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ABSTRACT

Despite the rapid development in fossil fuel, biomass is still the main energy resource in rural China. However, the research on household energy consumption on the Qinghai-Tibet Plateau is limited. We investigated the differences in household energy consumption pattern, the influencing factors of fuel type choice, and the willingness to use clean energy in agricultural, pastoral and agro-pastoral transitional zones in eastern part of Qinghai-Tibet Plateau. Information was collected through Participatory Rural Appraisal (PRA) and Physical Monitoring (PM). We found that biomass was the main energy resource in pastoral regions while fossil energy was the main fuel in agricultural regions. Energy consumption per capita in pastoral regions was higher than that in agricultural regions in our study area, and annual household energy consumption in pastoral regions was much higher than the provincial average. Altitude, livelihood and education level were main factors affecting domestic fuel type choice, while altitude and household size were two factors determining energy consumption per capita. The use of biomass as fuel could have negative influence on the material cycle in ecosystem and affect the carbon budget on the Qinghai-Tibet Plateau. Householders were willing to use clean energy and most interviewees chose electricity as their favorite fuel type. Therefore, the modern utilization of biomass and the exploration of renewable energy are promising in future energy development in eastern part of Qinghai-Tibet Plateau. However, energy transition might be constrained by poor local transportation and traditional consumption habit of indigenous community.

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1. Introduction

Energy issue has aroused increasing interests and become a key point in economic growth and national welfare in the past

decade. Despite the rapid development and exploration of fossil energy, biomass is by far the major domestic energy in many rural areas in developing countries [1-6]. China has experienced sharp increase in economy and energy demand in recent years, and become the largest emitter in the world

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since 2009, however, biomass energy is still widely used in the rural area [7]. China Energy Statistical Yearbook mainly focuses on fossil energy supply and consumption, with little concern on biomass consumption in rural areas. Several researches have been done on rural household energy consumption in eastern and central China, however, energy consumption patterns in most areas of China are yet unknown [8–18].

The Qinghai-Tibet Plateau is recognized as the third pole of the Earth with average altitude over 4000 m above sea level (asl). Scientists have predicted that the Qinghai-Tibetan Plateau experiences "much greater than average" increase in surface temperature and regarded increasing anthropogenic green house gas (GHG) emission as the main reason for recent climate warming [19,20]. Due to the particular role it plays in climate regulation and social-economic welfare, the energy issues of the Qinghai-Tibet Plateau have attracted interests from many researchers and policy makers. Among them, most studies are conducted in Tibet with little attention being paid to energy supply and consumption in Qinghai Province in eastern part of the plateau [16,21–25].

Herdsmen and farmers living on the plateau have used yak dung, sheep fecal pellets, firewood and crop residues as fuel for thousands of years. Such biotic energies are still the main energy resources for household energy consumption on the Qinghai-Tibet Plateau due to the financial constraints, lack of alternative energy resources and traditional custom [26]. However, the specific energy consumption pattern of rural households on the Qinghai-Tibet Plateau is poorly understood. Household interview and questionnaire are two effective ways of gathering information on the energy use patterns of rural households which have been used in many areas like India, Bangladesh, South Africa and China, etc [1,16,17,27–29].

The present study used open-structural questionnaire and interview methods to investigate the fuel use pattern at household level in five counties with different livelihoods in Qinghai Province. We tested the hypothesis that energy consumption per capita was higher in the pastoral zone than that in the agricultural zone due to the colder physical environment and coarser energy consumption mode. We compared the energy consumption per capita in five counties to study how household energy consumption structure changed from agricultural regions to pastoral regions and investigated influencing factors of fuel type choice. Finally, we discussed the ecological impact of energy consumption pattern and the direction of future energy choice in rural Qinghai.

2. Materials and methods

2.1. Study area

Qinghai Province lies in northeastern part of Qinghai-Tibet Plateau (31°39'-39°21'N, 89°35'-103°04'E) with area of 717,400 km² and population of 5.54 million in 2008 [30]. Pastoral lands account for 59.11 percent whereas farming lands and woodland account for 0.79 percent and 3.90 percent in whole lands. This area is characterized by strong solar radiation with long cold winter, short cool summer and a short frost-free period. Mean annual temperature is 6.8 °C and mean annual precipitation varies from 14.9 mm in northwest to 774.3 mm in southeast with most falling between June and September. Annual evaporation is about four times greater than the annual precipitation [31].

