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Household carbon dioxide emissions from peasants and herdsmen in northwestern arid-alpine regions, China

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HIGHLIGHTS

- ► Per capita emissions decrease as the household size increases.
- ► The subsistence emissions accounts for 93.24% of the total emissions.
- ► If heating related emissions are excluded, household emissions are negligible.
- ► The reduction of emissions below current levels is almost impossible.
- ► Poor and vulnerable groups should be given special consideration.

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ABSTRACT

This study assessed household CO_2 emissions (related to the consumption of necessary and luxury goods and services) of peasants and herdsmen households in arid-alpine regions in Gansu, Qinghai and Ningxia provinces, China. We also explored whether agriculture types, family income and family size have played any role in household CO_2 emissions. In order to address these issues, we: (i) developed assessment indicators for household emissions; (ii) conducted semi-structured questionnaire household surveys; and (iii) employed input-output analysis (IOA). The results showed that, the average household CO_2 emission per capita is 1.43 tons (t) CO_2; the proportion of subsistence emissions (related to the consumption of necessary goods and services) accounts for 93.24%, whereas luxury emissions (generated due to consumption of specific goods and services that are consumed only when household income improves) only account for 6.76%t. Moreover, household CO_2 emissions increase with family income and family size, but per capita emissions are inversely related to family size. The highest average household emissions were found in the alpine agricultural and pastoral region (6.18 t CO_2), followed by the irrigated agricultural region (6.07 t CO_2) and the rain-fed agricultural region (5.34 t CO_2). In consideration of insignificant amount of household emissions from these poor and vulnerable groups of the society, this study suggests to follow the principle of fairness while making energy conservation, emission reduction and adaptation policies.

1. Introduction

Climate change adaptation and greenhouse gas (GHG) mitigation measures are inevitable, but they create additional costs for society. These measures are critical to the human right to survival and development (Ding et al., 2009; Gao, 2006; Ge et al., 2010), especially, for poor and vulnerable groups in society. On the one hand, these groups could not afford climate change adaptation costs due to poor socio-economic conditions (Robert et al., 2006; Stern, 2006). On the other hand, living costs will increase and living standards will decline due to climate change mitigation and adaptation actions (Jacoby and Reiner, 1997). Although newly released data show historic declines in poverty worldwide, there are still 1.29 billion people living below 1.25 USD per day (The World Bank, 2012). Therefore, it is crucial to know GHG emission levels of these poor and vulnerable peoples for climate change

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negotiations and to make fair and rational emission reduction and energy conservation policies and plans.

Currently, the vulnerability of the poor and sensitive areas to climate change is being reviewed under an international climate policy framework (Niklas et al., 2003; Parry et al., 2009; Weitzman, 2009). However, GHG emission assessment mainly focuses on the analyses of inter-national and intra-national (regional) emissions based on macroeconomic data. Results from these data only reflect inequality of GHG emissions among different nations or regions. For example, per capita emissions are often used as an indicator to compare emissions amongst countries (Heil and Wodon,1997; Qu et al., 2010; Zhang, 2008). However, this indicator, based on macroeconomic data, cannot accurately reflect the emissions of poor and vulnerable groups whose emission levels may be much lower than the national and regional averages (Qu et al., 2008).

The family is the basic unit of society and consumer of social programs. However, families have differences in lifestyle, size, income, and consumption of goods and services. Therefore, the study of household level CO_2 emissions is able to better reflect inequalities than per capita emissions. There are some studies conducted along this line, beginning with Vringer and Blok′s research on direct and indirect household energy demand (1995). After their study, some scholars have applied input-output analysis to measure household emissions (Biesiot and Noorman, 1999; Bin and Dowlatabadi, 2005; Lenzen, 1998; Munksgaard et al., 2000). But these papers are based on macro-consumption data for statistical analysis and have the same shortfalls as described above.

This article examines inequality in per capita CO_2 emissions from direct and indirect energy consumption at the household scale by calculating emissions for the whole family based on data from field surveys conducted in arid-alpine regions in northwest China and communities typical of less-developed groups in western China. Economic inequality within China has been and will be in existence for a long time, which is the main cause of inequality in income, expenditures and CO_2 emissions per capita in China (Golley et al., 2008; Weber and Matthews, 2008). Household inequality between the different developmental regions is obvious (Clarke-Sather et al., 2011). Therefore, it is particularly necessary to carry out an investigation on household level CO_2 emissions to make an appropriate climate policy and to allocate the right to emit carbon to poor and vulnerable people.

