Rural household energy demand modelling

A case study of Nepal

Kamal Rijal, N. K. Bansal and P. D. Grover

This paper describes the methodology adopted to arrive at a causal linear multiple regression to estimate and project end-use energy requirements of a rural household of Nepal. The general model developed is capable of estimating and projecting the total end-use energy requirements if eight variables are known. These are: standard population, household expenditure, agricultural commodity, number of livestock, number of cookstoves, area covered by housing, topography and forest accessibility condition, of a particular village. The method has been applied to estimate primary energy requirements in the household sector of a few surveyed villages typical of Nepal's different physiographical regions. Total useful energy is estimated considering the end-use efficiency of the devices employed for specific end-use activities. Relevance of the socio-economic variable for estimating end-use energy requirements for different villages varies according to the availability, price and choice of specific fuels for different end-use activities.

Keywords: Rural household; End-use; Regression analysis

In recent years developing nations have started taking a serious stand to counter energy crises. In order to arrive at rational energy planning and policy formulation and their adoption, efforts have been made to understand the energy use behaviour at micro and macro level. In Nepal though a few studies have been attempted to arrive at energy consumption figures of rural villages, they all lack appropriate analysis of database. No effort has so far been made to model rural household energy demand patterns.

The main focus of this study is to develop an energy demand model which could project energy requirements in rural Nepal. The choice of methodology depends on various factors like present and future availability of data and information and the type of problem to be addressed which dictate the level of accuracy desired in energy requirement estimates. In order to decide on an optimum energy resource and technology mix it is important to first develop a causal regression model for specific end-use energy requirements of the rural household sector. The reason for this is two-fold. First, it is not always possible to carry out extensive rural energy surveys in developing countries such as Nepal where resources are always in short supply. Second, time series data on energy consumption are not available and neither is it advisable to allocate funds to establish a national network for collection of time series data on energy use.

The level of disaggregation of end-use energy requirements considered for modelling is done on the substitutability of energy forms, which is mainly governed by the amount and intensity of energy released by particular fuels and the present day energy use practices in rural areas. The main end-uses considered in this analysis are cooking which includes cooking human food, cooking animal feed, hot water required for washing clothes and heat required for brewing alcohol at a household level, heating (space conditioning), and lighting.

A detailed household energy survey was carried out at three village sites in different physiographic zones of Nepal - Baijnathpur, Eastern Terai; Lekhgaun, Mid-
western Hill; and Marpha Village Panchayat, Western Mountain. The total number of households selected for sampling were 87 households from Baijnathpur (sampling rate - 13%, total hh - 664); 92 households from Lekhaun (sampling rate - 17%, total hh - 548); 51 households from Jomsom (sampling rate - 20%, total hh - 253).

Baijnathpur Village Panchayat lies in the south-eastern part of the country. It is a plain area with dwindling forest cover. The main energy sources are animal dung and agricultural residue, both mainly exploited for cooking and heating purposes. Electricity and kerosene are employed for lighting. Modern forms of energy are not utilized for cooking and space conditioning activities due to the high cost to users compared to their purchasing capabilities.

Lekhaun Village Panchayat lies in the central area of the mid-western part of the country. It is a hilly area with sufficient forest cover. The main energy sources are fuelwood and agricultural residue, both mainly exploited for cooking and heating purposes. Kerosene is employed for lighting. Modern forms of energy are not utilized for cooking and space conditioning activities also due to the high cost to users compared to their purchasing capabilities.

Marpha Village Panchayat lies in the northern area of the central part of the country. It is a mountainous area with 45% of the area covered by snow. The main energy sources are fuelwood and agricultural residue, both mainly exploited for cooking and heating purposes. Electricity and kerosene are employed for lighting. Modern forms of energy are not utilized for cooking and space conditioning activities due to the higher cost to users compared to the cost of fuelwood which is freely available.

**Research methodology**

The sampling unit for the household level survey was a household. Three to four communities from each village were chosen. Of the total households of the village panchayat 10-20% were randomly selected from each community within a village. Local units of energy, land area etc were converted into standard units in order to obtain comparable results (a 'Joule' is the chosen energy unit). Human population is converted into standard population assigning appropriate coefficients for different age groups. Similarly, livestock population is converted into livestock units with appropriate coefficients for each type of livestock. Variables such as forest accessibility, topography of an area, market accessibility and level of technological penetration are standardized developing an index table with appropriate scaling. For example, an area requiring 4-6 h for fuelwood collection from the forest is scaled as 2 and an area requiring more than 12 h is scaled as 5. Agricultural residue generated and dung produced are calculated by using standard coefficients. The method employed to develop a causal model capable of estimating energy requirements of a rural area is as follows.

