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Status and future perspectives of energy consumption and its ecological impacts in the Qinghai–Tibet region

Xiaoge Ping [a,b], Zhigang Jiang [a,*], Chunwang Li [a]

[a] Key Laboratory of Animal Ecology and Conservation Biology, Institute of Zoology, Chinese Academy of Sciences, No. 1 Beichen West Road, Chaoyang District, Beijing 100101, China
[b] Graduate University of the Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Qinghai–Tibet region is a unique geographic zone due to its average altitude of over 4000 m, sparse human population and prevalent pastoral system. However, little is known about the energy consumption in the region. We reviewed current situation of energy consumption and its ecological impacts, outlined future energy prospects in the region. Per capita household energy consumption was about two and three times of the national average in Qinghai and Tibet. Per urban household consumed more energy than rural household in the region. Moreover, the urban households and rural households used different energy resources, natural gas and electricity accounted for 57.57% and 42.29%, respectively in household energy consumption in urban areas while biomass accounted for 79.13% and 94.19% in household energy consumption in rural areas in Qinghai and Tibet in 2007. This region was abundant in renewable energy resources and was among the richest in hydro-power and solar energy resources in China. Hydro-power accounted for 67.88% and 92.04% in total electricity in Qinghai and Tibet in 2007. Population density was rather low in this region (4.35 versus 137.63 persons per 100 hm^2 in Qinghai–Tibet region and China in 2007), thus small photovoltaic power stations and hydro-power plants were more cost-effective than the electricity grid. The overuse of biotic energy resources in rural areas caused decline in soil fertility and desertification. Whereas the low utilization of fossil energy in this region released less waste gas which was beneficial to the local, national and global carbon budgets. Accelerating economic growth and booming tourism have increased energy demand and posed a challenge to the unique ecosystem in the Qinghai–Tibet region. It was estimated that energy consumption of tourism accounted for 6.06% and 14.18% of the total energy consumption in Qinghai and Tibet in 2007. Thus, exploitation of renewable energy resources like solar energy, wind energy and biomass briquette is crucial in striving for a balance among economic development, booming tourism, and environmental protection in this region.

Contents

* Corresponding author. Tel.: +86 1064807268; fax: +86 1064807268.
E-mail address: jiangzg@ioz.ac.cn (Z. Jiang).

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1. Introduction

Energy industry is fundamental to economy. With an average altitude over 4000 m above sea level (asl), Qinghai–Tibet Plateau is recognized as the third pole of the earth [1]. Though the plateau region is relatively underdeveloped because of its alpine environment and social infrastructure, it still undergoes rapid economic growth and booming tourism in recent years, which inevitably brings increase in energy demand and pollution, putting pressure on the unique ecosystem of Qinghai–Tibet Plateau [2]. Thus, the issue of energy situation on Qinghai–Tibet Plateau has aroused more and more interests of researchers and policy makers [3–8].

However, previous reviews mainly focused on renewable energy resources or just one type of the renewable energy resources [2,8–16]. Moreover, former studies usually separated Qinghai Province (thereafter called Qinghai) and Tibet Autonomous Region (thereafter called Tibet) and focused on energy issue only in one of the two above administrative regions [2,4,7]. In fact, Qinghai and Tibet belong to the same geographic unit and account for 73.76% of Qinghai–Tibet Plateau in area [1]. Due to the similar geography and location, the climate, social infrastructure and living condition in Qinghai and Tibet are similar, resulting in the similar energy consumption pattern in the two administrative regions. Therefore, a comprehensive and complete review of the energy situation in Qinghai and Tibet (thereafter called the Qinghai–Tibet region) is necessary.

In this paper, we intended to give a complete picture of energy situation in the Qinghai–Tibet region. Firstly, we briefly reviewed natural and social-economic backgrounds of the region and made a comparison of energy consumption patterns between the Qinghai–Tibet region and China. Then we gave an overview on the current status of energy distribution and consumption in the region, and the ecological impacts of the energy consumption pattern. Finally, we reviewed policies and projects on energy development and presented the prospect of energy use in the Qinghai–Tibet region.

2. Natural and social-economic backgrounds of study region

Qinghai–Tibet Plateau (26°00′12″N – 39°46′50″N, 73°18′52″E – 104°46′59″E), covering 257 million hm^2, forms the highest plateau in the world [1]. The climate is continental type with an annual mean temperature below 0 °C. Alpine meadow, alpine steppe, alpine shrub and alpine desert ecosystems are the main types of vegetations on the plateau and the dominant plant communities are *Carex* spp., *Kobresia* spp., *Stipa* spp., *Achantherum splendens*, and *Potentilla fruticosa* [17]. Qinghai (31°40′N – 39°15′N, 89°20′E – 103°05′E) lies in northeast Qinghai–Tibet Plateau with area of 72 million hm^2 [18]. Tibet (26°52′N – 36°32′N, 78°24′E – 99°01′E) lies in southwest Qinghai–Tibet Plateau, with area of 120 million hm^2 [19] (Fig. 1).

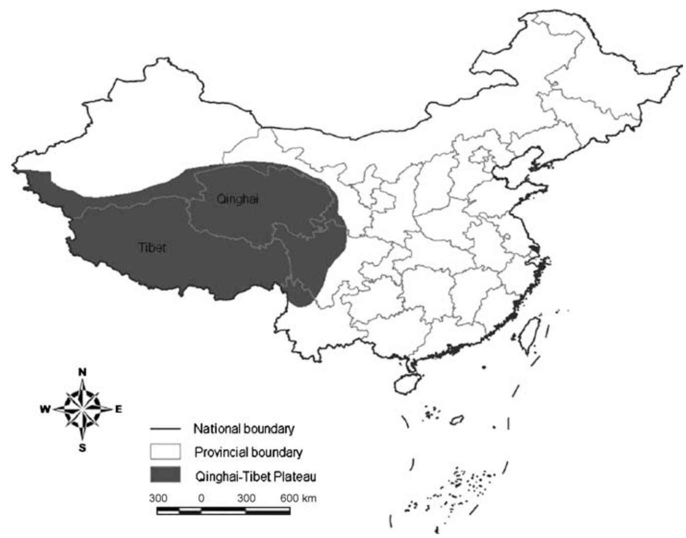

Fig. 1. Location of Qinghai Province and Tibet Autonomous Region in Qinghai–Tibet Plateau and China.

