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# Human and physical energy cycles in a subsistence village in South Africa

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***Abstract***

*A rural, self-contained village in Africa relies mainly on draft animals, energy provided by humans and energy from natural resources, especially firewood, for survival. The human metabolic energy cycle in a rural self-sufficient village in Venda in the Limpopo Province of South Africa is investigated, concentrating on selected activities that make up the routine livelihoods in the wet season. The selected village depended on only a slight extent on external 'modern' energy inputs such as electricity, paraffin and diesel in relation to overall energy consumption. Forty-three interviews were conducted in order to identify patterns of labour, sources of food, and foods consumed, while electronic pedometers were employed to quantify energy expended for weeding, firewood and water collection carried out in the wet season in February. A conceptual energy model showing flows of energy from one activity to another within the village was developed. An energy balance model, for an average adult male and female village resident, was developed quantitatively from the conceptual model, taking into account energy intake and energy expenditure. Energy expenditure for males was 1 991 kcal/d; females were 1 965 kcal/d, energy intake for males was 1 953 kcal/d and females was 2 007 kcal/d .This study is significant for future development of rural dwellers. It provides a baseline case for future developments in which modern energy carriers are introduced into remote areas. These may include conventional energy such as electricity, or renewable energies such as low energy devices powered off solar photovoltaic panels or off grid solar/wind systems.*

*Keywords: conceptual energy model, electronic pedometer, energy intake, energy expenditure, rural subsistence village, Venda*

## 1. Introduction

Most rural communities still depend on biomass for their basic household energy needs. It is reported that 73% of rural southern Africa depends on traditional biomass (wood or charcoal) as the main source of cooking energy (IEA, 2010).

An increasing population has resulted in shortages of firewood through clearing of woodlands for agriculture and human settlements. If villages are distant from woodland resources, additional time is required to collect firewood that might previously have been collected incidentally, while returning from the fields or fetching water. This additional time and effort may be at the expense of agricultural, household or social activities. As a result, communities have adopted various strategies to overcome firewood scarcity (Brouwer *et al*., 1997; Madubansi & Shackleton, 2007).

Firewood collection is predominantly the responsibility of women and children. Use of firewood for cooking results in what is termed household air pollution (HAP), referring to exposure of women and infants to combustion fumes, even in open or partially enclosed cooking spaces. Health effects associated with exposure to such fumes include infant mortality through pneumonia and maternal mortality through chronic obstructive respiratory disease (WHO, 2011). HAP has been identified as the fourth most prevalent cause of premature death and injury in the 2010 *Global Burden of Disease Study* (Lim *et al*., 2012).

To reduce firewood demand, and hence exploitation of woodlands, several international efforts have been initiated to develop, manufacture and distribute more efficient cook stoves throughout the developing world. These have the dual aim of protecting maternal and child health from the effects of smoke pollution, and to reduce the emissions of greenhouse gases (FAO, 1993; World Bank, 1994). One such initiative is the recently launched programme of the Global Alliance for Clean Stoves (GACC), which 'calls for 100 million homes to adopt clean and efficient stoves and fuels by 2020' (http://cleancookstoves.org/overview/).

Biomass energy is not the only source of energy utilised in rural households; human labour, powered by metabolic energy, performs diverse household and agricultural activities. Energy to perform these activities is obtained from food, most of which is locally produced. Relatively few studies have been conducted on establishing the metabolic energy balances of rural subsistence villages especially in Africa. Some studies have focused on energy expenditure of household activities in rural areas, in Upper Volta and Gambia (Brun *et al*., 1981). Studies in India by Edmundson and Edmundson (1988), and Dungarwal and Choudhry (2003) have quantified both energy to conduct such activities and energy intake from food consumed. Edmundson and Edmundson (1988) report the mean daily energy intake for males was 2 350 kcal and energy expenditure was 2 285 kcal, while mean daily energy expenditure for women was 1 968 kcal and energy intake was 1 852 kcal. Dungarwal and Choudhry (2003) report the mean daily energy intake for men was 2 085 kcal and energy expenditure was 2 463 kcal. Clearly there is a need for additional studies to establish baseline conditions of energy intake and expenditure in rural communities.

It is necessary to establish a baseline metabolic energy balance in terms of energy consumed and expended by determining energy inflows and outflows in the village. 'Energy balance is achieved when input (i.e. dietary energy intake) is equal to output (i.e. total energy expenditure), plus the energy cost of growth in childhood and pregnancy, or the energy cost to produce milk during lactation' (FAO/WHO/UNU, 2004:4). However, this study focused only on adult males and females who were not pregnant or lactating. Such a baseline is needed against which to quantify the benefits of proposed interventions, for example, through the introduction of clean cook stoves, to validate any claims of health benefits or greenhouse gas emissions reductions.

