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Review

# Rural household energy consumption in the millennium villages in Sub-Saharan Africa

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ABSTRACT

This paper summarizes the main findings regarding household energy use from nearly 3000 households across 10 different rural agro-ecological locations in Sub-Saharan Africa. The data were collected with a baseline energy survey as part of the Millennium Villages Project, a multi-sectoral development effort. The results document the households' reliance on biomass and other traditional fuels across all project sites. The two most commonly used fuels for cooking were fuelwood and farm residue, representing 74% and 12% of all cooking respectively. Fuelwood was used primarily for cooking, and mostly acquired through collection by women on foot. Eighty-six percent of household cooks reported using kerosene, and 80% of this use was for lighting. Kerosene provided 61% of the lighting hours on average, followed by dry cell batteries, at 18%. Although one site, Ikaram, Nigeria, had extensive household grid electricity access, only 1% of households in all other sites had an electric grid connection. Averaged across all households surveyed, households spent USD 58 per year on fuels and USD 19 per year on batteries. Of these expenses, USD 21 went to cooking-related purchases and USD 48 went to purchases related to lighting and electricity.



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## Introduction

In the absence of affordable modern fuels and electricity, 90% of the Sub-Saharan African population relies on traditional fuels for cooking, heating and lighting (Brew-Hammond and Kemausuor, 2009; Karekezi et al., 2008; Wolde-Rufael, 2009). The use of biomass fuels for cooking has a range of adverse consequences. Fuelwood collection places a substantial time-labor burden on families, particularly women, and can place additional pressure on local forest resources, particularly in places where fuelwood is scarce. Indoor air pollution caused by exposure to domestic smoke from biomass fuels is a major cause of respiratory diseases in the developing world (Chen et al., 1990; Ellegard, 1996; Pandey et al., 1989; Smith et al., 2000).

Africa has the lowest electrification rate in the world. Excluding South Africa and Egypt, it is estimated that less than 20% overall, and in some countries as little as 5%, of the population in Africa has direct access to grid electricity. In rural areas, this figure is as low as 2% (Madamombe, 2005). The lack of electricity services limits the use of key technologies such as electric motors, cooling systems, information and communications technologies (ICT), and others which in turn restricts the delivery of key public services in health and education, and limits income-generation and labor productivity (Modi et al., 2005).

Energy is widely recognized as an essential input for socio-economic development (Davidson and Sokona, 2002; Johansson and Goldemberg, 2002), and strong links between energy and the Millennium Development Goals (MDGs) make it important to address the challenges to the provision of energy services to Sub-Saharan Africa (Modi et al., 2005). The MDGs are quantified and time-bound goals set forth by world leaders at the Millennium Summit in September 2000 to cut extreme poverty, while improving conditions in areas of health, environmental sustainability, drinking water and sanitation, and gender equality. In an effort to demonstrate a multi-sector development approach to alleviating poverty and achieving the MDGs in Sub-Saharan Africa, the Millennium Villages Project (MVP) was initiated in 2004. The project is a partnership between the Earth Institute at Columbia University, the United Nations Development Programme (UNDP), and Millennium Promise, and encompasses 80 villages with a total population of approximately 400,000 people, located on 14 sites in 10 countries throughout Sub-Saharan Africa (Sanchez et al., 2007; Sanchez et al., 2009). The project aims to achieve the MDGs through science-, evidence- and community-based interventions in the sectors of agriculture and nutrition, health, infrastructure (energy, transport, and communications), education, water and sanitation, and environment (Sanchez et al., 2007). The project includes a research component which informs intervention strategy, measures impacts and pilots new approaches. The survey results detailed here are a principal part of the project's research component.

## Data collection

Each MVP site includes one “Millennium Research Village” (MRV), with approximately 1000 households and 5000 residents (depending on household size). In most sites, additional villages nearby are also part of the project area. While the project's development interventions are undertaken throughout the entire project area, the project's survey efforts are focused in these MRVs, or “research villages”.

The MVP survey effort includes baseline and follow-up surveys using several household questionnaires. At baseline, a demographic survey and a population census were administered to all households in the research village. From this set, a sample of 300 households were identified using a stratified random selection process based on wealth category (i.e. an asset index), gender of household head, and household location and were surveyed at baseline with a battery of approximately 20 survey instruments, including one focused on household energy use and acquisition. Thus, the energy survey was administered orally to 300 households in each research village (with the exception of one village, Dertu, described below) in the respective local languages by enumerators who filled out the questionnaires during the interview.