**Simple regression analysis**

A simple regression analysis is performed between end-use energy requirement per household (hh) and demographic and socio-economic variables such as population and standard population of a household, cultivated land per hh, agriculture production per hh, agriculture commodity per hh, household expenditure, dung availability per hh, agriculture residue produced per hh, number of cooking stoves and livestock possessed by a household, and floor area of a house. Further, variables like forest accessibility, market accessibility, topography of an area, and the level of technological penetration are also considered. The reason for selecting per household energy requirement instead of per capita energy is that per household energy shows a linear relationship with chosen variables, while per capita energy shows non-linear behaviour.

The following formulae are used to calculate coefficients of a simple regression model, correlation coefficients, coefficients of determination, standard error of estimates, t-ratios and criteria for the level of significance of the coefficients (Dixon and Massey [2]).

The simple regression model can be represented as:

$$\hat{y} = a + bx$$

(1)

with \(x\) and \(y\) values measured as deviations from their means, the least square values of \(a\) and \(b\) are:

$$a = \bar{y}$$

(2)

$$b = \frac{\sum x_i y_i \sum (x_i)^2}{\sum (x_i)^2}$$

(3)

where \(i\) varies from 1 to \(N\).

The coefficient of determination \(\left( R^2 \right)\) is given by,

$$R^2 = \frac{\sum (\hat{y}_i - \bar{y})^2}{\sum (y_i - \bar{y})^2} = \frac{(\sum xy)^2}{\sum x^2 \sum y^2}$$

(4)

where

$$x = (x_i - \bar{x})$$

$$y = (y_i - \bar{y})$$

\(\bar{x}\) and \(\bar{y}\) are mean values of \(X_i\) and \(Y_i\).

The standard error of estimate \(\left( S_b \right)\) is given by:

$$S_b = \sqrt{\frac{1}{N-2} \sum (y_i - \hat{y}_i)^2 / \sum x_i^2}$$

(5)
The students’ r-ratio is given by:
\[ r = \frac{b - b_s}{S_b} \quad (6) \]
where, \( \hat{Y}_t \) is the fitted value of Y on the line of Equation (1).

Criteria to determine the level of significance is given by,
\[ \frac{b}{S_b} > 2 \quad (7) \]

**Step-wise multiple regression analysis**

Variables which resulted in a t-ratio higher than 2 and the highest coefficient of determination were considered in step-wise multiple regression analysis. This analysis is performed by introducing new independent regressors and each time the coefficient of determination and t-ratio are calculated. The level of coefficient of determination determined the priority of introducing variables in the analysis. The correction is essential for the coefficient of determination in the case of multiple regression analysis as the introduction of a new regressor will always increase the coefficient of determination even if correlation is bad. The corrected coefficient of determination (\( R^2 \)) is given by (Wonnacott and Wonnacott [6]),
\[ R^2 = \left( R^2 - \frac{k}{N-1} \right) \left( \frac{N-1}{N-k-1} \right) \quad (8) \]
where, \( k \) is the number of regressors.

On the one hand, the following criteria to determine the number of regressors to be kept in the model are applied. Criteria to decide on the number of variables to be retained in the model are that while adding a new regressor a parameter
\[ (1 - R^2)/(N-k-1)^2 \] should be minimum, and t-ratios > 2
\[ (9) \]

On the other hand, a Durbin-Watson test is also performed to check the dependency among independent variables of the regression model. The criterion to decide upon independency has been determined by the specific value of the coefficient of determination and the standard error of estimates of the coefficient. Criteria to check the level of dependence among independent variables are given by
\[ R^2 < 0.5 \] and/or \( t < 2 \)
\[ (10) \]

First, site specific analysis is carried out for each village adopting the methodology described above. This aided understanding of the main variables which dictated the energy consumption pattern in the household sector. Then the exercise is reiterated combining the data of all villages as there are differences in variables like topography, forest accessibility, market access and level of technological penetration. These variables are introduced into the regression model along with other variables as decided upon from site specific analysis. This exercise helped us to evolve a general model for each end-use energy requirement to estimate the total energy requirement of a rural Nepalese village.

