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An Analysis of Magnitudes and Trends of Household Carbon Emissions in China Between 1995 and 2011

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ABSTRACT:Global greenhouse gas emissions from 2000 to 2010 has grown more quickly (2.2%/yr) than in the previous three decades (1.3%/yr). China accounts for approximately 23% of global CO_2 emissions and the household sector is considered the major contributor. This study conducts a time series analysis of a per person household carbon emissions (HCEs) in China during 1995 to 2011. Annual macroeconomic data for the study were obtained from Chinese government sources. Direct HCEs estimates for all fossil fuels were obtained using the IPCC's reference approach, and indirect HCEs were calculated by input-output analysis. In 1995, per person direct and indirect HCEs for China were 0.30 tCO_2 and 0.24 tCO_2, respectively, and in 2011 these values had increased to 0.60 tCO_2 and 1.17tCO_2 respectively; an increase of 100% and 387%, respectively. This suggests that any policy based on the direct HCE sources could be misleading, highlighting a need for a comprehensive assessment of both direct and indirect sources of HCEs. A multiple regression model shows that the impact of per capita income (PCI) on per person HCEs is more significant than that of the household size. As PCI is increasing faster than household sizes are decreasing (308% *vs* 18% from 1990 to 2011), the impact of PCI will be dominant in the future. Therefore, while forecasting per person HCE, PCI could be used as an independent variable. As the trends of household size and PCIs are similar in many other developing countries, this conclusion could be replicated elsewhere.

Key words: Income, Coal, Emissions, Household-size, China

INTRODUCTION

Over past decades several multilateral institutions have been established and national policies have been developed in an attempt to mitigate greenhouse gas (GHG) emissions. Despite these efforts, global GHG emissions from 2000 to 2010 grew more rapidly (2.2%/yr) than in each of the three previous decades (1.3%/yr), reaching 49 (±4.5) $GtCO_2e$/yr in 2010 (IPCC, 2014). Improvements in infrastructure in rapidly emerging countries such as China and India account for much of this increase (Liu et al., 2011). This trajectory is consistent with the upper end of the emissions scenarios projected by the IPCC for the last decade (IPCC, 2014). As a result the impacts of global temperatures are also at the upper end of temperature scenarios. Therefore realizing the two degree climate change target as proposed by the UNFCCC at Cancun is problematic.

Several efforts are occurring in an attempt to reduce energy consumption and emissions reduction. Two areas that are richly researched are energy efficiency/intensity and rebound effect. Several studies have examined the energy efficiency/intensity in different countries including: (1) Germany, applying the TIMES model, Blesl et al. (2007) evaluated the role of energy efficiency standards in reducing CO_2 emissions; (2) China, using global data envelopment analysis, Wang et al. (2014a) analyzed regional energy efficiency from both dynamic and static perspectives

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and; (3) again in China, Zhang (2003) studied the reasons why the energy intensity reduced in the industrial sector in the 1990s. Similarly; (1) Wang et al. (2012a) identified key influencing factors of CO_2 emissions in Beijing, China, and explored pathways of developing a low-carbon economy and; (2) Wang et al. (2012b) identified key factors affecting CO_2 emissions for each of six key energy-intensive industries in China.

Some others have studied about the rebound effect of energy technology progress: (1) using time series data from 1949 to 1999 Bentzen (2004) analyzed the rebound effect for the US manufacturing sector; (2) using data from 3,500 households Jin (2007) evaluated the rebound effect of residential electricity use in South Korea; (3) Sorrell and Dimitropoulos (2008) refined the definition of the rebound effect by clarifying key conceptual issues and various assumptions; and (4) using 30 provincial government panel data from1996 to 2010, Wang et al. (2014a) investigated the direct rebound effect of urban residential electricity use in China. Setting aside these highly researched areas this study focusses on HCEs.

The household energy sector is a major contributor to global GHG emissions. For example, at the global scale in 2010, the building sector alone accounted for 19% of GHG emissions and approximately 33% of black carbon emissions (IPCC, 2014). In fact total GHG emissions from 1970 to 2010 have increased by only 61% whilst the building sector emissions have more than doubled during the same period (IPCC, 2014).

The household sector consumes a large amount of goods and services (Qu et al., 2013). Production and consumption of them requires energy, resulting in GHG emissions (Maraseni, 2007; Maraseni et al., 2011). There are some studies that have quantified the energy requirements of different household types for various countries including the USA (Herendeen et al., 1976), Norway (Herendeen, 1978), Netherlands (Vringer et al., 1995), Australia (Lenzen et al., 1998), India (Pachauri, 2004) and Brazil (Cohen et al., 2005). Similarly other studies have estimated the household GHG emissions for several countries including the USA (Weber, 2008; Weber et al., 2008), Netherlands (Kerkhof et al., 2009), the UK (Kerkhof et al., 2009; Büchs et al., 2013; Druckman et al., 2009), Sweden (Kerkhof et al., 2009), Norway (Kerkhof et al., 2009), Canada (Statistics Canada, 2011) and Australia (Australian Greenhouse Office, 2014).