Data from the baseline energy survey are reported in this paper for 10 of the 14 MVP sites. In two of the 14 sites – Gumulira (Malawi) and Toya (Mali) – no energy survey was fielded. The questionnaires used in two sites – Koraro (Ethiopia), and Sauri (Kenya) – differed substantially from the questionnaires used in the other locations, leading to problems with data availability and comparability, and so were excluded from the following analysis. Finally, in Dertu (Kenya), where a partly settled and partly pastoralist population raised unusual surveying issues, only 200 households were sampled and substantial modifications were made to the questionnaire, resulting in limited data availability for many questions for this site.

While household energy consumption patterns in developing countries have been studied before (e.g. Alabe, 1996; Miah et al., 2010; Reddy, 1982; Wang and Fend, 1996), this study is unusual both in its geographical scope – spanning 10 villages in as many major agro-

**Table 1**
Basic physiographic information for 10 Millennium Villages.

| Site (MRV Name, Country) | Latitude | Longitude | Agro-ecological Zone[1] | Elevation (m) | Precipitation (mm/annum)[2] |
|---|---|---|---|---|---|
| Bonsaaso, Ghana (GHA) | N 06°14′19″ | W 002°00′20″ | Tree crop | 147 | 1359 |
| Dertu, Kenya (KEN) | N 00°10′41″ | E 039°41′25″ | Pastoral | 0 | 495 |
| Ikaram, Nigeria (NGA) | N 07°36′43″ | E 005°51′58″ | Root crop (Guinea savanna) | 386 | 1605 |
| Mayange, Rwanda (RWA) | S 02°14′30″ | E 030°08′00″ | Highland perennial | 1432 | 1195 |
| Mbola, Tanzania (TZA) | S 05°03′24″ | E 032°32′56″ | Maize-mixed (unimodal) | 1168 | 960 |
| Mwandama, Malawi (MWI) | S 15°31′25″ | E 035°10′54″ | Cereal root-crops mixed (Southern Miombo) | 1035 | 986 |
| Pampaida, Nigeria (NGA) | N 11°19′03″ | E 008°09′23″ | Cereal root-crops mixed (Sudan savanna) | 603 | 987 |
| Potou, Senegal (SEN) | N 15°44′48″ | W 016°28′05″ | Coastal-artisanal fishing | 10 | 406 |
| Ruhiira, Uganda (UGA) | S 00°52′54″ | E 030°39′26″ | Highland perennial | 1495 | 1245 |
| Tiby, Mali (MLI) | N 13°35′14″ | W 005°46′30″ | Agrosilvo-pastoral | 283 | 677 |

1) Adapted from FAO, 2001.
2) Unpublished data: International Research Institute for Climate and Society, The Earth Institute at Columbia University. 2006. Monthly satellite estimated rainfall averaged over the period from 1979 to 2005. Data compiled by Eric Holthaus, using methodology by Janowiak, J. E. and P. Xie, 1999: CAMS_OPI: A Global Satellite-Rain Gauge Merged Product for Real-Time Precipitation Monitoring Applications. J. Climate, vol. 12, 3335-3342.

**Table 2**
Demographic information and survey fielding dates for 10 Millennium Villages.

| Site | Population density (persons/km$^2$)[1] | Persons per household[2] | Survey fielded (mm/yy) |
|---|---|---|---|
| Bonsaaso (GHA) | 76 | 5.2 | 04/07 |
| Dertu (KEN) | 4 | 6.0 | 11/07 |
| Ikaram (NGA) | N/A | 4.5 | 10/07–11/07 |
| Mayange (RWA) | 289 | 4.8 | 01/07 |
| Mbola (TZA) | 44 | 5.6 | 10/07–11/07 |
| Mwandama (MWI) | 496 | 4.0 | 03/07 |
| Pampaida (NGA) | 178 | 6.0 | 04/07–05/07 |
| Potou (SEN) | 64 | 9.7 | 09/07 |
| Ruhiira (UGA) | 325 | 5.3 | 03/07 |
| Tiby (MLI) | 80 | 13.8 | 09/07 |

1) Approximate population density in the study area.
2) MVP Demographic Survey, 2007.

ecological zones across Sub-Saharan Africa – and the range of energy types considered. It therefore provides a rich source of information for a wide range of rural sites throughout the region.

