however, per household HCEs in China in 2011 were still over 3.6 times smaller than those of the UK.

It is likely that there are more significant differences in HCEs between urban and rural China than that of UK and Canada. Therefore, it is worthwhile to compare Chinese urban and rural HCEs with that of Canada and UK. According to Liu et al. (2011) around 72.74% of total HCEs in China in 2007 were from urban households and 27.26% rural households. Similarly, as presented in Table 2 with a total of 1654,570 $ktCO_2$ of HCEs in 2007 (National Bureau of Statistics of China (NBSC), 1996–2012a,b), it would be reasonable to suggest approximately 1203,534.22 $ktCO_2$ of that might have come from urban households, leaving rural households to account for the remaining 451035.78 $ktCO_2$. China Statistics Yearbooks (National Bureau of Statistics of China (NBSC), 1996–2012b) show there were about 191,270,000 households in 2007 in urban China compared with 225,541,000 in rural China. Therefore, HCEs per household from urban and rural China in 2007 could be 6.29 tCO_2 and 2.0 tCO_2, respectively. Therefore, even the average HCEs of urban China (6.29 tCO_2) is much lower than the average HCEs of Canada (34.28 tCO_2) and the UK (23.86 tCO_2).

4.5. Comparison of per person HCEs between China, Canada and the UK

As reported in the literature (Liu et al., 2011; Statistics Canada, 2011) and indicated in Tables 2–4, household size is decreasing in many countries; however, the rate of decrease differs between countries. Therefore, per person HCEs is a fair means of comparison between the countries. For example, in 2007, per household HCEs in China were 8.6 times and 6 times lower than in Canada and the UK, respectively, whereas per person HCEs were 10.5 times and 8.1 times lower. As China had the highest household size, the proportional gaps between China and Canada and the UK had increased (Fig. 4).

The overall trends in per person HCEs followed those of the per household HCEs for each country. China had clear positive trend and UK and Canada had overall negative trends. Over the study period, per person HCEs in Canada and the UK decreased by 0.18%/yr and 1.14%/yr, respectively, whereas in China they increased by 7.70%/yr. However, in 2011, China's per person HCEs were still over 4.6 times smaller than that of the UK and probably much smaller than that figure in Canada.

Per person HCEs reported in this study for China (1.77 tCO_2 in 2011) is in close agreement with the Chinese study by Qu et al. (2013); 1.43 tCO_2. The lower value in the study by Qu et al. (2013) could be due to sampling bias as their sample sites were all from rural areas of Gansu, Qinghai and Ningxia provinces. Similarly, per household carbon emissions reported in this study for the UK concurs with various other studies including Druckman and Jackson (2009), Kerkhof et al. (2009), and Büchs and Schnepf (2013). The minor differences in HCEs estimates between these studies are largely due to the mode of survey and survey year. Therefore, we believe that our results are reliable and accurate.

Now a question may come why per person HCEs in China is much lower than those of UK and Canada. Compared to the UK and Canada, China has very poor affordability. For example, in 2007, the average per capita income (PCI) for Chinese people was US\$2651, while PCIs for Canada and UK were US \$44,329 and US\$46,591, respectively (see Section 4.1; Tables 2–4). Moreover, in 2010, about 23.19% of the population in China were under poverty line (living on $>$ US\$2.00 a day), whereas in UK and Canada it was only 0.34% and 1.35% of the populations, respectively (World Bank, 2015a,2015b). Therefore, people in the UK and Canada have more consumptive power than the Chinese, and therefore the

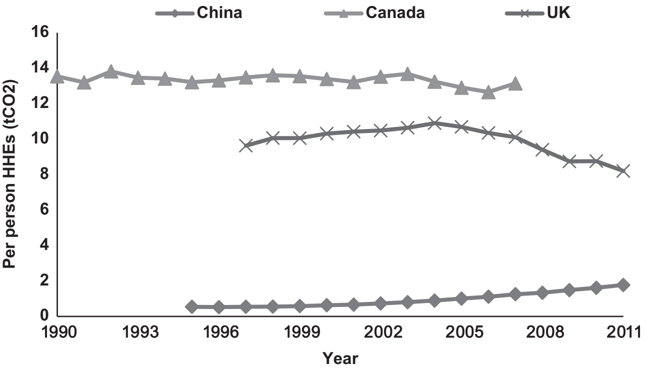

Fig. 4. Per person HCEs in China, Canada and UK.