**Estimation of total energy requirement**

The general regression model developed, as described above, for the estimation of total household energy requirement is used to predict total energy demand for the household sectors of the research villages. The model for the estimation of total energy demand for a specific village panchayat is given by:
\[ TPE = f (\text{some of the demographic and socio-economic variables, and macro variables}) \]
\[ (11) \]

where \( TPE = \) total energy requirement of household sector (MJ); demographic and socio-economic variables are population, household size, household expenditure and income, livestock holding, agriculture commodity etc; macro variables could be forest accessibility, market accessibility, topography, level of technological penetration, etc; and the suffix ‘r’ stands for a specific village panchayat.

The estimation of the end-use energy requirements for each village panchayat is carried out by using a general regression model for a specific end use. The estimation of total useful energy requirement is made taking into consideration the efficiency of end-use devices for various activities which follows (Codoni et al [1]; WECS [5]):
\[ UER_{s,u} = PER_{s,u} \times \eta_{s,u} \]
\[ (12) \]
where \( UER = \) useful energy requirement (MJ); \( PER = \) primary energy requirement (MJ); \( \eta_{s,u} = \) adjusted overall efficiency of converting particular types of energy sources for certain end-use; the suffix ‘s’ stands for energy sources; and ‘u’ stands for end uses.
\[ \eta_{s,u} = \sum \eta_{s,u,i} \times S_{s,u,i} \]
\[ (13) \]
where \( \eta_{s,u,i} = \) the efficiency of an end-use device for using energy sources for specific end use; \( S_{s,u,i} = \) the percentage share of energy forms in terms of total energy to be used in certain end-use devices for particular end use; and the suffix ‘i’ stands for technology.

**Evolution of rural household energy demand function**

As time series data were not available, a causal linear multiple regression model is developed for each site.
Once these site specific models were developed then a general model for each end-use requirement for the household sector is arrived at, which is capable of estimating and projecting the energy requirement of the household sector of a village.

**Site specific analysis**

Analysis is carried out for each village and for each end-use requirement as explained in the methodology. The demand functions resulted from a site specific analysis for each end-use requirement and for each site they are reported as follows:

**THE**

\[ THE_b = 20015.9 + 2631.2 \times AC_b + 2301.5 \times LS_b + 1.1 \times EX_b + 1549.5 \times SP_b \]  
Corrected coefficient of determination \( (R^2) = 0.80 \)  

**CHE**

\[ CHE_b = 21072.0 + 2368.4 \times SP_b + 1806.0 \times LS_b \]  
Corrected coefficient of determination \( (R^2) = 0.53 \)  

**HHE**

\[ HHE_b = -1087.8 + 3672.6 \times AC_b + 582.8 \times LS_b - 898.4 \times SP_b \]  
Corrected coefficient of determination \( (R^2) = 0.92 \)  

**LHE**

\[ LHE_b = 503.0 + 117.1 \times LS_b + 0.088 \times EX_b + 92.0 \times SP_b - 97.4 \times AC_b \]  
Corrected coefficient of determination \( (R^2) = 0.48 \)  

**THE**

\[ THE_l = 6562.0 + 11363.6 \times SP_l + 8088.4 \times AC_l + 10.6 \times EX_l \]  
Corrected coefficient of determination \( (R^2) = 0.93 \)  

**CHE**

\[ CHE_l = 8115.8 + 10000.2 \times SP_l + 8.2 \times EX_l + 1925.7 \times LS_l \]  
Corrected coefficient of determination \( (R^2) = 0.92 \)  

**HHE**

\[ HHE_l = -1911.2 + 1987.0 \times SP_l + 8.0 \times FA_l \]  
Corrected coefficient of determination \( (R^2) = 0.52 \)  

**LHE**

\[ LHE_l = -435.0 + 0.80 \times FA_l + 0.04 \times EX_l \]  
Corrected coefficient of determination \( (R^2) = 0.37 \)  

where:

\( THE \) = total household energy demand (MJ)

\( CHE \) = household cooking energy demand (MJ)

\( HHE \) = household heating energy demand (MJ)

\( LHE \) = household lighting energy demand (MJ)

\( SP \) = standard population per household

\( LS \) = livestock holding per household (LSU)

\( AC \) = agriculture commodity per household

\( EX \) = total household expenditure (NCR)

\( FA \) = floor area of a house (ft²)

\( NC \) = number of cookstoves possessed by a house

while the suffixes 'b', 'l', and 'm' represent Baijnathpur, Lekhaun, and Marpha Village Panchayat, respectively.

Table 1 lists the maximum possible percentage error in estimating and projecting per household end-use energy requirements for different villages at a 95% confidence interval using demand functions as derived in site specific analysis.

