International Journal of Sustainable Development & World Ecology

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/tsdw20>

Analysis of household energy consumption and related CO₂ emissions in the disregarded villages of Lijiang City, China

Gang Wu^a, Tao Liu^{a b} & Mingfang Tang^{a b}

^a State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, 100085, PR China

^b Graduate University of Chinese Academy of Sciences, Beijing, 100049, PR China

Published online: 16 Jul 2012.

To cite this article: Gang Wu, Tao Liu & Mingfang Tang (2012) Analysis of household energy consumption and related CO₂ emissions in the disregarded villages of Lijiang City, China, International Journal of Sustainable Development & World Ecology, 19:6, 500-505, DOI: [10.1080/13504509.2012.701242](https://doi.org/10.1080/13504509.2012.701242)

To link to this article: <http://dx.doi.org/10.1080/13504509.2012.701242>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

Analysis of household energy consumption and related CO₂ emissions in the disregarded villages of Lijiang City, China

Gang Wu^a, Tao Liu^{a,b*} and Mingfang Tang^{a,b}

^aState Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, PR China; ^bGraduate University of Chinese Academy of Sciences, Beijing 100049, PR China

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 (CO₂) 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 m³ of biogas, and 392 kWh of electricity annually. All households generated an annual average amount of CO₂ emissions of 3851 kg, of which 85.08% come 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 CO₂ 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 (CO₂) 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 CO₂ 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 CO₂ 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 km² (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.

*Corresponding author. Email: liutaocas@gmail.com

Figure 1. Map of the study area in the Yongsheng County of Lijiang City, China.

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.

CO₂ emissions. Each kind of household energy source was transformed into CO₂ 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 CO₂ emission factors of 1.87 kg CO₂/kg and 1.14 kg CO₂/m³, respectively. The CO₂ emission factor of electricity was calculated as follows:

$$EF_{\text{GRID}} = w_{\text{OM}}EF_{\text{OM}} + w_{\text{BM}}EF_{\text{BM}}, \quad (1)$$

where EF_{GRID} is the marginal CO₂ emission factor of electricity in the southern power grid, EF_{OM} is the marginal CO₂ emission factor of the quantity of electricity, EF_{BM} is the marginal CO₂ 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 CO₂/kWh.¹

Regression model

A multiple linear regression model was built to analyze the factors that influence CO₂ 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 CO₂ 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, ε 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 m³ 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

Table 1. Types and amounts of fuels used by the households in the disregarded villages of Lijiang City.

Income group (thousand RMB)	Average consumption per year		
	Firewood (kg)	Biogas (m ³)	Electricity (kWh)
G1 ≤ 6.4	1967 ^a (362)	316 (274)	170 ^a (79)
G2 = 6.5–9.0	1987 ^a (498)	290 (282)	225 ^{ab} (90)
G3 = 9.1–11.7	1811 ^a (466)	374 (254)	327 ^{bc} (96)
G4 = 11.8–13.8	1889 ^a (504)	348 (266)	424 ^{cd} (95)
G5 = 13.9–15.9	1584 ^{ab} (508)	161 (257)	490 ^d (161)
G6 ≥ 16.0	1274 ^b (405)	193 (270)	716 ^e (164)
Mean	1752 (515)	283 (272)	392 (227)
Number of households	102	54	97
Percentage of households	100	52	95

Notes: Superscript letters indicate the significant difference at 0.05 level from the other letters in the same column based on the income group. Figures in parentheses denote SEM.

Figure 2. Average consumption of firewood and electricity by the different income group households in the disregarded villages of Lijiang City. (a) Firewood. (b) Electricity.

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 2 at 0.05 significance level. For electricity,

Table 2. Energy consumption and literacy of the households in the disregarded villages of Lijiang City.

Education values	Average consumption per year		
	Firewood (kg)	Biogas (m ³)	Electricity (kWh)
G1: 1.0–6.0	1875 ^a (523)	245 (264)	337 ^a (186)
G2: 6.1–9.0	1538 ^b (425)	278 (254)	476 ^{ab} (269)
G3: 9.1–12.0	1470 ^{ab} (426)	191 (224)	576 ^b (219)

Notes: Superscript letters indicate the significant difference at 0.05 level from the other letters in the same column based on the educational values. Figures in parentheses denote the SEM.

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,

Table 3. Energy consumption and family size of the households in the disregarded villages of Lijiang City.