Chinese per person HCEs are lower. For example, in 2010, the number of motor vehicles owned per 1000 people in the UK and Canada were 519 and 607, respectively (World Bank, 2015a,2015b), whereas in China it was 101 in 2013 (http://auto.msn.com.cn/auto_industry/20140205/1658255.shtml).

4.6. Comparison of the ratio of per person HCEs and per capita incomes (PCIs) between China, Canada and the UK

The ratio of per person HCEs to per capita incomes decreased in all countries over the period for which data are available. The rate of decrease was greater in China than that in Canada or the UK (Fig. 5). As already noted, China had low per person HCEs and very low PCIs in the initial year of data reported and therefore a high HCEs:PCI ratio, whereas in Canada and the UK both per person HCEs and PCIs were high, therefore the ratios were relatively lower. China's per person HCEs increased by 228% from 1995 to 2011 while the PCI increased by 801%. In the final years, there are still certain gaps between the ratios of per person HCEs and PCIs in China and Canada and UK, indicating that the household sector in China is still relatively carbon-intensive. This is potentially because rural China is still heavily reliant on coal and its derivatives (Golley and Meng, 2012; Liu et al., 2012, 2013; Zhang et al., 2012; Cai and Zhang, 2014; Ren et al., 2014. While there is room for improvement, as the ratio decreases, the need for technical innovation and capital investment in China may increase, especially in rural areas.

4.7. Potential drivers of per person HCEs

As discussed, per capita income (PCI), household size and population density may impact on per person HCEs. We developed country-wise and collective (for all three countries combined) regression models for the individual and combined effects of these drivers. The best two models for each are presented in Table 5. In the case of China, PCI explained over 96% of the total variation in per person HCEs. The addition of another variable (household size) only marginally increased the explanatory power of the model; therefore, PCI with or without household size could be used as an independent variable/s to forecast per person HCEs in China. The importance of PCI on HCEs in China is also reported in Golley and Meng (2012) and Qu et al. (2013).

In the case of Canada, the best model generated to explain per person HCEs is included only one explanatory variable, PCI, but this explains less than 50% of the total variation in per person HCEs. As expected, household size has some influences in per person HCEs, not only in Canada but also in UK and China, as reducing household sizes increases per person HCE. This indicates that extended family households could be more carbon friendly than the nuclear family. This observation is in agreement with Qu et al. (2011), Underwood (2014) and IPCC (Intergovernmental Panel on Climate Change)

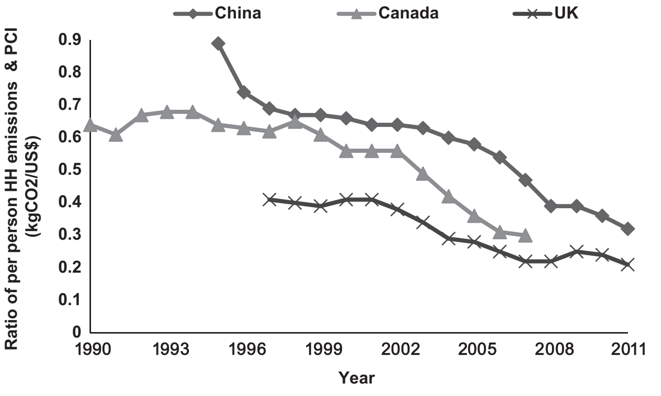

Fig. 5. Ratio of per person HCEs and per capita income (PCI).

(2014). This is likely to be due to the economies of scale of energy use within the household (Underwood, 2014).