**Evolution of a general multiple regression model**

Analysis is carried out combining data from all research villages to arrive at the general model which explains the energy use behaviour of rural areas. Variables such as forest accessibility, market accessibility, level of technological penetration and topographic features of a particular area along with other demographic variables are considered to explain variations in energy use. Forest accessibility and topographic features of an area play a significant role in determining rural energy consumption.

**Evolution of total energy demand function.** Various analytical steps were carried out to arrive at a robust model.
Table 2. Simple regression analysis between total energy requirement of a household and other independent variables (combined for all village panchayat of Nepal).

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Dependent variable (Y)</th>
<th>Independent variable (X)</th>
<th>Coefficient of determination</th>
<th>Degree of freedom</th>
<th>Constant (a)</th>
<th>Coefficient of X (b)</th>
<th>t-ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TE</td>
<td>SP</td>
<td>0.48</td>
<td>227</td>
<td>18478.7</td>
<td>12341.2</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>TE</td>
<td>AC</td>
<td>0.06</td>
<td>227</td>
<td>72639.9</td>
<td>6003.5</td>
<td>1.7</td>
</tr>
<tr>
<td>3</td>
<td>TE</td>
<td>EX</td>
<td>0.12</td>
<td>227</td>
<td>66493.9</td>
<td>50</td>
<td>1.7</td>
</tr>
<tr>
<td>4</td>
<td>TE</td>
<td>LS</td>
<td>0.35</td>
<td>227</td>
<td>53544.0</td>
<td>7020.2</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>TE</td>
<td>FA</td>
<td>0.32</td>
<td>227</td>
<td>52445.8</td>
<td>56.7</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>TE</td>
<td>NC</td>
<td>0.00</td>
<td>227</td>
<td>77963.9</td>
<td>5747.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Note: TE = total energy (MJ); SP = standard population (number); AC = agricultural commodity (tons); EX = total expenditure (NCR); NC = number of cookstoves; LS = Livestock holding (LSU); FA = floor area (ft²).

Table 3. Multiple regression analysis between total energy consumption and other independent variables – combined data of three villages of terai, (hill and mountain), Nepal.

<table>
<thead>
<tr>
<th>Descriptions</th>
<th>New independent variables introduced</th>
<th>SP</th>
<th>LS</th>
<th>FA</th>
<th>EX</th>
<th>AC</th>
<th>NC</th>
<th>TP</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Coefficient of determination</td>
<td>0.48  0.60  0.62  0.63  0.67  0.69  0.78  0.83</td>
<td>9685.78  4435.88</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2 Corrected coefficient of determination</td>
<td>0.48  0.59  0.62  0.62  0.66  0.68  0.77  0.82</td>
<td>8518.93  3606.20  20.29</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>3 Degree of freedom (df)</td>
<td>227  226  225  224  223  222  221  220</td>
<td>8577.94  3853.40  23.32  1.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4 Constant (a)</td>
<td>18478.70  12281.46  10414.95  11638.52  10243.08  26843.75  25497.53  29281.85</td>
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<td></td>
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</tr>
<tr>
<td>5 Coefficient of each regressor</td>
<td>TE = f(SP)</td>
<td>12341.23</td>
<td>9685.78  4435.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS)</td>
<td>8518.93  3606.20  20.29</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA)</td>
<td>8577.94  3853.40  23.32  1.13</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX)</td>
<td>10438.72  3819.74  20.06  0.99  -6644.50</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX,AC)</td>
<td>10801.64  3573.49  23.14  0.93  -567.45  -14221.95</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX,AC,NC)</td>
<td>11384.64  2426.41  7.17  -1.53  184.12  4052.85  32586.12</td>
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<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX,AC,NC,TP)</td>
<td>9720.50  1639.46  5.47  1.25  42.10  7737.91  -67924.94  -63989.51</td>
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<td></td>
</tr>
<tr>
<td>6 t-ratios of each regressor</td>
<td>TE = f(SP)</td>
<td>14.47</td>
<td>11.80  8.90</td>
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<tr>
<td></td>
<td>TE = f(SP,LS)</td>
<td>10.11  6.36  4.12</td>
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<tr>
<td></td>
<td>TE = f(SP,LS,FA)</td>
<td>10.20  6.57  4.42  -1.58</td>
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</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX)</td>
<td>11.88  6.86  3.98  1.24  -5.06</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX,AC)</td>
<td>12.51  6.54  4.64  1.19  -4.34  -3.56</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX,AC,NC)</td>
<td>15.60  5.10  1.58  -2.18  0.15  1.05  9.58</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX,AC,NC,TP)</td>
<td>14.47  3.38  1.38  1.77  0.04  2.26  -5.38  -8.19</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TE = f(SP,LS,FA,EX,AC,NC,TP,FF)</td>
<td>7.75  3.54  1.72  0.76  0.70  0.70  0.70  0.70</td>
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</tbody>
</table>