Some of these studies have only considered carbon emissions related to a limited number of household goods and services (Kerkhof et al., 2009; Büchs et al., 2013; Druckman et al., 2009; Australian Greenhouse Office, 2014) and others have used lifecycle analysis of 300 distinct commodities including all potential GHGs (Weber, 2008; Weber et al., 2008) but they are based on a consumer expenditure survey of 17,250 households. Moreover these studies are limited to brief time periods and have not considered a time series analysis. A time series analysis not only shows the trends and magnitudes of consumptions but also assists in predicting future consumption behaviors and related emissions. Furthermore, in most of the countries, household sizes are decreasing (Statistics Canada, 2011; Office of National Statistics, 2013; NBSC, 1996-2012) and over time this might have some negative impacts on per person HCEs. Therefore per person HCEs are a more accurate metric for comparing HCES between countries. Using China as a case study, this study aims to analyze the dynamics of per person HCEs over the period of 1995 to 2011 using time series techniques. Specific objectives of this study include an analysis of the; (1) per person consumption of direct and indirect household goods and services; (2) proportion of direct and indirect HCEs contributed by different goods and services; (3) magnitudes and trends of per person direct and indirect HCEs; and (4) impacts of per capita income and household size on per person HCEs.

Direct household goods considered in this study are raw coal, washed coal, moulded coal, cooking coal, coke oven gas, other gases, gasoline, kerosene, diesel, liquid petroleum gas (LPG), natural gas and electric power. Similarly, indirect household goods and services include food, clothing, reside (residential), household equipment, transportation and communication, cultural & educational entertainment and also medical care. The emissions related to these sources are referred to as direct and indirect HCEs respectively.

China, along with being second largest economy and the most populated country in the world, is also the largest GHG emitting country in the world. Therefore it has the largest number of Clean Development Mechanism projects in the world (Maraseni and Xu, 2011; Maraseni, 2013). It shares 14.63% of global GDP, 19.42% of global population and 22.95% of global CO_2 emissions (Burck et al., 2014). Therefore, without China's involvement, achieving global GHG mitigation targets is almost impossible. Moreover, due to rapid increases in household incomes, consumption levels of household goods and services have and are growing rapidly in China (Liu et al., 2011; Qu et al., 2013; Liao et al., 2013). Realizing this critical problem, at the 15th APEC meeting, China's then president Hu Jintao stressed the importance of compatibility between production and consumption in achieving sustainable development and reducing ecological footprints. In fact this is the global problem facing every emerging economy today.

MATERIALS & METHODS

Data source: As noted, this study is based on macro-economic data of China between 1995 and 2011. Annual data for household size, per capita income, population, and also household consumption of different types of direct and indirect goods and services were obtained from 17 volumes of; (1) China Statistical Yearbook (NBSC, 1996-2012); (2) China Energy Statistical Yearbooks (NBSC, 1996-2012); and (3) China Population Statistical Yearbook (NBSC, 1996-2012). Consumed direct and indirect goods and services amounts were converted into HCEs amounts using their emission factors (discussed below).

Estimation of direct HCEs: As noted, direct HCEs are related to the combustion of different types of fossil fuels. Direct HCEs estimate for each fossil fuel were obtained using the IPCC's reference approach as per Equation 1 (IPCC, 2006).

$$E_D = \sum_{i=1}^{i=n} (f_i \times e_i \times c_i \times o_i) \times 44/12 \times 10^{-4} \quad (1)$$

where "E_D" is the amount of total direct carbon emission (t CO_2), "i" is the number of fuel types, "f_i" is the fuel consumption of household (in t or m3), "e_i" is the Net Calorific Value (NCV) of the fuel "f_i" (TJ/ten thousand t), "c_i" is the carbon Emission Factor (CEF) of the fuel "f_i" (t C/TJ), "oi" is the fraction of carbon oxidized (COF) for the fuel "f_i", and 44/12 is the ratio of molecular weight of CO_2/C. The coefficients of each fuel type are presented in Table1.

In the case of electricity, as suggested in the National Development and Reform Commission report (NDRC, 2009), an emission factor of 0.9976 t CO_2/MWh was used. The emission factor for electricity depends on the mix of energy sources since some sources are more carbon intensive than others. The China Statistical Yearbook (NBSC, 1996-2012) regularly updates emission factors for China because the aforementioned energy mix, and thus emission factors, may change over time. For this study, the latest weighted average emission factors based on the proportion of different electricity sources were used.

Estimation of indirect HCEs: As noted, indirect HCEs are related to the consumption of indirect household goods and services. Due to the lack of data availability of the life cycle of certain goods, indirect CO_2 emissions from household consumption were calculated by input-output analysis, following Vringer and Blok (1995) , Wang et al.(1996) , Liu et al. (2011) , Zhu et al. (2012) and Qu et al. (2013). CO_2 emission factors for different types of goods and services are presented in Table 2. The emission factors of given goods and services were multiplied by their consumptions (in RMB) and individual and total indirect emissions were estimated (Equation 2).

$$E_I = \sum_{d=1}^{d=n} (I_d \times C_d \times 10^{-3}) \quad (2)$$

where E_I is the total indirect HCEs (t CO_2), "d" is the number of household consumption items, "I_d" (RMB) is the consumption of household goods and services and "C_d" is the CO_2 emissions (kg CO_2/RMB) from the consumption of goods and services.