In the case of the UK, PCI has very low explanatory power (not shown) while population density explains some 50% of the total variation in PCE. However, including all three variables dramatically improves the explanatory power of per person HCEs. At the collective level, when data for the three countries is pooled across all years, household size and population density explains over 90% of the total variation in total PCE, while adding the PCI variable increases the explanatory power of the model to 93%. Therefore, in case of the UK and at the collective level, a model including all three drivers may be more powerful.

On the basis of the regression models, we can make some predictions and stimulate discussions. If the current trend in emissions continues in China and if the PCI increases to the UK (U$38,927 in 2011) and Canadian (U$44,329 in 2007) levels, China's per person HCEs will be similar to those of the UK (China 11.1 tCO_2 vs UK 10.11 tCO_2) and Canada (China 12.59 tCO_2 vs Canada 13.11 tCO_2). However, as discussed above, there are several reasons to believe why China's per person HCEs may not reach the UK and Canadian levels. On the other hand, given international and national climate change and emission reduction policies and programs, Canada and the UK may also reduce their HCEs.

As discussed in Sections 2 and 4.2, China is successfully achieving its goal of 40–45% emissions intensity reductions with various actions towards low carbon-intensity fuels, energy efficiency, renewables and demand side management (Australian Government Climate Change Authority, 2014; Network for Climate and Energy Information, 2012). However, current use of biomass in China is relatively small, mostly for heating or cooking. Therefore, Chinese government has created price and tax incentives for biomass and waste incineration project investment through feed-in tariffs (US EIA [US Energy Information Administration), 2014). This policy will have positive impact on the use of carbon–neutral biomass fuels against the fossil-fuel alternatives (Duan et al., 2014). Another policy working nicely towards low carbon housing in rural China is "concentrated housing" which has potential to improve energy efficiency and living conditions of households, compared to traditional stand-alone modes of housing (Liu et al., 2014).

Despite these initiatives coal still accounts for around 65% of China's overall energy consumption (Hart, 2014). This is because coal already has a huge lead. However, because of the coal dependent economy and aging energy infrastructure, compared to OECD and other developing countries, the marginal abatement cost curve of emissions reduction for China is nearly flat (Wetzelaer et al., 2007). China has enormous potential for developing large-scale emissions reduction projects with low transaction costs (Maraseni et al., 2011, 2013), and has started national emissions trading scheme from early 2015. Therefore, China is in track to lead global community on carbon emissions and may never reach to UK and Canada's levels.

Table 5
Effect of household size (HHsize), population density (PopDensity) and per capita income (PCI) on per person household carbon emissions (PCE).

Country	Best fitted regression equations	R^2	AdjR^2
China	$PCE = 0.404 + 0.000275PCI$	0.963	0.961
	$PCE = 2.397 - 0.550HHsize + 0.000203PCI$	0.990	0.988
Canada	$PCE = 13.996 - 0.00002513PCI$	0.447	0.412
UK	$PCE = 30.961 - 0.084PopDensity$	0.494	0.455
	$PCE = 129.368 - 30.579HHsize + 0.00006439PCI - 0.197PopDensity$	0.923	0.902
All	$PCE = 44.346 - 11.477HHsize - 0.031PopDensity$	0.929	0.925
	$PCE = 36.854 - 9.345HHsize + 0.00006811PCI - 0.030PopDensity$	0.935	0.931

Table 6
Comparison of ambient air quality between China, Canada and UK.

Country	Annual mean PM10 (μg/m^3)	Annual mean PM 2.5 (μg/m^3)	Reference year	Rank
China	90	41	2010	14
United Kingdom	21	14	2011	71
Canada	11	8	2010–2012	85

Adopted from WHO [World Health Organisation) (2014).

4.8. Comparison of ambient air quality between China, Canada and UK

The World Health Organisation (WHO) compares the relative concentration of fine particulate pollution of 2.5 micrometers or less (PM2.5) and 10 micrometers or less (PM10) in diameters in the troposphere. The latest report of WHO [World Health Organisation) (2014) shows that the Pakistan is the most polluted country followed by Qatar, Afghanistan and Bangladesh, whereas China ranks 14th UK 71st and Canada 85th (Table 6). Although China's 'per person' carbon emissions are many times lower than that of Canada and UK its air quality is very poor, largely due to heavy use of dirty coal which still accounts for around 65% of China's overall energy consumption (Hart, 2014). As a result of coal burning the life expectancy of residents in northern China is 5.5 years lower than that of southern China (Chen et al., 2013).

