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Empirical study on regional differentiation of rural household energy use in Northwest China

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Abstract. To better understand regional differentiation of rural household energy use, data of energy use of 232 rural households in the Linwei District located in the lower reaches of the Weihe River of Northwest China were collected by questionnaires combined with face-to-face interview. Location quotient of energy use (LQEU) method is adopted in the paper. The results show that multiple energy sources are utilized due to market orientation in the plain area, and biogas is prominent as a result of policy orientation in the loess tableland, whereas firewood is dominant due to the influence of natural environment in the Qinling mountainous area. Regional differentiation of energy use is comprehensively affected by income level, air temperature, development conditions, energy policy, etc.

1. Introduction

In recent years rural household energy consumption in China is changing from a traditional model of using biomass fuel as the major energy type to the new pattern of using a variety of energy, which is coordinate with the market orientation, income growth and government support. The structure of energy use is in the process of transformation, as the biogas and solar energy are incorporated in the local energy consumption structure, and definitely substitute for relatively large amounts of low-efficiency biomass energy in Northwest China [1]. Many solar stoves, small power stations, gasification furnaces, biogas digesters and wind generators have been distributed and constructed [2]. Multiple energy such as biomass energy, coal, electricity, liquefied petroleum gas (LPG), biogas and solar energy are simultaneously utilized in many areas. However, it is different to the source, consumption behavior and pattern of energy use among areas due to disparities in natural environment, agricultural production and external surroundings so that it inevitably leads to diverse structure and features of rural household energy use. Therefore, this paper to study regional differentiation of rural household energy is significant for people, especially for the researchers and policy makers to realize and guide reasonable energy utilization.

It is well known that fuel wood or biomass has remained the most widespread fuel in rural areas of the developing countries [3], despite there being an increase in the proportion of commercial energy [4].It is argued that with proper economic support and utilization of efficient solar energy technologies, developing countries can meet their basic energy demands and alleviate the problems of energy shortages [5]. Biogas energy is widely used by the rural households throughout the world, especially the developing countries, and has received a positive evaluation on its eco-economic benefit in rural areas [6]. In general, the consumption of fuels is determined by income, resource availability, household size, coal prices, terrain features, education, and so on [7]. Income is a crucial factor affecting the choice of fuel for cooking, but there are some socio-cultural factors which are equally important in making the preferences at household level [8]. Moreover, economies of scale in energy use in adult-only households are significantly found while small households suffer a double penalty of greater per capita energy use and higher charge per unit of energy, with older households the most affected [9]. Access to modern energy has numerous and complex links with poverty reduction, therefore it is vital to estimate the impacts of energy access improvement on socio-economic situation in the rural areas [10]. Rural energy consumption might lead to a series of the eco-environment problems such as deforestation, soil erosion, grassland degradation, desertification, carbon emission and some other problems such as human disease and loss of time for education and recreation [11]. Throughout these studies, most of them are based on the problems and influences of energy use by themselves, whereas the meso-level or macro-level cognition of rural household energy in different types of areas from spatial perspective is not enough. Accordingly, further study on spatial differentiation of household energy is necessary for scientific eco-environment management and adaptable energy policy.

2. Materials and methods

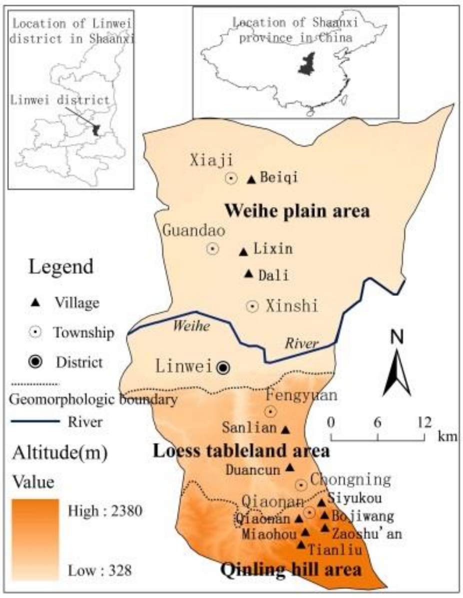

Figure 1. Survey places and spatial differentiation pattern in Linwei district.

Table 1. Basic survey data in three types of areas.

