Renewable Energy 65 (2014) 137–145

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Rural household energy consumption and its implications for eco-environments in NW China: A case study

Hewen Niu [a,b,*], Yuanqing He [a,b,*], Umberto Desideri [c,**], Peidong Zhang [d], Hongyi Qin [e], Shijin Wang [a]

[a] State Key Laboratory of Cryosphere Sciences, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China
[b] MOE Key Laboratory of Western China's Environmental System, Research School of Arid Environment and Climate Change, Lanzhou University, Lanzhou 730000, China
[c] Dipartimento di Ingegneria Industriale, Universita' di Perugia, Via G. Duranti 93, 06125 Perugia, Italy
[d] College of Environment and Safety Engineering, Qingdao University of Science & Technology, Qingdao 266042, China
[e] College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China

ARTICLE INFO

Article history:
Received 18 February 2013
Accepted 31 July 2013
Available online 30 August 2013

Keywords:
Biomass resources
Emission reduction
Energy use
Renewable energy

ABSTRACT

Rural household energy consumption plays an essential role in the daily life of farmers, especially in developing regions. In this paper, we present a study of household energy consumption in terms of energy sources and energy end uses, and analysis of technical and economic issues associated with the use of biomass and renewable energy and the replacement of fossil fuels. Results show that energy from biomass represents the largest share of total energy supply, and that 41.15% of total energy is consumed for home heating and cooking. The average cost of household energy is 1259 RMB ($US193.6) and this expense is no longer subsidized by the government. It takes less than one year to make a solar stove profitable and less than two years to pay back the household cost of biogas digesters. An 8 m^3 digester can produce as much energy as 500–550 kg of standard coal or 940 kg of firewood, while a solar stove can generate 1.76×10^3 MJ heat each year. Moreover, it is estimated that in rural China the annual reduction of CO_2 and SO_2 emissions in 2020, due to the replacement of fossil fuel by biomass, will be 68.86×10^6 and 54.37×10^4 tons, respectively. Overall, the investigations and analyses have revealed that the structure of rural household energy consumption is undergoing a transformation from traditional low-efficiency biomass domination to integrated consumption of traditional and renewable energies. Renewable energy will significantly contribute to the sustainable development of rural households.

1. Introduction

Energy poverty is a global threat to sustainable development and improved livelihoods, making the availability of clean, affordable, reliable and sustainable energy a central issue to national sustainable development objectives. Among the estimated 2.5 billion people around the world that do not have access to modern fuels, burning of biomass in traditional stoves is associated with a host of ills [1]. Indoor air pollution (IAP) or Household Air Pollution (HAP) from traditional biomass burning contributes to serious health problems, particularly cancer and respiratory infections that cause an estimated 4 million deaths annually (3.5 million from direct premature deaths, 0.5 million from child pneumonia) [2–5]. Moreover, a growing body of literature suggests that incomplete combustion products and black carbon from traditional biomass burning have a significant contribution to climate change [6,7].

Technologies are reasonably well-established for "improved cookstoves" that burn biomass more cleanly and efficiently, and could thus help mitigate the above problems [8–10]. Clean energy generation becomes more crucial every day due to the growing significance of environmental issues. Especially after the oil crisis of 1973 caused soaring fuel prices, there has been a strong body of research into renewable energy technologies. Currently, renewable energy resources supply about 14% of total world energy demand and their future potential is remarkable [11–13].

* Corresponding authors. Suite 216, No. 1 Science Research Building, 320, West Donggang Road, Lanzhou city 730000, China. Tel./fax: +86 931 4967371.
** Corresponding author. Tel.: +39 0755853743; fax: +39 0755853736.
E-mail addresses: niuhw11@lzu.edu.cn (H. Niu), yqhe@lzb.ac.cn (Y. He), umberto.desideri@unipg.it (U. Desideri).

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.07.045

With the rapid social and economic development since the reform and opening policy of China in 1978, the structure of rural household energy consumption is experiencing dramatic changes. Historically, energy is one of the most basic needs for human existence and development. A shortage of energy supply severely affects the quality of life. In underdeveloped countries, where electric energy and fuels are not widely accessible, an increase in energy consumption is necessary to improve the quality of life. However, where electric energy and fuels for heating and cooking are easily accessible to the vast majority of people and where reducing the energy intensity is one of the primary societal goals, it is of prime importance to introduce systems that have high efficiency to avoid further steps to replace obsolete and inefficient systems. With this in mind, we can actually state that increasing energy consumption is linked to economic development. Up to the first oil crisis in 1973, energy consumption and economic growth increased in tandem, giving the impression that in order to have economic growth, energy consumption must increase, though such a link was broken for many industrialized countries [14].

Due to the scarcity and unavailability of commercial energy sources in most rural areas of China, the energy demand of rural households has heavily relied on traditional self-produced fuels, such as firewood, crop residues, and animal dung. Traditional biomass stoves cause significant greenhouse gas (GHG) emissions due to formation of products of incomplete combustion [15–18].