Qinghai Province could be divided into three parts: eastern part of the province is agricultural zone with altitude between 1700 and 2500 m and about 3.5 million people living in this zone; areas around the Qinghai Lake are agro-pastoral transitional zone with altitude between 2500 and 4500 m and approximately 100 thousand people whose majority are Tibetan living in this zone; areas in southern Qinghai with altitude above 4500 m are alpine meadow with sparse population and majority of population are Tibetan.

We carried out our survey in five counties: Huzhu, Wulan, Gangcha, Gonghe, and Tianjun from April to August 2009 (Fig. 1). These five counties could be divided into three groups according to livelihoods of local people. Huzhu is located in agricultural zone; Gonghe and Tianjun are located in pastoral zone; Wulan and Gangcha are located in agro-pastoral transitional zone. Wulan is mainly agricultural zone with relatively less people living on livestock stocking while Gangcha is mainly pastoral zone with less people living on agriculture. The main crops grown in agricultural regions are Brassica napus and Hordeum coeleste and the trees in agricultural regions are mainly Populus tomentosa and Betula platyphylla. Farmers often took stem and stalk of crops, trunk and branch of trees which were not far away from their houses as fuel. The dung, crop residues and firewood were often dried under sun light, stored outside their houses in the open air without further processing before burning.

2.2. Data collection

We chose household as the basic survey unit as it was the basic socioeconomic unit of decision-making and consumption. We collected energy consumption data in the following two ways: (a) Participatory Rural Appraisal (PRA); and (b) Physical Monitoring (PM). We chose one *Xiang* (township, an administrative level below county level in China) per county in our survey and the households were randomly chosen to cover all the income levels.

PRA has been proved to be an acceptable methodology of participation in rural survey [32]. This was conducted by using an open-structured questionnaire. The original version of questionnaire was firstly used in a household energy consumption survey in four nature reserves in southern China in 2004 [15] and further refined to the local situation in Qinghai Province for this study. We are interested in family structure, education, annual income, expenditure, energy supply and consumption, cooking preference and the perspective on energy choice, with emphasis on household energy consumption. We did not split cooking, water boiling, lighting, heating and domestic animal food preparation from domestic energy uses in our study since these activities were closely related that rooms and tent space could be heated during cooking and water heating. The energy supply and consumption were got through practical expenditure and estimation. We limited the recall period to one year before the interview since shorter recall period might produce more accuracy and less variance [33].



Fig. 1 – Survey sites in Qinghai Province, China. The location of Qinghai Province inside the China map is shown in the smaller diagram on the right upper corner, and the larger map shows the study area of five counties in Qinghai Province.

PM was used to quantify biomass consumption for daily cooking, including yak dung and sheep fecal pellets (collectively called as dung thereafter), crop residues and firewood. Sufficient amount of biomass materials were weighed by a spring balance and then packaged in bags in the kitchen for the use of the next 24 h. We asked housewives to burn fuel only from the bags and weighed the remaining fuel the next day. PM was conducted in about 10 percent of sampled households doing the PVA to validate the cooking energy use figures obtained via PRA.

Our questionnaire included three parts: (1) basic information on age, gender, occupation, education, household size and annual income, etc.; (2) domestic appliances, fuel supply and consumption; (3) perspectives on energy choice.

2.3. Data analysis

The economic status of household was determined in terms of pasture or farmland holding, livestock owning, employment type and total income. Education level was divided into five types: illiterate, primary school, junior high school, senior high school and college and university which were recorded as 1, 2, 3, 4 and 5, respectively. We took the highest education level in each household as education level of household. Household size only included those people who lived in the family during the last six months before the investigation. All energy resources consumed were transformed into standard coal equal (SCE). The consumptions of electricity, gasoline and diesel were recorded and then transformed into amounts and SCE. The utilization of photovoltaic (PV) and wind were calculated by using hours per day. According to our investigation, the utilization of PV was about 180 days per year and could supply bulb (power of 25–50 W) for four to 6 h per day; wind power could supply a television (average power of 200 W) for one to 3 h per day; the average TV-watching time was 2 h per day and 180 days per year per household; the average use of biogas in household with five people was 1.5 m³ per day and 120 days per year; solar stoves were used for boiling water and about two boilers were needed per day for 120 days per year on average; candles were often used in pastoral regions for lighting and each candle weighted 0.05 kg on average.