The aim of the study is to develop an energy balance model for rural subsistence village that depends mainly on human labour and locally produced food. This will be developed from a questionnaire and checklist, and by monitoring the energy expended in various activities using electronic pedometers.

## 2. Methodology

A conceptual model of a semi-subsistence village (Landmann *et al*., 2008) was adopted as the initial concept for understanding human and physical energy cycles in a rural subsistence village. A conceptual diagram is presented on the major energy transfers and transformations, material flows of the subsistence village, centred on human consumption and human energy expenditure (Figure 1).

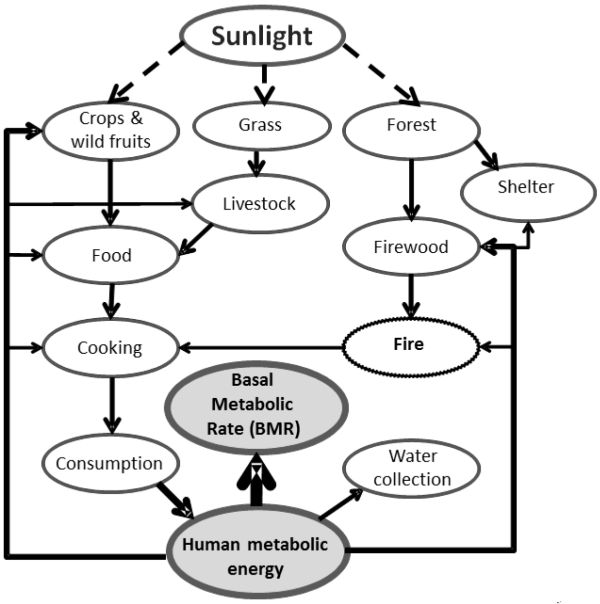


**Figure 1: Model framework showing energy sources, energy and material flows and interrelationships of energy consuming/transforming activities in a subsistence village**

This study focuses on the main activities performed by households in the village (agricultural field work - weeding at the time of the survey, firewood and water collection and cooking) (Figure 1). Cultural activities and shelter building that occur intermittently were omitted. Such activities are harder to more difficult to quantify in a short survey as they occur intermittently at various times of the year. By the same measure, as they are not regular daily tasks, the energy consumed is a small fraction of the overall annual energy expenditure, and hence, they fall outside of the scope of this first pass energy balance study.

The following were the critical characteristics of the village:

- the village should not be connected to the national electricity grid;
- inhabitants should be practicing subsistence agriculture and animal husbandry as their major source of food;
- inhabitants should be entirely dependent on collected firewood as a source of cooking energy;
- inhabitants should collect water from a natural water source; and
- cash income should be a minor component of overall livelihood.

The village chosen was in Venda, Limpopo

Province, of South Africa. The main dwelling type is a thatched, mud-walled hut. Roads within the villages are unpaved; only the main road from Thohoyandou past the village is paved. Maize is the main crop, supplemented by vegetables. Harvested maize is stored in above-ground wooden granaries. Small amounts of cash income are generated from occasional activities including brick-making, brewing beer (*mukumbi*) using marula fruit (*Sclerocarya birrea*), sale of agricultural crops, fruits, mopani worms and traditional *Tshivenda* clothing.

During the wet season, agricultural activities consisting of tilling planting, weeding and harvesting are performed. These are performed either very early in the morning or late afternoon when ambient temperatures are cooler, and are carried out using hoes.

Water collection is carried out usually when respondents come back from the fields. Water utilised in the households is collected either from a piped communal tap, natural fountain or river within the village. Water from the piped communal tap and fountain is used mainly for cooking while river water is used for bathing and washing clothes. The methods for transporting water containers are head load, wheel barrow and hand carrying.

Firewood is collected mainly seasonally, this is when large quantities of firewood are cut from forests and collected, left to dry to be used for longer periods of time up to 3 months. This activity is performed in the dry season and firewood will be used in the wet season, when labour is required for agriculture. Firewood is cut using a *panga* (machete) or an axe. Supplementary requirements are collected from nearer but sparser woodlands daily or weekly when there is need. The main form of transport for collected firewood to the respective households is head load, carried by females. In the *Tshivenda* traditional society, females perform most household tasks. Although in this study males shared the task of firewood collection, they collected in a different way with different effort, as will be reported in this paper.