Table 1. Net calorific value, carbon emission factor and fraction of oxidized carbon for different fossil fuels used in China

F Fossil fuel type	Net calorific value (e_i) (TJ/ ten thousand t)	C emission factor (c_i) (tC/TJ)	Fraction of C oxidized (o_i)
Raw coal	209.08	26.37	0.94
Washed coal	94.09	25.41	0.90
Moulded coal	147.60	33.60	0.90
Cooking coal	284.35	29.50	0.93
Coke oven gas	173.54	13.58	0.99
Other gas	182.74	12.20	0.99
Gasoline	430.70	18.90	0.98
Kerosene	430.70	19.60	0.98
Diesel	426.52	20.20	0.98
LPG	501.79	17.20	0.98
Natural gas	389.31	15.30	0.98

Source: NDRC, 2007

Table 2. CO2 emission factors for different types of indirect goods and services

Items/sectors	CO_2 emission
Food	0.095
Clothing	0.126
Reside	0.192
Household equipment	0.156
Transportation &	0.160
Cultural &	0.177
Medical care	0.159
Others	0.064

Source: NBSC, 2008

RESULTS & DISCUSSIONS

Per capita consumption of direct and indirect goods and services: As aforementioned, production and use of goods and services requires energy. Therefore amounts of household consumption of these goods and services decide the amount of HCEs. Per capita consumption of direct and indirect goods and services in China are provided in Table 3 and 4. As expected, in general, when compared to 1995, per capita consumption of direct goods and services increased in 2011 (Table 3). The three highest increments were observed in diesel (6500%), gasoline (2060%) and natural gas (1124%). However, in the case of cooking coal, raw coal and washed coal, per capita consumption decreased by 72.7%, 45% and 13%, respectively. These observed trends are mainly because of; (1) rapidly changing lifestyles, such as moving away from conventional coal-based energy towards petroleum products (Wu et al., 2006; Lu et al., 2014); (2) the positive response of government policy on coal consumption (Australian Government Climate Change Authority, 2013) and; (3) the increasing consciousness of health costs arising from the use of coal (IPCC, 2014).

Unlike direct goods and services, real consumption data for indirect goods and services are difficult to present. Therefore, following previous studies (Liu et al., 2011; Qu et al., 2013; Wang et al., 1996; Zhu et al., 2012), consumption of indirect goods and services are presented in RMB values (Table 4). From 1995 to 2011, per capita consumption of all indirect goods and services has increased. However, the increasing rates for these goods and services were not similar. Over the 17 year period, the largest observed increment was in medical care (by 887%), followed by "cultural and educational entertainment" (792%) and "transportation and communication" (715%), whereas the lowest observed increment was in food (90%).

There are some reasons for these higher increment rates; (1) people are more concerned about their health and hygiene; (2) increasing pollution has forced them to seek more medical care and; (3) with increased income and exposure to global opportunities, people are more likely to pursue higher education and more recreational travel. Similarly, the lowest increment in food consumption expenditure could be explained by Engel's Law (1857); when people are richer, they give relatively less attention to food and more attention to quality lifestyle. The food-related findings are consistent with several other international studies (Liu et al., 2011; Dai et al., 2012; Liu et al., 2011). Moreover, with rapid economic development, people become further aware of the many goods and services which influence residential energy consumption such as the different fuel types, electricity-using appliances and house heating (Glicksman et al., 2001; Riley, 2002; Deng, 2007; Zhou et al., 2009). Increasing numbers of people tend to prefer cleaner energy, energy efficient electronic products and a comfortable living environment, while also devoting less attention to food.

A brief snapshot of per capita national and HCEs: Per capita carbon emission is a broad figure, calculated by dividing the total national carbon emissions by the total population, whereas per person HCEs is the sum of both direct and indirect HCEs, coming from the division of total HCEs by total number of people. The gap between these two emissions shows the emissions from non-household sources (Table 5).

There were 1.21 billion people in China in 1995 and this increased to 1.34 billion in 2010. Over the same period, national population and national carbon emissions increased by 10.7% and 149.6% respectively. As a result per capita national carbon emissions increased by over 129%, from 2.7 tCO_2 in 1995 to 6.2 tCO_2 in 2010. However, although China is the world largest carbon emitter since 2007, its per capita carbon emission is much lower than several other countries, such as Australia (24.3 tCO_2e/yr), USA (17.9 tCO_2e/yr), Canada (16.33 tCO_2e/yr) and Russia (12.03 tCO_2e/yr) (DCCEE, 2012; World Bank, 2012).

During the study period per person HCEs increased by 198.1%, the largest increment among the above noted measures. As a result, during this period, the contribution of household emissions to the national emissions also increased tremendously, from as low as 18.6% in 1996 to 26% in 2010. If this trend continues, the contribution of HCEs to national emissions will increase by over 4.9% every decade.

