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Factors Influencing Households' Firewood Consumption in the Western Pamirs, Tajikistan

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Firewood is a major energy source, especially in many high mountainous regions in developing countries where other energy sources are limited. In the mountainous regions of Tajikistan, current energy consumption is limited owing to geographic isolation and numerous challenges—including in the energy sector—that emerged after the collapse of the Soviet Union and Tajikistan's independence. The sudden disruption of external supplies of energy forced people to rely on locally available but scarce biomass resources, such as firewood and animal dung. We conducted an empirical study to gain an understanding of current household energy consumption in the Western Pamirs of Tajikistan and the factors that influence firewood consumption. For this purpose, we interviewed members of 170 households in 8 villages. We found that, on average, households consumed 355 kg of firewood, 253 kWh of electricity, 760 kg of dung, and 6 kg of coal per month in the winter of 2011–2012. Elevation, size of a household's private garden, and total hours of heating had a positive relationship with firewood consumption, and education level and access to a reliable supply of electricity showed a negative relationship.

Keywords: *Energy; firewood consumption; dung; mountainous regions; Tajikistan.*

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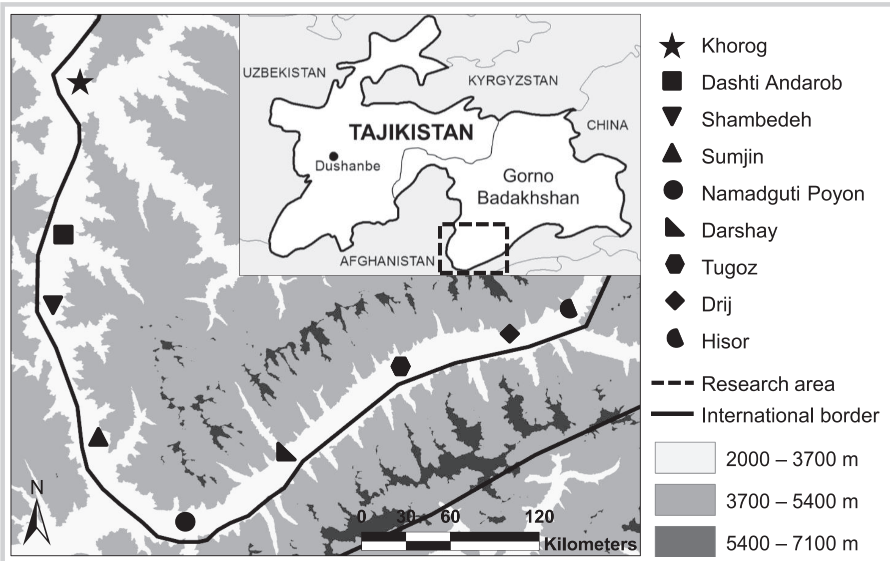
Introduction

In the past few decades, increasing consumption levels have led to more pressure on natural resources worldwide (Tilman et al 2001; Arrow et al 2004; Imhoff et al 2004; Godfray et al 2010; Liu et al 2010; Zhen et al 2011). The demand for energy is partly met by firewood, which is a primary energy source in many developing countries (Kennes et al 1984; Hosier and Kipondya 1993; Bhatt et al 1994; Tabuti et al 2003; Chen et al 2006; Khuman et al 2011; San et al 2012; Rehnus et al 2013). This is particularly critical in mountainous regions, where limited energy sources lead to high pressure on scarce natural resources.

In the mountainous areas of Gorno Badakhshan Autonomous Oblast in Tajikistan (also known as the Tajik Pamirs), the high demand for energy is believed to be one of the main reasons for natural resource degradation (Breu and Hurni 2003; Hoeck et al 2007; Kirchhoff 2010). Here, winter lasts up to 6 months, during which local people heat their homes all day because of very low temperatures. The unique history of Tajikistan during and after the Soviet era also shaped the current energy situation. During the Soviet period in Gorno Badakhshan, local homes and office buildings were supplied with a large quantity of highly subsidized fuel, including coal, kerosene, diesel, oil, and gas (Breu and Hurni 2003; Hoeck et al 2007; Mislimshoeva et al 2013). This external supply abruptly stopped after the Soviet Union dissolved and Tajikistan gained independence in 1991.

The transition away from a subsidized energy system has had massive consequences for the availability, quantity, and quality of energy. The current energy situation forces reliance on scarce locally available resources. In many villages, firewood and animal dung are the main source of energy for cooking and heating (Breu and Hurni 2003; Hoeck et al 2007). Energy scarcity also influences trade-offs between ecosystem services such as energy and food. For example, in Gorno Badakshan, the quality of agricultural products is reduced because the demand for dung for heating is high, leaving less available for farming.

FIGURE 1 Map of the study area with study site locations and elevations. (Map by first author; digital elevation model by NASA LP DAAC 2013; country border line by APRS 2013)



Despite the importance of firewood in the daily lives of people in the Western Pamirs, very few empirical studies of firewood consumption exist (see Hoeck et al 2007), and official data on forests and other woody vegetation are lacking. Furthermore, no attempts have been made to quantify the association between firewood consumption and factors that influence it. This empirical study was carried out to gain an understanding of the extent and patterns of household consumption of firewood and other sources of energy in the Ishkashim District in the Western Pamirs and the factors influencing it. This understanding is crucial for sustainable management of energy sources not only in the Western Pamirs but also in other regions of the world with similar historical background or biophysical conditions.