## Background

Tables 1 and 2 provide basic physiographic and demographic information for these 10 Millennium Villages sites, including all villages comprising the total project area and population.

## Results

### *Overview*

The principal energy services utilized by households residing in rural agriculture-based settings in developing countries can be categorized into a) lighting, power for mobile phone recharging, other media and information technologies such as radio and television, b) cooking and heating and c) agro-processing and/or pumping. In our study, the first category of services was frequently met through kerosene (for lighting) and disposable or rechargeable batteries and the second category of services was met through gathered solid biomass such as fuelwood or crop residues. While the third category which encompasses agro-processing services is not reported on in this paper, these services were primarily derived from small engines or electric motors at community level businesses. Prior to examination of the survey data, observations drawn from site visits, community-level investigations, market surveys and enumerator trainings are presented to provide an overview of the availability of various energy sources for households throughout the Millennium Villages.

The largest single energy requirement for rural households is fuel for cooking, which requires approximately 1 GJ per year per capita 'into the pot' (within a factor of two) (Modi et al., 2005). The primary fuel resource to which African villagers have affordable, ready access is biomass, either fuelwood or biomass waste from farming, also referred to as farm waste or farm residue (World Bank, 1996). In these study areas, fuelwood can be collected from the nearby landscape or purchased in local markets, and farm waste may include stalks, husks, straw or other remnants from a variety of crops such as maize, rice, sorghum, millet and others, depending upon local farming practices. The availability, cost and usability of locally obtained biomass fuels depend on a range of local factors including rainfall; population density and settlement patterns; public and private traditions and choices about farming, forestry and other land use; and household wealth and labor constraints. Charcoal is another potentially important cooking fuel that is widely available in local markets; however, actual use as well as engagement in charcoal-making appears to be low among those studied. While households throughout these study areas are aware of the possible use of fossil fuels such as kerosene and liquefied petroleum gas (LPG) for cooking, only the former is nearly universally available in small markets.

Although lighting consumes relatively little energy compared to cooking in primary energy terms, lighting appears to be an important energy need in rural African households (as in any household), constituting a large part of energy expenditures, and as observed by Leach and Gowen (1987), lighting is likely to be seen as a priority for better living standards. Electric lighting is desired by rural households throughout the developing world, but very low levels of grid penetration and high costs of frequent battery purchase limit the use of electricity for 1.6 billion people worldwide, leaving them reliant upon inefficient and costly fuel-based lighting, primarily kerosene (Dutt, 1994; Mills, 2005) for activities such as dining, reading, preparing for sleep and household work.

Battery power for mobile phone charging is an important energy need, making the accessibility and cost of charging important concerns of this study.

The energy source and service needs mentioned above, including the potential for less expensive, more efficient or cleaner alternatives, as well as increased access to familiar energy resources, are the key concerns of this study. Thus, the following study explores these energy use patterns from a variety of perspectives — sometimes with attention to specific fuels, sometimes prioritizing the energy services themselves, and at other times analyzing the magnitude and composition of household energy expenditures.

The predominance of use of different energy types is shown in Table 3. The most commonly used fuel in the Millennium Villages was fuelwood, which was used by an average of 99% of households