However, as discussed in Section 4.2 with the example of US, replacing coals with low carbon fuel and renewable energy has huge public health and climate benefits. With this in mind, China has implemented caps on coal consumption and domestic coal production of 4 billion tonnes and 3.9 billion tonnes, respectively (Australian Government Climate Change Authority, 2014). This will have positive outcomes towards air pollution reduction.

4.9. Comparison of China, Canada and the UK's HCEs with other countries

As discussed, annual [time series] HCEs data is not available for other countries. Therefore, in order to investigate the trends and develop some comparative arguments, we have only focussed on the three countries included in this study. However, some studies have quantified HCEs from different countries for specific years (Table 7). Most of the HCEs data for different countries are for years prior to 2006. For the sake of comparison, we use data for 2005. If more than one estimate was available for a country, these were averaged (second last row, Table 6). From this comparison, as expected, the Philippines had the lowest HCEs, while the US, Canada, the UK, the Netherlands, Australia, Norway and Sweden's HCEs were 1438%, 981%, 614%, 504%, 473%, 333% and 254% higher than China's emissions, respectively. Although China is the largest carbon emitting country in the world, per household HCEs in 2005 were relatively very low. Therefore, while developing global policy and programs principle of fairness and equity should be considered.

The average HCEs presented here for the USA are based on lifecycle analysis which considered all six GHGs stipulated in the Kyoto Protocol. Therefore, these USA figures are not directly comparable with others. Nevertheless, the USA has higher HCEs than other countries based on reports that about 76% of total GHGs emissions derive from CO_2 emissions (SDSN (Sustainable Development Solutions Network), IDDRI (the Institute for Sustainable Development and International Relations), 2014). Currently in the USA, several decarbonisations polices are in place: (1) vehicle fuel economy standards; (2) appliance energy efficiency standards; (3) an aggressive target of 30% emissions reduction by 2030 from 2005 levels; (4) state level emission reduction targets, renewable portfolio standards for electricity generation and building energy codes; (5) a Regional GHG Initiative in nine northeast states; and (6) a legally binding carbon trading scheme in California (EPA, 2014; SDSN (Sustainable Development Solutions Network), IDDRI (the Institute for Sustainable Development and International Relations), 2014). Therefore, there is a very good chance of decreasing carbon emissions in the future.

Table 7
Comparison of China, Canada and the UK's per household carbon emissions (tCO_2) with other countries.

Sources	China	Canada	UK	Netherlands	Sweden	Norway	US	Philippines	Australia
Our research (from 2005 data)	3.14	33.93	25.24						
Kerkhof et al., 2009 (Based on hybrid approach of process analysis and input–output analysis; Netherland, 2000; UK, 1998; Sweden, 2002; & Norway, 1997 data)			20.2	18.96	12.2	13.6			
Büchs and Schnepf, 2013 (Based on expenditure survey, sample size of 24,446 households in year 2008/09)			20.2						
Druckman and Jackson, 2009 (based on a quasi-multi-regional input–output (QMRIO) model, based on 2004 data)			24						
Statistics Sweden, 2003 (based on input–output analysis, used year 2000 data)					10				
Peters and Hertwich, 2006 (based on input output analysis, used year 2000 data)						13.5			
Weber, 2008; Weber & Matthew, 2008 (Based on consumer expenditure survey of 17,250 households in 2004). This is lifecycle analysis.							40		
Weber, 2008; Weber & Matthew, 2008 (Based on input–output analysis, used 2004 data).This is lifecycle analysis.							57		
Jones and Kammen, 2011 (based on 2000 household survey in 2005). This is lifecycle analysis.							48		
Seriño, 2010 (based on input output analysis, data from 2006)								1.84	
EPA Victoria (2013)									18
Average of reported HCEs (without considering dates)	3.14	33.93	22.41	18.96	11.1	13.6	48.3	1.84	18
% Higher than China's HCEs		980.6	613.7	503.8	253.5	333.1	1438.2	(41.4)	473.2