Area type	Per capita income/yuan	Per capita arable land/hm^2	Altitude/m	Accessibility	Irrigation conditions	Per capita total energy consumption/kgce	Per capita commercial energy/kgce	Per capita non-commercial energy/kgce
Weihe plain	7608	0.107	358	Superior	Good	678.01	205.57	472.45
Loess tableland	6076	0.093	656	Average	Very bad	736.14	124.04	612.10
Qinling mountain	5857	0.053	774	Poor	Irrigable partly	989.66	80.06	909.60

Note: 1 yuan RMB = 0.1452 US dollars.

2.1. Study area

The study is conducted in Linwei district, Weinan City, Shaanxi Province of northwest China, which is located in the lower reaches of the Weihe River and consists of plain area, loess tableland and mountainous area (figure 1). The district is a warm temperate zone with a semi-humid continental monsoon climate. Annual mean temperature is 13.6℃ and annual precipitation is 555.8 mm. In the Weihe plain area, the rural economy develops rapidly and average per capita annual income of farmers is relatively high up to 7608 yuan (1 yuan RMB = 0.1452 US dollars) because of the low altitude (358 m), convenient transportation system, abundant cultivated land per capita (0.107 hm^2), and superior irrigation conditions (table 1). In the loess tableland area, harvest is fluctuant and per capita annual income of farmers is 6076 yuan on account of the relatively high altitude (656 m), inconvenient transportation and dry farming agriculture, but per capita cultivated land is plenty (0.093 hm^2) and farmland is easy to be cultivated, so farmers are used to relying on their arable land. In the Qinling mountainous area, the height of survey sites reaches to 774 m and the transportation is inconvenient; furthermore, per capita cultivated land is scarce (0.053 hm^2) due to the 'grain for green' policy [12], and mechanization of farming is difficult because of the topographical relief, so the development conditions of farmers are very disadvantageous and per capita annual income is as low as 5857 yuan.

2.2. Location quotient of energy use

In this paper, the conception of location quotient of energy use (LQEU) is put forward to evaluate the structural differentiation of rural household energy use among different areas. The LQEU can be described as a ratio that the proportion of one type of energy consumption in one kind of area compared to the proportion of this type of energy consumption in the entire areas. The equation of LQEU is as follows.

$$LQEU_i = \frac{e_i}{\sum_{i=1}^{n} e_i} \Bigg/ \frac{E_i}{\sum_{i=1}^{n} E_i} \qquad (1)$$

where $LQEU_i$ represents the location quotient of the ith type of energy. e_i is the amount of the ith type of energy consumed in one kind of area and E_i is the amount of the ith type of energy consumed in the whole areas. i stands for the type of energy including crop residues, firewood, coal, biogas, etc. Through this formula it contributes to assessing the differentiation level of energy use in different area. If the LQEU value of the ith type of energy is higher than 1, which means that this type of energy is dominant in the area. On the contrary, if it is less than or equal to 1, this type of energy is not dominant. Furthermore, the higher the value of location quotient is, the more predominant the energy is.

2.3. Surveys

Table 2. Standard coal coefficient of energy.

Energy type	Crop straw	corncob	firewood	coal	electricity	biogas	LPG
Standard coal coefficient	0.529	0.5	0.571	0.714	0.123	0.71	1.714
Conversion unit	kgce/kg	kgce/kg	kgce/kg	kgce/kg	kgce/kw h	kgce/m^3	kgce/kg

The villages investigated were dispersed throughout the three types of areas (figure 1), and the rural households were randomly selected in each village. The investigator communicated with the villager face to face and filled out the questionnaire, and then 232 valid questionnaires were obtained. In detail, there are 80 questionnaires from the plain area, 59 questionnaires from the loess tableland and 93 questionnaires from the mountainous area. It was found in our survey that rural households in each type of area have similar living habits and the same conditions to access energy resources, so the sample might reflect the basic situation of regional energy consumption to a certain extent. Topics investigated included population per household, crop production and yield, types, quantities and appliances of energy use, income level, etc. Energy consumption such as crop residues, firewood and coal was measured by repeatedly weighing in rural households. Energy supply and demand are calculated by the actual quantity of energy. However, the heat values of various types of energy differ

[13]. In order to compare the differences in the quantity of energy consumption, a unified unit of standard coal equivalent (kgce: 1 kg standard coal. 1 kgce=29.31 MJ) is adopted. Standard coal coefficient of partial energy is shown in table 2 [14, 15].