Human population in the Qinghai–Tibet region has increased at high rate since 1985. Household sizes both in the Qinghai–Tibet region and China have decreased since 1985, however, household sizes in the Qinghai–Tibet region were larger than the national average all the time (Table 1). Population densities of Qinghai and Tibet were still very low compared with the national average despite the persistent increase since 1985 (Table 1). Per capita

Table 1
Population, population density and household size in China, Qinghai and Tibet from 1985 to 2007 [20,21].

Year	China			Qinghai			Tibet		
	Population (10,000 persons)	Population density (persons/100 hm^2)	Household size (persons)	Population (10,000 persons)	Population density (persons/100 hm^2)	Household size (persons)	Population (10,000 persons)	Population density (persons/100 hm^2)	Household size (persons)
1985	105851.00	111.00	4.39	407.38	5.66	5.16	199.48	1.62	5.62
1990	114333.00	120.00	4.12	447.66	6.22	4.57	221.47	1.78	5.78
1995	121121.00	127.00	3.82	481.20	6.68	4.53	239.84	1.92	5.67
2000	126743.00	132.00	3.64	516.50	7.17	4.10	259.83	2.02	5.20
2005	130756.00	136.20	3.31	543.20	7.54	3.68	277.00	2.21	4.70
2007	132129.00	137.63	3.18	551.60	7.66	3.82	284.15	2.28	4.57

Table 2
Per capita annual income, urbanization ratio and education status in China, Qinghai and Tibet in 2007 [22].

	Per capita annual income of households (Yuan[a])		Urbanization ratio (%)	Education status				
	Urban	Rural		Illiterates (%)	Primary school (%)	Junior high school (%)	Senior high school (%)	Colleague and university (%)
China	13785.80	4140.40	44.94	6.34	25.76	52.91	11.01	3.99
Qinghai	10276.06	2683.80	40.07	23.57	39.01	29.01	6.87	1.54
Tibet	11131.00	2788.00	38.30	49.68	45.40	4.22	0.58	0.12

[a] 1 Yuan RMB = 0.146 U.S. dollars (exchange rate of October 22, 2009).

annual incomes of Qinghai and Tibet have increased greatly since 1980 but were still lower than the national average [20,21]. Per capita annual incomes of urban areas in Qinghai and Tibet were close to the national average whereas per capita annual incomes of rural areas in Qinghai and Tibet were far lower than the national average (Table 2). Urbanization rates were lower than the national average and there were deep gaps of per capita incomes between urban and rural areas in Qinghai and Tibet (Table 2). Proportions of illiterates were high in Qinghai and Tibet with only less than 5% of people having junior high school education in Tibet in 2007 (Table 2).

Qinghai–Tibet region has experienced high economic growth rate since the implementation of Opening-up Policy in 1978 and per capita Gross Domestic Product (GDP) of Qinghai and Tibet have increased remarkably during recent years (Fig. 2). GDP in Qinghai and Tibet were 9.62 and 3.96 billion Yuan (US$ 1.41 and 0.58 billion) respectively in 2008 [23,24]. In addition, the construction of Qinghai–Tibet railway has promoted local tourism and economy, and numbers of tourists in both Qinghai and Tibet showed sharp increases in recent years (Fig. 3). Although number of tourists declined for some political reason, there were still 9.05 million and 2.25 million tourists and the total income of tourism was 4,751 million Yuan (US$695.61 million) and 2259 million Yuan (US$330.75 million) in Qinghai and Tibet in 2008 [23,24].

3. Comparison of energy consumption between the Qinghai–Tibet region and China

3.1. Energy consumption pattern

Energy resources are unevenly distributed in China: energy reserves are mainly concentrated in the north and west, whereas most of energy is consumed in the southern and eastern China. Imbalance between energy distribution and consumption stimulates the development of transportation in the country [3]. Compared with the world average, biomass occupies higher proportion in energy consumption while percentage of nuclear energy is lower in China [3]. Renewable energy resources are rich in reserve but poor in technical exploitation and development, and coal is still the most important energy resource in China [27]. The energy production in China is mainly for self-consumption and there is still a long way to go into the commercial stage [28].

Most of conventional energy reserves in the Qinghai–Tibet region are concentrated in Qinghai [21]. Tibet is short of known fossil energy resources and most of the fossil energy is transported to Tibet by road or pipeline from other provinces of China [29]. Thus, we focused on energy production in Qinghai in this study. Overall energy production and consumption have increased continuously in both the Qinghai–Tibet region and China since 1980 [30]. Total energy consumed in China was 2.66 billion tons of coal equivalent (tce) in 2007 [30]. Total energy consumed in Qinghai was 20.95 million tce and total energy consumed in Tibet calculated by average energy consumption per capita was 1.99 million tce in 2007 [21,31]. The proportions of coal, crude oil, natural gas and other energy both produced and consumed have not changed much since 1980 in China while proportions of natural gas both produced and consumed have increased remarkably in recent years in Qinghai (Fig. 4). Compared with coal-dominating energy production and consumption pattern in China, natural gas and hydro-power accounted for higher proportion in Qinghai, while hydro-power was the dominant energy resource in Tibet (Fig. 4).