The conversion factors of fossil fuel (LHV-lower heating value) were obtained from China Energy Statistical Yearbook [34]. The gross calorific value (higher heating value, HHV) of dung, crop residues and firewood sampled from the five counties were determined by a Parr 1281 oxygen bomb calorimeter (Parr Instrument Company Inc., Moline, IL, USA) with benzoic acid as the standard (Tables 1 and 2). Biomass samples were collected from five counties in different seasons and we took the weighted average as the energy conversion factor. Fossil energy using ratio, biomass using ratio, firewood using ratio, crop residues using ratio, dung using ratio, electricity using ratio and renewable energy using ratio were calculated by consumption of each fuel type divided total household energy consumption.

All statistical analyses were performed with SPSS for Windows version 15.0 (SPSS Inc., Chicago). We used Kolmogorov–Smirnov test to check the normality of data. Annual energy consumption per capita was *ln* transformed, electricity using ratio was firstly *ln* and then square-root transformed to Table 1 – Energy conversion factors of fossil energy (LHV-lower heating value) [34].

Energy type		alents	
	Unit	MJ	kg of standard coal equivalent
Electricity	kWh	3.60	0.12
Coal	kg	20.91	0.71
LPG	kg	50.18	1.71
Gasoline	kg	43.07	1.47
Diesel oil	kg	42.65	1.46
Paraffin ^a	kg	41.50	1.42
Biogas	m ³	20.91	0.71

a Note: We used the energy conversion factor of paraffin to indicate that of candle.

meet assumptions of normality and homogeneity of variances. Fossil energy using ratio, biomass using ratio, dung using ratio, crop residues using ratio, firewood using ratio and renewable energy using ratio could not be transformed to be normally distributed, thus we used non-parametric analysis to compare the differences. Paired sample t-test was used to check the difference between biomass consumptions got from PM and PRA. One-way ANOVA was used to compare the differences of annual energy consumption per capita and electricity using ratios among different counties. Kruskal-Wallis H was used to test the differences of fossil energy using ratio, biomass using ratio, dung using ratio, crop residues using ratio, firewood using ratio and renewable energy using ratio among five counties. Stepwise regression analysis was used to find out the leading factors on energy consumption per capita and electricity using ratio. Spearman's correlation analysis was used to test the correlation between annual income, household size, livelihood, education level, altitude and energy consumption parameters. All significant main effects with three or more categories were compared with a Fisher's least significant difference (LSD) post hoc comparison. All values were presented as means \pm SE. All statistical tests were two-tailed and P \leq 0.05 was considered statistically significant.

Table 2 – Gross calorific value (higher heating value, HHV) of biomass.						
Energy type	Unit	Equivalents of heat (MJ)				
		Huzhu	Wulan	Gangcha	Gonghe	Tianjun
Sheep fecal pellets	kg		14.15	14.20	12.81	14.14
Yak dung	kg		15.52	16.26	14.40	15.39
Firewood	kg	19.47	19.45			
Crop residues	kg	18.02	18.26	18.15		

Note: Energy contents of biomass were determined in a Parr 1281 oxygen bomb calorimeter (Parr Instrument Company Inc., Moline, IL, USA) with benzoic acid as the standard. Biomass samples were got from five counties in different seasons. We took the weighted averages as energy conversion factors.

3. Results

Altogether, 485 households were sampled, and among them, seven households gave incomplete information. Thus, we discarded the incomplete questionnaires and the valid number of households sampled was 478. The basic information of sampled households in five counties was given in Table 3. Energy characteristics of the rural households in five counties were given in Table 4. PM was conducted in 45 households in our investigation. There was no significant difference between figures we measured and estimated by householders ($t_{44} = 0.94$, P = 0.39) although the figures estimated were little higher than the measured values.

3.1. Energy consumption pattern

Annual household energy consumptions in agricultural regions were close to the provincial average (2095 SCE per household in 2008) while annual household energy consumptions in pastoral regions were much higher (Fig. 2) [34]. One-way ANOVA showed that there were significant differences in the annual energy consumption per capita ($F_{4,473} = 69.60$, P < 0.001) (Fig. 2) and electricity using ratio ($F_{4,325} = 56.50$, P < 0.001) (Fig. 3) among five counties. Many households used PV for lighting in pastoral regions due to the low availability of grid electricity. Kruskal–Wallis H test showed that significant differences existed in biomass using ratio (P < 0.001), fossil energy using ratio (P < 0.001), dung using ratio (P < 0.001), crop residues using ratio (P < 0.001) and firewood using ratio (P < 0.001) among five counties.