**Table 3**
Fraction of all households who report any use of each of the following fuels[1].

| | Fuelwood | Charcoal | Kerosene | Candles | Farm residue | Dung/ manure | Grid electricity connection in the home[2] | Solar PV[2] | Dry cell batteries | Cell phone batteries |
|---|---|---|---|---|---|---|---|---|---|---|
| Bonsaaso (GHA) | 1.00 | 0.14 | 1.00 | 0.34 | 0.43 | 0.06 | 0.00 | 0.00 | 0.83 | 0.03 |
| Dertu (KEN) | 0.96 | 0.02 | 0.43 | 0.00 | N/A | N/A | 0.00 | 0.00 | 0.22 | 0.02 |
| Ikaram (NGA) | 0.96 | 0.30 | 0.96 | 0.10 | 0.01 | 0.00 | 0.85 | 0.00 | 0.74 | 0.52 |
| Mayange (RWA) | 0.96 | 0.07 | 0.86 | 0.15 | 0.28 | 0.04 | 0.00 | 0.00 | 0.53 | 0.06 |
| Mbola (TZA) | 0.98 | 0.18 | 0.99 | 0.00 | 0.61 | 0.02 | 0.00 | N/A | 0.58 | N/A |
| Mwandama (MWI) | 1.00 | 0.22 | 0.97 | 0.52 | 0.68 | 0.01 | 0.02 | 0.00 | 0.62 | 0.04 |
| Pampaida (NGA) | 1.00 | 0.23 | 0.88 | 0.02 | 0.97 | 0.16 | 0.00 | 0.00 | 0.97 | 0.02 |
| Potou (SEN) | 1.00 | 0.60 | 0.53 | 0.68 | 0.15 | 0.01 | 0.05 | 0.13 | 0.89 | 0.68 |
| Ruhiira (UGA) | 1.00 | 0.07 | 0.99 | 0.25 | 0.77 | 0.02 | 0.00 | 0.00 | 0.68 | 0.12 |
| Tiby (MLI) | 0.99 | 0.26 | 0.99 | 0.03 | 0.32 | 0.04 | 0.00 | 0.01 | 0.88 | 0.07 |
| **Average (all sites)[3]** | **0.99** | **0.21** | **0.86** | **0.21** | **0.47** | **0.04** | **0.09** | **0.02** | **0.69** | **0.17** |

1) Figures for fuelwood and charcoal represent straight averages of data reported by season. Figures for other fuels represent responses only for the season in which the survey was fielded.
2) For grid electricity and solar PV, households for which the data were missing were assumed not to have access to theses energy sources.
3) In this table and all subsequent tables the phrase "Average (all sites)" indicates a simple average of the numbers in the column above, and is not weighted in any way to reflect the populations, household sizes, or other factors particular to each site.

**Table 4**
For households who reported using fuelwood, the fraction used for different purposes.

| | Cooking | Income generation | All other uses |
|---|---|---|---|
| Bonsaaso (GHA) | 0.84 | 0.10 | 0.06 |
| Ikaram (NGA) | 0.84 | 0.10 | 0.06 |
| Mayange (RWA) | 0.98 | 0.02 | 0.01 |
| Mbola (TZA) | 0.79 | 0.03 | 0.18 |
| Mwandama (MWI) | 0.83 | 0.09 | 0.07 |
| Pampaida (NGA) | 0.87 | 0.01 | 0.11 |
| Potou (SEN) | 0.86 | 0.03 | 0.11 |
| Ruhiira (UGA) | 0.84 | 0.10 | 0.06 |
| Tiby (MLI) | 0.86 | 0.04 | 0.11 |
| **Average (all sites)** | **0.86** | **0.06** | **0.08** |

**Table 5**
Fraction of fuelwood acquired through different means (average over all seasons and households who reported having used fuelwood).

| | Collected | Purchased | All other sources |
|---|---|---|---|
| Bonsaaso (GHA) | 0.91 | 0.03 | 0.07 |
| Dertu (KEN) | 0.53 | 0.43 | 0.04 |
| Ikaram (NGA) | 0.85 | 0.11 | 0.04 |
| Mayange (RWA) | 0.67 | 0.32 | 0.01 |
| Mbola (TZA) | 0.98 | 0.01 | 0.01 |
| Mwandama (MWI) | 0.86 | 0.10 | 0.04 |
| Pampaida (NGA) | 0.82 | 0.11 | 0.07 |
| Potou (SEN) | 0.64 | 0.36 | 0.00 |
| Ruhiira (UGA) | 0.95 | 0.05 | 0.00 |
| Tiby (MLI) | 0.65 | 0.24 | 0.11 |
| **Average (all sites)** | **0.79** | **0.18** | **0.04** |

**Table 6**
Fraction of fuelwood collected in different locations (average over households who reported having collected fuelwood).