Percentages of renewable energy in energy production and consumption in China had increased from 3.1% and 3.4% to 8.2% and 7.8% from 1978 to 2007, respectively [30]. Nevertheless, the proportions of renewable energy in total energy production and

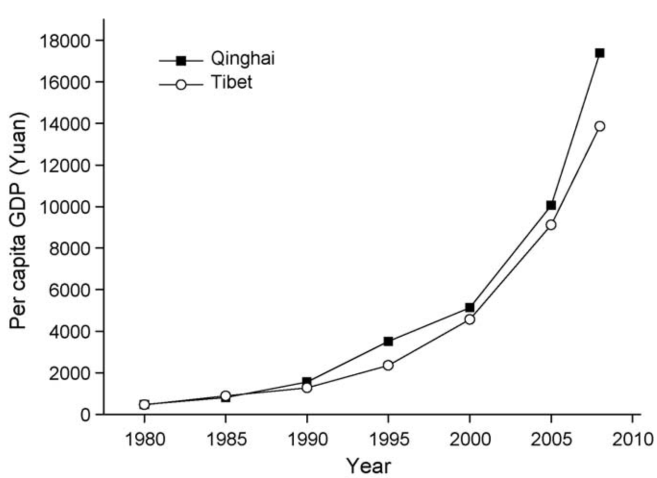

Fig. 2. Per capita GDP in Qinghai and Tibet from 1980 to 2008 [20,21].

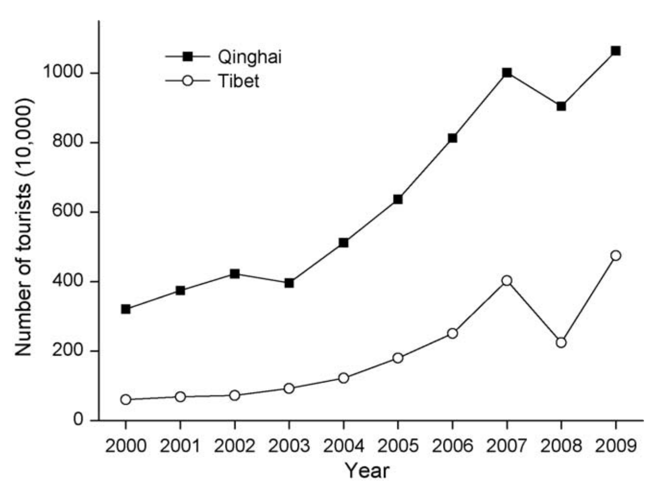

Fig. 3. Number of tourists in Qinghai and Tibet from 2000 to 2009. Number of tourists in Qinghai in 2009 was the statistical data from January to October and data of Tibet in 2009 was the statistical data from January to September [20,25,26].

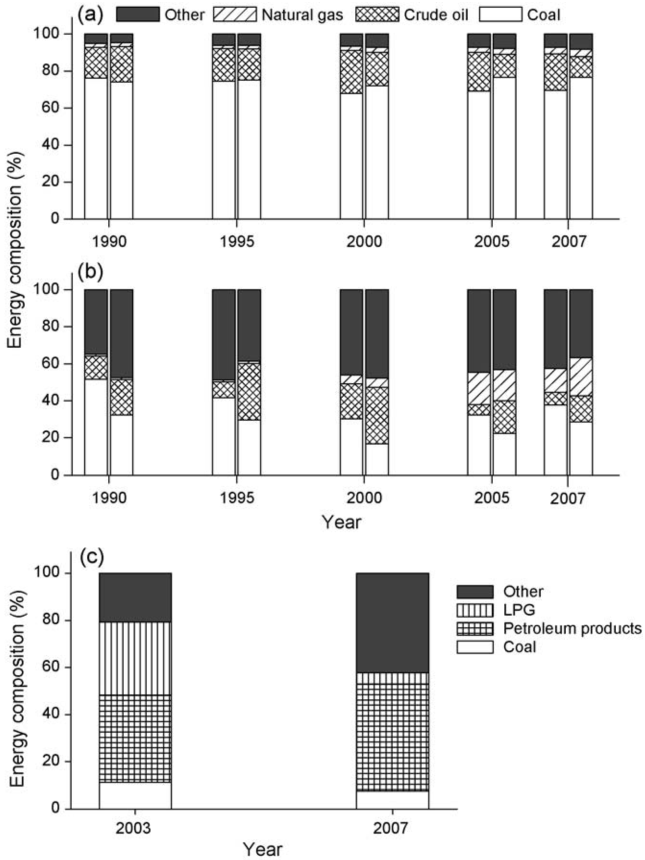

Fig. 4. Composition of commercial energy resources consumed and produced in China, Qinghai and Tibet in recent years. (a) Energy produced (left bar) and consumed (right bar) in China from 1990 to 2007; (b) energy produced (left bar) and consumed (right bar) in Qinghai from 1990 to 2007; (c) energy consumed in Tibet in 2003 and 2007 [21,27,31,32]. Other: hydro, nuclear and wind power; Petroleum products: diesel oil, kerosene and gasoline together.

consumption in China were still very small [33]. China mainly relied on coal for electricity while hydro-power accounted for higher percentage in electricity in the Qinghai–Tibet region (Fig. 5). Hydro-power made up 67.9% of total electricity and renewable energy accounted for 36.87% in whole energy consumption in Qinghai in 2007 while hydro-power made up 92.4% of total electricity in Tibet in 2007, and 51.2% of villages in Tibet relied on renewable energy for electricity in 2005 [21,34,35].

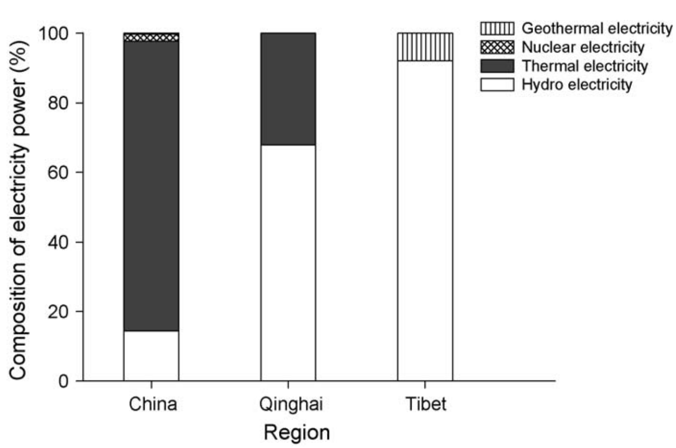

Fig. 5. Composition of electricity power in China, Qinghai and Tibet in 2007 [34].