Note: TE = total energy (MJ); AC = agricultural commodities; LS = livestock; EX = total expenditure; FA = floor area; SP = standard population; NC = number of cookstoves; AL-IN = altitude index; FA-IN = forest accessibility index; TP = topography; FF = forest accessibility factor.

that explains the total energy use pattern of rural villages in Nepal. Table 2 shows the result of simple regression analysis. The regression analysis performed between total energy consumption of a rural household and standard population, and livestock holding per household resulted in a coefficient of determination between 0.3 and 0.5 and the t-ratios are greater than two. Independent variables like agriculture commodity per household, total household expenditure, and number of cookstoves possessed by a house exhibit a coefficient of determination lower than 0.15 and t-ratios, also, do not indicate the significance of the relationship. The low level of the coefficient of determination indicates that there may be other significant variables to explain the total household energy consumption pattern.

Under the general understanding about the relationship between total household energy consumption and independent variables, step-wise multiple regression analysis is carried out. The independent variables chosen for carrying out step-wise multiple regression analysis with respect to total household energy consumption.
Table 4. Simple regression analysis among independent variables of a household combined data for three villages, Nepal.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Dependent variable (Y)</th>
<th>Independent variable (X)</th>
<th>Coefficient of determination</th>
<th>Degree of freedom</th>
<th>Constant (a)</th>
<th>Coefficient of X (b)</th>
<th>t-ratios (Y)</th>
<th>t-ratios (X)</th>
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<tbody>
<tr>
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<td>EX</td>
<td>SP</td>
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<td>1.1</td>
<td>5.2</td>
</tr>
<tr>
<td>2</td>
<td>EX</td>
<td>FA</td>
<td>0.28</td>
<td>227</td>
<td>1974.7</td>
<td>3.690</td>
<td>1.3</td>
<td>9.4</td>
</tr>
<tr>
<td>3</td>
<td>EX</td>
<td>LS</td>
<td>0.21</td>
<td>227</td>
<td>2210.2</td>
<td>383.717</td>
<td>1.2</td>
<td>7.8</td>
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<td>1.1</td>
<td>3.4</td>
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<td>AC</td>
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<td>LS</td>
<td>0.12</td>
<td>227</td>
<td>1.5</td>
<td>0.165</td>
<td>1.1</td>
<td>5.5</td>
</tr>
<tr>
<td>8</td>
<td>AC</td>
<td>FA</td>
<td>0.12</td>
<td>227</td>
<td>1.5</td>
<td>0.001</td>
<td>1.1</td>
<td>5.5</td>
</tr>
<tr>
<td>9</td>
<td>AC</td>
<td>SP</td>
<td>0.26</td>
<td>227</td>
<td>0.3</td>
<td>0.368</td>
<td>2.5</td>
<td>8.8</td>
</tr>
<tr>
<td>10</td>
<td>LS</td>
<td>NC</td>
<td>0.01</td>
<td>227</td>
<td>3.6</td>
<td>0.718</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>11</td>
<td>LS</td>
<td>FA</td>
<td>0.22</td>
<td>227</td>
<td>2.3</td>
<td>0.004</td>
<td>1.2</td>
<td>8.1</td>
</tr>
<tr>
<td>12</td>
<td>LS</td>
<td>SP</td>
<td>0.16</td>
<td>227</td>
<td>1.4</td>
<td>0.599</td>
<td>1.1</td>
<td>6.6</td>
</tr>
<tr>
<td>13</td>
<td>FA</td>
<td>NC</td>
<td>0.21</td>
<td>227</td>
<td>149.1</td>
<td>81982</td>
<td>1.3</td>
<td>7.8</td>
</tr>
<tr>
<td>14</td>
<td>FA</td>
<td>SP</td>
<td>0.08</td>
<td>227</td>
<td>199.8</td>
<td>269525</td>
<td>1.2</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Note: SP = standard population; AC = agricultural commodities (tons); LS = livestock holding (LSU); NC = number of cookstoves; FA = floor area (ft²); EX = total expenditure (NCRs)