A reconnaissance and pilot survey were conducted to select a village that matched the criteria. A survey of forty three households in the selected village proceeded. An energy balance model of the village was developed, using an Excel® spread sheet, to account quantitatively for energy inputs from food and the energy expenditure (activity and resting related metabolic rates) for an average adult male and female villager.

Qualitative and quantitative methods were utilised. Interviews provided an insight on the village livelihoods through energy consuming activities, self-reported times taken to complete identified tasks, and types of food consumed. A checklist quantified amounts of and types of foods consumed, and for selected meals, residents were asked to weigh and record quantities of food prepared. Electronic pedometers were used to quantify energy expended in various mobile activities, by recording motion (number of steps).

Tshidzini village, located in the Limpopo Province of South Africa, matched the criteria, with a minor exception on the water criterion – water for drinking and cooking was collected from a standpipe in the village, while water for washing and ablutions was collected from a nearby river.

### *2.1. Study area: physical features and demographics*

The village is located in Vhembe District Municipality, Limpopo Province, South Africa (20°50'10. 72' S and 30°40'7.97' E), 30 km north-east from Thohoyandou. Tshidzini comprises several sub-villages – those selected were Lukau, Mutshili, Tshilaphala and Mutshetoni. Table 1 shows the socio demographic characteristics of Tshidzini. Annual rainfall ranges from 380 mm to over 700 mm. Rain falls between October and March. There were 110 household stands in the four sub-villages.

**Table 1: Socio-demographic characteristics of Tshidzini village**

| *Category* | *Number in group (N = 43)* | *Valid percentage (%)* |
|---|---|---|
| Sex | | |
| Male | 10 | 23.3 |
| Female | 33 | 76.7 |
| Age group (years) | | |
| Below 30 | 13 | 30.2 |
| 30–40 | 23 | 53.5 |
| 41–75 | 7 | 16.3 |
| Length of stay in village (years) | | |
| Less than 2 | 14 | 32.6 |
| 2–6 | 22 | 51.1 |
| 7–13 | 7 | 16.3 |
| Household size (people) | | |
| 1–3 | 13 | 30.2 |
| 4–6 | 26 | 60.5 |
| 7–9 | 4 | 9.3 |
| Number of people working | | |
| Unemployed | 33 | 76.7 |
| Employed | 7 | 16.3 |
| Informal traders | 3 | 7.0 |

### *2.2. Data collection tools*

Foods recorded for energy intake were maize meal, vegetables, beans, *mopani* worms, sour milk and meat. Pre-cut meat was purchased from shops in Thohoyandou for occasional consumption. For special occasions, animals were slaughtered by the villagers. For maize meal, respondents were asked to measure out the quantity for daily consumption by the family. This quantity was determined using the mass balance and recorded. Quantities of mopani worms and vegetables were estimated by comparison with pre-weighed local standard R20 packet of *mopani* worms and a local bundle of vegetables as a reference. As meat was consumed infrequently, it was not possible to obtain reliable observations of meat consumption during the short period of this campaign and so an estimate was used.

*2.2.1. Activity level monitoring using a pedometer*
An electronic pedometer was utilised in monitoring energy expenditure activities (Digi-Walker® Model CW 700; www.yamax.co.uk/index.php). A pedometer is an electronic impulse counter worn on the body, that estimates the amount of metabolic energy expended during walking or running by counting the number of steps taken (impulses) multiplied by a constant set according to the mass of the wearer. Ten sets of pedometer readings were conducted for each of the following activities: agricultural field work (weeding at the time of the survey), cooking, firewood and water collection.

*2.2.2. Metabolic energy from food and energy associated with human tasks*
Metabolic energy of food consumed was obtained from food composition tables developed by the Food and Agricultural Organisation (FAO, 1968). Reports of studies on human energy requirements conducted by the Food and Agricultural Organisation, World Health Organisation, United Nations University (FAO/WHO/UNU, 1985, 2004) provided physical activity ratios for energy expenditure associated with human tasks. The following values were extracted: sleeping, tilling and planting, cooking, harvesting animal husbandry and other activities.

*2.2.3. Energy cost of performing various activities within a subsistence village*
Energy expended in the agricultural field work (weeding at the time of survey), cooking, firewood and water collection was acquired from pedometers. Physical activity ratios for these activities were calculated from the expended energy values derived from the pedometers. The physical activity ratio (PAR) is defined as 'The energy cost of an activity per unit of time (usually a minute or an hour) expressed as a multiple of BMR. It is calculated as energy spent in an activity/BMR, for the selected time unit' (FAO/WHO/UNU, 2004). Thus:

$$PAR(i) = \{E_{exp}(i)/t(i)\} / \{BMR/24\} \quad (1)$$

where $E_{exp}(i)$ is the energy per individual expended per activity $i$ (kcal), and $t(i)$ is the time per individual activity (h), and BMR is the Basal Metabolic Rate (kcal/d).