3.2. Composition of household energy consumption

Urban areas in both the Qinghai–Tibet region and rest of China mainly relied on fossil energy for household energy consumption, while rural areas used more biomass (Fig. 6). Households in urban Qinghai mainly relied on natural gas, and households in urban Tibet mainly used electricity and LPG for energy consumption while households in urban China used variety of energy resources (Fig. 6). Crop residues and firewood were main energy resources for households in rural areas in China while pastoralists in Qinghai and Tibet used yak dung and sheep fecal pallets as their main energy resources (Fig. 6). Winter is long in the Qinghai–Tibet region but heating in the pastoral communities mainly depends on biomass [4]; such unique energy using manner is important for pastoralists to go through harsh environment on the plateau [36]. The limited statistical data on biomass for heating might cause bias in estimating heating proportion in household energy consumption in Qinghai (Fig. 6).

3.3. Energy consumption per capita in urban and rural areas

Climate is an important factor that affects energy consumption pattern [37]. Winter is rather long and cold in Qinghai–Tibet Plateau and oxygen density is low in the plateau, moreover, most of burning equipments in local households are outmoded, which result in a very low burning efficiency [4]. Therefore, per capita energy consumption in the Qinghai–Tibet region is much higher than the national average [27]. Per capita energy consumption in Qinghai was about two times that of the national average (Fig. 7). Per capita energy consumption in Tibet was about 700 kilogram coal equivalent (kgce) in 2007 which was much higher than the national average [31]. Since the proportion of commercial energy in effective heat consumption and annual electricity consumption for livelihood per capita characterized rural household energy consumption, energy consumption in rural area in the Qinghai–Tibet region is at very low level [38]. There were big gaps between rural and urban areas on energy consumption per capita both in Qinghai and China. Annual average residential energy consumption per capita in urban area was about three times that of rural area in Qinghai (Fig. 7). Biomass consumption was not included in the statistical data, which might be the main reason that energy consumption per capita in rural area was much lower than that in urban area both in Qinghai and China.

4. Energy production and consumption in the Qinghai–Tibet region

4.1. Conventional energy

Energy self-sufficiency rate of Qinghai has been more than 100% since 2005 [21]. The theoretical reserves of coal are 38 billion tons and reserves in Haibei and Haixi regions of Qinghai Province compose 95.88% of total coal reserves in the province [7]. Crude oil and natural gas centralize around northwest edge of Qaidam Basin with the natural gas reserves of 400.5 billion cubic meters in 2005 [39]. Total energy produced and consumed in Qinghai have showed gradual increases since 1990 and consumption of crude oil has decreased since 2000 while consumption of natural gas and hydro-power has increased evidently since 1995 [21]. The proportion of coal in household energy consumption decreased while proportions of electricity and natural gas increased in Qinghai [27]. Coal reserves in Tibet concentrate in Chamdo, Nakchu and Ngari region and theoretical reserves of coal resources are 44.02 million tons. Verified reserves of oil and gas are few in Tibet. Oil and gas are mainly from Qinghai, and Tibet has to import about 0.1 million tons coal annually from Qinghai or adjacent provinces

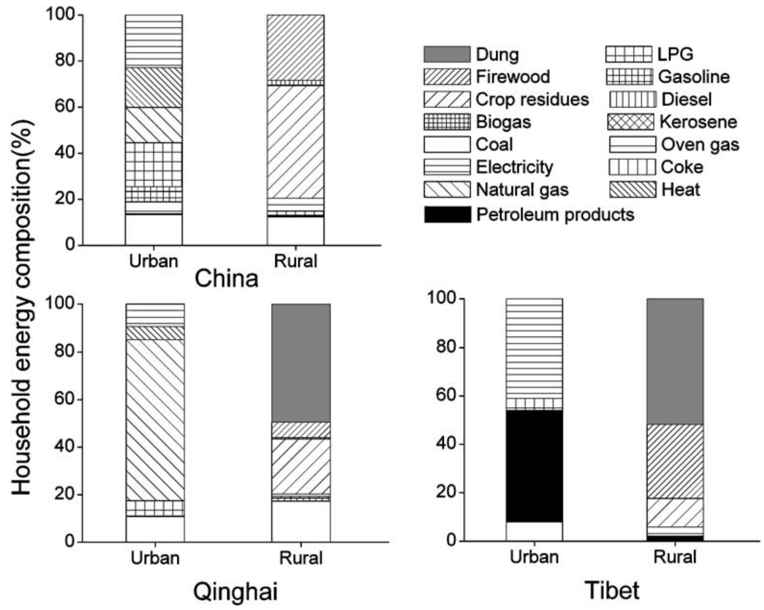

Fig. 6. Composition of household energy consumption in China, Qinghai and Tibet in 2007 [21,27,31]. Dung: yak dung and sheep fecal pellets; Petroleum products: diesel oil, kerosene and gasoline together; LPG: liquefied petroleum gas.

[32]. Natural gas in Tibet is mainly used for cooking in Lahsa and other central cities. Diesel was chiefly used for agricultural engines and the consumption of diesel was 14,000 tons in Tibet in 2008 [22].

4.2. Renewable energy

4.2.1. Biomass energy

Farmers and herdsmen living on the plateau have relied on yak dung and sheep fecal pellets, firewood and crop residues for cooking and heating for thousands of years. Such biotic energies are still the main energy resources for household energy consumption on Qinghai–Tibet Plateau due to the economic condition constraints, lack of alternative energy resources and traditional custom [4]. Distributions of biomass energy are highly related to geographic location and climate. Qinghai could be divided into two parts according to climate, geography and livelihood: eastern area is predominately agricultural zone and the other areas are pastoral zone. Altitude of agricultural zone is below 2700 m, with weak solar radiation, short sunshine hours and low average wind speed. People living in agricultural zone mainly use crop residues and firewood for cooking. Pastoral zone has strong solar radiation, long sunshine hours and high average wind speed, with altitude above 2700 m. People living in pastoral zone mainly use yak dung and sheep fecal pellets as the energy resources for household consumption [40]. Annual consumption of crop residues was about 1.28 million tons which was 599,400 tce; annual consumption of firewood was about 333,900 tons which was 170,300 tce and annual consumption of yak dung and sheep fecal pellets was about 14.3 million tons which was 1.28 million tce in Qinghai in 2007 [27,41].