In order to address these issues: we (i) developed assessment indicators for household CO_2 emissions; (ii) conducted questionnaire-based household surveys; and (iii) employed the IPCC′s reference approach and input-output analysis (IOA). Household CO_2 emissions, which are related to the consumption of necessary and luxury goods and services, is further divided into two categories: (i) subsistence household CO_2 emissions which refer to the necessary emissions from the fundamental consumption of the household, including the CO_2 emissions due to use of coal, LPG, gasoline and diesel oil, and the CO_2 emissions from the production, transportation and service processes of goods and services, such as electricity, food, clothing, medicine and medical care; and (ii) luxury household CO_2 emissions, which are generated due to using specific goods and services that are used when household income improves (to some extent) and families can afford these goods and services, such as CO_2 emissions due to the consumption of education, recreation, transportation and communication services. Although consumption of these services looks basic for many developed communities, the luxury emissions in our research are defined as all emissions excluding basic emissions for subsistence.

This paper proceeds as follows: Section 2 discusses the concept of household carbon dioxide emissions. Sections 3 and 4 address the methodology and the results and discussion, respectively. Finally, Section 5 presents some concluding remarks.

2. The concept of household carbon dioxide emissions

Household CO_2 emissions (HHEs) are defined as the emissions of individuals or their families in order to meet the demands of their existence and development under certain socio-economic conditions, which includes both direct and indirect emissions. Direct emissions come from energy use including fossil fuels and for this research electric power. If CO_2 emissions occur before or after a product or service is in use, they are called indirect CO_2 emissions, in this research indirect emissions mainly come from household expenditures on products and services. Indirect emissions are related to the energy consumption and associated emissions embodied in consumer goods and services such as food, clothing, medicine, education, transport and communication. From an economic perspective, as noted above, the HHEs are divided into subsistence household CO_2 emissions (SEs) and luxury household CO_2 emissions (LEs) (Wang et al., 2010). In this study, we conducted intensive field surveys and assessed HHEs, SEs, and LEs for 2008–2009.

The HHEs are used to reflect shared emission levels for the limited emission space and the fairness of allocating levels of interpersonal carbon emissions for individuals in different regions. Since the family and its members are the basic units of human society, HHEs are regarded as the assessment units of individual emissions. This paper adds to current emissions studies by identifying the amounts of CO_2 emissions that are absolutely necessary for poor and vulnerable groups in society.

3. Methodology

3.1. A brief snapshot of the study area and data collection

This paper purposively selected rural households in Gansu, Qinghai and Ningxia Provinces, located in northwest China, as a study area. This study area is characterized by rich landforms (the transition zone of the Mongolian Plateau, Loess Plateau and Tibetan Plateau), fragile ecosystems, less developed economies and high vulnerability to the impacts of climate change (Fig. 1).

The annual average minimum temperature is generally lower than 10 °C. The altitudes of the household samples are from 1300 to 3400 m. So they usually choose coal for heating. The per capita consumption expenditures of rural household in this area are about 3000 RMB per year, and most of consumption expenditures are for food, education and medicine. In order to recruit households to participate in the survey we initially gave numbers to each household in the study area. Then we used simple random sampling techniques to select the samples. We selected 125 rural households in 49 villages of 32 townships distributed in 22 counties. Among them, even with repeated attempts we could not find people in two selected households. Therefore, our sample size is limited to 123, with a sampling ratio of 1/9425. This sample size looks small but given the homogeneity of the lifestyle and living standards in the study area, these response rates are enough for a benchmark study.

We have collected four types of data for this research: (i) household expenditure data (including consumption of food, clothing, medical care, education, entertainment, transportation and communication); (ii) energy consumption data (amount of electricity, coal, LPG, gasoline and diesel oil used); (iii) income, family size and education level data; (iv) geographical location data (altitude and coordinates). All of these four types of datasets