The greatest dependence on traditional fuels in developing countries is in rural areas. In 1975, it was estimated that only 15% of commercial energy consumption in these countries took place in the rural areas [19]. In rural Africa, the gathering of fuel-wood and other traditional fuels is a strenuous and time consuming task mainly performed by women. Modern fuels and appliances allow households to reduce their exposure to smoke from biomass cookers and heaters [20,21]. The energy consumption in rural areas of China deserves more attention, especially from the perspective of its relations with energy demand and supply, land degradation, social behavior and lifestyle changes, and GHG reduction strategies [22]. Due to the large population of China, high demand of all energy sources and low utilization efficiency, the Chinese government faces a distinct challenge in its plans for nationwide CO_2 emission reductions.

Like many other developing countries, China has a renewable energy program for its citizens living in rural areas, which are often very remote. Within the framework of this program, many renewable energy technologies have been, and are being developed to reduce rural energy shortages [23,24]. The two most important renewable energy technologies used in rural areas of China are biogas digesters and solar stoves. Biogas production is an important aspect of China's energy strategy [25].

In the study area of Gansu province, Northwest China, the rural energy construction program was initiated in the 1970s, having thus experienced a relatively long history. In 2000 the national government strengthened the program and Gansu's rural renewable energy construction profited of this development opportunity. Therefore, the construction of renewable energy systems, especially rural biogas digesters, had reached its peak—about 78% of the digesters built by the government are still in operation. At the end of 2007, rural biogas digesters could be found in 308,000 households, covering 60% of rural areas. Concurrently, 788,000 solar stoves were distributed in Gansu province. The annual energy saved by these renewable energy techniques (including wind energy, hydropower etc.) implemented in Northwest China was equivalent to 1.84 million tons of standard coal. Of these the wind energy and hydropower contributed to approximately 22.7% and 37.1% of the renewable energy, respectively.

Apart from the shortage of energy supply in remote areas, the use of renewable energy has other benefits in poverty alleviation. For example, the use of the residue from biogas digestion has a positive effect on farm production, and thus farm income; the solar stove is completely non-polluting and environmentally friendly and local households saw great benefits (mainly ecological) from its use. Renewable energy systems installed in Costa Rica [26] and Egypt [27] showed similar effects. In Lesotho, Taele et al. [28] argued that with proper economic support and utilization of efficient renewable energy technologies, developing countries can meet their basic energy demands and alleviate the problems of energy shortages. In Zimbabwe, tremendous economic, social and environmental benefits have been achieved from using solar water heating technology [29,30].

Previous research had explored the changes in energy consumption in Southern China [31–35], but quality data for Northwest China are lacking. There are clear differences between the two regions as far as rural household energy consumption is concerned. In Northwest China's long and cold winter, large amounts of energy are consumed for home heating. In addition, the rural economy of Northern China is poorer, and the natural environment more vulnerable than in southern China. We conducted studies in 2012 in two representative counties of Gansu Province, Northwest China, to better understand the status of energy consumption and the issues concerning renewable energy utilization. We investigated household energy consumption structure, economic costs and benefits of renewable energy, and quantity of GHG and pollutant emissions, and estimated the potential of emission reductions from the replacement of fossil fuel.

2. Material and methods

2.1. Description of study area

Northwest China (92°13′ ~ 108°46′ E, 32°31′ ~ 42°57′ N), lies in the northern upper-basin of the Wei River [36], the largest branch of the Yellow River. Sparse vegetation and loose soil structure in the region offers poor protection against heavy rainfall events, leading to severe soil displacements and water loss. Gansu Province, Northwest China, has a complex topography with crisscrossing mountain ranges, and significantly elevation variation. The mean elevation of Gansu is 1200 m above sea level and its ecosystem is very vulnerable, with severe soil erosion and limited water resources. Western Gansu is covered by vast deserts and Eastern Gansu by several humid zones as well as multiple meteorological types of cold and dry zones, all often subject to drought. The upper westerlies are the prevailing winds over the entire area and most of precipitation/moisture is transported from the west by the atmospheric circulation.

Gansu province is prone to many kinds of natural and meteorological disasters, which have a strong impact on the local social and economic development. The major disasters include drought, landslides, debris flow, earthquakes, dust storms, and frost. Drought and landslides are predominant with high rate of incidence. In addition, compared with other provinces in China, Gansu is underdeveloped with lower per capita and gross income, and lower per capita energy consumption. Energy use is minimal, with rural households obtaining fuel from local sources, in most cases for heating and cooking only. A biomass mix of straw, wood, weeds and animal dung is used for cooking and space heating, which means that there is a competition between its uses as fuel, fodder and organic fertilizer [36].

Gansu has a total population of 26 million and an area of 454,574 km^2 with a tillage area amounting to 46,852 km^2. The climate is a temperate, semi-arid type with annual precipitations reaching 400 mm (generally, the climate of this area is influenced by the light monsoon in summer and the strong westerlies in