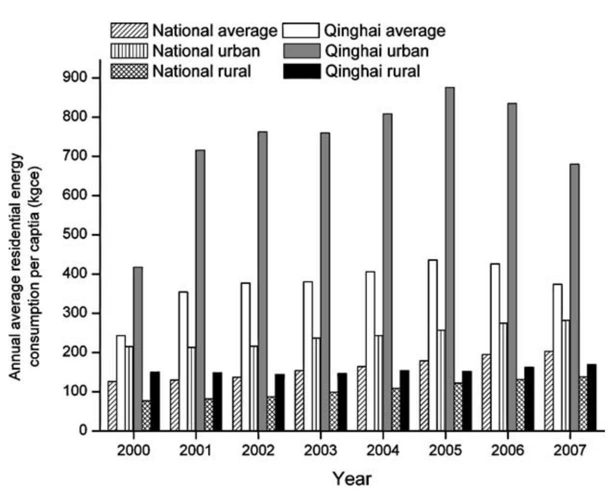

Fig. 7. Annual average residential energy consumption per capita in China and Qinghai from 2000 to 2007 [21,27]. We only have the statistical data on energy consumption of Qinghai, no data for Tibet.

Whole biomass amounts to 1.28 billion tons in Tibet [42]. Central and eastern Tibet regions are predominately agricultural zone and farmers living there mainly use crop residues for cooking; forests mainly locate in southeastern Tibet regions and people living there mainly use firewood as fuel; northern Tibet regions are grassland and people living there rely on yak dung and sheep fecal pellets for heating and cooking [43]. Biomass accounts for more than 80% of total energy consumption in rural Tibet [34]. Annual consumption of crop residues was about 219,900 tons which was 103,400 tce; annual consumption of firewood was about 220,000 tons which was 112,200 tce in Tibet in 2007; Annual consumption of yak dung and sheep fecal pellets in Tibet was about 24.26 million tons which was 2.18 million tce and some people burned grass directly and consumed about 480,000 tons of grass which was 240,000 tce every year [44].

4.2.2. Solar energy

Solar energy is abundant on Qinghai–Tibet Plateau for its high-transparency atmosphere, low water and dust content in the atmosphere [2]. Qinghai's annual average sunlight ranges between 2315 and 3550 h; the average annual solar energy radiation is about 6700 MJ/m^2 and annual solar power is about 162.3 billion tce [45]. Annual average sunlight ranges between 1600 and 3400 h in Tibet, and the average annual number of days with 6 h of sunshine is 275–330 in the region [2]. The solar irradiation intensity increases from east to west in Tibet and four zones of solar energy resources can be distinguished according to their solar energy radiative quantities: western and northern Tibet which have two-thirds of the total solar energy resources in Tibet, receiving an annual radiation of 7000–8400 MJ/m^2 and 2900–3400 h of sunshine; western Himalayas, middle and eastern Nagqu Prefecture and Qamdo Prefecture, receiving an annual radiation of 6250–7000 MJ/m^2 and 2250–2900 h of sunshine; southeastern Tibet, receiving an annual radiation of 5850–6250 MJ/m^2 and 2000–2250 h of sunshine; Brahmaputra, receiving an annual radiation of less than 5850 MJ/m^2 and less than 2000 h of sunshine [2].

Solar energy can be used directly by exploiting its heat characteristics in many ways including solar cooker, passive solar building and passive solar heater for domestic applications [2]. By the end of 2007, 159,260 solar cookers, 23,500 square meters of solar water heating equipments, and 0.43 million square meters of solar buildings had been built in Qinghai [45]. Up to 2007, 400 solar power plants with generating capacities of 10,000 kW, providing nearly nine MW electricity; 3 million square meters of solar buildings and 0.4 million square meters of solar water heating equipments had been built in Tibet [43].

4.2.3. Wind power

Wind power in China is not even in distribution, Qinghai–Tibet Plateau, Inner Mongolia and coastal regions are rich in wind power while central, southern and southwest China are poor in wind power [9]. Most regions in Qinghai are rich in wind power except few mountains and valleys in southeast [46]. Wind power decreases from west to east and could be used in about 50% of the time in a year in central and western Qinghai, such as Qaidam basin and Qinghai Lake watershed [46]. Theoretical wind power is about 78.54 million tce, and there are 1500 small size stand-alone wind power plants with total power of about 100 kW in Qinghai [46].

There are two main wind belts in Tibet: one is in northern plateau along Nagqu and Ngari in which the annual valid wind (wind speed is 3–20 m/s) hours are above 4000 h with annual valid wind energy density of 130–200 W/m^2; the other one is in the eastern valley of Himalaya in which annual valid wind hours are between 3500 h and 4000 h. Total annual wind power in Tibet is about 93 billion kW h which is about 11.43 million tce [32].

4.2.4. Hydro-power

Hydro-power is abundant in the Qinghai–Tibet region for it is the origin of several big rivers like Yellow River and Yangtze River [47]. Theoretical hydro-power is 23.37 million kW and the explorative power amounts to 20.96 million kW in Qinghai with annual electricity of 83.2 billion kWh that is 10.23 million tce [45]. There were 68 large and middle hydro-power plants with theoretical power of 20.96 million kW and 117 small hydro-power plants with theoretical power of 8910.80 kW in Qinghai, and to the end of 2007, total hydro-power electricity attained to 5.83 million kW and accounted for 67.88% of whole electricity in Qinghai [34–35].

