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Analysis of household energy consumption and related CO$_2$ emissions in the disregarded villages of Lijiang City, China

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Energy is one of the most important elements required for poverty alleviation and socioeconomic development, and it has a particularly strong impact on households in rural areas. An extensive survey on household energy consumption patterns that interrelates socioeconomic and demographic factors was conducted in the disregarded villages of Lijiang City by using the stratified random sampling technique for 120 households. This study focuses on household energy consumption and the related carbon dioxide (CO$_2$) emissions in the study area. Firewood, biogas, and electricity were identified as the main energy sources of the rural households. This study demonstrates that 100% of the households use firewood, 52% use biogas, and 95% use electricity as fuel types. On average, each household consumed 1752 kg of firewood, 280 m$^3$ of biogas, and 392 kWh of electricity annually. All households generated an annual average amount of CO$_2$ emissions of 3851 kg, of which 85.08% came from firewood, 7.66% from biogas, and 7.26% from electricity. Family size, income, and educational level were found to be the major factors that influence CO$_2$ emissions. The results of this study may be useful in explaining the energy consumption characteristics in the rural areas of Lijiang City and are expected to be useful in policy formulation for energy consumption and environmental protection.

Keywords: household energy; energy consumption; firewood; carbon dioxide emissions; rural areas

Introduction

In China, approximately one-fifth of the total population lives in rural areas. In most of these areas, biomass – including straw, stalks, and firewood – is the main source of energy (Wang and Feng 2001). Most of the energy is used for cooking, heating, feeding, and lighting (Feng et al. 2011). Biomass supplies account for approximately 70% of the household energy consumed in rural areas, especially in the remote ones (Wang and Feng 2005). This pattern of energy consumption has brought severe environmental consequences, such as soil erosion, land desertization, biodiversity loss, and higher carbon dioxide (CO$_2$) emissions (Li et al. 2005; Liu et al. 2011).

In the backward rural areas of Lijiang City, firewood is an important source of household energy (Li et al. 2005). The wood-dominated energy consumption structure not only brought serious environmental problems, but also posed severe threats to the health of local residents (Chowdhury et al. 2011). However, no research on the energy consumption patterns of the households in the rural areas of Lijiang City has been conducted to date because of the lack of specific data. This study was conducted to examine the energy consumption characteristics and the factors that influence CO$_2$ emissions in a number of disregarded villages in Lijiang City, China. The results of this study are expected to be useful in policy formulation and implementation, which will assist in guiding the behavior of household energy consumption and help reduce CO$_2$ emissions in the rural areas of Lijiang City.

Data sources and methods

Description of the data source

The study was conducted in the Liude Township of Yongsheng County of Lijiang City, located within 26°33′10″ N latitude and 100°57′74″ E longitude, with an area of 330.8 km$^2$ (Figure 1). The Liude Township consists of eight villages and 69 hamlets (Lijiang Municipal Statistical Bureau 2010). As of 2010, Liude has a total population of 14,220, among which 50.48% are males and 49.52% are females. Ethnic minority groups, such as the Lisu, the Yi, and the Han, account for 80.52%, 14.63%, and 3.23% of the total population, respectively (Liude Township Government Office 2011). Among all the respondents, 32% were males and 68% were females. Among all the respondents, 92% were housewives and 8% were engaged in other activities. Hence, data collection with female respondents was easier. The educational attainment of most of the respondents was observed to be below the secondary level, and only 6% of the respondents were high school graduates. Those who reached the secondary level accounted for 29%, whereas 50% passed primary school and 10% did not finish grade school. Only 5% of the respondents were found to be illiterate. The literacy rate was low in households with a large family size. Most of the respondents’ families had three, four, or five members, accounting for 22.5%, 18.6%, and 26.5% of the total number of surveyed households, respectively.

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**Methods**

This study involved a sociodemographic survey and an analysis of the energy consumption pattern of the households in the study site. A pilot survey was conducted in September 2010, in which 30 families were randomly selected. The formal survey was conducted in the selected households through personal visits conducted from 1 February 2011 to 30 April 2011.