Methodology

Research area

The Western Pamirs are rocky, high mountains with an elevation range of 2200–7500 masl (Figure 1). The topography features fast-flowing glacier-fed rivers in deeply incised valleys. The high elevation has a direct impact on the climate of the region. The Western Pamirs are characterized by low temperatures, lack of large surface water bodies, dry air, and moderate diversity of microclimatic conditions. High mountain ranges in the north and south form a natural barrier against the flow of moist air, thus creating a continental climate. Maximum temperatures occur in July and are on average between 18 and 20°C. Minimum temperatures typically occur in January and are on average between −8 and −2°C. The average annual rainfall is 100–300 mm, mostly occurring from December to April (Miehe et al 2001; Breckle and Wucherer 2006).

The district of Ishkashim was selected as the study site (Figure 1). According to data obtained from the district administration, about 25,000 people live in the district, dispersed among 47 villages. The number of households per village ranges from 15 to 260. Farming and livestock breeding are the main sources of livelihood; some households are also involved in forestry. In total, district residents own about 12,000 large and 47,000 small livestock animals. Total surface area of the district is 350,000 ha, including around 21,000 ha of agricultural land (arable and rainfed lands, where summer crops are cultivated) and 11,000 ha of pastures for livestock grazing. Roughly 2300 ha are designated as forest; of this, only about 1800 ha are actually covered by forest. The other 500 ha are currently bare soil; a few decades ago, this was also a forested area. The total area of gardens (a piece of private land owned by a household, where trees and hay are grown) in the district is 290 ha (IDA 2013; SFA 2013). Although total garden area is small, each household maintains a private garden in which hay, fruit and nonfruit trees, and vegetables are grown.

Firewood and dung are the main heating fuels. Firewood is extracted from private gardens; gorges and roadsides; and state, community, and private forests. Almost all households have livestock and thus have dung available. Our 2013 field observations showed that trade-offs are taking place between firewood and dung provision. As there is not enough precipitation, many forest plots are additionally irrigated, and there is not always enough water to irrigate both forests and agricultural land. As agricultural products are required for daily life, people give priority to irrigating agricultural land. In the case of dung, the trade-off is between its use as fuel and fertilizer. In that case, local people give priority to its use as fuel; the resulting lack of fertilizer potentially reduces crop yield and quality.

TABLE 1 Case study villages and sample sizes.

Village	Location	Households in village	Households surveyed	Surveyed households as % of total households
Darshay	36°79′N, 71°99′E	58	23	40
Dasht	37°22′N, 71°48′E	41	16	40
Drij	37°00′N, 72°49′E	58	23	40
Hisor	36°03′N, 72°65′E	98	32	33
Namadguti Poyon	36°67′N, 72°74′E	41	16	40
Shambedeh	36°09′N, 71°45′E	56	21	38
Sumjin	36°83′N, 71°55′E	41	16	40
Tugoz	37°00′N, 72°49′E	57	23	40
Total		450	170	38

In some villages, especially those closer to Khorog (the capital of Gorno Badakhshan), energy demand for cooking is partly met by electricity. A very small amount of coal reaches the more remote villages but is often expensive and of poor quality.

Site selection, data collection, and analysis

The fieldwork was carried out in February and March 2013 to coincide with the heating season and observe the use of different energy sources. Before selecting the study villages, semistructured interviews were conducted with the official heads of all 7 *jamoats* (subdistricts) in Ishkashim District. The *jamoats* have an average of 6 villages each. During the interviews, information was collected on the number of inhabitants, number of households, migration rate, livestock numbers, main source of energy in summer and winter, and duration of the heating season. Based on this information, 3 criteria were developed for selecting study villages:

1. Number of households in the village: Although this number ranges widely in Ishkashim District (from 14 to 365), medium-size villages were selected with a similar number of households to balance the total number of visited villages and the total number of interviews.
2. Energy use: Villages that used a variety of energy sources and types were selected.
3. Duration of heating season: Villages with different heating season lengths (from 4 to 6 months, depending on the elevation) were chosen, again to ensure variety.

In total, 8 case study villages were selected in the 7 *jamoats*. Next, a list of households was obtained from the village leader in each village. Nearly 40% of the total households in the village were selected for interviews using simple random sampling. Table 1 and Figure 1 give an overview of the villages and the number of interviews.

All interviews were based on a questionnaire administered at the household level; the questionnaire took approximately 35 minutes to complete and had 5 sections:

1. Demographic and socioeconomic characteristics: number of household members, age, education, occupation, and monthly income amount and source;
2. Property: size of the private garden, including private forest (a piece of forest that is owned by a household), size of agricultural land, number of small and large livestock, and source of fodder;
3. House and heating infrastructure: type and size of the room(s), type of stove, number of heating hours per day in winter, heating season duration, and availability of electricity;
4. Energy: types of energy used, sources, quantity, purpose, and price;
5. Firewood: sources, collection methods, and species.