Hydro-power in Tibet ranks the first in China and the theoretical power amounts to 0.2 billion kW. Tibet mainly relies on hydro-power for electricity [34]. The explorative hydro-power comes to 0.116 billion kW and annual hydro-power electricity is 600 billion kWh which is 73.74 million tce [42]. Sixty percent of hydro-power in Tibet distributes in southeast while less than 1% of hydro-power distributes in large areas of northern Tibet (two-thirds of Tibet in area) [42].

4.2.5. Biogas

Biogas is mainly used in agricultural zones in eastern Qinghai–Tibet Plateau. Agricultural zones are of low altitude and the air temperature is always high enough to develop biogas; on the other hand, crop residues, yak dung and sheep fecal pellets are abundant in those zones which are necessary for biogas producing. The state allocated 3000 Yuan (US$439.24) for each household as subsidy to encourage the development of biogas in Qinghai–Tibet Plateau in 2009 [48]. Number of households using biogas in Qinghai was 66,200 and annual biogas production was 19.86 million cubic meters which was 14,200 tce in 2007; number of households using biogas in Tibet was 25,000, consumed eight million cubic meters which was 5700 tce in 2007 [49,50]. Utilization of biogas has increased remarkably in recent years. In 2008 alone, there were 15,600 and 18,000 more households using biogas in Qinghai and Tibet respectively and the number of people using biogas in Tibet reached 215,000 by the end of 2008 [49,50].

4.2.6. Geothermal energy

Geothermal energy resources in Tibet are mainly distributed along Qinghai–Tibet railway, which account for 80% of total high temperature geothermal resources in China [42]. Since 1970s, the state has begun to explore, develop and utilize geothermal energy and to the end of 2007, there have been 4 reserves with whole power of 28 MW and 703 geothermal energy sites in Tibet and available energy was 0.152 billion kW [42].

5. Ecological impacts of energy consumption pattern

The rich renewable energy resources and poor conventional energy resources result in the specific energy consumption pattern in the Qinghai–Tibet region where renewable energy resources are the most important part in total energy consumption. Such energy consumption pattern is environment-friendly and reduces emission of greenhouse gas which is a good choice considering the fragile ecosystem on Qinghai–Tibet Plateau due to its special geographical location and climate [13]. Crop residues and firewood release less sulphur dioxide compared with fossil fuel, moreover, the prevalence of improved stoves and other technologies like biomass briquette can increase the burning efficiency which make biomass good alternative to fossil fuel [51,52]. Per capita waste gas emission and sulphur dioxide emission by household in Qinghai and Tibet were less than the national average, but the emissions of soot by industry and household in Qinghai were high which might be caused by the small population number in Qinghai (Table 3). There were few industries in Tibet and households were main consumer of energy resources which resulted in low emission of waste gas and soot (Table 3) [24].

Fuel is essential on Qinghai–Tibet Plateau for the harsh natural condition. Most biomass is directly burned as fuel for cooking and heating with low burning efficiency [53]. Such way of energy consumption will disturb the material cycle and energy flow in ecosystem and reduce soil fertility [53]. On one hand, the direct use

Table 3
Per capita emission of waste gas and soot in China, Qinghai and Tibet in 2007 [44].

	Waste gas emission from fuel burning (cubic meter)	Sulphur dioxide emission by industry (kg)	Sulphur dioxide emission by household (kg)	Emission of soot by industry (kg)	Emission of soot by household (kg)
China	15,887	16.20	2.48	5.84	1.63
Qinghai	11,059	22.66	1.63	9.06	4.53
Tibet	457.50	0.35	0.35	0.35	No data

Table 4
Desertification and sandy land in Qinghai and Tibet in 2005 [44].

	Desertification land		Sandy land	
	Area (10,000 hm^2)	% total area	Area (10,000 hm^2)	% total area
Qinghai	1916.62	26.55	1255.83	17.39
Tibet	4334.87	36.13	2168.43	18.10

of firewood and grass as fuel damaged vegetation straightly and about 4000–6700 hm^2 of shrub lands were destroyed annually in Tibet for fuel need; on the other hand, few crop residues and dung were returned to farmland and grassland, according to previous investigation, only 40% of yak dung and sheep fecal pellets were returned to farmland and grassland in Tibet, which reduced the soil fertility [54].

Reduction in household size is proved to increase the resources consumption since more materials are needed for housing construction and lower efficiency of resource use per capita [55]. Rapid increase in human population and decrease in household size increase the energy demand in the Qinghai–Tibet region. In addition to the low burning efficiency, biotic energy resources are being overused, which has become the main factor for land desertification, soil erosion, grassland degradation and soil fertility reduction on Qinghai–Tibet Plateau [54]. Desertification area increased 146,750 hm^2 from 1991 to 1997, and the degraded grassland increased 116.1% from 1987 to 1996 and reached 26 million hm^2 in Tibet in 1997; and to the end of 2004, degraded grassland area reached 26 million hm^2, accounting for 32.1% of its total grassland area and about 13.8% of total farmland area suffered from desertification in Tibet [54]. According to "*the Third Monitoring Report on Desertification in China*" in 2005, percentage of desertification and sandy land in Qinghai and Tibet increased at a rate of 3–5% annually (Table 4), furthermore, more than 80% of grasslands were degraded in some regions on Qinghai–Tibet Plateau [44,56].

Energy consumption for tourism plays an important role in whole energy consumption in the Qinghai–Tibet region. Calculated by energy consumption per 10,000 Yuan (US$1,460) GDP, whole energy consumption of tourism was 1.27 million tce which was 6.06% of total energy consumption in Qinghai while energy consumption of tourism was 14.18% of total energy consumption in Tibet in 2007 [20,21]. Majority of tourists come to the Qinghai–Tibet region from June to August, and the huge energy demand in such short period brings challenge on energy production and transportation. Moreover, fossil energy is the main energy resource for tourism associated sectors, releasing greenhouse gases and presenting threats to the unique ecosystem in the Qinghai–Tibet region.