## *2.3. Development of an energy balance model of a subsistence village*

The physiological energy transfers of typical inhabitants of the subsistence village were represented in a quantitative balance. Values for energy intake and expenditure were derived from various measurements during the study and from literature. The sources of energy intake were the foods consumed. Energy from typical daily food intake per person was used to quantify the energy available (energy intake) for the representative individuals (male and female adults). Energy expenditures of routine subsistence tasks within the rural subsistence economy village were calculated. The following activities were concluded in the energy balance model for the village: sleeping, tilling, planting, weeding, harvesting, animal husbandry, cooking, cleaning, social activities, and water and firewood collection. Energy consumed during sleep is taken as the Basal Metabolic Rate.

The following steps were carried out in developing the quantitative aspects of the energy balance model. Calculations were carried out in an Excel® spread sheet.

*2.3.1. Energy intake*
A checklist provided food types and quantities consumed by the household per meal. The quantity consumed per individual was determined by dividing the total food consumed per household by the average household size (Equation 2). The local custom is to partake in meals from central plate(s). It is thus not possible to apportion and weigh consumptions of individual portions directly.

$$FC_{pppd} = FC_{hhpd} / hh_{av} \quad (2)$$

where $FC_{pppd}$ is the food consumed per person per day (kg); $FC_{hhpd}$ is the food consumed per household per day (kg); $hh_{av}$ is the average household size.

Average mass of adult males and females was calculated from direct mass measurements (obtained from the population subset measured during use of pedometers). *Fractional weights* for males and females respectively ($FW_m$ and $FW_f$) were calculated from the average mass of the total measured group ($AM_p$) as:

$$FW_m = AM_m / AM_p \quad (3)$$

where $FW_m$ is the fractional weight (male); $AM_m$ is the average mass of male subjects (kg); $FW_f$ is the fractional weight (female), and $AM_p$ is the average mass of the combined group of males and females (kg). These ratios were used to partition estimated food intake between adult males and females.

The food intakes per average male and female were calculated as:

$$FC_{m/f} = FC_{pppd} * FW_{m/f} \quad (4)$$

where $FC_{m/f}$ is the food consumed male/female respectively (kg); $FC_{pppd}$ is the food consumed per person per day (kg); and $FW_{m/f}$ is the fractional weight of a male/female respectively (Equation 3).

The number of times a meal was consumed per week was used to determine the average quantity of food consumed per day per individual (daily consumption) from each food source:

$$DC_{Av} = (FC_{pppd} * NM_{week}) / 7 \quad (5)$$

where $DC_{av}$ is the average daily consumption by the average individual (kg); $FC_{pppd}$ is the food consumed per person per day (kg), and $NM_{week}$ is the number of times the meals is consumed in a week.

Energy from each food source for each individual was obtained from food composition tables (FAO, 1968) (Table 2). Total energy intake per individual per day was obtained from the summation of energy contents of each food source in the diet.

$$TEI_{pi} = \Sigma (DC_{av} * EC_{av} * 10) \quad (6)$$

where $TEI_{pi}$ is the total energy intake per individual (kcal/d); $DC_{av}$ is the average daily consumption by an average individual (kg); $EC_{av}$ is the energy content of food (kcal per 100 g), which is converted to energy content per kg by multiplying by a factor 10.

**Table 2: Food energy content**
*Source: FAO (1968)*

| *Food type* | *Food energy (kcal per 100 g)* |
|---|---|
| Maize meal | 357 |
| Beans | 405 |
| Vegetables | 27 |
| Meat | 237 |
| Mopani worms | 444 |
| Sour milk | 122 |

To account for the different mean body weight of males and females, the total energy intake per individual is distributed in proportion to the fractional body weights of males and females to obtain the energy consumed per day for males and females respectively.

$$EC_{m/f} = TEI_{pi} * FW_{m/f} \quad (7)$$

where $EC_{m/f}$ is the food energy consumed by males and females respectively (kcal); $TEI_{pi}$ is the total energy intake per individual (kcal) from Equation 6; and $FW_{m/f}$ are the respective fractional weights of males and females.