The level of dependency among variables is decided with the help of the coefficient of determination between the variables from the simple regression analysis carried out between them. Table 4 enumerates the coefficient of determination and t-ratios among these variables. The resulting coefficient of determination is below 0.40 and t-ratios below two. While simple regression carried out between standard population and agriculture commodity per household shows a t-ratio higher than two. So, standard population and agriculture commodity together is not introduced into a model. The rest of the independent variables are found to be independent of each other. The corrected coefficient of determination is also calculated in order to see the robustness of the model. Finally, six variables were retained and the resulting total household energy demand function for rural areas of Nepal is as follows.

\[ \text{THE}_r = 291848 \times 9993SP_r + 1707LS_r + 1.5EX_r + 9248NC_r - 67465TP_r - 64565FF_r \]  (26)

Note: SP = standard population; AC = agricultural commodities (tons); LS = livestock holding (LSU); NC = number of cookstoves; FA = floor area (ft²); EX = total expenditure (NCRs)
indicate the significance of the relationship, except in the case of the number of cookstoves.

The variables chosen to carry out step-wise multiple regression are standard population, livestock holding per household, floor area of a house, total agricultural commodities, total household expenditure, number of cookstoves, topography and forest accessibility in order of priority as determined by the coefficient of determination from simple regression analysis. It should be noted that those independent variables which are dependent on each other are excluded from the model. Step-wise regression is performed by introducing new independent variables and each time the coefficient of determination and t-ratios are calculated. To decide on the number of variables to be retained in the model the criteria mentioned in research methodology are applied. Finally, five variables are retained in the model and the resulting household cooking energy demand function for rural areas of Nepal is as follows:

\[
\text{CHE}_r = 283378 + 8593SP_r + 1360LS_r + 6555NC_r - 66982TP_r - 59929FF_r,
\]

(27)

<table>
<thead>
<tr>
<th>Standard error</th>
<th>(510)</th>
<th>(343)</th>
<th>(2795)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-ratio</td>
<td>(16.8)</td>
<td>(4.0)</td>
<td>(2.3)</td>
</tr>
<tr>
<td>95% CI</td>
<td>(±1000)</td>
<td>(±672)</td>
<td>(±5478)</td>
</tr>
<tr>
<td>Standard error</td>
<td>(8804)</td>
<td>(5621)</td>
<td></td>
</tr>
<tr>
<td>t-ratio</td>
<td>(7.6)</td>
<td>(10.7)</td>
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</tr>
<tr>
<td>95% CI</td>
<td>(±17256)</td>
<td>(±11017)</td>
<td></td>
</tr>
</tbody>
</table>

Coefficient of determination \( (R^2) = 0.81 \)
Corrected coefficient of determination \( (R^2) = 0.80 \)

This model is capable of explaining 80% of total variation in cooking energy consumption per household in rural Nepal. Further, it can predict the cooking energy demand per household in rural Nepal with a possible error of ±14% at the 95% confidence interval.

**Evolution of heating energy demand function.** The exercise explained in the research methodology is applied to arrive at the heating energy demand function for rural Nepal. The result of the analysis is presented below. Simple regression analysis performed between the heating energy requirement of a rural household and standard population, agriculture commodity, livestock holding, household expenditure, and floor area of a house resulted in a coefficient of determination between 0.2 and 0.35 and t-ratios more than two. Independent variables like the number of cookstoves exhibit a coefficient of determination lower than 0.1 and a t-ratio less than two.

Variables chosen to carry out step-wise multiple regression analysis are household expenditure, floor area, agricultural commodities, livestock holding, standard population, number of cookstoves, topography and forest accessibility condition in order of priority as determined by the result of simple regression analysis. Step-wise regression analysis is performed by introducing new independent variables and each time the coefficient of determination and t-ratios are calculated. The criteria mentioned in the methodology is applied in order to decide on the number of regressors to be retained in the model.

Finally, four variables are retained in the model and the resulting household heating energy demand function for rural areas of Nepal is given by the following relationship:

\[
\text{HHE}_r = -19099 + 0.5EX_r + 2704AC_r + 1215SP_r + 9921TP_r,
\]

(28)

<table>
<thead>
<tr>
<th>Standard error</th>
<th>(0.2)</th>
<th>(391)</th>
<th>(206)</th>
<th>(849)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-ratio</td>
<td>(2.4)</td>
<td>(6.9)</td>
<td>(5.9)</td>
<td>(11.1)</td>
</tr>
<tr>
<td>95% CI</td>
<td>(±0.4)</td>
<td>(±766)</td>
<td>(±404)</td>
<td>(±1664)</td>
</tr>
</tbody>
</table>

Coefficient of determination \( (R^2) = 0.66 \)
Corrected coefficient of determination \( (R^2) = 0.66 \)

This model is capable of explaining 66% of total variation in heating energy consumption per household in rural Nepal. Further, it can predict the heating energy demand per household in rural Nepal with a possible error of ±29% at the 95% confidence interval.