| | Fallow lands owned by household | Other land owned by household | Roadside/other's field/community land//forest | Other |
|---|---|---|---|---|
| Bonsaaso (GHA) | 0.64 | 0.29 | 0.07 | 0.00 |
| Ikaram (NGA) | 0.36 | 0.41 | 0.23 | 0.00 |
| Mayange (RWA) | 0.19 | 0.44 | 0.38 | 0.00 |
| Mbola (TZA) | 0.26 | 0.16 | 0.58 | 0.00 |
| Mwandama (MWI) | 0.03 | 0.26 | 0.21 | 0.49 |
| Pampaida (NGA) | 0.05 | 0.51 | 0.44 | 0.00 |
| Potou (SEN) | 0.01 | 0.03 | 0.96 | 0.00 |
| Ruhiira (UGA) | 0.23 | 0.18 | 0.59 | 0.00 |
| Tiby (MLI) | 0.10 | 0.39 | 0.47 | 0.04 |
| **Average (all sites)** | **0.21** | **0.30** | **0.44** | **0.06** |

across the research villages. Next was kerosene, used by 86% and farm residue used by 47% of households across all sites. Other less prevalent fuels include charcoal, used by 22%, candles, used by 21%, and dung, which was used by only 4% of households across the villages. Candle use varied substantially among villages, with 68% of households using them in Potou (SEN), while no significant use of candles was reported in Dertu (KEN) and Mbola (TZA).

## *Energy types*

### *Fuelwood*

In all villages, the households who used fuelwood used it virtually every day. Household daily fuelwood use was quantified by first asking household cooks if they had in their home at the time of the interview sufficient fuelwood for one typical day's cooking needs, and if so, they were asked to set aside this quantity and it was weighed (in kg units) and the number of sticks in that quantity was counted.[1] The per capita daily fuel use varied from a low of 1.2 kg in Potou to a high of 4.9 kg in Ikaram, with an average of 2.5 kg across all sites. These values for the study sites fell within the range reported in the literature for other African sites (Cline-Cole et al., 1990) and India (Awasti et al., 2003; Bhatt et al., 1994; Kumar and Sharma, 2009; Mahat et al., 1987; Reddy, 1981).

The predominant use of fuelwood was cooking, accounting for 86% of all fuelwood use across the villages (Table 4). A small amount of fuelwood (less than 6%) was used for income generation.

The majority of the fuelwood used in households across all MVP sites (79%) was acquired by collection, whereas 18% was purchased. Thirty-one percent of households reported having purchased any fuelwood (Table 5). This average fell at the upper end of the range for fuelwood collection data from rural India of approximately 30% to 80% (Reddy, 1982). The highest reported percentages of fuelwood purchase are generally seen in the MVP sites with the lowest annual precipitation: the two Sahelian sites, Potou (SEN) and Tiby (MLI), as well as Dertu (KEN), all of which have rainfall below approximately 700 mm/year (Table 1). This suggests that fuelwood collection is more difficult in more arid climates. The one exception, Mayange (RWA), which has both a relatively high fraction of fuelwood purchase and above-average rainfall, is a peri-urban settlement, where homes are closely-spaced with few trees among them, potentially limiting the fuelwood supply immediately surrounding most homes.

Households were asked to report the fraction of fuelwood gathered from four different sources — the roadside, fallow lands owned by the household, other land owned by the household, and “other”, and results are reported in Table 6. These data show that roughly equal percentages of fuel are obtained from lands owned by households (around 51% when fallow and other household lands are considered together) and from more public lands (at 44%). The only site where respondents report a large fraction of fuelwood gathered from an “other” source is Mwandama (MWI), where fuelwood is gathered in substantial amounts from nearby “estates”, large commercial farms managed by foreign owners where many local villagers work for cash and are permitted to collect fuel.

### *Fuelwood gathering*

Fuelwood gathering is the primary mode of acquisition, requiring on average, 6 hours per gatherer each week (Table 7), and ranging from 2.9 hours per week in Mwandama (MWI) to 10.8 hours per week in Potou (SEN). Consistent with the observation noted above with regard to greater fuelwood purchase in drier sites, fuelwood collection data suggest that gathering is more difficult in drier conditions. Gatherers in Potou (SEN) made 5.2 trips per week, more than twice the average frequency across these MVP sites. Gatherers in Tiby (MLI) traveled 10.3 km on a typical trip, more than double the average. The greater distance in Tiby was enabled by the use of pack animals, with 50% of all fuelwood collection trips undertaken with the help of animal power, and 2% with assisted human power, such as a cart, wheelbarrow, or other non-motorized equipment. These practices were not seen to any