Rural household energy consumption structures were similar among counties with similar livelihood. Fossil energy was the main energy resource in Huzhu and Wulan, biomass was the main energy resource in Gonghe and Tianjun, while the energy consumption pattern in Gangcha was between that of Wulan and Gonghe (Fig. 4). Dung using ratio increased gradually from agro-pastoral transitional regions to pastoral regions. More crop residues and biogas were used in Huzhu than in Wulan, and more gasolines were used in Tianjun than in Gangcha and Gonghe.

3.2. Factors affecting energy choice

We included altitude, household size, annual income, education level and livelihood into the original regression model. Stepwise regression analysis showed that altitude, household size and annual income were important influencing factors of energy consumption per capita while altitude, annual income and education level were leading factors of electricity consumption. Altitude and household size were main determinants of energy consumption per capita while annual income could explain little variance in the regression model. Altitude was a crucial explanatory factor of electricity consumption while annual income and education level were subordinate factors in regression models. There were significant correlations between livelihood and all energy consumption ratios except renewable energy using ratio. The same situation could be seen between altitude, education level and energy consumption ratios. Annual income was

Table 3 – Socio-economic conditions of the surveyed households in five counties (Mean ± SE).							
County	Altitude (km)	Education ^a	Household size ^b	Annual income (10 ³ USD) ^c	Distance to town (km)	Ν	
Huzhu	$2.60\pm0.0087A$	$2.08\pm0.088BC$	4.47 ± 0.14	$1.44\pm0.071A$	5	96	
Wulan	$2.97\pm0.00028B$	$\textbf{2.33} \pm \textbf{0.073C}$	$\textbf{4.28} \pm \textbf{0.12}$	$1.70\pm0.11A$	5	120	
Gangcha	$\textbf{3.30} \pm \textbf{0.0085C}$	$1.90\pm0.088BC$	4.32 ± 0.099	$1.65\pm0.28\text{A}$	27	110	
Gonghe	$3.34\pm0.017\text{C}$	$\textbf{1.24} \pm \textbf{0.071A}$	4.86 ± 0.18	$1.82\pm0.14\text{A}$	40	97	
Tianjun	$3.80\pm0.016\text{D}$	$1.62\pm0.15B$	4.67 ± 0.27	$3.21\pm0.34B$	50	55	

a Note: Education level was divided into five types: illiterate, primary school, junior high school, senior high school and college and university which were recorded as 1, 2, 3, 4 and 5, respectively. We took the highest education in household as education level of each household.
b Note: Household size did not include those people who did not live in the family during the last six months before the investigation.
c Note: We took record of annual income in terms of CNY, and transformed into USD that 1 CNY = 0.146 USD (exchange rate of March 9, 2010).

Means with different uppercase letters in the same column were significantly different (Kruskal–Wallis H).

significantly correlated with renewable energy using ratio (Table 5).

3.3. Perspective on fuel type choice

Households in different counties had the similar perspectives on fuel type choice. They all took price as the primary factor, and were willing to use clean energy but showed no environmental care when choosing fuel. Slight differences could be found in the favorite fuel among different counties (Table 6). Most households in agricultural regions and agro-pastoral regions chose electricity as their favorite fuel for its convenience, and some households in Huzhu and Wulan began to use electromagnetic oven instead of LPG for cooking. About 45 percent of interviewees in Tianjun chose electricity as their favorite fuel if there were no financial burden, while 25 percent and 30 percent of interviewees chose coal and dung as their favorite fuel. Some households in pastoral regions chose dung and coal because they did not know how to use electricity or LPG and thought it was dangerous to use the new technology.

4. Discussion

Our results supported the hypothesis that energy consumption per capita in the pastoral zone was higher than that in agricultural zone. The colder physical environment and coarser energy consumption mode in pastoral regions could explain part of the differences. Besides that, higher fossil energy using ratio and higher burning efficiency of fossil energy in agricultural regions might also contribute to the differences. Rural household energy consumption followed similar

trajectories across five counties, mainly driven by the availability of goods and consumption habit. Bari et al. (1998) found that most households over-estimated energy use in the questionnaire surveys [27]. However, our results showed that there was no significant difference between the results of PM and PRA, thus, the data from questionnaire surveys could be reliable. Compared with average household energy consumption in Qinghai Province, the result reported here was much higher. The possible explanation was that the official statistical data did not include biomass consumption in their analysis. The same situation could be seen in a survey in Shanxi province that annual household energy consumption was about two times higher than the provincial average in 1999 [14]. Besides that, energy consumption per capita of five counties on the Qinghai-Tibet Plateau was much higher than those in agricultural zone in central and southern China [15]. Winter is longer and colder and oxygen density is lower on the plateau, moreover, most of the burning equipments in local households are outmoded, which all induce higher energy consumption on the Qinghai-Tibet Plateau.