Increasing HCEs is also a major issue in many other countries including Canada (Statistics Canada, 2011) and the USA (Underwood, 2013). Therefore, if the reduction of HCEs is not given higher priority, it will create several problems. Thus development of

Table 3. Per capita consumption of direct goods and services (units for coke oven gas, other gas and natural gas are in m3, electric power in KWhr and all other in tonnes) in China

Year	Raw coal	Washed coal	Moulded coal	Cooking coal	Coke oven gas	Other gas	Gasoline	Kerosene	Diesel	LPG	Natural gas	Electric power
1995	0.1033	0.0080	0.0004	0.0011	1.831	2.849	0.0005	0.0005	0.0001	0.0044	1.603	83.023
1996	0.0677	0.0066	0.0083	0.0011	1.976	4.367	0.0015	0.0005	0.0009	0.0058	1.693	87.266
1997	0.0624	0.0064	0.0080	0.0011	3.243	5.644	0.0016	0.0005	0.0010	0.0062	1.716	98.131
1998	0.0597	0.0059	0.0072	0.0012	2.944	6.739	0.0017	0.0006	0.0012	0.0069	1.933	103.758
1999	0.0566	0.0061	0.0069	0.0011	2.788	6.474	0.0018	0.0006	0.0013	0.0067	2.045	108.182
2000	0.0545	0.0064	0.0058	0.0011	2.916	7.058	0.0018	0.0006	0.0014	0.0068	2.550	114.559
2001	0.0533	0.0067	0.0059	0.0011	2.771	6.551	0.0019	0.0006	0.0016	0.0067	3.299	126.089
2002	0.0532	0.0061	0.0062	0.0009	2.820	6.974	0.0021	0.0003	0.0017	0.0075	3.594	137.904
2003	0.0563	0.0064	0.0069	0.0009	3.027	7.118	0.0026	0.0003	0.0019	0.0086	4.015	159.258
2004	0.0607	0.0069	0.0075	0.0008	3.168	7.455	0.0035	0.0002	0.0029	0.0104	5.171	183.439
2005	0.0620	0.0073	0.0075	0.0007	3.380	7.693	0.0040	0.0002	0.0031	0.0102	6.075	220.625
2006	0.0627	0.0067	0.0069	0.0007	3.484	9.172	0.0047	0.0002	0.0036	0.0111	7.807	254.974
2007	0.0603	0.0066	0.0070	0.0006	3.120	10.922	0.0059	0.0001	0.0041	0.0124	10.852	307.481
2008	0.0573	0.0068	0.0047	0.0005	3.135	10.710	0.0064	0.0001	0.0045	0.0110	12.810	331.027
2009	0.0570	0.0070	0.0043	0.0004	2.927	9.536	0.0075	0.0001	0.0049	0.0112	13.314	365.093
2010	0.0568	0.0071	0.0044	0.0003	3.972	8.473	0.0091	0.0001	0.0057	0.0109	16.921	382.176
2011	0.0569	0.0070	0.0045	0.0003	2.837	8.004	0.0108	0.0002	0.0066	0.0119	19.622	417.120
Changed % (1995-2011)	(45)	(13)	1025	(72.7)	55	181	2060	(60)	6500	170.45	1124	402

Table 4. Per capita expenditures (in RMB) in indirect good and services in China

Year	Food	Clothing	Residential	Household equipment	Transportation & communication	Cultural & educational entertainment	Medical care	Others
1995	1057.96	202.88	201.95	134.83	73.62	163.47	62.12	60.33
1996	1111.63	223.55	235.73	136.71	80.70	208.96	76.21	67.15
1997	1141.22	217.86	262.32	139.17	82.38	253.29	89.55	70.27
1998	1163.31	205.88	288.27	147.50	84.93	295.56	105.66	74.89
1999	1218.03	213.58	308.11	161.02	92.82	351.62	125.66	87.31
2000	1270.47	230.05	352.01	173.60	108.52	423.07	167.81	103.89
2001	1316.64	252.55	394.54	176.15	129.70	469.26	174.54	116.08
2002	1458.60	289.10	453.09	166.53	175.26	604.73	211.05	89.34
2003	1512.81	322.98	505.56	173.35	210.33	664.13	233.62	91.39
2004	1572.73	361.16	540.80	179.97	248.06	741.61	260.07	98.88
2005	1693.26	439.22	609.67	207.69	300.37	827.51	301.55	110.45
2006	1779.03	507.69	715.30	235.62	342.58	900.59	328.59	121.06
2007	1848.57	599.70	807.48	280.60	399.93	989.46	378.59	137.68
2008	1909.35	684.80	927.38	320.06	408.77	1024.99	436.83	149.60
2009	1852.22	781.00	1024.73	367.33	480.87	1152.39	491.21	175.84
2010	2052.49	906.15	1115.79	416.55	558.35	1289.44	519.18	182.96
2011	2009.27	1067.67	1185.55	480.16	600.08	1458.87	613.35	208.49
Increased % (1995-11)	90	426	487	256	715	792	887	246

Table 5. Share of national carbon emissions by HCEs in China

Year	Total population (10,000)	Total national C emissions	National per capita emissions (tCO2)*	Per person household C emissions (tCO2)**	Share of national emissions by household
1995	121,121	3,320,285	2.7	0.54	20.0
1996	122,389	3,463,089	2.8	0.52	18.6
1997	123,626	3,469,510	2.8	0.54	19.3
1998	124,761	3,324,345	2.7	0.55	20.4
1999	125,786	3,318,056	2.6	0.58	22.3
2000	126,743	3,405,180	2.7	0.63	23.3
2001	127,627	3,487,566	2.7	0.66	24.4
2002	128,453	3,694,242	2.9	0.73	25.2
2003	129,227	4,525,177	3.5	0.80	22.9
2004	129,988	5,288,166	4.1	0.89	21.7
2005	130,756	5,790,017	4.4	1.00	22.7
2006	131,448	6,414,463	4.9	1.11	22.7
2007	132,129	6,791,805	5.2	1.25	24.0
2008	132,802	7,035,444	5.3	1.33	25.1
2009	133,450	7,692,211	5.8	1.48	25.5
2010	134,091	8,286,892	6.2	1.61	26.0
Increased % (1995-2010)	10.7	149.6	129.6	198.1	30.0

Note: *Per capita C emissions comes from the division of total national emissions by total population. ** Per person household C emission is the sum of both direct and indirect household emissions, coming from the division of total household emissions by total number of people.

household centric policies and practices and extension activities are crucial for reducing HCEs and improving the health and hygiene of the local people.