[1] An alternate method was devised for calculating daily fuelwood use for homes that did not have sufficient fuelwood in the home at the time of the enumerator's visit. These cooks were asked to report either the number of bundles or sticks of fuelwood used in a typical day's cooking. If the cook reported daily fuel use in bundles, the number was multiplied by the weight of fuelwood bundles purchased for reference at local markets. If the cook reported sticks, the average weight of sticks from households who had sufficient fuelwood present was used for the calculation. However, both calculations, whether based on sticks or bundles, were found to be both highly variable and inconsistent with literature values. We suspect this is due to the inherent unreliability of self-reported fuel use, the highly variable definition of a “bundle,” and the relatively small number of responses for households who reported consumption in units of sticks or bundles as well as the small number of reference bundles weighed in local markets. Since these calculations based on sticks and bundles were deemed unreliable, daily fuelwood consumption was only reported for households for which a full day's fuel supply could be weighed at the time of the enumerator's visit.

**Table 7**
Number of gatherers and trips; time spent; distance traveled; and speed of travel for fuelwood gathering.

| | Total number of gatherers (n) | Gatherers per household | Number of weekly trips per gatherer | Hours spent collecting fuelwood… | | Typical roundtrip distance per collection trip (km) | Average speed of travel for collection trips (km/h)[1] |
|---|---|---|---|---|---|---|---|
| | | | | …per gatherer per week | …per household member[2] | | |
| Bonsaaso (GHA) | 616 | 2.1 | 3.2 | 6.7 | 2.6 | 4.3 | 2.0 |
| Dertu (KEN) | 153 | 0.8 | 3.4 | 6.7 | 0.8 | 6.6 | 3.4 |
| Ikaram (NGA) | 527 | 1.9 | 1.6 | 4.0 | 1.6 | 5.5 | 2.3 |
| Mayange (RWA) | 325 | 1.6 | 2.8 | 7.1 | 2.3 | 4.1 | 1.6 |
| Mbola (TZA) | 501 | 1.8 | 1.9 | N/A | N/A | N/A | N/A |
| Mwandama (MWI) | 409 | 1.6 | 1.8 | 2.9 | 1.1 | 2.2 | 1.3 |
| Pampaida (NGA) | 604 | 2.0 | 3.0 | 4.0 | 1.4 | 2.1 | 1.6 |
| Potou (SEN) | 506 | 2.3 | 5.2 | 10.8 | 2.6 | 4.0 | 1.9 |
| Ruhiira (UGA) | 571 | 1.9 | 2.6 | 4.5 | 1.7 | 1.9 | 1.0 |
| Tiby (MLI) | 224 | 2.0 | 2.3 | 7.7 | 1.1 | 10.3 | 3.2 |
| **Average (all sites)** | **443.5** | **1.8** | **2.8** | **6.0** | **1.7** | **4.6** | **2.0** |

1) Numbers in this column are calculated using numbers in this table.
2) Numbers in this column are calculated using numbers in this table and Table 2 (household size).

significant degree in other locations where at least 94% of all fuelwood collection trips were made on foot without the aid of any equipment. The use of pack animals in Tiby is also reflected in the higher average speed of travel for fuelwood collection there than in all other sites (3.2 km/h versus an average of 1.9 km/h). In contrast, Ruhiira, which has the steepest topography of the sites, has the lowest average speed of travel for gatherers (1.0 km/h). The number of gatherers per household was reported to be around two for almost all locations, in spite of the fact that the average household size varied from around 4 to around 13 across the sites.

By all metrics measured, fuelwood gathering is primarily undertaken by women and, to a lesser degree, girls. Adult men represented only a small fraction of the gatherers, and tended to be primarily responsible for fuelwood gathering mostly in households with no adult female spouse. Across villages, 56% of gatherers were women, 20% were girls, 13% were men and 9% were boys (Table 8). (Girls and boys were defined as being under the age of 18 and not being the head of household or the spouse of the head of household.)

Adult women also collected the most wood, gathering 62% of the households' supply across the sites, followed by adult males, who gathered 19%. Girls gathered 12% and boys gathered 6% (Table 9). Adult gatherers, both men and women, tended to obtain the majority of the fuelwood for their respective households. Adult females gathered the majority of fuelwood in 63% of households across the sites, and for adult males, this was 18%; however, in 76% of households where adult males gathered the majority of the fuelwood, there was no female spouse.

*Charcoal*

Across the aggregate of all households studied, only 5% of the cooking was carried out with charcoal. When charcoal was used at all, the two primary uses were cooking (50% of all use) and ironing (36% of all use) on average across all sites.