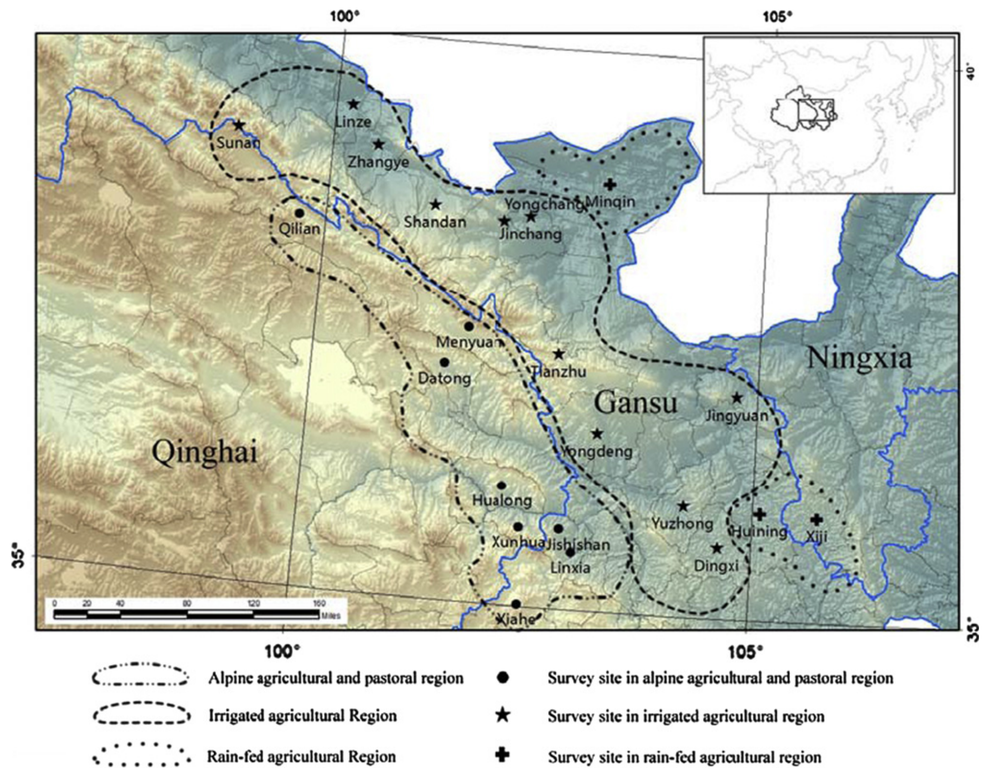

Fig. 1. The location of study area, agriculture regions and survey sites.

were collected from field surveys in the summers of 2008 and 2009. The fifth type of data "CO_2 emission factors for different goods and services" was taken from China's input-output table and the China Energy Statistical Yearbook published by the National Bureau of Statistics of China (2008). On the basis of these data, we estimated the HHEs for the surveyed households and also explored whether altitude, family income and family size have influenced CO_2 emissions levels from these households.

Here a pertinent question may arise whether the collected date are of good quality. In the study area, people generally: buy coals every year; pay electricity bills every month; do transport occasionally; and receive Medicare service when badly needed. They kept most of the receipts. If the data were unexpected, we tried our best to verify them from receipts and or asking some indirect and explanatory questions. For example, how many members of the family were sick, where you got treatment, how many times you traveled and where etc. Therefore, the quality of data is reasonably good.

3.2. Household CO_2 emissions

Calculating total HHEs was conducted in two steps. First, direct CO_2 emissions from household energy use were analyzed using the IPCC's reference approach. Second, indirect CO_2 emissions were estimated using the input-output method. Thus, the total HHEs were estimated using Eq. (1):

$$E_i = E_{fi} + E_{ei} + E_{gi} \quad (1)$$

where E_i (tons (t) CO_2) is the total HHEs from the ith household, E_{fi} (t CO_2) is the direct CO_2 emissions from the combustion of fossil fuels in the ith household, E_{ei} (t CO_2) is the CO_2 emissions from the electricity consumption in the ith household, and E_{gi} (t CO_2) is the indirect CO_2 emissions from the goods/services consumption in the ith household.

3.2.1. Direct CO_2 emissions

Direct household CO_2 emissions are related to the combustion of fossil fuels including coal, gasoline, diesel oil, LPG, and the consumption of electricity in the household (Wang et al., 2010; Liu et al., 2011;Munksgaard et al., 2000). Though biomass is also used as a fuel source in the study area, it has not been considered in this study. It is difficult to compare with other research that does not analyze biomass carbon emissions, since biomass is part of a natural cycle that will not release additional emissions. Direct CO_2 emission estimates for each household were obtained using the IPCC's reference approach as in Eq. (2) (IPCC, 2006).

$$E_{fi} = \sum_{f=1}^{n} \left(F_{fi} e_f p_f O_f \right) \frac{44}{12} \times 10^{-3} \quad (2)$$

where n is the number of fuel types, F_{fi} (t) is the fuel consumption of the fth fuel in the ith household, e_f (TJ/Gg) is the Net Calorific Value (NCV) of the fth fuel, p_f (Kg C/GJ) is the Carbon Emission Factor (CEF) of the fth fuel, O_f is the fraction of carbon oxidized (COF) for the fth fuel, and 44/12 is the ratio of molecular weight of CO_2 C. The coefficients of each fuel type are presented in Table 1.