3. Results

3.1. Differentiation of energy structure

According to the survey data, per capita annual household energy in three types of areas is listed in table 3. Firewood is crucial to rural households in the entire area, which is related to the apple trees planted widely and so easily has access to a large number of tree branches. Taking per capita energy consumption 50 kgce as the approximate boundary, the differentiation of energy structure throughout the whole area shows that firewood, coal, honeycomb briquette and corncob are dominant in the plain, firewood, biogas, electricity and crop residues are prominent in the loess tableland, and firewood and crop residues are main in the mountainous area. In addition, compared the amount of each type of energy consumption in different area, coal, honeycomb briquette, corncob and LPG used in the plain are the most among three areas, biogas, electricity and solar energy in the loess tableland are the most, and firewood and crop residues in the mountainous area are the most.

Table 3. Per capita annual household energy in three types of areas (kgce/person).

Area type	Crop residue	Corncob	Firewood	Honeycomb briquette	Coal	Electricity	Biogas	LPG	Solar energy
Weihe plain	16.95	63.82	388.19	62.81	87.87	41.90	3.49	10.19	2.79
Loess tableland	50.03	36.23	457.33	39.00	15.08	58.17	68.51	7.26	4.53
Qinling mountain	50.07	26.52	812.60	25.32	10.07	38.91	12.41	4.67	1.09

3.2. Difference of energy use based on LQEU

Through dealing with the survey data, the proportion of rural household energy consumption in three types of areas is obtained in table 4. Then LQEU of each area is respectively calculated via formula (1) and the results are shown in table 5. The rural household energy with comparative advantage in the plain are coal, corncob, LPG, honeycomb briquette, electricity and solar energy, of which coal consumption is the most prominent and its LQEU value is up to 2.667. Likewise, the major energy judged by LQEU value in the loess tableland are biogas, solar energy, crop residues, electricity, honeycomb briquette and LPG, of which the LQEU value of biogas is the highest, reaching to 3.361. In the mountainous area, the firewood and crop residues only are preponderant and the LQEU values are 1.169 and 1.162, respectively.

Table 4. Proportion of rural household energy consumption in three types of areas (%).

Area type	Crop residue	Corncob	Firewood	Honeycomb briquette	Coal	Electricity	Biogas	LPG	Solar energy
Weihe plain	2.50	9.41	57.25	9.26	12.96	6.18	0.51	1.50	0.41
Loess tableland	6.80	4.92	62.13	5.30	2.05	7.90	9.31	0.99	0.62
Qinling mountain	5.87	2.68	82.11	2.56	1.02	3.93	1.25	0.47	0.11

By comparing the rural energy structures of three types of areas, it can be found that the rural household energy use is diversified in the plain and loess tableland areas, but the former uses more commercial energy of continued investment including coal, LPG, honeycomb briquette and electricity, whereas the latter uses more commercial energy of non-continuous investment such as biogas andsolar energy. Comparatively, the energy structure in the mountainous area is simple and non-commercial energy firewood is absolutely dominant. In general, the regional differential features of household energy are obvious, namely, multiple energy are complementarily utilized as a result of market orientation in the plain, whereas the biogas is used more relatively due to the orientation of energy policy in the loess tableland, and the firewood and crop residues are dominant under the influence of natural resources in the mountainous area.

Table 5. LQEU value of rural household energy consumption in three types of areas.

Area type	Crop residue	Corncob	Firewood	Honeycomb briquette	Coal	Electricity	Biogas	LPG	Solar energy
Weihe plain	0.495	1.806	0.815	1.788	2.667	1.130	0.184	1.667	1.323
Loess tableland	1.347	0.944	0.884	1.023	0.422	1.444	3.361	1.100	2.000
Qinling mountain	1.162	0.514	1.169	0.494	0.210	0.718	0.451	0.522	0.355

4. Discussion

Differentiation of rural household energy structure in different areas is the result of comprehensive influences of a series of factors. According to the related literatures [7-8] and our practices, the main influence factors of differentiation on the rural household energy use are explained as follows.

4.1. Difference of per capita income level

Per capita cultivated land and irrigation conditions influence agricultural income, total household income and per capita income on the regional level. Furthermore, based on the research findings [16] and our survey data, it is found that per capita income generally affects rural household energy structure. The higher income per capita is, the more comfortable energy such as electricity and LPG might be consumed for a certain area. On the contrary, the lower income per capita, the less the commercial energy, and then the more traditional non-commercial energy such as firewood and crop residues are used. Seen from the basic data (table 1) that in the plain, there are sufficient cultivated land, advantageous irrigation conditions, and also high income per capita, so commercial energy including coal, honeycomb briquette and electricity are consumed more, the structure of energy use is diversified, and commercial energy consumption per capita is far ahead among the three areas. In the loess tableland, the cultivated land is also abundant but difficult to be irrigated, so per capita income is at an average level, and the commercial energy per capita is not too much. In the mountainous area, the arable land is scarce and difficult to be cultivated, thus per capita income is of a low level, and the commercial energy consumption is the least. Of course, due to a small per capita annual income gap (219 yuan), the difference of per capita commercial energy consumption between the loess and mountain areas is not relatively significant (43.98 kgce).