Most families spend the winter in a single room to save heating costs. Houses have mainly two types of rooms: (1) a traditional Pamiri room with a large space, relatively high ceilings, two windows to the outside, and a skylight; and (2) a small room with low ceilings and usually one window to the outside. Almost all interviews were conducted in such rooms.

The interviewees were not necessarily the heads of the families but, rather, those who were usually responsible for lighting and maintaining the fire and cooking. Interviewees included men and women. During the interviews, the unit of measure was the one used locally: a bag. Interviewees were shown a bag of 50 × 100 cm, and they estimated the number of bags of firewood and dung used per day. These quantities was multiplied by 30 to get a monthly value. Electricity was measured in kilowatt hour (kWh), by dividing the average amount of money paid for electricity per month by the price for 1 kWh of electricity, which was TJS0.13 (US$0.6). Coal was measured in kilograms per month. Units were later converted to megajoules (MJ) for direct comparison of energy amounts, as shown below (Equations 1 to 4; conversion sources: Hoeck et al 2007; GIZ 2011; FAO 2013).

$$firewood[MJ] = \frac{x\ bags/day\ *30\ days}{16\ bags/m^3} * 150\ kg/m^3 * 15MJ/kg \quad (1)$$

$$dung[MJ] = x\ bags/day * 30\ days\ * 20kg/bag * 12MJ/kg \quad (2)$$

$$electricity[MJ] = x\ kWh * 3.6\ MJ/kWh \quad (3)$$

$$coal[MJ] = x\ kg * 28\ MJ/kg \quad (4)$$

The data were analyzed using the statistical software R (version 3.0.0; R Core Team 2014). Given the nature of interview data, a basic linear model was used, including only main effects and no interactions. As the data set consisted of 170 data points and 51 potentially influential variables, a variable selection had to be done in the linear regression. The variable selection was done using LASSO (R-package "glmnet," Friedman et al 2010; 2012), which is a straightforward method based on penalized regression. It is suitable for large numbers of potentially influential variables and not limited to any critical assumptions like the normal distribution (see Hastie et al 2009 for details). All variables that were noninfluential according to the LASSO estimate were removed, and the effect coefficients of the remaining variables were estimated by ordinary least-squares regression. The resulting regression model was validated by a 10-fold cross-validation, which also considered the prior variable selection.

Results

Demographic and socioeconomic features

The study villages contained 6 people per household on average. Several households had as many as 17 family members and some as few as 2 or 3. The following age categories were used in this study: younger than 3 years (babies), 3–6 years old (small children), 7–17 years old (schoolchildren), 18–25 years old (young adults), 26–40 years old (adults I), 41–55 years old (adults II), and older than 56 years (older adults). The greatest number of household members were in the 7–17 years old group, followed by the 26–40 years old group; the 18–25 years old group was much smaller than either of these (Table 2).

Three occupational categories were used: unemployed (children and other family members without a cash income), employed (state employees with low but regular wages, persons with small-scale enterprises with regular income, and self-employed people with seasonal income, and retired (pensioners with relatively low incomes; retirement age is 63 for men and 58 for women in Tajikistan) (Falkingham et al 2009).

Most (75%) of the household members were in the unemployed category (children were included in this group as they did not have any income that could influence firewood consumption). Of the remainder, 10% were retired and 15% were employed.

Education levels were categorized as follows: school level (9–11 years of education at a primary and secondary school), education level I (3–4 years of vocational and technical education), and education level II (>5 years of higher university education). For the statistical analysis, the family member who completed the highest education level was chosen. It was assumed that education might influence energy consumption level, for example, through use of energy-efficient technology. Of the 170 households, 55% had at least one member with a level I education, 25% had a member with a level II education, and 20% had a member with school-level education.

Monthly household cash income included salaries, remittances from family members working in Russia, and income from trade. For this study household cash income was categorized as low (less than TJS200 or US$42), medium (TJS201–500 or US$42–104), or high (more than TJS501 or US$104). Most households (54%) were in the middle-income category; the rest were almost evenly divided between the high and low categories. Income in the study area is relatively low. Per capita per month income is around TJS100 (US$20), which is below the national poverty line of TJS139 (US$42) per capita per month (World Bank 2009).

Energy consumption

Households use a combination of different energy sources. Out of these different sources, in all villages dung was the most commonly used, followed by firewood (Figure 2). Households used an average of 9095 MJ of energy from dung and 5329 MJ of energy from firewood per month during winter. Because of the low quality or irregular supply of electricity and the lack of coal, these 2 sources of energy were used the least. On average, households used 911 MJ electricity and 187 MJ coal. Average total annual energy consumption is 86 gigajoules (GJ) per household and 17 GJ per person. Energy consumption varies along the altitudinal gradient (Table 3). It also differs considerably depending on the heating and nonheating season (Table 4).

Dung and firewood were mainly used for heating and cooking, and electricity was mostly used for lighting and sometimes for cooking and boiling water. Heating devices in 97% of the interviewed households were the same—a typical, locally made stove with a bake-oven (Figure 3). Only 2 houses were insulated and had improved stoves for heating and cooking.

TABLE 2 Demographic and socioeconomic characteristics of the respondents.