Among the developed countries, Sweden and Norway had much lower HCEs in 2005, probably due to the production of electricity from hydro and nuclear sources and centralised heating system in Sweden, and the production of electricity by hydropower in Norway (Kerkhof et al., 2009). In Sweden, heat is produced in a central combustion plant, which can have different low carbon fuel mixes such as biomass, and then distributed to households. Therefore, their efficacies are much higher than those of individual household heating systems. The CO_2 emission intensities of electricity produced in Sweden (1.35 $kgCO_2$/Euro) and Norway (0.04 $kgCO_2$/Euro) are much lower than that of the Netherlands (5.14 $kgCO_2$/Euro) and UK (4.76 $kgCO_2$/Euro) (Kerkhof et al., 2009).

5. Conclusions and recommendations

Due to differences in household numbers, consumption behaviours and household sizes between countries, a comparison of per person HCEs is more meaningful than that of per household carbon emissions which in turn is better than total HCEs. If we consider total HCEs, China had the highest followed by the UK and Canada; while, if we consider per household and per person HCEs, the order is reversed. In fact, total HCEs in Canada increased by 0.84%/yr during 1990–2007 but, due to increasing household numbers per person HCEs decreased by 0.61%/yr. Moreover, higher household sizes in China meant that, while comparing per person HCEs, the proportional gaps between countries was greater. For example, in 2007 per household HCEs in China were 8.6 times and 6 times lower than those of Canada and the UK, while per person HCEs were 10.5 times and 8.1 times lower, respectively.

In the beginning years (1995 in China, 1990 in Canada and 1997 in UK), per HCEs in China, Canada and UK were 1.99 $mtCO_2$, 38.06 $mtCO_2$ and 23.22 $mtCO_2$, respectively, and in the end years (2011 in China and UK and 2007 in Canada), these values were changed to 5.34 $mtCO_2$, 34.28 $mtCO_2$, 19.36 $mtCO_2$, respectively; an increase of 6.36%/yr in China, and a decrease of 0.61%/yr in Canada and 1.29%/yr in UK. The overall trends in per person HCEs are similar. These show that the HCEs in China increased much faster, probably due to low starting base and rapidly increasing household incomes and affordability. However, China's per person HCEs in 2011 were still more than 4.6 times smaller than those of the UK and probably much more smaller than [UK's figure] in Canada's.

Regression models developed in this study show that, in most instances, the average per capita incomes (PCIs), average household size and population density explained a large proportion of the per person HCEs of a country. In the case of China, PCI either solely or with household size could be used as an independent variable/s, whereas in Canada PCI has better explanatory power than other variables. In case of UK and collective level (all countries) a model including all three variables could work well. If the current trend in emissions continues in China and if their PCIs increase to the levels of the UK and Canada, China's per person HCEs will be similar to those of the UK and Canada. However, China has started several decarbonisation policies and programmes and may not follow similar emissions pathways to those of Canada and the UK.

Household emissions contribute a large proportion of national emissions and this proportion had increased over time. However, this is a much overlooked area. Without addressing issues associated with HCEs, climate stabilisation targets may not be achieved. Therefore, co-ordinated and harmonised action between the major emitting countries towards addressing this issue is crucial. This harmonised action should include standard global rules for categorising direct and indirect goods and services as there are some inconsistencies between the countries. In addition, principle of fairness and equity should continue to be considered while developing global policy and programs.