**Sampling procedure**

This study was conducted through stratified random sampling with a semi-structured questionnaire as the research instrument. The sequence of selection started from the Township to the Village, and then to different households. Out of the eight villages in the Liude Township, four – Liude, Shuanghe, Beihua, and Tuanjie – were selected based on the socioeconomic information obtained from the local village committees. Thirty households were selected randomly from each village, totaling 120 households. Randomization was performed using a random number table in the first two stages. Unfortunately, 15 respondents refused to answer the questionnaire and 3 heads of the households were at work, and thus only 102 questionnaires were taken back.

**Data processing**

*Family income.* Five cut-points were placed in all the annual income values of the households to base the
income group on an equal percentile. Hence, six income groups (with income expressed in thousands of RMB) were formed as follows: group 1: ≤6.4; group 2: 6.5–9.0; group 3: 9.1–11.7; group 4: 11.8–13.8; group 5: 13.9–15.9; and group 6: ≥16.0. The Tukey’s Honestly Significant Difference (HSD) multiple comparison test was employed to compare the means of the different parameters.

Age structure. The age of each family was classified based on the family life cycle first proposed by Glick (Murphy and Staples 1979). According to Glick (1977), a family undergoes six stages, namely formation, enlargement, stability, shrinkage, empty nest, and disintegration. With the formation of a new family and as the family goes through the six-stage process, its energy consumption changes significantly. Thus, the age structure was used to represent the stage of each family, which was measured based on the proportion of family members aged 25–45 years old.

Educational level. The literacy level of the family members was coded with a meaningful number, i.e., illiterate = 01, primary = 06, secondary = 09, higher secondary = 12, graduate = 16, and postgraduate = 19. The coding is based on the usual time span in which an educational degree is awarded in China. To obtain the weighted score of household literacy, the education values of each household were summed and then divided by the number of family members, excluding infants.

\( CO_2 \) emissions. Each kind of household energy source was transformed into \( CO_2 \) emissions based on different emission factors. According to the Intergovernmental Panel on Climate Change’s (IPCC’s) Guidelines for National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change 2006), firewood and biogas have \( CO_2 \) emission factors of 1.87 kg \( CO_2 \)/kg and 1.14 kg \( CO_2 \)/m³, respectively. The \( CO_2 \) emission factor of electricity was calculated as follows:

\[
EF_{GRID} = w_{OM}EF_{OM} + w_{BM}EF_{BM},
\]

where \( EF_{GRID} \) is the marginal \( CO_2 \) emission factor of electricity in the southern power grid, \( EF_{OM} \) is the marginal \( CO_2 \) emission factor of the quantity of electricity, \( EF_{BM} \) is the marginal \( CO_2 \) emission factor of the installed capacity, and \( w_{OM} \) and \( w_{BM} \) are the corresponding weight coefficients.

According to the 2010 Baseline Emission Factors for Regional Power Grids in China (National Development and Reform Commission 2010), the computed \( EF_{GRID} \) was 0.7134 kg \( CO_2 \)/kWh.\(^1\)

Regression model
A multiple linear regression model was built to analyze the factors that influence \( CO_2 \) emissions from household energy consumption. Five independent variables were selected based on existing studies, and all the data were gathered from questionnaires. These variables include family income, family size, age structure, educational level, and house square. The model to be estimated is given by

\[
CE = a + bR + cP + dA + eE + fS + \varepsilon, \quad (2)
\]

where \( CE \) is the annual amount of \( CO_2 \) emissions from household energy consumption, \( R \) is the annual family income, \( A \) is the age structure; \( E \) is the educational level of the family, \( S \) is house square, \( \varepsilon \) is the error term of the model, \( a \) is the constant term, and \( b, c, d, e, \) and \( f \) represent the corresponding regression coefficients, respectively.

The data processing and analysis were conducted using the statistical package SPSS 17.0 (SPSS, Inc., Chicago, IL, USA).