Furthermore, the Qinghai–Tibet region plays an important role in carbon storage both in China and in the world. Carbon density in forest soils in southeastern part of Qinghai–Tibet Plateau is among the highest in China [57]. Alpine region has the highest carbon storage in grasslands of China which covers 54.5% of total carbon storage in grasslands of China and 4.90–8.72% of total carbon storage in the world grasslands [58]. 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 effects on carbon cycles in China even at the global level.

6. National policy and energy projects

The national government issued a series of administrative regulations, namely Further Support on the Development of Renewable Energy, 1996–2010 New Energy and Renewable Energy Development Principles, 2000–2015 New Energy and Renewable Energy Development Principles, etc. to promote the development of renewable energy in the country [33]. Other notable programs include the "Brightness Program" and the "Ride the Wind Program", aiming to make percentage of renewable energy in total energy consumption reaches 15% in 2020 and 30% or more in 2050 in China [59]. Renewable Energy Law of the People's Republic of China was passed by the Standing Committee of National People's Congress on 28 February 2005, which brought the exploitation and use of renewable energy to the strategic height. Then state government sectors took quick actions to stipulate relevant regulations, including investigations on renewable energy resources, programs on exploitation and use, electricity price policy, cost sharing, special capital, financial support and other policies to promote the development of renewable energy. Economy Promotion Law of the People's Republic of China, passed on August 29, 2008, was closely linked to Renewable Energy Law of the People's Republic of China, aiming to facilitate recycling economy, protect the environment and realize sustainable development [60].

Subsidy, taxation policy and price policy have been used to encourage renewable energy power generation in the Qinghai–Tibet region. The government invested about two billion Yuan (US$0.29 billion) in 2002 on "*Delivering Power to Village*" project, primarily to solve lighting problem in remote rural areas of western China [33]. About 8620 million Yuan (US$1,209.37 million) have been invested in the construction of energy system in rural areas in China since 2001 [22]. Qinghai is within the range of "*Brightness Program*" and "*Delivering Power to Village Project*" and has carried several projects to popularize the utilization of electricity in rural areas i.e. "*Yushu (A prefecture in Qinghai Province) Power up Plan*", "*Guoluo (A prefecture in Qinghai Province) Power up Plan*" and "*Qinghai Rural Region Electricity Development Plan (1995-2020)*" since 1995. The state invested about 101 million Yuan (US$14.79 million) in Qinghai in 2009 to promote the development of biogas and planed to build six middle or large biogas ponds and 10,831 household biogas pools [49].

The government invested 4500 million Yuan (US$657 million) on biogas development in "*11th Five-Year Plan*" from 2006 to 2009 and facilitated about 40,000 households to use biogas in Tibet [48]. The state has invested about 5.81 billion Yuan (US$0.85 billion) in Tibet to launch "*Development Program of Alternative Energy for Firewood*" since 2008 to develop biogas, electricity, solar power and straw briquette (Table 5) [61]. The State Grid Corporation of China plans to invest about three to five billion Yuan (US$0.44 to 0.73 billion) in Tibet to develop the solar and geothermal power in "*12th Five-Year Plan (2010-2015)*" [29].

Apart from energy development and economy construction, the state government is spending about 15.5 billion Yuan (US$2.27 billion) on environment conservation on Qinghai–Tibet Plateau from 2008 to 2015 [62]. In 2004, 70.78 million Yuan (US$10.36 million) was invested in the ecological compensation of 0.94 million hm^2 natural forests (compensation for conversion of cropland to forest), and this number came to 750 million Yuan (US$109.81 million) to ensure the conservation of 10.04 million hm^2 natural forests in 2008. Apart from that, government began to

Table 5
Development program of alternative energy resources for firewood in Tibet [61].

Region	Total households	Households for alternative energy resources			
		Biogas	Straw briquette[a]	Electricity	Solar energy
Lhasa	37,783	37,783		13,976	10,000
Shigatse	75,492	52,482		18,426	20,000
Lhoka	50,831	46,878		17,833	15,000
Nyingtri	18,596	18,596		6,749	1,250
Chamdo	55,160	41,500		17,986	13,750
Nakchu	8,742	1,600	53,449	13,388	13,750
Ngari	3,396	1,161	9,693	1,301	8,750

[a] Straw briquette: a technology that presses crop residues into shaped fuel.

invest 200 million Yuan (US$29.28 million) in the experiment of ecological compensation of natural grasslands (compensation for conversion of cropland to grassland) in 2008 [62].

7. Energy in the future

The rich renewable energy resources make the development of renewable energy greatly promising in the Qinghai–Tibet region. Sparse population in grassland regions makes small photovoltaic power stations and hydro-power plants more cost-effective than the expansion of electricity grid to satisfy the lighting need for herdsmen. Abundant biomass resources and investments will assure the great development potential of biogas in the Qinghai–Tibet region in the future.

7.1. Conventional energy development

According to "*11th Five-year Energy Development Plan in Qinghai Province*", Qinghai will continue to promote the development of coal, crude oil, natural gas and electricity. Production and consumption of primary energy will come to 32.4 and 28.6 million tce in 2010, with coal, crude oil, natural gas accounting for 33%, 11.2% and 24.4% in production and 54.1%, 8.1% and 20.5% in consumption respectively in Qinghai [63]. Consumption of conventional energy in Tibet will reach three million tce and 6.30 million tce in 2010 and 2020; LPG and natural gas will be used in central town and utilization rate of natural gas in Lahsa will be 40% in 2010 and 100% in 2015 [61].