Dynamics of direct HCEs from different sources: During the 17 year study period, direct HCEs in China increased by 122.9%, from 363 $MtCO_2$ in 1995 to 809 $MtCO_2$ in 2011 (Table 6). In 1995, "raw coal" sourced the highest percentage of HCEs (62.8%), followed by electric power (27.67%) and washing coal (4.87%). From 1995 to 2011, the proportion of 'raw coal" related emissions decreased significantly to 17.24%, whilst the proportion of "electric power" related emissions increased to 69.31%. However the percentage share of these two sources combined remained almost the same, both in 1995 (90.47%) and 2011 (86.55%). This is mainly due to type of energy access and affordability issues. Urban households have higher affordability and greater access to electricity whereas rural households have less affordability but have greater access to cheap coal (Feng et al., 2011; Liu et al., 2011; Liao et al., 2013). The overall trend of decreasing reliance on coal could be due partly to health and hygiene issues related with coal and also the government's capping policy on coal consumption (Australian Government Climate Change Authority, 2013).

During the 17 year period, the proportion of emissions from diesel, gasoline and molded coal increased by over 2412%, 925% and 491% respectively but collectively they are still only a very small source of emissions (<3%) whilst, in the case of cooking coal, kerosene and washed coal, the proportion of emissions decreased by more than 86%, 84% and 56% respectively. These changes are due to changes in people's behavior, evolving from increased household incomes, technological improvements and rapid urbanization and industrialization (Hu et al., 2006; Wei et al., 2009; Yu, 2012; Wang et al., 2012; Li et al., 2012).

Dynamics of indirect HCEs from different sources: In 1995, indirect HCE was responsible for only 290 $MtCO_2$ emissions but, by 2011, this value had skyrocketed to 1572 $MtCO_2$ (Table 7). During this 17 year period, direct HCEs increased by only 123% whereas indirect HCEs increased by over 442%. Therefore indirect HCE is becoming an emerging issue in China.

In 1995, food related emissions presented the highest percentage of indirect HCEs (42.07%), followed by residential (16.9%), cultural and educational entertainments (12.41%) and clothing (10.34%). However, during the 17 year period, the shares of food and reside related emissions decreased by 58% and 39% respectively. Conversely, the shares of cultural and educational entertainments and clothing related emissions increased by 79.9% and 16.2% respectively. The largest increment was observed in "transportation

Table 6. Percentage share of direct HCEs by different sources in China

Year	Emission 100 million t CO_2	Raw coal	Washed coal	Moulded coal	Cooking coal	Coke oven gas	Other gas	Gasoline	Kerosene	Diesel	LPG	Natural gas	Electric power
1995	3.63	62.80	4.87	0.23	0.66	0.11	0.17	0.32	0.32	0.08	2.68	0.10	27.67
1996	3.14	48.00	4.69	5.86	0.75	0.14	0.31	1.04	0.38	0.63	4.14	0.12	33.95
1997	3.19	43.96	4.49	5.65	0.78	0.23	0.40	1.11	0.36	0.68	4.34	0.12	37.89
1998	3.23	41.96	4.13	5.04	0.84	0.21	0.47	1.17	0.41	0.82	4.84	0.14	39.97
1999	3.24	39.98	4.29	4.91	0.80	0.20	0.46	1.24	0.39	0.94	4.76	0.15	41.89
2000	3.28	38.26	4.52	4.07	0.76	0.20	0.49	1.26	0.40	0.99	4.76	0.18	44.11
2001	3.44	36.00	4.52	3.97	0.71	0.19	0.44	1.29	0.40	1.06	4.53	0.22	46.67
2002	3.62	34.31	3.95	4.00	0.58	0.18	0.45	1.37	0.20	1.07	4.87	0.23	48.78
2003	4.06	32.60	3.73	4.01	0.50	0.17	0.41	1.52	0.16	1.11	4.98	0.23	50.56
2004	4.61	31.13	3.54	3.85	0.41	0.16	0.38	1.80	0.11	1.47	5.32	0.27	51.55
2005	5.18	28.48	3.35	3.46	0.32	0.15	0.35	1.84	0.09	1.43	4.67	0.28	55.59
2006	5.70	26.31	2.83	2.89	0.29	0.15	0.38	1.97	0.07	1.50	4.65	0.33	58.64
2007	6.45	22.48	2.46	2.61	0.23	0.12	0.41	2.20	0.05	1.54	4.62	0.40	62.88
2008	6.66	20.79	2.49	1.72	0.18	0.11	0.39	2.34	0.03	1.62	3.98	0.46	65.88
2009	7.17	19.32	2.37	1.47	0.12	0.10	0.32	2.54	0.05	1.66	3.80	0.45	67.81
2010	7.49	18.51	2.32	1.42	0.11	0.13	0.28	2.95	0.05	1.87	3.54	0.55	68.27
2011	8.09	17.24	2.12	1.36	0.09	0.09	0.24	3.28	0.05	2.01	3.61	0.59	69.31
Change % (1995-11)	122.9	(72.5)	(56.5)	491.3	(86.4)	(18.2)	41.2	925.0	(84.4)	2412.5	34.7	490.0	150.5