4.1. Factors affecting fuel type choice

Altitude and livelihood were leading factors of fuel type choice. Households with different livelihoods had different energy consumption patterns. This might be due to the availability of fuel types and fuel using habit. Energy carriers in rural areas are always determined by the local availability of resources [35]. Households in pastoral regions mainly depended on dung for energy while households in agricultural regions used firewood and crop residues as fuel. The dung using ratio increased while crop residues using ratio decreased from agricultural regions to pastoral regions. Dung

Table 4 – Main domestic fuel sources in rural household in five counties.							
Usage	Main sources						
	Huzhu	Wulan	Gangcha	Gonghe	Tianjun		
Cooking	Coal, electricity	Coal, electricity	Coal, dung	Dung	Dung		
Boiling water	Coal, electricity, solar stove	Coal, electricity, solar stove	Coal, dung	Dung	Dung		
Lighting	Electricity	Electricity	Electricity, PV, candle	Electricity, PV, candle	PV, candle		
Heating	Coal, crop residues	Coal, Dung	Dung, coal	Dung	Dung		
Motive power	Gasoline, electricity	Gasoline, electricity	Gasoline	Gasoline	Gasoline		

Note: There were many fuel types used for cooking and boiling water, and we only chose those main fuels here. PV was short for photovoltaic.



Fig. 2 – Annual household energy consumptions (1) and annual energy consumptions per capita (2) in five counties. SCE is short for standard coal equal. The dash line in (1) is the provincial average of annual household energy consumption in Qinghai Province [34]. Solid line is median, square is mean, edges of box are quartiles, and whiskers are 5th and 95th percentiles. There were significant differences in the annual energy consumption per capita among five counties ($F_{4,473} = 69.60$, P < 0.001; ANOVA).

was abundant in pastoral regions while commercial energy resources were beyond the reach of herdsmen because of the poor transportation. Both crop residues and fossil energy were easy to get in agricultural regions. Besides that, some herdsmen in Tianjun moved to town and began to use coal and electricity instead of dung as their main energy resources,



Fig. 3 – Comparison of electricity using ratios (%) among five counties. Different letters indicate significant differences among households in five countries ($F_{4,325} = 56.50$, P < 0.001; ANOVA).



Fig. 4 – Rural household energy consumption structures in five counties.

which indicated that changing in livelihood could alter the fuel type choice.

There have been "behavioral lock-in" in energy consumption in many researches that changing existing habits was an implicitly obstacle [36]. Livestock was not just the economic source but also the sources of meat, milk, clothes, transportation and energy consumption in pastoral regions. Dung and crop residues have been used as main fuels for thousands of years on the Qinghai-Tibet Plateau and householders are accustomed to old habits and do not want to change their current energy consumption patterns. Some households in pastoral regions chose dung as their favorite fuels even if there were no financial burden. Households we surveyed in Huzhu and Wulan were close to town and it was convenient for them to use fossil energy, however, most of them did not abandon biomass even with high annual income. The same situation could be seen in Tibet that the traditional lifestyle leads to the special energy consumption structure and behaviors [16].

Besides that, the choice of domestic fuel in rural areas depends largely on the cost of fuel. Most householders considered fuel price as the primary factor when choosing fuel type. Biomass was widely used in study area for their local availability and low cost. When interviewees were asked which fuels they preferred if there were no financial burden, most of them in five counties chose electricity for its cleanness and convenience.