**Evolution of lighting energy demand function.** The lighting energy demand function for rural households in Nepal is arrived at by carrying out various steps of analysis as explained in research methodology. The result of the analysis is as follows. Simple regression analysis performed between lighting energy consumption and agriculture commodity per household, total household expenditure, number of cookstoves, and floor area of a house resulted in a coefficient of determination between 0.15 and 0.25 and t-ratios more than two. Independent variables like standard population, and livestock holding resulted in an irregular coefficient of determination but t-ratios indicate the significance of the relationship.

The variables chosen to carry out step-wise multiple regression analysis are total household expenditure, number of cookstoves, floor area, agricultural commodities, standard population, livestock holding per household, topography and forest accessibility factor, in order of priority, as determined by the results of simple regression analysis. Step-wise multiple regression is performed by introducing new independent variables and each time the coefficient of determination and t-ratios are calculated. The criteria mentioned in the methodology is applied in order to decide on the number of regressors to be retained in the model.

Finally, four variables are retained and the resulting
household lighting energy demand function for the
rurals of Nepal arrived upon, which follows:

\[ LHE, = -4737 + 0.06EX_r + 0.79FA_r + 1234TP_r + 1076FF_r \]  

(29)

<table>
<thead>
<tr>
<th>Standard error</th>
<th>(0.18)</th>
<th>(0.12)</th>
<th>(386)</th>
<th>(241)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-ratio</td>
<td>(3.4)</td>
<td>(6.6)</td>
<td>(3.2)</td>
<td>(4.5)</td>
</tr>
<tr>
<td>95% CI</td>
<td>(±0.04)</td>
<td>(±0.23)</td>
<td>(±757)</td>
<td>(±473)</td>
</tr>
</tbody>
</table>

Coefficient of determination \( (R^2) = 0.44 \)
Corrected coefficient of determination \( (R^2) = 0.43 \)

This model is capable of explaining 43% of total variation in lighting energy consumption per household in rural areas. Further, it can predict lighting energy demand per household in rural Nepal with a possible error of ±40% at the 95% confidence interval.

**Total household energy requirement**

The general model developed for the estimation of total household energy requirements is used to predict total primary energy demand for the household sectors in the research villages. The model for the estimation of total primary energy demand of the household sector for a specific village panchayat is given by:

\[ TPE_r = (THE_r) \times NOH \]  

(30)

\[ TPE_r = 291848 + 9993TP_r + 1707TL_r + 1.5TX_r + 9248TN_r - 67465TT_r - 64565TF_r \]

where

- \( TPE = \) total energy requirement of household sector (MJ)
- \( NOH = \) total number of households in a village
- \( TP = \) total standard population of a village
- \( TL = \) total livestock population of a village (LSU)
- \( TX = \) total household expenditure of a village (NCR)
- \( TN = \) total number of cookstoves in a village
- \( TT = \) topography of a region (topography index number)
- \( TF = \) forest accessibility (forest access index number)

The suffix ‘r’ stands for a specific village panchayat.

The estimation of the end-use primary energy requirements for each village panchayat is carried out by using a general model for a specific end use. These are as follows:

\[ CPE_r = 283378 + 8592TS_r + 13601TL_r + 6555TN_r - 66982TT_r - 59929TF_r \]  

(32)

\[ HPE_r = 19099 + 0.5TX_r + 2704TC_r + 1215TS_r + 9921TT_r \]  

(33)

\[ LPE_r = -4737 + 0.6TX_r + 0.79TA_r + 1234TT_r + 1076TF_r \]  

(34)

The total primary energy estimated from Equation (30) and the summation of the end-use requirement calculated from Equations (31), (32) and (33) results in a deviation of less than 2%. The quantification of specific energy forms is based on the current energy use pattern.

The estimation of total useful energy requirement is made from total primary household energy requirement taking into consideration the efficiency of end-use devices for various activities as explained in the research methodology. The adjusted overall efficiency of technology to convert energy sources for a certain end use is calculated as explained in the research methodology and is reported in Table 5 (Rijal and Graham [4] and Hossain and Joshi [3]).