Results and discussion
Household energy consumption pattern
Firewood, biogas, and electricity were identified as the main energy sources used in the rural households of the study area. This study indicates that all households used firewood, 52% used biogas, and 95% used electricity (Table 1). On average, each household in the study area used 1752 kg of firewood, 280 m² of biogas, and 392 kWh of electricity. Firewood and electricity consumption were significantly different within some income groups. For firewood consumption, income group 6 was different from income groups 1–4 at 0.05 significance level. However, groups 1–4 did not exhibit significant differences. For electricity consumption, income group 6 was different from the other income groups at 0.05 significance level. Income groups 1 and 2 were different from income groups 4 and 5 at 0.05 significance level. No significant differences among the different groups were observed in terms of biogas consumption.

The energy ladder model hypothesizes that as households become wealthier, they abandon energy technologies that are considered outdated and start using more modern technologies (Masera et al. 2000). Electricity is at the top of the ladder, while traditional fuel sources, such as firewood, dung, and crop wastes, are at the bottom (Chambwera and Folmer 2007). This study espoused these inferences. Given that most of the households in rural areas have limited income,\(^2\) most of them use firewood as a source of noncommercial fuel, and the variation in firewood consumption is due to the differences among income groups. For electricity, the increase in household income was clearly shown to result in higher consumption, whereas firewood consumption decreased with increasing income (Figure 2). The electricity consumption of income group 1 (≤6.4) was 170 kWh per year, while that of group 6 (≥16.0) was 716 kWh. Moreover, the firewood consumption of group 1 was 1967 kg per year, while that of group 6 was 1274 kg.

The results of this study show that the households with a higher literacy score consumed more electricity and...
less firewood. The households with the highest education had an average electricity consumption of 576 kWh per year, while the households with the lowest education had 337 kWh per year (Table 2). The corresponding consumption amount of firewood increased from 1470 to 1875 kg per year. For firewood consumption, group 1 was different from group 3 at 0.05 significance level. No significant differences among the different groups were observed in terms of biogas consumption.

The mean of the family size was 4.05 with a minimum of two and a maximum of eight members. The median was four and the mode was five. A significant relationship between family size and firewood consumption was observed. Larger families consumed more firewood than smaller ones. The households with two members had an average firewood consumption of 1309 kg per year, while households with more than five members had an average firewood consumption of 2276 kg per year (Table 3). For firewood consumption, groups 1 and 6 were different from other nonadjacent groups at 0.05 significance level.
while group 2 was different from group 4 at 0.05 significance level. No significant differences among the different groups were observed in terms of electricity and biogas consumptions.

This study was not able to find a stronger relationship between age structure and household energy consumption. Furthermore, no significant relationship was found between house square and household energy consumption.

Factors that influence CO₂ emissions

Household energy consumption generated a total amount of CO₂ emissions of 392,796 kg per year, with 85.08% from firewood, 7.66% from biogas, and 7.26% from electricity. Each household had an average amount of CO₂ emissions of 3851 kg per year, with the same proportion of constitutes. To analyze the factors that influence CO₂ emissions based on rural household energy consumption, all variable data of Equation (2) were processed using the stepwise regression method (Table 4). As can be seen in Table 4, three independent variables, namely family size, family income, and educational level, were reserved in the regression equation, whereas house square and age structure were excluded. The independent variable of family size had the highest contributing rate (R² increment = 0.396), followed by family income (R² increment = 0.068) and educational level (R² increment = 0.027).

The most probable reasons for the positive and significant relationship between the amount of CO₂ emissions and the family size are as follows: (1) the number of family members has a clear link with the cooking (or water heating) energy consumption of the households and (2) more family members meant more labor because large families usually raise more pigs to increase their income, and pig feeding requires more fuel. Therefore, the impact of family size on CO₂ emissions of firewood consumption was highly notable.

The results also show that the amount of CO₂ emissions had a negative impact on family income and literacy increase, at p < 0.01 and p < 0.05 significance levels, respectively (Table 4). The probable explanations for the negative impact are as follows: (1) with the increase in family income and education level, family members can afford and tend to buy more appliances to improve their quality of life (Chambwera and Folmer 2007) and (2) when household incomes and literacy increase, families tend to search for better energy sources, as explained in the energy ladder model (Masera et al. 2000). Thus, households switch from firewood to electricity for lighting, cooking, and other purposes provided by appliances. For example, some families used electric rice cookers instead of firewood for cooking, or electric heaters instead of firewood for heating. Consequently, the amount of CO₂ emissions decreased as families consumed more electricity and less firewood because the marginal CO₂ emission factor of firewood was higher than that of electricity.