### *2.3.2. Energy expenditure*

A questionnaire survey was used to survey the time taken per activity per day. For activities that are not performed daily (i.e. firewood collection, tilling, planting and harvesting), an equal fraction of the total recorded time for such activities was allocated to each day. This was implemented by estimating the number of days the activity was performed in a month. This value was multiplied by the number of hours taken to perform the task (from the questionnaire) to give the total number of hours per month. This value was divided by thirty to attribute the notional daily hours for the task.

Times taken to perform various tasks were divided into two sections - maximum exertion time and resting time. Maximum exertion time is when the respondent is engaged in a physical activity, while resting time is the sum of intervals between maximum exertions, estimated in 10% increments. The value assigned for the resting metabolic rate was taken from Coward-Mckenzie and Johnson (2008).

During analysis, it was found that the total time taken for the summed average time per activity was more than twenty-four hours. This difficulty was resolved by normalising the time for all activities to twenty-four hours in order to quantify energy expended against energy intake per day.

Energy expended in any activity was calculated by multiplying the time taken to accomplish the task by the Physical Activity Ratio (PAR) for that activity. The energy cost values $E_c(i)$ were obtained from either the pedometer measurements (Equation 1) or literature values (see Table 3).

**Table 3: PAR values**

| *Source* | Activity | *Male* | *Female* |
|---|---|---|---|
| Sleeping | 1.0 | 1.0 | FAO/WHO/UNU, 2004 |
| Tilling & planting | 4.1 | 4.1 | FAO/WHO/UNU, 2004 |
| Cooking | 1.8 | 1.8 | FAO/WHO/UNU, 1985 |
| Water collection | 3.2 | 3.2 | Chikava W, 2011 |
| Firewood collection | 2.2 | 2.6 | Chikava W, 2011 |
| Other activities | 1.2 | 1.2 | FAO/WHO/UNU, 2004 |
| Weeding | 2.0 | 2.0 | Chikava W, 2011 |
| Harvesting | 5.1 | 5.1 | FAO/WHO/UNU, 2004 |
| Cleaning | 2.5 | 2.5 | FAO/WHO/UNU, 2004 |
| Animal husbandry | 3.1 | 3.1 | FAO/WHO/UNU, 2004 |

The following steps (Equations 8–14) were taken to determine the energy expended in the activities.

The hourly mean Physical Activity Level (PAL) is calculated, in principle as:

$$PAL = \Sigma_{i=1}^{10} \{T_a(i) * PAR(i)\} / 24 \quad (8)$$

where $T_a(i)$ is the mean time allocation taken for an activity (derived from the questionnaires) (hours), $PAR(i)$ are the physical activity ratios from Equation 1, derived from pedometer readings or literature, for the ten listed activities $i = 1$ to 10. The mean reported time allocations $T_a(i)$ for the ten activities have been normalised so that $\Sigma_{i=1}^{10} T_a(i) = 24$ hours.

However, this does not take into account that the reported duration of an activity does not imply full exertion for the entire time. The reported duration of an activity, $T_a(i)$, is split into two, the maximum exertion time and resting time; the reported duration of an activity is multiplied by an estimated percentage of maximum exertion (on the assumption that arduous physical activity is interspersed with periods of rest) to give maximum exertion duration (h):

$$T_{me}(i) = T_a(i) * F_{max}(i) \quad (9)$$

where $T_a(i)$ is the reported time allocation (h); $F_{max}$ is the percentage of time when an activity is at maximum exertion. The complementary resting time $T_r(i)$ is calculated by subtracting $T_{me}$ from activity time $T_a$:

$$T_r(i) = T_a(i) - T_{me}(i) \quad (10)$$

To obtain the effective Physical Activity Ratio, $PAR_{eff}(i)$ using the split durations (maximum exertion time and resting time), the maximum exertion duration is multiplied by the physical activity ratio (from pedometer recordings or literature) and the resting duration is multiplied by the resting energy expenditure, REE (kcal/h) from literature:

$$PAR_{eff}(i) = \{T_{me}(i) * E_c(i) + T_r(i) * REE\} / \{BMR/24\} \quad (11)$$

The final Physical Activity Level is derived by substituting PAReff (i) into Equation 8.

The above steps are performed separately for males and females.

The Basal Metabolic Rate is determined by mean body mass, age and sex. The sample population is divided into age groups (a) 18–29 and (b) 30–60 years, following procedures of FAO/WHO/UNU (2004). The average body mass per age group for each sex cohort is determined as:

$$BM_{av} = {}^{n}\Sigma_{i=1} BM_i / n \quad (12)$$

where $BM_{av}$ is the average body mass per age group (kg). $BM_i$ is the body mass (kg); and n is the number of individuals for each sex cohort according to the respective age groups.