Eq. (3) showed the estimate approach for the emissions(t CO_2) from the electricity consumption:

$$E_{ei} = P_{ei} \times C_e \times 10^{-3} \quad (3)$$

where P_{ei} (kWh) is the electricity consumption in the ith household, C_e (t CO_2/MWh) is the CO_2 emission factor of the electricity sector in the study area. In this paper, we use 1.0246 t CO_2/MWh as the emission factor which is calculated from the weighted average of the emission factors in 2005–2007 in North-western grid of China[1] .

[1] The National Development and Reform Commission of China, 2009. China's Regional Grid Baseline Emission Factors 2009. download at http://cdm.ccchina.gov.cn/WebSite/CDM/UpFile/File2413.pdf, reference at http://www.cdm-watch.

Table 1
Net calorific value and carbon emission factors coefficients for different types of fuels.
Source: Energy Research Institute, National Development and Reform Commission. The People's Republic of China National Greenhouse Gas Inventory. Beijing: China Environmental Science Press. 2007.

Fuel	Net calorific value (NCV, e_f) (TJ/Gg)	Carbon emission factor (CEF, p_f) (kg C/GJ)	Fraction of carbon oxidized (COF, o_f)
Gasoline	44.8	18.9	0.98
Diesel oil	43.33	20.17	0.982
Kerosene	44.75	19.2	0.98
LPG	47.31	17.2	0.989
Coal	22.35	26.03	0.915

Table 2
CO_2 emissions factors for different types of goods and services (related to indirect energy consumption).
Source: National Bureau of Statistics of China (2008)

Items of indirect emissions/sectors	CO_2 emissions factors (C_g, kg CO_2/RMB)
Food	0.09
Clothing	0.13
Medicine and medical care services	0.07
Education, cultural and recreation services	0.14
Transportation and communication services	0.12

3.2.2. Indirect CO_2 emission

Usually, indirect CO_2 emissions from household consumption are measured by input-output analysis (Wang et al., 2010; Liu et al., 2011; Vringer and Blok, 1995) and the consumer lifestyle approach (Bin and Dowlatabadi, 2005; Wei et al., 2007). Due to the lack of availability of certain goods' life cycle data in China, we applied the basic input-output method to calculate indirect household CO_2 emissions as suggested in China's input-output table and the China Energy Statistical Yearbook published by the National Bureau of Statistics of China (2008). Then the household CO_2 emissions factors were multiplied by household consumption to evaluate the indirect CO_2 emissions (Eq. (4)):

$$E_{gi} = \sum_{g=1}^{n} \left(S_{gi} C_g \times 10^{-3} \right) \quad (4)$$

where n is the number of household consumption sectors, S_{gi} (RMB) is the gth household goods/services consumption in the ith household, C_g (kg CO_2/RMB) is the CO_2 emissions from the consumption of goods/service of gth household. The CO_2 emissions factors for various goods and services are given in Table 2.

4. Results and discussion

4.1. Total household CO_2 emissions

In this study, all the household emissions related to the use of: electricity; coal; gasoline and diesel oil; LPG; food; clothing; medicine and medical care services; education, cultural and recreation services; and transportation and communication services were estimated. Emissions from these uses were considered to estimate the total HHEs. Table 3 shows the average HHEs in the whole study area and in three geographical regions. The inequalities in CO_2 emissions at household levels between the regions are noticeable. The highest HHE (16.95 t CO_2) is more than 68 times higher than the lowest value (0.25 t CO_2). However, 85.37% of the HHEs concentrated within the range of 2.489.94 t CO_2, and average HHEs in the study area were 5.99 t CO_2, of which the direct emissions are 4.95 t CO_2 and indirect emissions are 1.04 t CO_2, respectively. Overall, the direct and indirect emissions account for 82.64% and 17.36% of total emissions, respectively.