Table 7. Percentage share of indirect HCEs by different sources in China

Year	Emission 100 million t CO_2	Food	Clothing	Residential	Household equipment	Transportation & Communication	Cultural & Educational Entertainment	Medical care	Others
1995	2.90	42.07	10.34	16.90	8.28	4.83	12.41	4.14	1.03
1996	3.21	40.19	10.59	15.89	8.72	5.92	12.46	4.67	1.56
1997	3.45	38.55	9.86	15.65	8.70	6.67	13.62	5.22	1.74
1998	3.67	37.60	8.72	15.80	8.99	7.36	15.26	5.18	1.09
1999	4.04	35.89	8.42	14.60	9.65	8.91	16.09	5.20	1.24
2000	4.66	33.05	7.94	14.59	8.15	11.59	17.17	6.44	1.07
2001	5.01	31.94	8.18	14.57	8.18	12.97	16.57	6.59	1.00
2002	5.77	30.85	8.15	13.34	7.63	14.56	17.50	6.93	1.04
2003	6.32	29.27	8.39	12.97	7.75	16.46	17.09	7.28	0.79
2004	6.97	27.98	8.46	12.20	7.32	18.36	17.22	7.60	0.86
2005	7.93	26.48	9.33	11.35	7.57	19.92	16.52	8.07	0.76
2006	8.89	24.97	9.67	11.59	7.54	21.15	16.42	7.87	0.79
2007	10.10	23.07	10.20	11.39	8.12	22.67	16.14	7.62	0.79
2008	10.98	22.04	10.75	11.66	8.47	22.68	15.66	7.92	0.82
2009	12.58	20.27	10.81	11.92	8.66	24.40	15.26	7.79	0.87
2010	14.06	18.71	11.38	10.88	9.17	26.39	15.36	7.25	0.85
2011	15.72	17.49	12.02	10.31	9.54	26.53	15.78	7.44	0.89
Change % (1995-11)	442.1	(58.4)	16.2	(39.0)	15.2	449.3	27.2	79.7	(13.6)

and communication", with a more than 449% increase. Therefore, as aforementioned, once people secured an adequate and safe nutrition level, they tend to prioritize money on other things such as transport, education and medical care rather than food. The findings are in agreement with several other studies (Glicksman et al., 2001; Riley, 2002; Deng, 2007; Zhou et al., 2009).

Dynamics of per person HCEs: Trends of per person HCEs from direct and indirect sources are given in Figure 1. In 1995 per person direct and indirect HCEs for China were 0.3 tCO_2 and 0.24 tCO_2 respectively. By 2011 these values had increased to 0.60 t CO_2 and 1.17 tCO_2, respectively, an increase of 100% and 387%, respectively. However one thing is worthwhile to mention here; due to the decrease in carbon intensity, the emissions factor for indirect household goods and services might have changed. As noted, for this study we have used the latest (2007) emissions factors so that our estimation is as accurate as possible. However, we acknowledge that the real emissions for the years before 2007 due to consumption of indirect household goods and services could be higher than the estimated value and, after 2007, could be lower than the estimated value, as, in China, carbon intensity decreased by an average of 1.9% per annum between 2007 and 2012 (PWC, 2013).

Due to the large geographical area, energy sources are varied in China. Urban households often have greater access to efficient and cleaner energy, whilst rural households usually have greater access to coal (Feng et al., 2011). Therefore rural households are more emission-intensive in their direct energy consumption because of their heavy reliance on coal, whilst urban households are more emission-intensive in their indirect energy consumption (Golley et al., 2012).

Furthermore, with economic growth, people tend to give greater consideration to medical treatments and health, housing, education, transportation, household electrical appliances in both urban and rural areas. This may be a reason as to why we observe a greater increase in indirect HCEs in comparison to direct HCEs. This suggests that the direct HCEs do not provide complete picture and any policy based on direct energy consumption (or direct HCEs) could be misleading, highlighting a need for comprehensive assessment of both direct and indirect sources of HCEs.

In aggregate, per person HCEs increased from 0.54 t CO_2 in 1995 to 1.77 t CO_2 in 2011, increasing by 227.8%. If this current trend continues, the total per person HCEs at 2020 will be 3.64 t CO_2 (Fig. 1). As a result resource use will also increase in the future. However, the ratios of exploitation to reserve of fossil fuels in China are lower than the global average values. Large amount of energy resources will be imported to meet the requirements of economic development in the future (Jiang et al, 2010). Moreover, China has set an ambitious goal of 40–45% carbon intensity reduction by 2020 when compared to 2005 (Network for Climate and Energy Information, 2014). Similarly, it has put a cap on coal consumption (Australian Government Climate Change Authority, 2013). To achieve these goals, many studies proposed energy-saving methods for different sectors such as the building sector (Li et al., 2007), transportation sector (Jia et al., 2010) and urban heating system (Chen et al., 2014). Similarly many energy efficient vehicles and appliances are being promoted (Australian Government Climate Change Authority, 2013). Therefore the increasing rate of emissions could decrease in the future, mainly from direct sources.