Variable	Category	Number	%
(By person; N = 1012)			
Age (years)	<3	52	5
	3–6	97	10
	7–17	254	25
	18–25	99	10
	26–40	200	20
	41–55	176	17
	56 or older	134	13
Work status	Retired	104	10
	Unemployed	758	75
	Employed	150	15
By household (N = 170)			
Education level	School level (9–11 years)	35	20
	Education level I (3–4 years)	92	55
	Education level II (+ 5 years)	43	25
Monthly income[a)]	Low (≤TJS200)	38	22
	Medium (TJS201–500)	92	54
	High (≥TJS501)	40	24
Source of income	Local	95	56
	Abroad	14	8
	Both	61	36

[a)]US$1 = TJS4.8 (National Bank of Tajikistan 2013).

To save energy, all household members live in the same room during winter. Of the families participating in the study, 66% spent winter in a traditional Pamiri room, with an average size of 49 m^2. These were mostly households with more than 6 family members. The other 34% had a separate room with an average size of 24 m^2, in most cases specially built for winter but not necessarily insulated. Given the harsh winter conditions, every household heats the room during the day and typically prepares warm meals 3 times a day. Heating hours per month ranged from 120 to 480 with an average of 380.

Interview participants were also asked to rate their satisfaction with the availability of different energy sources (Table 5). Most were moderately or very satisfied with dung availability. Each household owned, on average, 11 small and 3 large livestock animals and thus had dung available. Households were only moderately satisfied with the availability of firewood, which was not as universally available. Satisfaction with electricity availability varied; those who were very satisfied were mostly those who received electricity from the city of Khorog, and this source was stronger and more reliable than the electricity supplied by a local plant. Very few participants were satisfied with the availability of coal.

The variety of firewood sources is summarized in Figure 4. The biggest share came from private gardens, which contained fruit trees and other woody vegetation used as firewood; the average size was around 830 m^2. Unlike firewood from other sources, this wood has no extra cost. The price of firewood is higher in villages where it must be transported from far away. Only 5 households relied completely on purchased firewood for the winter months, 93 households obtained their firewood at no cost, and 72 households bought firewood from different sources as well as extracting it from their private gardens. On average, households pay TJS29 (US$6) per month for firewood in winter. The cost of a cubic meter of firewood was around TJS50 (US$10).

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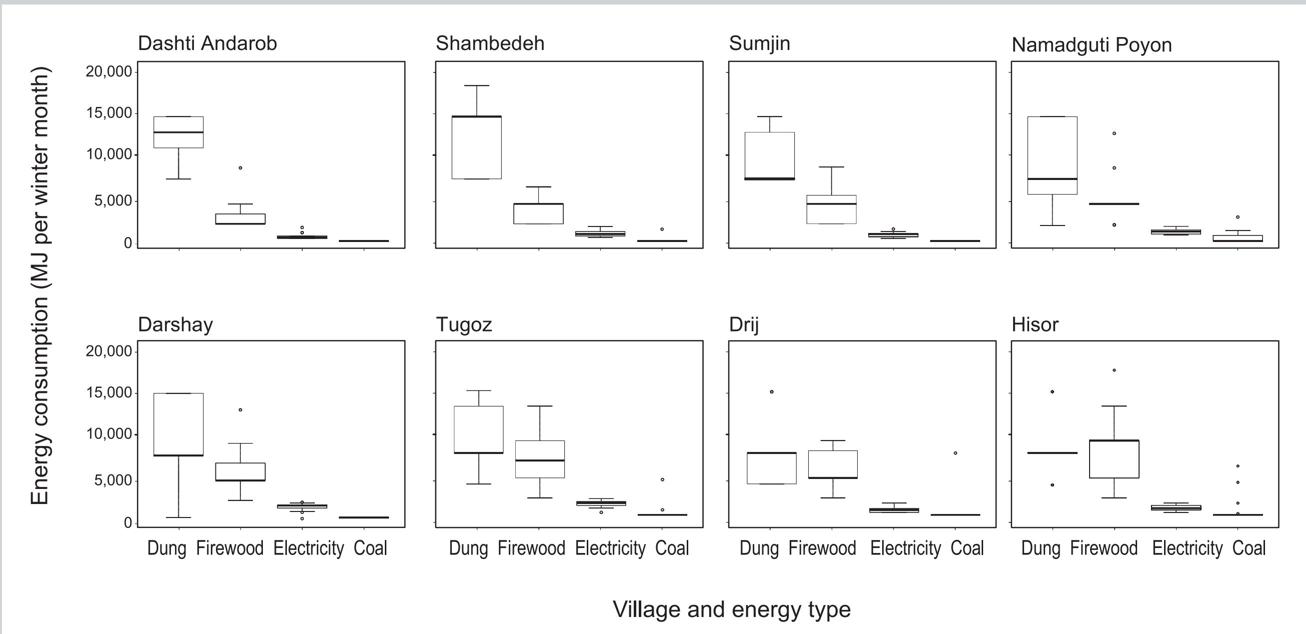
FIGURE 2 Use of different energy sources in the studied villages.