In the end, three areas are recommended for the further research: (1) although China's HCEs is much lower than that of Canada and UK, its ambient air quality is much poorer than these two countries. Therefore, a comprehensive comparative analysis of pollutants such as PM2.5, PM10, nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone and carbon could be more useful; (2) climate change may have various impacts on HCEs for different countries. Countries in the northern (severe winter) and equatorial parts (hot summer) could have more HCEs than that of countries in between. Therefore, research which addresses this issue could be helpful in developing energy policy; and (3) household sizes are largely varied between the three countries and are decreasing during the study periods, but with different rates. So far, household has been used as a unit for comparing HCEs between and within the country but this study hypothesises 'per person' as a better approach. A comparative analysis with a larger number of countries could be applied to test this hypothesis.

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References

Australian Government Climate Change Authority, 2014. Reducing Australia's Greenhouse Gas Emissions-targets and Progress Review: Final Report, 401p.
Baiocchi, G., Minx, J., Hubacek, K., 2010. The impact of social factors and consumer behavior on carbon dioxide emissions in the United Kingdom. J. Ind. Ecol. 14, 50–72.
Bin, S., Dowlatabadi, H., 2005. Consumer lifestyle approach to US energy use and the related CO_2 emissions. Energy Policy 33 (2), 197–208.
Büchs, M., Schnepf, S.V., 2013. Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO_2 emission. Ecol. Econ. 90, 114–123.
Burck, J., Marten, F., Bals, C., 2013. The Climate Change Performance Index Results 2014. German Watch and Climate Action Network, Europe28.
Cai, B.F., Zhang, L.X., 2014. Urban CO_2 emissions in China: spatial boundary and performance comparison. Energy Policy 66, 557–567.
CDIAC, 2014. Preliminary 2011 and 2012 Global & National Estimates. ⟨http://cdiac.ornl.gov/ftp/trends/co2_emis/Preliminary_CO2_emissions_2012.xlsx⟩ (access 07, 24, 14).
Chen, Y., Ebenstein, A., Greenstone, M., Li, H., 2013. Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. Proc. Natl. Acad. Sci. (PNAS) 110 (32), 12936–12941.
Duan, X., Jiang, Y., Wang, B., Zhao, Z., Shen, G., Cao, S., Huang, N., Qian, Y., Chen, Y., Wang, L., 2014. Household fuel use for cooking and heating in China: results from the first Chinese Environmental Exposure-Related Human Activity Patterns Survey (CEERHAPS). Appl. Energy 136, 692–703.
DEFRA (Department for Environment, Food & Rural Affairs), 2014. UK's Carbon Footprint 1997–2011, UK Government. ⟨https://www.gov.uk/government/publications/uks-carbon-footprint⟩ (accessed 07.07.14).
Druckman, A., Jackson, T., 2009. The carbon footprint of UK households 1990–2004: a socio-economically disaggregated, quasi-multi-regional input–output model. Ecol. Econ. 68 (7), 2066–2077.
EPA Victoria, 2013. ⟨http://www.epa.vic.gov.au/agc/r_emissions.htmlpage-2/!⟩.
EPA (Environmental Protection Agency of US), 2014. Carbon pollution emission guidelines for existing stationary sources: electric utility generating units, Washington DC. USA, 645p.
Government of Canada, 2012. Greenhouse Gas Emissions (Carbon Dioxide Equivalents) by Sector (1990–2007). ⟨http://www5.statcan.gc.ca/ca nsim/a37⟩ (07.08.14).
Golley, J., Meng, X., 2012. Income inequality and carbon dioxide emissions: the case of Chinese urban households. Energy Econ. 34, 1864–1872.
Hart, M., 2014. Primer on Beijing's Slice-and-dice Approach to Energy and Climate Reform. Center for American Progress, USA14.
IPCC (Intergovernmental Panel on Climate Change), 2014. Technical summary of climate change 2014: mitigation of climate change, Working Group III Contribution to the IPCC Fifth Assessment Report (AR5). Intergovernmental Panel on Climate Change.
Jones, C., Kammen, D.M., 2011. Quantifying carbon footprint reduction opportunities for U.S. households and communities. Environ. Sci. Technol. 45 (9), 4088–4095.
Jones, C., Kammen, D.M., 2014. Spatial distribution of U.S. household carbon footprints reveals suburbanization undermines greenhouse gas benefits of urban population density. Environ. Sci. Technol. 48 (2), 895–902, http://dx.doi.org/10.1021/es4034364.
Kerkhof, A.C., Benders, R.M.J., Moll, H.C., 2009. Determinants of variation in household CO_2 emissions between and within countries. Energy Policy 37 (4), 1509–1517.
Liao, H., Cao, H.S., 2013. How does carbon dioxide emission change with the economic development? Statistical experiences from 132 countries. Global Environ. Change 23 (5), 1073–1082.
Liu, L.C., Wu, G., Wang, J.N., Wei, Y.M., 2011. China's carbon emissions from urban and rural households during 1992–2007. J. Cleaner Prod. 19 (15), 1754–1762.
Liu, W.L., Wang, C., Mol, A.P.J., 2012. Rural residential CO_2 emissions in China: where is the major mitigation potential? Energy Policy 51 223–232.
Liu, W.L., Spaargaren, G., Heerink, N., Mol, A.P.J., Wang, C., 2013. Energy consumption practices of rural households in north China: basic characteristics and potential for low carbon development. Energy Policy 55, 128–138.