**Bahinthpur village panchayat (terai)**

The total primary energy requirement of the household sector amounted to 45 427 GJ/year (equivalent to 2720 tons of fuelwood or 12.6 million kWh), of which 73% is
required for cooking, 23% for heating and 4% for lighting. The total useful energy requirement amounted to 8763 GJ per annum, of which 33% is required for cooking (equivalent to 174 tons of fuelwood), 67% for heating (equivalent to 349 tons of fuelwood), and a nominal amount for lighting (equivalent to 3333 kWh of electricity) as shown in Figure 1. It should be noted that the overall energy use efficiency in the household sector of Baijnathpur is 20%.

Almost 96% of the total energy consumed is in the form of traditional energy. The main forms of traditional energy are animal dung (63%), agricultural residue (23%) and fuelwood (9%) as there are no nearby forests. The main supplier of energy for cooking is animal dung, while a few households use fuelwood. Agricultural residue provides the main energy for heating. Only 4% of total energy required is in the form of commercial energy – mainly for lighting purposes, of which 23% is electricity and the rest is kerosene as few households have electricity connections.

Lekhgaun village panchavat (hill)
The total primary energy requirement of the household sector amounted to 44 497 GJ (equivalent to 2664 tons of fuelwood or 12.4 million kWh of electricity), of which 82% is required for cooking, 16% for heating and 2%
for lighting. The total useful energy requirement in the household sector amounted to 10 097 GJ per annum, of which almost 50% is required for cooking (equivalent to 300 tons of fuelwood), about 50% for heating (equivalent to 305 tons of fuelwood) and a negligible percentage for lighting (equivalent to 278 kWh of electricity) as shown in Figure 2. The overall energy use efficiency in the household sector of Lekhgaun is 23%.

Almost 98% of total energy is in the form of traditional energies. The main suppliers of traditional energies are fuelwood (97%) and agricultural residue (3%). Kerosene is the only source of commercial energy being used in Lekhgaun and that only for lighting.

Marpha village panchayat (mountain)
The total primary energy demand of the household sector amounted to 18 501 GJ (equivalent to 1107 tons of fuelwood or 5.1 million kWh of electricity), out of which 74% is required for cooking, 19% for heating and 4% for lighting. The total useful energy requirement in the household sector amounted to 4782 GJ per annum, of which about 45% is required for cooking (equivalent to 130 tons of fuelwood), 54% for heating (equivalent to 155 tons of fuelwood) and 0.7% for lighting (equivalent to 9167 kWh of electricity) as shown in Figure 3. It should be noted that overall energy use efficiency in the household sector of Marpha is 26%.

Almost 93% of total energy consumed in Marpha is estimated to be in the form of traditional energy. The main form of traditional energy is fuelwood, while electricity is used for lighting. No kerosene is used as almost all households have electricity supplied which is preferred for lighting.

Conclusions
The general model which has been developed is capable of estimating and projecting the energy requirements by end use of Nepalese villages within ±13% error at the 95% confidence interval if eight variables of the village in question are known. The result of the percentage error arising from demand functions in the case of site specific analysis, when compared with the result of a sampling study of the same village carried out by us, resulted in a lesser percentage error in estimates (+5% to ±11% v ±9% to ±12%). However, the general model resulted in an increase percentage error in estimates (±13%), but this model can be employed to estimate energy requirement for any rural site in Nepal.

The variables which must be known prior to estimating and projecting energy requirements using this model are standard population, household expenditure (NCR), agricultural commodities (tons), number of livestock (LSU), number of cookstoves, area covered by housing, topography and forest accessibility for a particular village.

It should be noted that different variables dominate the determining of specific end-use requirements depending on the availability of fuels, price of fuels and suitability of specific fuels for different end-use activities. It is observed that the total household energy demand function of Baijnathpur (terai) depends on livestock holding because animal dung is the main source of energy in terai, but this is not so for Lekhgaun (hill) and Marpha (mountain). It is also important to note from the general model developed that household expenditure, area covered by housing and agricultural commodities do not play a significant role in determining cooking energy requirements. For heating energy requirements forest accessibility condition, livestock holding and the number of cookstoves do not play a significant role and for lighting energy requirements agricultural commodities, standard population, livestock holding and number of cookstoves do not play a significant role. It is also worth mentioning that per household energy consumption shows a better linear relationship with the variables considered compared to per capita energy consumption in the household sector.

References