Annual income is fundamental to all activities and is an important affecting factor of household energy consumption pattern [15]. Families always abandon the inefficient and more polluting technologies when socioeconomic status improve, that typically a household may shift from using biomass, to kerosene, LPG and finally electricity for cooking [37]. Devi et al. (2009) found that with the increase in income and improvement of education condition, the demand for electricity and LPG increased while the consumption of crop residues decreased [1]. Lenzen et al. (2006) also found that annual income affected energy consumption especially in rural region [38]. Former research in Shaanxi Province confirmed energy transition theory that as income increased, the energy people

Table 5 – Correlations between energy resource using ratios and explanatory factors (Spearman's correlation).							
	Livelihood	Household size	Education	Income	Altitude		
Fossil energy using ratio	0.80 ^a	-0.078	-0.51 ^a	0.020	-0.64 ^a		
Biomass using ratio	-0.81 ^a	0.080	0.51 ^a	-0.021	0.66 ^a		
Dung using ratio	-0.84 ^a	0.060	-0.50 ^a	0.008	0.78 ^a		
Crop residues using ratio	0.74 ^a	-0.011	0.29 ^a	-0.078	-0.77 ^a		
Firewood using ratio	0.72 ^a	0.007	0.27 ^a	-0.064	-0.68 ^a		
Renewable energy using ratio	-0.061	0.047	-0.007	0.14 ^a	0.055		
a Note: Correlation was significant at the 0.01 level (two-tailed).							

chose shifted from low quality biomass to high quality commercial fuels [17]. Whereas, many researches found that there was no significant difference among householders with different socioeconomic conditions [14,39]. The rural households in Mexican villages do not switch fuels, but more generally follow a multiple fuel or "fuel stacking" strategy that new cooking technologies and fuels are added while traditional systems are rarely abandoned [37].

We could not find any proof of energy transition theory in our study. A number of factors called the energy transition into question: household incomes in pastoral regions were higher than that in agricultural regions in general, however, the poor transportation made fuel supply quite a problem in pastoral zone; furthermore, the crop residues and dung had been used for thousands of years, householders did not want to abandon their traditional using habits in the short run.

Education has been proved to have immense importance in planning and utilizing firewood in India that high level of education is always related to low energy use and high level of transportation energy use [40,41]. Our results also indicated that education could affect fuel type choice. Householders with higher level of education consumed more fossil energy and less biomass than those with lower level of education.

Table 6 — Perspectives on fuel type choice in different counties.								
	Huzhu	Wulan	Gangcha	Gonghe	Tianjun			
Primary factor	r in consid	leration w	hen choosii	ng fuel type	e (%)			
Price	98.96	93.52	100.00	100.00	100.00			
Efficiency		2.78						
Habit	1.04							
Convenience		3.70						
Favorite fuel i	f there we	re no fina	ncial burder	n (%)				
Electricity	83.33	83.33	90.77	82.22	45.00			
Coal	9.38	11.67	1.54	4.44	25.00			
LPG	4.17	5.00	3.08	11.11				
Natural gas	1.04							
Biogas	2.08							
Dung			4.61	2.22	30.00			
Willing to use	Willing to use clean energy or not (%)							
Yes	100.00	99.17	100.00	100.00	100.00			
No		0.83						
Considering environmental impact or not when choosing fuel type (%)								
Yes	3.13							
No	96.88	100.00	100.00	100.00	100.00			

Note: Perspectives on fuel choice were obtained through openended questions. Besides that, householders with high education always chose electricity as their favorite fuel type if there were no financial burden while householders with low education might chose traditional energy as their favorite. Many herdsmen in Tianjun were illiterate and 30 percent of interviewees there chose dung as their favorite fuel for some householders did not know how to use LPG or electromagnetic oven.

4.2. Factors affecting energy consumption

Altitude was the main explanatory factor for energy consumption per capita in regression model. Areas with higher altitude were always pastoral region with colder weather, lower oxygen pressure and lower burning efficiency while areas with lower altitude were predominately agricultural region with warmer weather, higher oxygen pressure and higher burning efficiency. Additionally, biomass was the dominant fuel in high altitude area while fossil energy took more than half in fuel composition in low altitude area. The burning efficiency of fossil energy was higher than that of biomass. These all resulted in higher energy consumption in higher altitude areas.

Household size was another factor that could affect the energy consumption. Liu et al. (2003) found that with the increase in household numbers and the decline in household size, the efficiency of resource use decreased and the demand for resources increased which posed big challenge to biodiversity conservation [42]. Family size is an important factor in energy consumption in Shaanxi Province [17] and small families consume more firewood per capita than those of medium and large families in mountain villages in India [43]. Larger household size also goes along with higher domestic energy use in Netherlands [41]. We took energy consumption per capita instead of household energy consumption as explanatory parameter to minimize the influence of household size on energy consumption. However, household size was still the main factor for energy consumption per capita in the regression model, indicating household size could affect energy consumption dramatically.