Income impact on per person HCEs: Per person direct, indirect and total HCEs by per capita income (PCI) are given in Fig. 2. The PCI of Chinese people increased by 308%, from RMB2,904 in 1995 to RMB11,849 in 2011. Per person indirect and total HCEs are highly positively correlating to PCIs. In both cases, through a linear regression, the PCI explains over 97% of the total variations in per person HCEs. However, the explanatory power of PCI to per person direct HCEs is lower, indicating that the direct HCEs are relatively less affected by income level. This is because the direct HCEs are a sort of 'compulsory emissions', required to meet basic needs (Qu et al., 2013). At lower income levels, people use most of their income for direct goods and services and therefore direct HCEs are higher than indirect HCEs (Qu et al., 2013). However, when PCI increases, their spendable income quickly moves towards indirect goods and services and, as a result, indirect HCEs increases faster than direct HCEs.

China's economy is growing faster than many other countries across the world. Therefore it is highly likely that HCEs will increase, mainly from indirect sources. However China has been aggressively launching different policies in response to this growth and has become a global leader in renewable energy. China obtains 8% of its energy and 17% of its electricity from renewable sources, values which are projected to increase to 15% and 21% respectively by 2020 (Martinot et al., 2007). Therefore, in the future, the slope of the trend-line may plateau but it will still increase with PCI.

Household size effect on per person HCEs: Household size (number of people per house) has a negative correlation with per person HCEs (Fig. 3). In China, due to the increasing influence of the western society and increasing preference of individualistic lifestyles, household size has been slowly decreasing. In 1995, household size was 3.7 and by 2011, it has decreased to 3.02. During the same period, per person HCEs increased by 227.8%. There is a negative correlation between these two parameters. Therefore extended family is more carbon friendly than nuclear family. This is in agreement with the study from Qu et al. (2013), Underwood (2013), IPCC (2014) and Wang et al. (1996). Globally, due to increasing population, household numbers are increasing and household sizes are decreasing. Both of these factors could result in escalating per person HCEs.

Combined impact of PCI and household size effect on per person HCEs: A multiple regression model (Equation 3) is developed for finding the combined impact of per capita income (PCI) and household (HH) size on the per person household carbon emission (PCE). The model is well fitted and its predictive power is very good (R^2=0.997; p=000). According to this

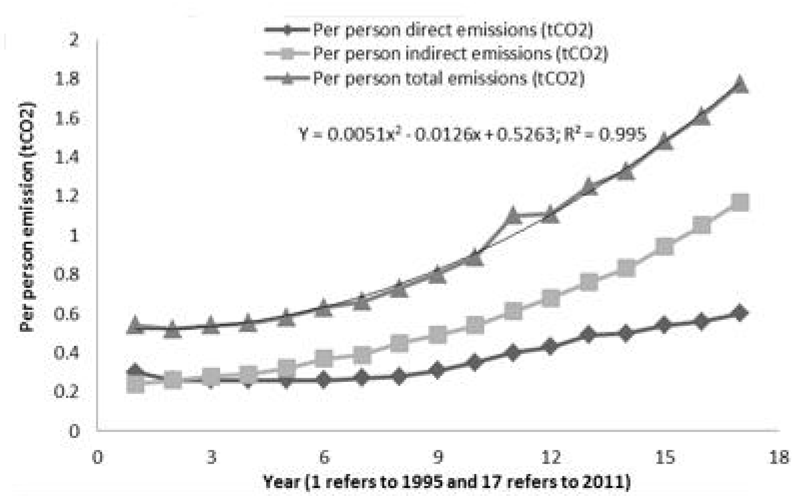

Fig. 1. Per person HCEs from direct and indirect sources in China (trend line and best fitted model, binomial equation, are shown for total CO_2 emissions)

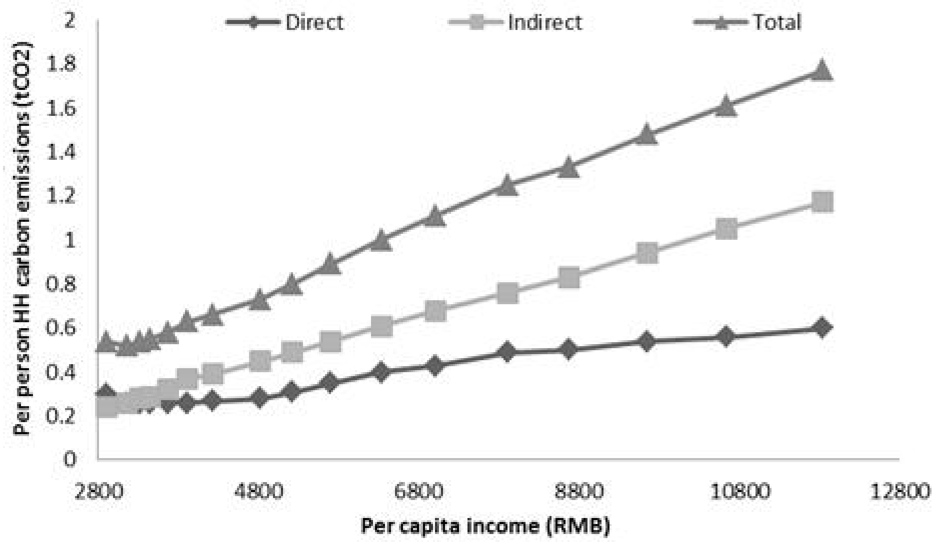

Fig. 2. Showing relationships between per capita income and direct, indirect and total per person HCEs in China