Liu, W., Spaargaren, G., Mol, A.P.J., Heerink, N., 2014. Low carbon rural housing provision in China: participation and decision making. J. Rural Stud. 35, 80–90.
Maraseni, T.N., 2013. Selecting a CDM investor in China: a critical analysis. Energy Policy 53, 484–489.
Maraseni, T.N., Xu, G., 2011. An analysis of Chinese perceptions on unilateral Clean Development Mechanism projects. Environ. Sci. Policy 14 (3), 339–346.
Maraseni, T.N., Maroulis, J., Cockfield, G., 2009. An analysis of Australia's carbon pollution reduction scheme. Int. J. Environ. Stud. 66 (5), 591–603.
Morrison W.M., 2013. China's Economic Rise: History, Trends, Challenges, and Implications for the United States, Congressional Research Service (Retrieved from http://fpc.state.gov/documents/organization/219638.pdf (accessed 07.02.2015).
National Bureau of Statistics of China (NBSC), 1996–2012. China Population Statistical Yearbook. China Statistics Press, Beijing.
National Bureau of Statistics of China (NBSC), 1996–2012. China Statistical Yearbook. China Statistics Press, Beijing.
Network for Climate and Energy Information, 2012. China's Latest Energy Consumption Data Reveals New Opportunities and Challenges. Available at (⟨www.chinafaqs.org/blog-posts/chinas-latestenergy-consumption-data-reveals-new-opportunities-and-challenges-0⟩).
Office of National Statistics, 2013. Families and Household 2013, Statistical Bulletin. ⟨http://www.ons.gov.uk/ons/dcp171778_332633.pdf⟩ (accessed 08.07.14).
Peters, G.P., Hertwich, E.G., 2006. The importance of imports for household environmental impacts. J. Ind. Ecol. 10, 89–109.
PWC (PricewaterhouseCoopers International Limited), 2013. Busting the Carbon Budget: Low Carbon Economy Index 2013, London, UK.
Qu, J.S., Zeng, J.J., Li, Y., Wang, Q., Maraseni, T., Zhang, L.H., Zhang, Z.Q., Clarke-Sather, A., 2011. Household carbon dioxide emissions from peasants and herdsmen in Northwestern arid-alpine regions, China. Energy Policy 57, 133–140.
Qu, J.S., Zeng, J.J., Li, Y., Wang, Q., Maraseni, T., Zhang, L.H., Zhang, Z.Q., Clarke-Sather, A., 2013. Household carbon dioxide emissions from peasants and herdsmen in Northwestern arid-alpine regions, China. Energy Policy 57, 133–140.
REN21 [Renewable Energy Policy Network for the 21st Century], 2013. Renewables 2013, Global Status Report, 178p, ⟨http://www.ren21.net/portals/0/documents/resources/gsr/2013/gsr2013_lowres.pdf⟩ (accessed 07.04.2014).
Ren, H.B., Wu, Q., Ren, J.X., Gao, W.J., 2014. Cost-effectiveness analysis of local energy management based on urban–rural cooperation in China. Appl. Therm. Eng. 64, 224–232.
SDSN (Sustainable Development Solutions Network), IDDRI (the Institute for Sustainable Development and International Relations), 2014. Pathways to Deep Decarbonization, Interim 2014 Report, the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations, 218p.
Seriño, M.N.V., 2010. Do Philippine Households Lead a Carbon Intensive Lifestyle? Discussion Paper (no 158), University of Göttingen.