4.3. Ecological impact of energy consumption pattern

The use of biomass reduces household expenditure but affects material cycle and energy flow in ecosystem. On one hand, direct combustion of firewood caused deforestation; on the other hand, dung and crop residues used as fuel could not be returned to ecosystem, which could result in a growing gap between N and P input and output, and consequently reduce soil fertility [6]. According to previous investigation, only 40 percent of yak dung and sheep fecal pellets were returned to grassland and a wide range of adverse feedbacks on ecoenvironment like deforestation, grassland degradation, desertification, soil erosion and decrease in soil fertility can be identified in Tibet [6,22,23]. In our study, ashes of dung were all poured at random in pastoral areas and only 16.29 percent of interviewees in agricultural areas said that ash were returned to farmland as fertilizer. The imbalance between input and output of N and P caused grassland degradation. We included questions about the grassland change in our interview, among all the surveyed households in pastoral region, only 2.86 percent said that grasslands were better than before, while 65.71 percent told that grasslands were worse than before and 31.43 percent showed that grassland did not change much in recent years.

Furthermore, the Qinghai-Tibet Plateau plays an important role in carbon storage both in China and in the world. Alpine region covers 54.5 percent of total carbon storage in grasslands of China and 4.90–8.72 percent of total carbon storage in the grasslands all over the world [44]. Low temperature and low evapotranspiration in alpine region make soil carbon difficult to decompose. However, the overuse of biotic energy resources might change the vegetation type and then release much carbon which might have significant effect on carbon cycles in China even at the global level.

4.4. Future direction of energy consumption

The Qinghai-Tibet Plateau is rich in renewable energy like solar energy, hydropower and wind power [26]. Besides that, biomass has been used for many generations and would not be easy to abandon in short term. Thus, the future of energy consumption could be developed in two directions: the exploration of renewable energy and finding new ways of biomass use.

Solar cooker, passive solar building and photovoltaic power are promising in utilization of solar energy. Solar cooker with an area of 1.6 m^2 has the power of 800–1000 W and if it is used 6 h per day and 280 days per year per household, about 2140 t of firewood or 2260 t of dung would be saved [45]. Passive solar building can maintain interior thermal comfort throughout the daily sunshine hours and annual cycles by choosing proper location, building materials and structures [24]. Small photovoltaic power stations and hydropower plants are more cost-effective than the expansion of electricity grid in pastoral regions. Hydro-power is abundant in Qinghai Province since it is the origin of several big rivers like Yellow River and Yangtze River [46]. Besides that, the state government put much effort on technical and financial support, thus, the exploration of renewable energy is promising in rural Qinghai Province.

Traditional use of biomass is unsustainable and has inherent disadvantages: collection is arduous and timeconsuming; combustion is difficult to control and capture only a fraction of the fuel's available energy; and it releases high concentrations of CO, NO₂, SO₂ and TSP which might lead to chronic diseases such as pneumonia, eye diseases and even lung cancer [47]. Biogas and straw briquette are new technologies that are efficient and environment-friendly which could expand the use of biomass in rural regions [5,48]. Agricultural zones in Qinghai Province are warm enough to develop biogas; on the other hand, crop residues, yak dung and sheep fecal pellets which are necessary for biogas and straw briquette producing are abundant in those zones. In addition, financial support are given to develop biogas and straw briquette on the Qinghai-Tibet Plateau [49], which all make biogas and straw briquette large room for development in the future.

5. Conclusions

Rural household energy consumption pattern in eastern part of Qinghai-Tibet Plateau was different from those in low altitude area in eastern China. Households in pastoral region consumed more energy than households in agricultural region considering physical climate, burning efficiency and fuel type availability. Biomass was the main fuel in pastoral region while fossil energy accounted for most in household energy composition in agricultural region. Livelihood was the main influencing factor of fuel type choice while altitude and household size were the leading factors of energy consumption per capita. Householders were willing to use clean energy and most interviewees chose electricity as their favorite fuel if there were no financial burden but showed no environmental care on energy consumption. The use of biomass as fuel would reduce household expenditure but affect material cycle and carbon budget of ecosystem. The exploration of renewable energy resources and finding new ways of utilizing biomass are promising in eastern part of Qinghai-Tibet Plateau.

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