To calculate energy required for Basal Metabolic Rate, a set of predictive equations published by the FAO is used, based on age and average body mass (FAO/WHO/UNU, 2004). An example is presented using 18-30 years age group:

$$BMR_{ma} = 15.057 * BM_{av} + 692.2 \text{ (kcal d}^{-1}\text{)} \quad (13)$$

where $BMR_{ma}$ is the basal metabolic rate for males in age group *a* with corresponding numerical parameters (for the full set of equations see FAO/WHO/UNU, 2004).

To calculate the total energy expenditure per day (EE), the basal metabolic rate is multiplied by the Physical Activity Level determined in the mentioned steps. For example, for males, age group 18-30 years:

$$EE_{ma} = BMR_{ma} * PAL_m \quad (14)$$

where $EE_{ma}$ is the total energy expenditure per male for the specified age group (kcal/d); and PAL is the Physical Activity Level from Equation 8 using the effective Physical Activity Ratios, $PAR_{eff}$ from Equation 11.

*2.3.3 Energy balance*

The energy balance was achieved comparing the average daily energy expenditure to the daily energy intake, separately for each sex and for the overall adult population:

$$EE_{exp\ (m/f)} = EC_{int\ (m/f)} \quad (15)$$

where $EE_{exp}$ is total energy expenditure for each sex cohort (kcal/d) (from Equation 15), and $EC_{int}$ is energy intake for each sex (male, female respectively) cohort (kcal/d) (from Equation 7). Assumptions, estimates and measured values were adjusted until balances were achieved, within the uncertainties of the methods used.

## 3. Results

The questionnaire results were analysed using the Statistical Package for the Social Sciences (SPSS-version 18). Under SPSS, the following functions were used to analyse the data: descriptive statistics and frequencies that gave mean, standard deviation, variance, maximum and minimum values of measured parameters.

The quantitative energy balance model was developed as a spread sheet using Microsoft Excel, incorporating the equations 1 to 14. As some activity levels had inherent uncertainties, for example, in the fraction of time for maximum exertion and for resting during weeding, walking with loads of firewood, there were large uncertainties in the expended energy of the average behaviours. To achieve a balance of input versus output energies in the model, some of these estimates of the relative time of resting and exertion were adjusted. For example, on the input side, the initial model of food consumed produced a value so low that it barely accounted for the base metabolic activity of a healthy active adult – this was a reality check. Hence the quantity of maize (the staple food) consumed per individual was adjusted upward, within realistic limits.

### *3.1 Energy intake*

Calculated food and energy intakes by men and women respectively are presented in Table 4. Fractional weight was used to the calculate food and energy intake for adult males and females. Average household size was 4.23. Fractional weight for males was 0.99 and for females 1.01. However, the meal sizes consumed were based on the householders estimates of quantities of raw ingredients – the estimated quantities of food per person had to be adjusted upwards, as the corresponding energy supplied by the food barely sufficed to cover the basal metabolic rate. The average amount of fire-

**Table 4: Energy equivalent of food consumed by males and females**

| *Food source* | *Food consumed /meal/person (kg)* | *No. of times a week* | *Daily food consumption per individual (kg)* | *Energy content of food source (kcal per 100 g)* | *Energy equivalent of food consumed/individual (kcal)* | *Energy equivalent of food consumed male (kcal)* | *Energy equivalent of food consumed female (kcal)* |
|---|---|---|---|---|---|---|---|
| Maize meal | 0.39 | 7 | 0.43 | 357 | 1 532 | 1 511 | 1 553 |
| Beans | 0.17 | 2 | 0.04 | 405 | 159 | 157 | 161 |
| Vegetables | 0.16 | 5 | 0.11 | 27 | 30 | 30 | 31 |
| Mopani worms | 0.02 | 2 | 0.01 | 444 | 12 | 12 | 13 |
| Sour milk | 0.22 | 2 | 0.05 | 122 | 222 | 219 | 225 |
| Beef | 0.07 | 2 | 0.02 | 237 | 24 | 24 | 24 |
| **Total** | | | | | **1 980** | **1 953** | **2 007** |