The total average emissions decrease from the highest values in the alpine agricultural and pastoral region (6.18 t CO_2) to irrigated agricultural region (6.07 t CO_2) and then to rain-fed agricultural region (5.34 t CO_2). The contribution of emissions from coal consumption is the highest for each region, accounting for 60.68%, 62.16%, 64.27% of the total emissions in the alpine agricultural and pastoral region, irrigated agricultural region and rain-fed agricultural region, respectively, followed by electricity emissions (9.74%, 8.15% and 11.05%). In addition, emissions from three consumption categories in the alpine agricultural and pastoral region, including electricity, clothing and transportation and communication services, are higher than that in the other two regions (Fig. 2). In the alpine agricultural and pastoral region, coal consumption contributes more to the total emissions due to low temperatures in winter and at night in the study area.

Table 3
Total household CO_2 emissions from direct and indirect energy consumption.

CO_2 emissions(tons)	Average total HHEs	Direct emissions	Indirect emissions
The whole study area	5.99	4.95	1.04
Alpine agricultural and pastoral region	6.18	5.12	1.06
Maximum value	16.95	14.11	2.84
Minimum value	0.25	0.01	0.24
Irrigated-agricultural region	6.07	4.96	1.11
Maximum value	10.66	5.89	4.76
Minimum value	0.30	0.06	0.24
Rain-fed-agricultural region	5.34	4.56	0.78
Maximum value	9.10	7.35	1.76
Minimum value	1.28	1.01	0.27

Note: HHE referrers to household emissions. There is a discrepancy between the total household CO_2 emissions and the sums of direct CO_2 emissions and indirect CO_2 emissions due to rounding error.

4.2. Per capita CO_2 emissions

Based on the total CO_2 emissions from household consumption and family size[2] , and assuming equity in household consumption levels for every family member in a household, we calculated per capita CO_2 emissions. In the study area it is about 1.43 t CO_2, far lower than the macro data-based per capita emissions for China (5.24 t CO_2) (Boden et al., 2011). These values, for the study area and national level emissions, are far lower than the per capita emissions of America (17.97 t CO_2) and Australia (18.96 t CO_2) (Boden et al., 2011). In the study area, coal consumption accounts for the highest part of per capita emissions (0.90 t CO_2 or 62.71%), followed by gasoline and diesel oil (10.23%), electricity (9.67%), food consumption (5.29%), education, cultural and recreation services (4.91%), clothing (3.14%), medicine and medical care services (2.00%), transportation and communication services (1.91%) and LPG (0.13%) (Fig. 3).

(*footnote continued*)
org/wordpress/wp-content/uploads/2011/02/rule_consistency_of_grid_emission_factors_published_by_CDM_host_country_authorities_14_Feb_2011-.pdf

[2] Family size refers to the people residing in a household. It does not include the family member/s who do not currently live in the household.

According to a study conducted by Ironmonger et al. (1995), economies of scale in energy use and household expenditures exist among adult-only households. This means, as the number of adults in an adult-only household increases, the per capita energy use and thus CO_2 emissions decrease. In this study, we found that the larger the family size, the lower the per capita CO_2 emissions. Our result is in line with the conclusions from other studies such as Weber and Matthews (2008). Therefore, it is not necessary to have adult-only households to gain economies of scale. Even a mixed-age family could achieve economies of scale if they lived together. This finding fits well with the traditional Chinese culture approach to extended family in which four generations live together (see Fig. 4).

As noted, there is a reasonable homogeneity of the lifestyle and living standards of the people in the study site. Therefore, the range of per capita emissions for each household sizes are not that large. However, in case of family size two (2 people per family) the range of per capita emissions seems to be very high (Fig. 4). There are two reasons: (1) the highest emitting household of this category has used a lot of coals than the other households; and (2) in this particular year, he used a lot of medicines and Medicare services, as both of them were sick.

A plot showing how household income per capita and family size are related is given in Fig. 5. There is a negative relationship between household income per capita and family size ($r = -0.315$). This means when family size increases, household income per capita decreases and so do the emissions per capita. This is because income per capita and emissions per capita are positively correlated.

4.3. Subsistence and luxury CO_2 emissions

As noted above, household CO_2 emissions (HHEs) include subsistence household CO_2 emissions (SEs) and luxury household CO_2 emissions (LEs). The proportion of SEs (which is impossible to avoid for subsistence) reflects the quality of life for household residents.