The second most significant source of firewood was state forest land, used mostly by villagers living near a state forest. Local people either buy this firewood or harvest it according to the Joint Forest Management approach (see Mislimshoeva et al 2013 for details about this approach). The third most common source was the free firewood available in the mountains (mainly gorges), along roadsides, and around fields. This option was usually used by villages that have no forest area nearby, such as Shambedeh and Dashti Andarob.

Factors influencing firewood consumption

Firewood consumption in the villages is positively influenced by elevation, size of the household's private garden, and hours of heating in winter, and it is negatively influenced by level of education and electricity received from the city (Table 6; Figure 5). We found that elevation correlates positively with heating hours per month and firewood consumption, as winter tends to be colder and lasts longer at high elevations. Education tended to play a role in firewood consumption, and education level I correlated positively with lower firewood consumption. Firewood use also appeared to increase with the size of the garden. Households that received electricity from Khorog, on the other hand, used less firewood than those that did not.

Model validation

To estimate the prediction error, the widely used 10-fold cross-validation method was chosen (Oslon and Delen 2008; Fushiki 2009; Hastie et al 2009). During cross-validation, the estimation of the effect of the coefficients and the prior variable selection by LASSO were taken into consideration. The square root of the overall mean squared prediction error in the cross-validation was 2500 MJ. As the standard deviation for firewood consumption was about 3000 MJ, this showed that the model explains a considerable part of the firewood consumption patterns but that the variability of firewood consumption is rather high. One reason for this relatively high prediction error might be the fact that the amount of firewood consumption was only estimated by the interviewed households, and this incorporates an additional random error that cannot be predicted. The high variability can also be seen from the adjusted coefficient of determination (equal to 0.35) and the square root of the mean squared residuals (equal to 2300 MJ). However, the meaning of these values is limited,

TABLE 3 Average energy consumption per household by elevation/heating season.

Elevation (masl)	Heating season	Firewood (kg)	Dung (kg)	Coal (kg)	Electricity (kWh)
Low (2450)	4 months	1100	3700	19	980
Middle (2650)	5 months	1900	3900	17	1800
High (2800)	6 months	2700	3500	70	1200

TABLE 4 Average energy consumption per household for all elevations.

Time frame	Firewood (kg)	Dung (kg)	Coal (kg)	Electricity (kWh)
Per month during heating season	355	760	6	253
Total heating season	1840	3700	35	1270
Total nonheating season	*	100	0	2300
Full year	1840	3800	35	3570

*Negligible amount (0.07 kg).

as they are not cross-validated and do not take into account the prior variable selection.

Discussion

Factors influencing firewood consumption

As energy consumption is very heterogeneous, it is challenging to directly compare these findings with those of other studies. Nevertheless, similar energy consumption patterns can be observed in other comparable regions (for example, see Samant et al 2000; Bhatt and Sachan 2004; Hoeck et al 2007; SEEDS 2008; Sharma et al 2009; Singh et al 2010; Démurger and Fournier 2011; Rehnus et al 2013).

Many studies have explored the different relationships between firewood consumption and such factors as income, family size, number of heated rooms, price of firewood, and climate (Kennes et al 1984; Dunkerley et al

FIGURE 3 (A) Dung, one of the main energy sources; (B) a typical village stove with bake-oven. (Photos by Mislimshoeva, 2013)

TABLE 5 Level of satisfaction with the availability of energy sources.

	Not at all satisfied	Slightly satisfied	Moderately satisfied	Very satisfied	Extremely satisfied
Dung	3	5	91	71	0
Firewood	0	13	115	42	0
Electricity	1	62	51	56	0
Coal	167	1	1	1	0

1990; Mahapatra and Mitchell 1999; Bhatt and Sachan 2004; Johnson and Bryden 2012; Onoja 2012; San et al 2012; Song et al 2012; Rehnus et al 2013). These interactions are dependent on biophysical conditions, socioeconomic and ownership factors, and energy availability.

Elevation plays a critical role in firewood consumption. Whereas Khuman et al (2011) found a decrease in firewood consumption with increasing elevation, most studies have found that firewood consumption increases with increasing elevation (Negi et al 1999; Mustafa and Kaygusuz 2001; Ali and Benjaminsen 2004; Bhatt and Sachan 2004; Förster et al 2011). Our results are consistent with the latter finding. At higher elevations, not only is the heating season longer but also on any given day households need more hours of heating and thus consume more firewood.

More than half of the participating households had members whose highest level of education was education level I. This relates to the Soviet period (ending in 1991), during which colleges for vocational education were the most common places to receive an education beyond school level. This in turn relates to the relatively small size of the 18- to 25-year-old age bracket in the studied villages, as there is an enormous labor migration by young people to Russia due to the lack of job opportunities in the villages. The correlation of firewood consumption with education level I might indicate that households with more educated members use less firewood, but we did not see the same correlation with education level II. One might assume that higher education levels would be associated with a preference for energy-efficient technology; however, almost all households participating in the study used the same heating technology, and almost no houses were insulated. Whether or not the awareness of energy-efficient technologies is related to education level needs to be investigated more explicitly (see an example in Wiedemann et al 2012). Some researchers have shown that education level was a factor influencing firewood use in households in Cambodia and Nigeria (Nnaji et al 2012; San et al 2012).