Implications on the rural energy policy of Lijiang City

The major dependency of rural households on firewood reflects the need to emphasize energy source issues in rural energy policies, which should be a significant part of the Lijiang City’s municipal energy policy, as rural areas occupy the major part of Lijiang. Policymakers should focus on formulating and implementing policies that can reduce the demand for firewood and mitigate environmental degradation, such as deforestation. Moreover, these issues are also related to climate change and socioeconomic problems (Deng et al. 2011; Xiao et al. 2011).

Although urbanization usually results in the greater use of modern fuel sources, such as electricity, and in the less use of firewood, this situation has not occurred in many counties of Lijiang City (Duan et al. 2008). The current consumption status indicates that deforestation is likely to continue in the foreseeable future, given the highest average annual firewood consumption of 3851 kg per household. Besides, the indoor air pollution caused by the use of firewood has negative effects on the users (United Nations Environment Programme 2008). Biomass smoke contains a large number of chemicals, many of which have been associated with adverse health effects (Naheer et al. 2007). Thus, improving the degree of electrification can help mitigate the effects of the problems above.

Improving the degree of electrification can also bring positive effects on the economic development of rural areas and local environmental amelioration. The present “Appliances Subsidy Policy” in rural areas has an important objective of promoting electricity consumption and is expected to contribute toward reducing firewood consumption. More kitchen appliances should be included in the subsidy list, and the policy coverage should be expanded to most of the remote rural and mountainous areas of Lijiang City.

In this study, household income was found to be an important determinant of energy consumption. High-income households tend to consume more electricity and less firewood than low-income households. Therefore,

Table 4. Factors that influence CO₂ emissions based on the energy consumption by households in the disregarded villages of Lijiang City.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>R² increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3192.46*</td>
<td>353.424</td>
<td>--</td>
</tr>
<tr>
<td>Family size</td>
<td>391.698*</td>
<td>53.928</td>
<td>0.396</td>
</tr>
<tr>
<td>Family income</td>
<td>-38.898*</td>
<td>14.418</td>
<td>0.068</td>
</tr>
<tr>
<td>Educational level</td>
<td>-69.678**</td>
<td>30.744</td>
<td>0.027</td>
</tr>
<tr>
<td>House square (removed)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Age structure (removed)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>R²</td>
<td>0.491</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significance level</td>
<td>0.026</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: * and ** Significant at 1% and 5% levels, respectively.
the rural development policy should emphasize poverty alleviation through income-generating programs or government subsidies that can enable families to use more electricity and consequently reduce CO₂ emissions. For example, the cultivation of economic crops, such as porcini mushroom and medicinal plants, can be promoted.

Rural development policy should also emphasize the improvement of education because higher literacy leads to greater electricity consumption and less firewood consumption. In the long run, the implementation of a more rational educational policy will improve the literacy and environmental awareness of households, and therefore bring a positive impact on changing household energy consumption behaviors.

Conclusion
This study demonstrated that energy consumption varied among households classified under different income groups, family sizes, and educational statuses. Most of the surveyed local households were dependent on firewood as an energy source. This behavior placed substantial pressures on homestead forests and on the local environment. The family size, income, and educational level in varying degrees were found to have significant impact on the household energy consumption. Larger families consumed more firewood and emitted more CO₂ than smaller ones. With an increase in household income and educational level, household energy sources shifted from firewood to electricity, which would ultimately reduce deforestation and CO₂ emissions. Therefore, efficient initiatives should be taken to create income-generating opportunities for rural households. Moreover, the educational system should be strengthened and the extent of electrification should be improved to make more rural families switch from firewood to electricity or other modern energy sources. Furthermore, community awareness regarding the use of modern kitchen appliances and environmental protection should be enhanced.

Acknowledgement
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Notes
1. The National Development and Reform Commission did not provide the weight coefficients. This study used equal weights to simplify the calculations.
2. The households have a mean annual income of 11,920 RMB, with the minimum of 1440 RMB and maximum of 30,000 RMB.

References