7.2. Renewable energy development

7.2.1. Biomass energy and biogas

From 1995 to 2005, China produced some 630 million tons of crop residues per year, and most of crop residues were directly combusted or discarded in the field [10]. The low burning efficiency causes great waste of energy and pollutes the environment [9]. Straw briquette is one of the new technologies that could help in expanding the use of crop residues in energy production in rural China. Straw briquette technology refers to pressed crop residues of about 10% moisture content into all kinds of shaped fuel such as bar-formed, pellet-formed or block-formed under certain pressure and this technology has been continuously improved since 1995 [11]. The energy density of straw briquette is about 3000 kJ/kg, which is equivalent to medium quality coal [64]. Burning efficiency of straw briquette is 30–40%, much higher than direct burning efficiency of crop residues which is 10–15%. There is no dust and smoke discharged and concentrations of CO, CO_2, SO_2 and NO_x in the fume gas during the burning of straw briquette are much lower than the standard stipulated for coal [65]. Straw briquette has great potential of development since the crop residues resources are rich in agricultural areas in the Qinghai–Tibet region and priority of development of straw briquette has been inscribed in *Mid and Long-Term Development Plan for Renewable Energy in China* [64,66]. Tibet plans to establish two straw briquette factories with annual production of 6300 tons of straw briquette in Lahsa and Nyingtri in 2009 and about 10% of farmers will use straw briquette in 2010 [67].

The promotion of improved stove in the Qinghai–Tibet region is promising. Burning efficiency of old stoves is only about 10–12% and old stoves release smokes and noxious gas which cause indoor air pollution and induce respiratory problems [4,68]. The improved stoves double burning efficiency and have chimneys, which direct fumes to the outside of the households [4]. If all households in rural areas use improved stoves, about 1–1.5 tons of firewood could be saved for each household and about 238,300 tons and 50 million tons of CO_2 emissions could be avoided annually in Qinghai and China [11].

In agricultural regions in the Qinghai–Tibet region, comprehensive utilization of biogas by integrating the livestock residue and crop residues can promote agricultural production and improve the environment in rural areas [11]. A biogas pool with area of 10 m^3 will produce about 360 m^3 biogas annually which have the same heat of about 180 kg LPG and save 1386 Yuan (US$202.93) per household per year [69]. Qinghai invests about 1.01 billion Yuan (US$0.15 billion) to develop biogas in rural areas by which 10,931 new biogas pools will be built in 2009 [70]. Tibet plans to promote the use of biogas and number of households using biogas will come to 200,000 in 2010 [71].

7.2.2. Solar and wind power

Solar cooker and passive solar building are two promising energy saving equipments. Solar cooker with area of 1.6 m^2 has the power of 800–1000 W [69]. If a solar cooker is used 6 h per day and 280 days per year per household, 2140 tons of firewood or 2260 tons of yak dung and sheep fecal pellets; 800 m^2 grasslands; or 800 Yuan (US$117.13) would be saved per household per year [69]. Passive solar buildings aim to maintain interior thermal comfort throughout the sun shine daily and annual cycles whilst reducing the requirement for active heating and cooling system by choosing proper location, building materials and structures [2]. In 2007, an experiment by the Tibetan Energy Research Center showed that solar building technology increased indoor temperature at least 8–10 °C [2]. According to *the solar energy industry development and promotion plan of Qinghai Province (2009-2015)*, there will be 574,100 solar cookers and 81.43% of households will use solar cookers in rural Qinghai in 2010 [45]. Tibet plans to install 267,700 solar cookers from 2008 to 2010 and the passive solar heating buildings will come to 3.3 million square meters in 2010 [71].

Two drawbacks of renewable energy resources are the poor stability and low density of electricity power depending on uncontrollable weather and climatic conditions. However, such drawbacks could be compensated by combining two or more kinds of renewable energy together i.e. wind-diesel hybrid, solar-diesel hybrid, solar-wind hybrid, etc. Solar energy and wind energy tend to be highly complimentary: good solar irradiation and poor wind

Table 6
Current status and prospect of household energy consumption in Qinghai and Tibet.

	Qinghai			Tibet		
	Urban	Agricultural area	Pastoral area	Urban	Agricultural area	Pastoral area
% to Population	28.17	53.07	18.76	16.80	59.44	23.77
Current status	Electricity, natural gas	Coal, crop residues, firewood	Dung	Hydro-power, coal, LPG	Crop residues, firewood	Dung
Prospect	Hydro-power, natural gas	Biogas, straw briquette, hydro-power	Solar, wind, dung, hydro-power	Hydro-power, natural gas	Biogas, straw briquette, hydro-power	Solar, wind, dung, hydro-power

energy in summer while good wind energy and poor solar irradiation in winter; high solar irradiation and poor wind energy in daytime while relatively good wind energy at night. Thus solar-wind hybrid system could achieve higher generating capacity and reliability and is becoming more and more popular [9]. Solar energy and wind energy are the most abundant energy resources on Qinghai–Tibet Plateau, and the good compensation characters of the two energy resources make solar-wind hybrid a promising system in the future energy development plan [2].

With special financial allocations from the central government, Qinghai and Tibet have launched sets of programs in the past 30 years to advance solar energy applications. However, the lack of technical know-how and follow-up obstructs the utilization efficiency of solar cooker. Lack of technicians comes to a bottleneck in solar energy applications, and the training of local technicians for management and maintenance of solar equipments becomes crucial in expanding the use of solar cookers [2].

8. Conclusion

With rapid economic growth and near-exponential rise in tourism, energy consumption in the Qinghai–Tibet region has increased remarkably but is still in a very low level compared with the national average in China. Besides, there is a large gap in energy consumption between urban and rural areas. The Qinghai–Tibet region is short of conventional energy but rich in renewable energy. Renewable energy has gained big achievement in the past 10 years in the Qinghai–Tibet region due to policies and funds support from central government. However, the traditional use of biotic energy resources not only leads to serious eco-environment problems but also causes diseases in human being. The future energy development should focus on finding new ways of utilizing biomass energy resources i.e. the biogas and straw briquette, and developing solar power, wind power, and hydro-power (Table 6). Continuous researches should be made in terms of techniques and long-lasting and effective mechanism should be formulated in the future. Only in this way, could the Qinghai–Tibet region strive for a balance among economic development, booming tourism and environmental protection.

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