Household firewood consumption was also correlated to the size of the household's private garden. Private gardens are the largest source of firewood (Figure 4) in the study area; households with larger gardens are able to plant more woody vegetation to meet their firewood needs. This firewood is also free. Indeed, the availability of energy sources influences the level of consumption. However, this is not necessarily the case for all households. Tree species, age, and productivity also play an important role. Further research is needed on extraction of firewood from private gardens.

Some of the study villages receive electricity from the city Khorog and others from a local hydropower station. During winter, electricity is available on alternating days,

FIGURE 4 Firewood sources in winter. Each household extracted firewood from more than one source.

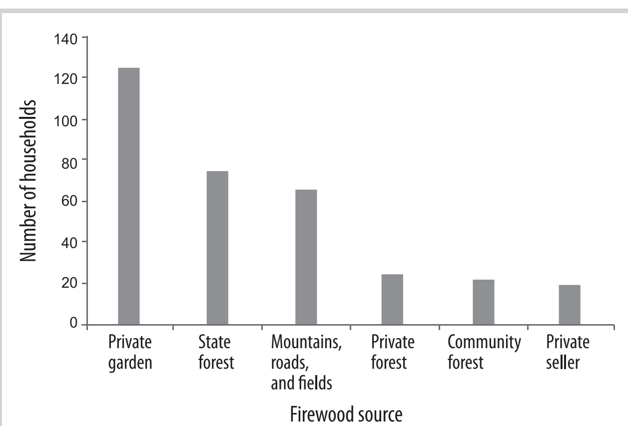


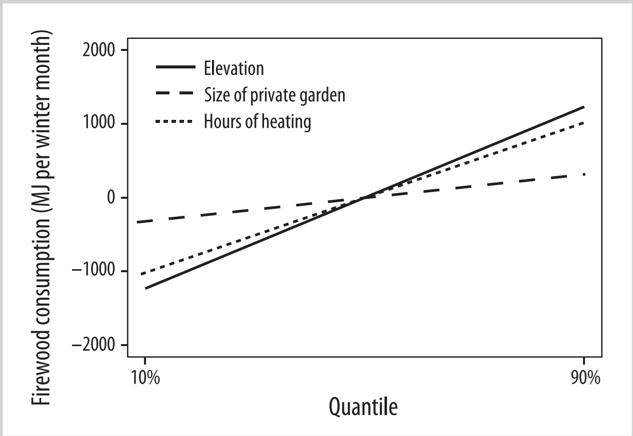
TABLE 6 Ordinary least square coefficients.

Variable	Coefficient
Elevation[a)]	5.69
Education level I[b)]	−888
Size of private garden[a)]	0.489
Electricity supplied from Khorog[b)]	−1200
Hours of heating per month in winter[a)]	11.2

[a)]Continuous variables.

[b)]Categorical variables.

FIGURE 5 Influence of the continuous variables (elevation, size of private garden, and heating hours per month in winter) on firewood consumption. To ensure comparability among results, the scale of each variable ranges from the respective 10% to the respective 90% sample quantile. The coefficients are listed in Table 6.



especially in those villages where electricity is provided locally. The voltage of the locally provided electricity is so low that in some places it is impossible to use for heating and cooking, whereas the electricity provided from Khorog is better. Households that receive electricity from Khorog used less firewood than the others. Electricity did not substitute fully for firewood; rather, it was used for cooking and boiling water, which reduced the pressure on firewood to a certain degree.

Methodological issues

Several limitations remain in this study and suggest potential avenues for future research. First, there is a need for more precise measurement of energy use at the household level, particularly with respect to measuring firewood and dung in the local unit of measure (the bag). Though this seemed to be the easiest way for local people to assess their energy use, it could still be improved, for example, by combining it with other local units and offering different illustrations during the interviews. Nevertheless, this very simple approach to data collection on firewood and dung consumption has great advantages as it is low in cost and easy to apply in any region.

Second, there are some uncertainties associated with the accuracy of the conversion of household-level measurements of firewood and dung amounts. Some of the conversions were based on other studies, thus containing a certain degree of error.

Third, the nature of the interview data, the limitations of the relatively small sample size, and the high number of (potentially) influential variables limit the application of more complex models and more refined statistical analysis.

Finally, it cannot be claimed that the winter of 2011–2012 is representative, as no long-term energy consumption data are available to confirm this. However, the heating season in the study region is usually relatively constant, and thus the obtained quantities of energy consumption give a valuable overview.

In spite of these limitations, this study clearly defines the quantities of different sources of energy, patterns of use, and their relationship with other independent factors.

Conclusions

Energy consumption patterns in the Tajik Pamirs are still far from being fully understood. In particular, the amounts of available energy sources remain unknown. Further research is needed to study the origins of firewood supplies, especially from private gardens and forests. This will allow these sources to be linked to demand in order to explain the wider context of firewood consumption and its impact on land use and land cover.

Though energy consumption differs from village to village, some general patterns can be observed. Findings from this study suggest that in the mountainous areas of the Tajik Pamirs, rural villages depend heavily on animal dung and firewood for winter heating. This dependence varies with elevation and availability of different types of energy, such as electricity and firewood from private gardens. At higher elevations, villages require more energy, as the heating season lasts longer. These are also the most remote villages; they have weak infrastructure, and because of the harsh climatic conditions, there is less biomass. Thus, sustainable energy production efforts such as forestry should be considered.