Table 4 shows the SEs and LEs in the study area. The average value of SEs in the whole study area is 5.58 t CO_2 per household, which is about 93.24% of the total average HHE. This reflects that the expenditure and emissions from households in less developed regions in China are mainly occupied by the consumption of basic goods and services, and that their living standards are low as compared to other regions in the world. Some similar research has found that US households emit the highest amount of CO_2 with 48 t CO_2 per year (Jones and Kammen, 2011), followed by UK households with 33.2 t CO_2 per year (Gough et al., 2011). Although the CO_2 emissions per household are lower in the Netherlands, Norway and Sweden with 19, 13.6 and 12.2 t CO_2 per year respectively (Kerkhof et al., 2009), they are much higher than the poor and vulnerable groups studied.

4.4. Household CO_2 emissions per capita at different income levels

There is a direct relationship between income level and household CO_2 emissions. We divided households into ten different income levels, and then calculated per capita CO_2 emissions from households for different income levels (Table 5).

The per capita CO_2 emissions and the emissions from coal and food consumption increase with the rise of per capita household income. The per capita emissions (1.85 t CO_2/person) for the highest-income households (> 4000 RMB), is 2.18 times higher than those at the income level range of ≦1000 RMB, and 1.70 times higher than those at the income level range of 1000–1500 RMB. The higher CO_2 emissions of households at higher income levels mean that they use more goods and services to meet their increasing demands. Emissions per capita from households at the income level range of 2500–3000 RMB were a little higher possibly caused by the pursuit of improving their diet. Our findings are consistent with the findings of Weber and Matthews (2008), Golley et al. (2008) and Liu et al. (2011).

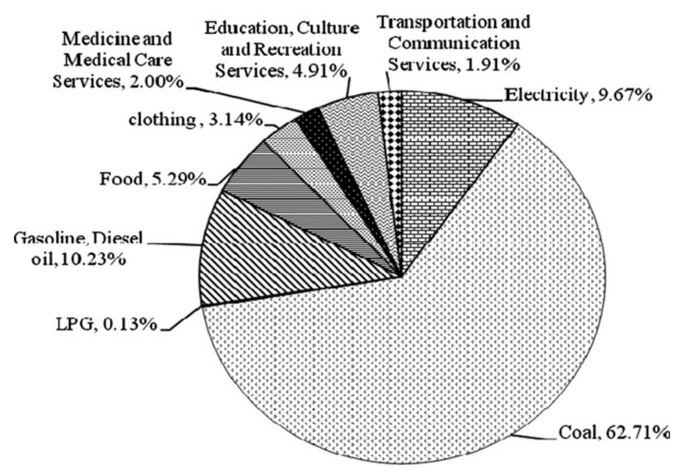

Fig. 3. Share of per capita CO_2 emissions from different sources.

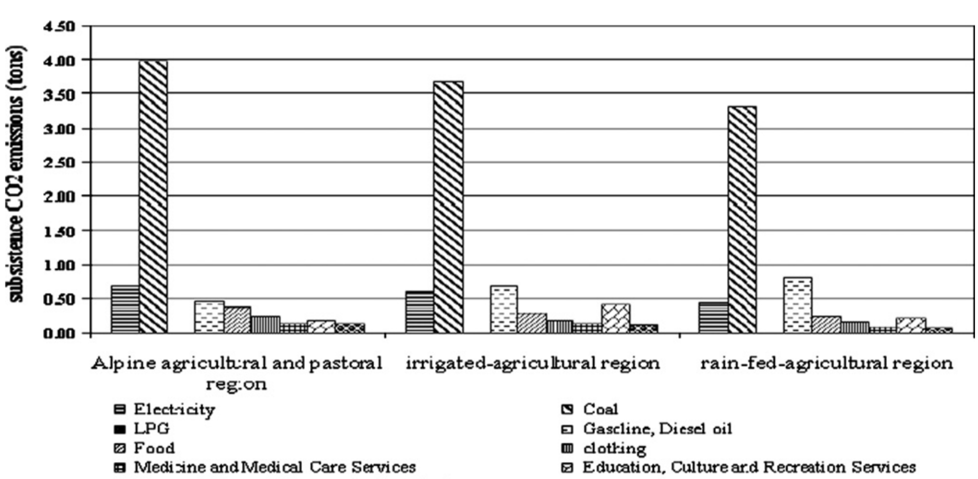

Fig. 2. Comparisons of CO_2 emissions from different sources in three different agricultural regions.