Family size	Average consumption per year		
	Firewood (kg)	Biogas (m ³)	Electricity (kWh)
G1: two members	1309 ^a (243)	258 (282)	205 (219)
G2: three members	1422 ^{ab} (309)	310 (278)	240 (253)
G3: four members	1707 ^{bc} (508)	167 (254)	370 (196)
G4: five members	2033 ^{cd} (447)	341 (267)	323 (219)
G5: ≥six members	2276 ^d (316)	295 (274)	346 (205)

Notes: Superscript letters indicate the significant difference at 0.05 level from the other letters in the same column based on the family size. Figures in parentheses denote the SEM.

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 constituents. 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 (R^2 increment = 0.396), followed by family income (R^2 increment = 0.068) and educational level (R^2 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 (Naeher 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.

Variable	Coefficient	SE	R^2 increment
Constant	3192.46*	353.424	—
Family size	391.698*	53.928	0.396
Family income	−38.898*	14.418	0.068
Educational level	−69.678**	30.744	0.027
House square (removed)	—	—	—
Age structure (removed)	—	—	—
R^2	0.491		
Significance level	0.026		

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

This research was supported by the Ministry of Environmental Protection of the People's Republic of China (201009055).

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

- Chambwera M, Folmer H. 2007. Fuel switching in Harare: an almost ideal demand system approach. *Energy Policy*. 35(4):2538–2548.
- Chowdhury MSH, Koike M, Akther S, Miah MD. 2011. Biomass fuel use, burning technique and reasons for the denial of improved cooking stoves by Forest User Groups of Rema-Kalenga Wildlife Sanctuary, Bangladesh. *Int J Sust Dev World Ecol*. 18(1):88–97.
- Deng HB, Liu TX, Zhao J. 2011. Strategic measures for an integrated approach to sustainable development in Lijiang City. *Int J Sust Dev World Ecol*. 18(6):559–562.
- Duan J, Yan Y, Zheng BF, Zhao J. 2008. Analysis of the relationship between urbanization and energy consumption in China. *Int J Sust Dev World Ecol*. 15(4):309–317.
- Feng ZH, Zhou LL, Wei YM. 2011. The impact of household consumption on energy use and CO₂ emissions in China. *Energy*. 36(1):656–670.
- Glick PC. 1977. Updating the life cycle of the family. *J Marriage Fam*. 39(1):5–13.
- [IPCC] Intergovernmental Panel on Climate Change. 2006. IPCC guidelines for national greenhouse gas inventories [Internet]. Kanagawa (Japan): Initial Graphics Exchange Specification (IGES); [cited 2011 Sep 25]. Available from: <http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html>.
- Li ZM, Tang RS, Xia CF, Luo HL, Zhong H. 2005. Towards green rural energy in Yunnan, China. *Renew Energy*. 30(2):99–108.
- [LMSB] Lijiang Municipal Statistical Bureau. 2010. Lijiang statistical yearbook 2009. Lijiang (China): LMSB. Chinese.
- Liu LC, Wu G, Wang JN, Wei YM. 2011. China's carbon emissions from urban and rural households during 1992–2007. *J Cleaner Prod*. 19(15):1754–1762.
- [LTGO] Liude Township Government Office. 2011. Annual government work report for 2010. Official document. Liude Township Government. Lijiang (China): People's Congress of Liude Township. Chinese.
- Masera OR, Saatkamp BD, Kammen DM. 2000. From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. *J World Develop*. 28(12):2083–2103.
- Murphy PE, Staples WA. 1979. A modernized family life cycle. *J Consum Res*. 6(1):12–22.
- Naeher LP, Brauer M, Lipsett M, Zelikoff JT, Simpson CD, Koenig JQ, Smith KR. 2007. Woodsmoke health effects: a review. *Inhal Toxicol*. 19(1):67–106.
- [NDRC] National Development and Reform Commission. 2010. 2010 Baseline emission factors for regional power grids in China [Internet]. Beijing (China): Climate Change Office, National Development and Reform Commission; [cited 2011 Dec 15]. Available from: <http://cdm.ccchina.gov.cn/WebSite/CDM/UpFile/File2552.pdf>. Chinese.
- [UNEP] United Nations Environment Programme. 2008. UNEP year book 2008: an overview of our changing environment. Nairobi (Kenya): United Nations Environment Programme.
- Wang XH, Feng ZM. 2001. Rural household energy consumption with the economic development in China: stages and characteristic indices. *Energy Policy*. 29(15):1391–1397.
- Wang XH, Feng ZM. 2005. Study on affecting factors and standard of rural household energy consumption in China. *Renew Sust Energ Rev*. 9(1):101–110.
- Xiao LS, Li XH, Wang R. 2011. Integrating climate change adaptation and mitigation into sustainable development planning for Lijiang City. *Int J Sust Dev World Ecol*. 18(6):515–522.