The trade-offs between energy and food provision may become more extreme as demand for both increases with population growth. Therefore, development of alternative energy sources (for example, small-scale solar energy) is recommended, along with promotion of energy-efficient technology (such as thermal insulation and efficient stoves).

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REFERENCES

Ali J, Benjaminsen TA. 2004. Fuelwood, timber and deforestation in the Himalayas. *Mountain Research and Development* 24(4):312–318.
APRS [Automatic Position Reporting System]. World map for APRS in ESRI Shapefile format. http://aprsworld.net/gisdata/world/; accessed on 18 July 2013.
Arrow K, Dasgupta P, Goulder L, Daily G, Ehrlich P, Heal G, Levin S, Mahler KG, Schneider S, Starrett D, Walker B. 2004. Are we consuming too much? *Journal of Economic Perspectives* 18:147–172.
Bhatt BP, Negi AK, Todaria NP. 1994. Fuelwood consumption pattern at different altitudes in Garhwal Himalaya. *Energy* 19(4):465–468.
Bhatt BP, Sachan MS. 2004. Firewood consumption along an altitudinal gradient in mountain villages of India. *Biomass and Bioenergy* 27(1):69–75.
Breckle S, Wucherer W. 2006. Vegetation of the Pamir (Tajikistan): Land use and desertification problems. *In:* Spehn E, Liberman M, Körner C, editors. *Land Use Change and Mountain Biodiversity*. Boca Raton, FL: Taylor & Francis, pp 225–237.
Breu T, Hurni H. 2003. *The Tajik Pamirs: Challenges of Sustainable Development in an Isolated Mountain Region*. Bern, Switzerland: Centre for Development and Environment, University of Bern, and Geographica Bernensia.
Chen L, Heerink N, van den Berg M. 2006. Energy consumption in rural China: A household model for three villages in Jiangxi Province. *Ecological Economics* 58(2):407–420.
Démurger S, Fournier M. 2011. Poverty and firewood consumption: A case study of rural households in northern China. *China Economic Review* 22(4): 512–523.
Dunkerley J, Macauley M, Naimuddin M, Agarwal PC. 1990. Consumption of fuelwood and other household cooking fuels in Indian cities. *Energy Policy* 18(1):92–99.
Falkingham J, Baschieri A, Evandrou M, Grant G. 2009. *Left Behind in Transition? The Well-Being of Older People in Tajikistan.* Discussion paper. London, UK: Centre for Research on Ageing.
Food and Agriculture Organization (FAO). 2013. Units and conversions. http://www.fao.org/docrep/x5667e/x5667e04.htm; http://www.fao.org/docrep/010/ah810e/AH810E13.htm; accessed on 1 June 2013.
Förster H, Pachova NI, Renaud FG. 2011. Energy and land use in the Pamir-Alai Mountains. *Mountain Research and Development* 31(4):305–314.
Friedman J, Hastie T, Tibshirani R. 2010. Regularization paths for generalized linear models via coordinate descent. *Journal of Statistical Software* 33(1):1–22.
Friedman J, Hastie T, Tibshirani R. 2012. Glmnet: Lasso and elastic-net regularized generalized linear models. Boston, MA: Free Software Foundation, Inc. R package version 1.9-3. http://cran.r-project.org/web/packages/glmnet; accessed on 27 May 2013.
Fushiki T. 2009. Estimation of prediction error by using K-fold cross-validation. *Statistics and Computing*. 21(2):137–146.
GIZ [Deutsche Gesellschaft für Internationale Zusammenarbeit]. 2011. *Elaboration of a Value Chain for Firewood in the Tajik Pamirs*. Khorog, Tajikistan: GIZ.
Godfray HC, Crute IR, Haddad L, Lawrence D, Muir JF, Nisbett N, Pretty J, Robinson S, Toulmin C, Whiteley R. 2010. The future of the global food system. *Philosophical Transactions of Royal Society B* 365:2769–2777.
Hastie T, Tibshirani R, Friedman J. 2009. *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*. New York, NY: Springer.
Hoeck T, Droux R, Breu T, Hurni H, Maselli D. 2007. Rural energy consumption and land degradation in a post-Soviet setting—an example from the west Pamir mountains in Tajikistan. *Energy for Sustainable Development* 11(1):48–57.
Hosier RH, Kipondya W. 1993. Urban household energy use in Tanzania: Prices, substitutes and poverty. *Energy Policy* 21(5):454–473.
IDA [Ishkashim District Administration]. 2013. Ishkashim district's statistics. Tajikistan: Gorno Badakhshan Autonomous Oblast.
Imhoff ML, Bounoua L, Ricketts T, Loucks C, Harriss R, Lawrence WT. 2004. Global patterns in human consumption of net primary production. *Nature* 429: 870–873.
Johnson NG, Bryden KM. 2012. Factors affecting fuelwood consumption in household cookstoves in an isolated rural West African village. *Energy* 46(1): 310–321.