**Table 5: Energy expenditure for males and females**

| | *Time taken* | *Energy cost (PAR)* | *Time X energy cost* | *% time at max* | *Max exertion time (h)* | *RMR time (h)* | *Time X energy cost (PAR hrs) (split time)* |
|---|---|---|---|---|---|---|---|
| **Males** | | | | | | | |
| Sleeping | 7 | 1 | 7 | 100 | 7.00 | 0.00 | 7.0 |
| Tilling and planting | 2 | 4.1 | 8.2 | 30 | 0.60 | 1.40 | 3.3 |
| Cooking | 2 | 1.8 | 3.6 | 20 | 0.40 | 1.60 | 1.7 |
| Firewood collection | 1.5 | 3.2 | 4.8 | 30 | 0.45 | 1.05 | 2.1 |
| Water collection | 0.8 | 2.2 | 1.8 | 70 | 0.56 | 0.24 | 1.4 |
| Other activities | 5 | 1.2 | 6 | 50 | 2.50 | 2.50 | 4.5 |
| Weeding | 2.2 | 2 | 4.4 | 50 | 1.10 | 1.10 | 2.9 |
| Harvesting | 1.2 | 5.1 | 6.1 | 70 | 0.84 | 0.36 | 4.5 |
| Cleaning | 0.8 | 2.5 | 2 | 60 | 0.48 | 0.32 | 1.4 |
| Animal husbandry | 1.5 | 2.1 | 3.2 | 10 | 0.15 | 1.35 | 1.1 |
| **Total** | **24.0** | | **47.0** | | **24.0** | | **29.8** |
| **Females** | | | | | | | |
| Sleeping | 7.00 | 1.0 | 7.0 | 100 | 7.00 | 0.00 | 7.00 |
| Tilling and planting | 2.41 | 4.1 | 9.9 | 50 | 1.21 | 1.21 | 5.67 |
| Cooking | 1.19 | 1.8 | 2.1 | 40 | 0.48 | 0.72 | 1.29 |
| Firewood collection | 1.19 | 3.2 | 3.8 | 30 | 0.36 | 0.83 | 1.65 |
| Water collection | 4.17 | 2.6 | 10.8 | 50 | 2.09 | 2.09 | 6.68 |
| Other activities | 2.98 | 1.2 | 3.6 | 50 | 1.49 | 1.49 | 2.68 |
| Weeding | 2.18 | 2.0 | 4.4 | 25 | 0.54 | 1.63 | 2.07 |
| Harvesting | 1.85 | 5.1 | 9.5 | 50 | 0.93 | 0.93 | 5.29 |
| Cleaning | 0.99 | 2.5 | 2.5 | 80 | 0.79 | 0.20 | 2.11 |
| Animal husbandry | 0.07 | 3.1 | 0.2 | 5 | 0.00 | 0.07 | 0.05 |
| **Total** | **24.0** | | **53.8** | | **24.05** | | **34.47** |

wood utilised per day per household to prepare food was 9 kg. Results of measurements and calculations of energy expenditure are presented in Table 5.

The calculated human energy balances for inhabitants of Tshidzini village in the wet season are presented in Table 6. Differences between males and females in terms of energy intakes and expenditure are similar within ~1%, despite taking into account differing mean body mass, and different tasks and levels of exertion. The major energy expenditure is taken up by base metabolic function, so the variations in exertions levels are proportionately reduced.

**Table 6: Energy balance for typical females and males in a subsistence village**

| | *N* | *Average energy expenditure (kcal/d)* | *Average energy intake (kcal/d)* |
|---|---|---|---|
| Male | 10 | 1 991 | 1 953 |
| Female | 22 | 1 965 | 2 007 |
| Weighted av. | | 1 973 | 1 980 |

## 4. Discussion

### *4.1 Energy associated with human tasks and metabolic energy of food*

Most research on energy expenditure of various human tasks has been carried out in developed countries; few studies have dealt with subjects in developing countries, or specifically, subsistence villages in Africa. Estimated energy expenditures for some activities were sourced from literature. A database of activity factors for an African context would be valuable for such studies, similar to existing tables of activity factors for inhabitants of developed countries.

Similarly, there are few studies on the metabolic energy from various types of traditional foods consumed in Africa. A study by FAO (1968) used is not recent; hence there is a need to update information on the metabolic energy of foods consumed in Africa. Furthermore, the current study used general predictive equations to determine the Basal Metabolic Rate. There is a need to quantify the Basal Metabolic Rate for African populations, so that these can be utilised in other similar studies.

### *4.2. Energy balance model for a subsistence village*

A quantitative energy balance model for typical inhabitants of a subsistence village was developed from separate components of energy intake and energy expenditure. It is a baseline study, developed from adult males and females only. Excluded from this first pass model are energy needs for human growth and development (children, pregnant women).