Statistics Canada, 2011. Human Activity and the Environment, Economy and the Environment. Environment Accounts and Statistics Division, Catalogue No 16-201-X (Table 7.1), 47p.
Statistics Canada, 2012. Canada Census Profile (Code 01), 2011 Census, Statistics Canada Catalogue no. 98-316-XWE. Ottawa.
Statistics Sweden, 2006. Household Budget Survey (hbs) 2003-2005—Expenditure and Income Report. Stockholm, Sweden.
Underwood, A.J., 2014. Household Carbon Dioxide Emissions in the United States: The Role of Demographic Change. Colorado State University, USA Ph.D. Dissertation.
UNEP (United Nations Environment Program), 2013. The Emissions Gap Report 2013. United Nations Environment Programme (UNEP), Nairobi.
US EIA [US Energy Information Administration), 2014. Energy Information Administration: China, ⟨http://www.eia.gov/countries/analysisbriefs/China/china.pdf⟩ (accessed 12 March 2015).
Wang, X.H., Fede, Z.M., 1996. Survey of rural household energy consumption in China. Energy 21, 703–705.
Wang, Z., Yang, L., 2014. Indirect carbon emissions in household consumption: evidence from the urban and rural area in China. J. Cleaner Prod. 78, 94–103.
Weber, C.L., 2008. Trade, consumption, and climate change: an input–output study of the United States. Carnegie Mellon University, Pittsburgh, PA Ph.D. Dissertation.
Weber, C.L., Matthews, H.S., 2008. Quantifying the global and distributional aspects of American household carbon Footprint. Ecol. Econ. 66 (2-3), 379–391.
WHO [World Health Organisation), 2014. Ambient Air Pollution Database, WHO, May 2014. Accessed from ⟨http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/⟩ on 18 February.
Wier, M., Lenzen, M., Munksgaard, J., Smed, S., 2001. Effects of household consumption patterns on CO_2 requirements. Econ. Syst. Res. 13, 259–274.
World Bank, 2014a. GDP Per Capita (Current US$). ⟨http://data.worldbank.org/indicator/NY.GDP.PCAP.CD⟩ (accessed 07.08.14).
World Bank, 2014b. Population Density (People per sq. km of land area). ⟨http://data.worldbank.org/indicator/EN.POP.DNST⟩ (accessed 07.11.14).
World Bank, 2014c. CO_2 Emissions (kt). ⟨http://data.worldbank.org/indicator/EN.ATM.CO_2E.KT/countries⟩ (accessed 07.24.14).
World Bank, 2015a. World Development Indicators. Poverty Headcount Ratio at US$2 a Day (PPP) (% of Population) ⟨http://databank.worldbank.org/⟩ (accessed 26/03/2015).
World Bank, 2015b. World Bank Data: Motor Vehicles (per 1000 people), ⟨http://databank.worldbank.org/⟩ (accessed 26/03/2015).
Wetzelaer, B.J.H.W., van der Linden, N.H., Groenenberg, H., de Coninck, H.C., 2007. GHG Marginal Abatement Cost Curves for the Non-Annex I Region. ECN—Energy Research Centre of the Netherlands, Petten.
Zhang, X.H., Han, J., Zhao, H., Deng, S.H., Xiao, H., Peng, H., Li, Y.W., Yang, G., Shen, F., Zhang, Y.Z., 2012. Evaluating the interplays among economic growth and energy consumption and CO_2 emission of China during 1990–2007. Renewable Sustainable Energy Rev. 16 (1), 65–72.