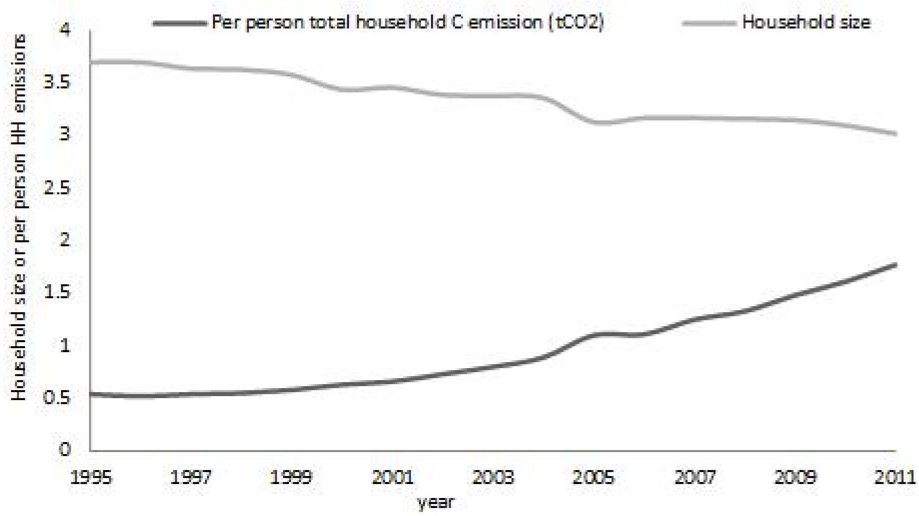

Fig. 3. Showing relationship between household size and per person HCEs in China.

model, if the current trend continues and household size remains constant, a 1% increase in PCI from current levels (RMB11,849) will increase PCE by about 0.017 tCO_2 (17 $kgCO_2$) per year.

$$\text{PCE} = 0.118 - 0.015 \times HHSize + 0.000145 \times PCI \quad (3)$$

Similarly, if the current trend continues and PCI remains constant, a one percent decrease in household size will increase PCE by 0.000453 tCO_2 (0.453 $kgCO_2$). These results indicate that the impact of PCI is much bigger than that of HH size. The impact of PCI is further compounded with the fact that the increasing rate of PCI is much faster than the decreasing rate of household size. Furthermore, in this model, PCI alone also explained about 99 percent variation in PCE. Addition of another independent variable (HH size) marginally increases the explanatory power of PCE. Therefore, whilst predicting HCE, PCI could be used as the sole determining/independent variable.

CONCLUSIONS

Every new decade is becoming a record setting decade for global GHG emissions. Due to increases in economic growth and population and also changes in technology and human behaviors, household consumption of goods and services has been growing. This has huge implications on HCE. Using horizontal (within a year) and vertical (between 17 years) analyses, this study assessed per person HCEs in China from 1995 to 2011. During the study period, the proportion of HCEs to the national carbon emissions increased from 18.6% to 26%. Therefore, HCEs are increasingly becoming a pressing issue in China, highlighting the need for development and implementation of household centric carbon friendly policies and practices, and extension activities. Furthermore, in addition to the cap on coal consumption, China also needs to cut the coal and oil subsidies and transfer these subsidies to cleaner non-fossil energy. Increasing HCEs is also a major issue in several other countries. Therefore a coordinated global effort towards addressing this problem could be instrumental.

Consumption of direct and indirect goods and services are rapidly increasing in China for multiple reasons including an increase in household incomes, increasing awareness on health issues and therefore more medical care, increasing use of private vehicles for transportation, increasing use of air-conditioners and hot water systems, increasing interest in pursuing higher education and also in travelling. As a result, compared to 1995, per person direct and indirect HCEs in 2011 increased by 100% and 387% respectively. However, although emission mitigation policies and programs have been developed, greater attention has been given to direct HCEs. If China wants to solve the household carbon mitigation puzzle, greater focus should be on indirect emissions. For this to happen, the consumption behavior of people should be directed towards less carbon intensive goods and services which will ultimately produce a win-win, sustainable solution.

China's PCI is growing rapidly. It has a significant impact on per person HCEs. However, when compared to indirect HCEs, direct HCEs are relatively less affected by PCI. At lower income levels, people use most of their income for direct goods and services and therefore direct HCEs— considered to be essentially 'compulsory emissions'— are higher than indirect HCEs. But, when PCI increases, their consumption behavior quickly shifts towards indirect goods and services. As a result, at higher income levels, indirect HCEs increase faster than direct HCEs, highlighting a need for greater attention to indirect HCEs. Similarly, during the study period, household size decreased by over 18%. As a result, economies of scale of an household might have been reduced.

The multiple regression model suggests that the impact of PCI is much bigger than that of household size. In fact, PCI alone explained over 99% of the total variation in per person HCEs. Moreover, the impact of PCI is further compounded with the fact that the rate of PCI is increasing much faster than the decreasing rate of household size. Therefore, PCI could be used as the sole independent variable in order to estimate per person HCEs.

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