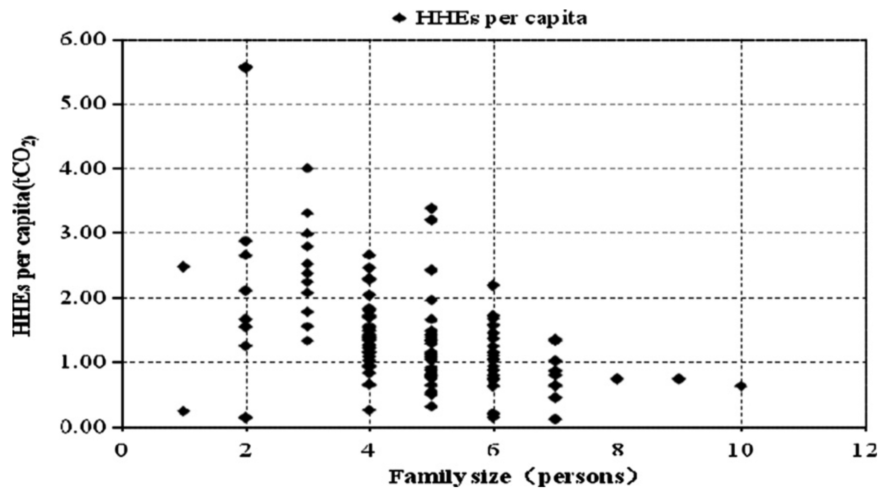

Fig. 4. Showing the relationship between household per capita CO_2 emissions and family size.

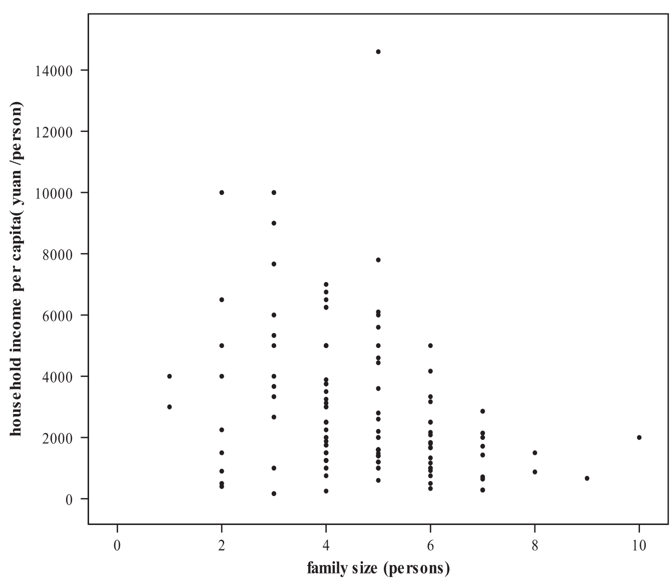

Fig. 5. Showing the relationship between household per capita income and family size.

Table 4
Total CO_2 emissions from the consumption of necessary and luxury goods and services.

CO_2 emissions (t)	Luxury emissions (t CO_2)	Subsistence emissions (t CO_2)	Share of subsistence emissions (%)
The whole study area	0.40	5.58	93.24
Alpine agricultural and pastoral region	0.31	5.87	94.93
The highest one	2.98	3.84	56.33
The lowest one	0.00	0.88	100.00
Irrigated agricultural region	0.52	5.55	91.49
The highest one	4.48	6.18	57.98
The lowest one	0.00	0.30	100.00
Rain-fed agricultural region	0.28	5.06	94.80
The highest one	1.26	7.85	86.18
The lowest one	0.00	3.71	100.00

Table 5
Per capita CO_2 emissions by income levels.

Household income per capita (RMB)	Per capita household emissions (t CO_2)	Per capita luxury emissions (t CO_2)	Share of luxury emissions (%)
≦1000	0.85	0.05	6.19
1000–1500	1.09	0.06	5.84
1500–2000	1.14	0.05	4.55
2000–2500	1.32	0.05	3.45
2500–3000	1.87	0.1	5.14
3000–3500	1.33	0.04	3.05
3500–4000	1.47	0.12	8.37
> 4000	1.85	0.20	10.95

By investigating the economic variables of LEs per capita, we concluded that the LEs per capita were strongly correlated with household income per capita, with an R^2 value of 0.767 (Fig. 6). The households with the highest income level have LEs more than four times that of households within the lowest income level. Fig. 7 shows that the percentage of LEs increases with the household income on a per capita basis.