Kennes W, Parikht JK, Stolwijk H. 1984. Energy from biomass by socio-economic groups—a case study of Bangladesh. *Biomass* 4:209–234.
Khuman YS, Pandey R, Rao KS. 2011. Fuelwood consumption patterns in Fakot watershed, Garhwal Himalaya, Uttarakhand. *Energy* 36(8):4769–4776.
Kirchhoff J. 2010. *Forestry Sector Analysis*. Eschborn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.
Liu S, Costanza R, Farber S, Troy A. 2010. Valuing ecosystem services: Theory, practice, and the need for a transdisciplinary synthesis. *Annals of the New York Academy of Sciences* 1185:54–78.
Mahapatra AK, Mitchell CP. 1999. Biofuel consumption, deforestation, and farm level tree growing in rural India. *Biomass and Bioenergy* 17(4):291–303.
Miehe G, Winiger M, Böhner J, Yili Z. 2001. The climatic diagram map of High Asia. Purpose and concepts. *Erdkunde* 55:94–97.
Mislimshoeva B, Samimi C, Kirchhoff JF, Koellner T. 2013. Analysis of costs and people's willingness to enroll in forest rehabilitation in Gorno Badakhshan, Tajikistan. *Forest Policy and Economics* 37:75–83.
Mustafa FT, Kaygusuz K. 2001. Investigation of the variables effects on fuelwood consumption as an energy source in forest villages of Turkey. *Energy Conversion and Management* 42:1215–1227.
NASA LP DAAC [National Aeronautics and Space Administration, Land Processes Distributed Active Archive Center]. *ASTER Global Digital Elevation Model*. http://gdex.cr.usgs.gov/gdex/; accessed on 18 July 2013.
National Bank of Tajikistan. 2013. http://www.nbt.tj/tj/; accessed on 3 February 2013.
Negi AK, Bhatt BP, Todaria NP. 1999. Local population impacts on the forests of Garhwal Himalaya, India. *Environmentalist* 19:293–303.
Nnaji CE, Uzoma CC, Chukwu JO. 2012. Analysis of factors determining fuelwood use for cooking by rural. *Environmental Sciences* 6(2):1–6.
Onoja AO. 2012. Econometric analysis of factors influencing fuel wood demand in rural and peri-urban farm households of Kogi State. *Sustainable Development* 8:115–127.
Oslon D, Delen D. 2008. *Advanced Data Mining Techniques*. Berlin, Germany: Springer.
R Core Team. 2014. *A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.
Rehnus M, Nazarek A, Mamadzhanov D, Venglovsky BI, Sorg JP. 2013. High demand for firewood leads to overuse of walnut-fruit forests in Kyrgyzstan. *Journal of Forestry Research* 24(4):797–800.
Samant S, Dhar U, Rawal R. 2000. Assessment of fuel resource diversity and utilization patterns in Askot Wildlife Sanctuary in Kumaun Himalaya, India, for conservation and management. *Environmental Conservation* 27(1):5–13.
San V, Spoann V, Ly D, Chheng NV. 2012. Fuelwood consumption patterns in Chumriey Mountain, Kampong Chhnang Province, Cambodia. *Energy* 44(1): 335–346.
SEEDS [Social Enterprise & Environmental Development Systems]. 2008. *Bio-Mass Energy Use in GBAO*. Khorog, Tajikistan: Social Enterprise & Environmental Development Systems.
SFA [State Forest Agency of Ishkashim District]. 2013. *Land Cover of Ishkashim District, Gorno Badakhshan Autonomous Oblast*. Ishkashim, Tajikistan: State Forest Agency of Ishkashim District.
Sharma CM, Gairola S, Ghildiyal SK, Suyal S. 2009. Forest resource use patterns in relation to socioeconomic status. *Mountain Research and Development* 29(4):308–319.
Singh G, Rawat GS, Verma D. 2010. Comparative study of fuelwood consumption by villagers and seasonal "Dhaba owners" in the tourist affected regions of Garhwal Himalaya, India. *Energy Policy* 38(4):1895–1899.
Song N, Aguilar FX, Shifley SR, Goerndt ME. 2012. Factors affecting wood energy consumption by U.S. households. *Energy Economics* 34(2):389–397.
Tabuti JR, Dhillion SS, Lye KA. 2003. Firewood use in Bulamogi County, Uganda: Species selection, harvesting and consumption patterns. *Biomass and Bioenergy* 25(6):581–596.
Tilman D, Fargione J, Wolff B, D'Antonio C, Dobson A, Howarth R, Schindler D, Schlesinger WH, Simberloff D, Swackhamer D. 2001. Forecasting agriculturally driven global environmental change. *Science* 292:8–10.
Wiedemann C, Salzmann S, Mirshakarov I, Volkmer H. 2012. Thermal insulation in high mountainous regions. *Mountain Research and Development* 32(3):294–303.
World Bank. 2009. *Republic of Tajikistan. Poverty Assessment.* Report No. 51341-TJ. Dushanbe, Tajikistan: World Bank.
Zhen L, Liu XL, Wie YJ, Yang L, Long X, Du B, Li F, Cao X. 2011. Consumption of ecosystem services: A conceptual framework and case study in Jinghe watershed. *Resources and Ecology* 2:298–306.