Energy intake from the various types and quantities of food is converted to available metabolic energy. Mean energy expenditures are calculated for Basal Metabolic Rates and for performing the diverse tasks in the subsistence village. Food composition tables developed by Food and Agricultural Organisation (FAO) were used to provide energy content of the foods. The main source of energy intake is *vhuswa* from the locally grown maize, supplemented by vegetables. A minority of the households own livestock. . During the survey no household was observed eating beef. Less animals being owned could mean meat consumed is purchased more often than slaughtered. In most cases, slaughtering is infrequent and for significant social events. *Mopani* worms are a seasonally significant source of protein.

Overall energy balances for energy intake and expenditure were obtained. There was essentially no difference between the energy intake and expenditure of males and females despite differences in mean body mass and ranges of tasks performed by the respective sexes. The custom in these households is for food to be consumed from the same plate, so it was difficult to quantify exactly the food consumed (and consequently energy intake) by individuals, males or females. Fractional weight only provided an estimate of the quantities of food consumed for each sex cohort. The number of males in the village was distinctly less than that of females and hence in the samples measured.

To achieve the above balance, mean activity times had to be adjusted by normalising the sum of values to 24 hours. Pedometer measurements for cooking activities were discarded, as the device generated unrealistically low values (~9 minutes) that did not conform to direct observations. A revised, time-based estimate was inserted.

The energy expenditure values observed over twelve days constitute only a snapshot. For example, energy expenditure for wood collection during the wet season was for small quantities of firewood collected daily from nearby sources. In the dry season, firewood is collected in bulk from more distant sites, with larger energy expenditure.

The energy balance model developed was for a subsistence village in South Africa. It is a case study and results and cannot be generalised for all subsistence villages in Africa. Nevertheless, this energy balance model informs energy expenditure and intake in a subsistence village. It is a step towards determining a baseline energy balance model for all activities practiced in such a village. Estimated Resting Metabolic Rate (RMR) and predicted Basal Metabolic Rate equations were used to determine energy expenditure. The overall sample size (43 households) was still smaller than an ideal experimental design, due to time and resource constraints.

In the light of these adjustments, no purpose would be served by carrying out a detailed error or sensitivity analysis on this set of results. Rather, the result should be considered as having created a complete framework for the calculation of an energy balance for the subsistence village.

## 5. Conclusion

An insight on the metabolic energy balance for a typical adult female and male within the study village was developed, applicable for wet season activities. This energy balance of village livelihoods could be maintained without recourse to exogenous energy sources, specifically energy and services dependent on fossil fuels (except indirectly through the use of metal artefacts and clothing).

Pedometers quantified the activity level of different specified tasks, by recording the number of impulses (steps) generated during the activity. This was regarded as a more accurate estimate of exertion levels than oral reports of activity levels from interviews. Reported times do not differentiate between periods of physical exertion and resting. However, the pedometers have limitations, as they record energy expenditure only during locomotion. Cooking, for example, is an activity performed mainly in a sedentary position, thus energy expenditure and time duration for this task could not be quantified accurately using this method. Another limitation of the study was the short time frame (a few weeks within only one season) the households were observed. More understanding would have been gained about the livelihoods if observations had spanned all seasons and corresponding different activities. Due to time and resource constraints, the sample size used in this study was relatively small, forty three households. Another weakness of the study was that the physical activity ratio is (PAR) values used in this study were obtained from the literature for areas with different climatic conditions, food consumed, metabolic rates, manner in which various tasks are performed and among different cultural groups, These factors could account for the PAR used differing from the PAR values in our study. Although PAR values reflect fundamental human physiology as the major component, the absence of locally determined PAR values is a limit on the precision of the final energy balance.

Areas of further study include developing an energy balance model for a longer duration including the dry season, as there are considerable differences in energy expenditure and energy consumption between the seasons. There is a need to consider additional activities in the energy balance model. Future studies should record both height and body mass of respondents, to determine the Resting Metabolic Rate using Benedict's equation, a better estimator than taking a single multiplier of the Basal Metabolic Rate.

This success of this study has been to set up a framework for a human energy balance, to provide a baseline study for energy use in a notional '*Garden of Eden*' subsistence village that is almost entirely independent of external energy sources; and to provide a baseline of fuelwood consumption in such a village using traditional cooking methods. Because of large uncertainties in basic assumptions, literature values of energy intensive parameters, and inherent uncertainties of in situ measurements, the results are regarded as indicative rather than representative of an energy balance in a subsistence village. As this study is a first of this nature in this area, it is significant for future development of rural dwellers in that it provides a baseline case on which the influences of modern energy carriers could be evaluated.

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