5. Conclusions

This paper makes a first step toward understanding the inter-household CO_2 emissions in northwest China and in particular in arid-alpine regions based on data derived from field surveys. This paper presents annual HHEs, including direct and indirect emissions, and disaggregates the emissions and their characteristics by geographical locations, income level and household size.

First, based on the findings presented in this paper, we conclude that there is inequality in inter-household CO_2 emissions per capita with the average value of 1.43 t CO_2. The majority of the HHEs per capita (0.90 t CO_2) come from the coal consumption. This is mainly because of high altitudes and the need for heating during the chilling winter. If we deduct the portion of emissions resulting from climate related factors, energy use for

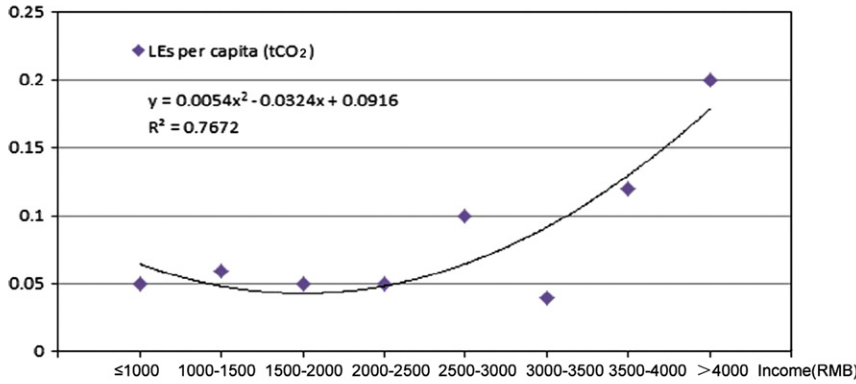

Fig. 6. The relationships between per capita luxury emissions (LEs) and per capita household income.

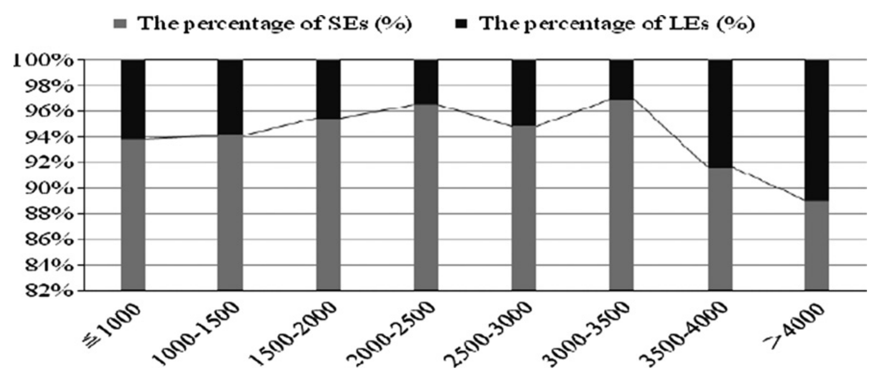

Fig. 7. The percentage of Subsistance emissions (SEs) and Luxury emissions (Les) by per capita household income.

heating which is unavoidable, their household level emissions are negligible.

Second, the SEs (related to the consumption of necessary goods and services) accounts for 93.24% of the total emissions, whereas LEs (related to consumption of luxury goods and services) accounts for 6.76%. This means, most of the households in the study area are consuming only those goods and services that are absolutely necessary for their subsistence and thus the reduction of emissions below these levels is almost impossible. Therefore, the low-income family will face more difficulties in the international/national environment of carbon emission reductions resulting in higher energy prices. These poor and vulnerable groups should be given special consideration when a new climate change mitigation policy is designed.

Third, the HHEs increase with household income and family size. However, per capita emissions decrease as the household size increases, indicating that households where large families and specifically extended family living together present a promising way for saving energy and reducing CO_2 emissions. Moreover, when family size increases household income per capita decreases and so do the emissions per capita.

Forth, per capita incomes of the people in the study area are rising. Therefore, their demands for the means of livelihood are expected to grow rapidly. We believe that the electricity and LPG will gradually replace the coal, and the petrol consumption for private travel will grow rapidly. Moreover, more money will be paid for cultural, and recreational activities, and educational and communication services. Therefore, the household CO_2 emission of the people in the study area will keep increasing. The SEs and LEs will both increase, and generally, the LEs will increase more rapidly.

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