4.2. Temperature influence

It is well known that altitude affects air temperature, heating time in winter and the demand of effective energy, and then influences the total household energy use and per capita energy consumption. In the plain, the low altitude results in shorter heating time (about three months); at the same time, the heat efficiency of commercial energy is higher, so per capita energy consumption is less. In the mountainous area, the high altitude leads to winter temperature usually 2~3℃ lower than that of the plain according to the local residents; in addition, sunlight is shaded by forest trees to some extent, and humidity is slightly high, so the heating time is longer (more than four months), which makes more energy consumption per capita.

4.3. Different development conditions

External surroundings such as terrain, altitude and transportation impact regional development and accessibility, and further affect rural economy development, energy supply, and the structure and level of energy consumption. In the plain, rural settlements with the flat terrain and developed transportation are close to the Linwei district which makes high family income and convenient energy supply of rural households, so the energy consumption is diversified and commercial energy is used more. In the mountainous area, due to the complex terrain, poor traffic conditions and less influence of the Linwei district, people contact with the outside world infrequently and agricultural and sideline production is underdeveloped, which causes single energy structure as well as low consumption level. Thus, firewood and crop residues are dominant and mainly used for such basic needs as cooking and heating. In the loess tableland, although the terrain is flat, high altitude coupled with adverse irrigation condition and inconvenient transportation leads to a general family income. Most of crop residues are left in the field in order to increase soil fertility as a result of mechanized harvesting. What's more, the residents could not access to firewood as conveniently as those of the mountainous area. Therefore, the non-commercial energy supply is limited and inadequate, which more possibly causes that some commercial energy such as coal and LPG are inevitably used and the structure of energy consumption is more various than that of the mountainous area.

4.4. Disparity in the adoption of energy policy

Though the supply of household energy is limited by many factors in the loess tableland, agricultural production is still in high level, and biogas digesters are applied extensively by local households, primarily due to China's 'Biogas Project' supported by the national budget. As a representative of loess tableland, Sanlian village has put this project into practice since 2005, and the proportion of households with biogas digesters accounts for more than 30% of the total. In general, biogas can meet the fundamental need of daily life from April to October, which improves the living standard and energy structure of rural households. In the meantime, an ecological economy model of agriculture–livestock–biogas–fruit (or agriculture) recycle is achieved. Of course, biogas digester is also demonstrated and popularized in the plain and mountainous area, but the utilization rate is relatively low and only three households use them in the investigated plain area. Households there are more inclined to the commercial energy because of their high living standard; moreover, urbanization and marketization make the residents unable to manage the biogas digester well, and in the mountainous area firewood is abundant, therefore the utilization rates of biogas in both areas are generally lower.

5. Conclusions

Main household energy in the plain area includes coal, corncob, LPG, honeycomb briquette, electricity and solar energy, in which the LQEU value of coal is up to 2.667. In the loess tableland area, biogas, solar energy, crop residues, electricity, honeycomb briquette and LPG are used obviously, in which the LQEU value of biogas reaches 3.361. In the Qinling mountainous area, the energy is dominated by firewood and crop residues, and the LQEU value of firewood is 1.169. The energy use is diversified in the plain and loess tableland, but the former uses more commercial energy of continued investment including coal, LPG, honeycomb briquette and electricity, whereas the latter uses more commercial energy of non-continuous investment such as biogas and solar energy.

Differential features of regional energy use are obvious. A variety of energy in the plain is complementarily utilized as a result of market orientation, whereas biogas is prominent due to energy policy in the loess tableland. In the mountainous area, firewood and crop residues are dominant and other fuels are auxiliary owing to the effect of natural environment.

Differentiation of energy structure is the results of comprehensive effects including income level per capita, temperature, development conditions, energy policy, etc. Per capita income level and regional development conditions have a positive effect on the commercial energy use of rural households but they do not necessarily influence the total household energy consumption. Local temperature influences residents' heating time in winter and amount of energy use. Energy policy plays a positive role to push for changes in the energy structure of rural households in some certain areas.

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