The majority of the households' charcoal – 60% across all sites – was acquired through purchase, and 28% was "made by the household" from collected wood (Table 10), though it is likely that the latter was charcoal remaining after cooking in kitchen fires, since household production with kilns was not seen in homes in these sites. In most villages, those households who cook with charcoal report using it roughly half of the days.

*Kerosene*

The most common household use of kerosene was domestic lighting, which accounted for 80% of all kerosene used by households across all sites (Table 11). Most of the remaining 20% of household kerosene consumption was used for cooking, either in a kerosene stove or for starting a fire in a non-kerosene stove.

In all sites except in Ikaram, the dominant use of kerosene was for lighting. In Ikaram, the data show that there was significant kerosene use for cooking as well. A more careful look is warranted to illustrate how the use of kerosene is different in Ikaram from that in other sites. In a site such as Ruhiira (UGA), virtually all kerosene (95% averaged across all households) is used for lighting. The small percentage of kerosene used for cooking in Ruhiira is primarily due to a small minority of households reporting that nearly all cooking is done with kerosene. In contrast, at an aggregate level, households in Ikaram (NGA) use about half of their kerosene for cooking, although the majority of the cooking in Ikaram (74%) is still done with fuelwood. Fig. 1 shows the variation across households in how kerosene is used. Nearly a quarter of the households surveyed in Ikaram still use kerosene exclusively for lighting, and it is amongst the remainder of the households that one observes an increasing fraction being used for cooking. In addition, use of kerosene for starting fires consumed roughly one quarter of the kerosene in two sites – Pampaida (NGA) and Potou (SEN) – which also were reported to be among the highest numbers of homes using charcoal.

**Table 8**
Fraction and number (n) of all gatherers by gender and age group.

| | Adult female | Adult male | Girl | Boy |
|---|---|---|---|---|
| Bonsaaso (GHA) | 0.50 (304) | 0.20 (125) | 0.16 (96) | 0.14 (85) |
| Dertu (KEN) | 0.77 (118) | 0.05 (8) | 0.15 (23) | 0.03 (4) |
| Ikaram (NGA) | 0.58 (288) | 0.15 (74) | 0.17 (87) | 0.10 (51) |
| Mayange (RWA) | N/A | N/A | N/A | N/A |
| Mbola (TZA) | 0.56 (275) | 0.11 (52) | 0.21 (105) | 0.12 (58) |
| Mwandama (MWI) | 0.62 (239) | 0.11 (43) | 0.23 (88) | 0.04 (15) |
| Pampaida (NGA) | 0.35 (207) | 0.36 (209) | 0.11 (62) | 0.19 (110) |
| Potou (SEN) | 0.61 (271) | 0.03 (13) | 0.33 (148) | 0.03 (14) |
| Ruhiira (UGA) | 0.46 (256) | 0.06 (32) | 0.26 (145) | 0.22 (124) |
| Tiby (MLI) | 0.49 (98) | 0.33 (66) | 0.09 (17) | 0.09 (17) |
| **Average (all sites)** | **0.56** | **0.13** | **0.20** | **0.09** |

**Table 9**
Fraction of household fuelwood gathered by each gender and age group category (average over households who reported gathering fuelwood).

| | Adult females | Adult males | Girls | Boys | n (households) |
|---|---|---|---|---|---|
| Bonsaaso (GHA) | 0.59 | 0.23 | 0.10 | 0.09 | 299 |
| Dertu (KEN) | 0.79 | 0.06 | 0.12 | 0.02 | 139 |
| Ikaram (NGA) | 0.65 | 0.16 | 0.11 | 0.07 | 268 |
| Mbola (TZA) | 0.72 | 0.12 | 0.10 | 0.05 | 271 |
| Mwandama (MWI) | 0.76 | 0.11 | 0.11 | 0.01 | 255 |
| Pampaida (NGA) | 0.35 | 0.49 | 0.05 | 0.10 | 285 |
| Potou (SEN) | 0.69 | 0.03 | 0.26 | 0.02 | 211 |
| Ruhiira (UGA) | 0.63 | 0.07 | 0.17 | 0.12 | 293 |
| Tiby (MLI) | 0.47 | 0.41 | 0.04 | 0.08 | 106 |
| **Average (all sites)** | **0.63** | **0.19** | **0.12** | **0.06** | **236.3** |

**Table 10**
Fraction of households who reported any charcoal use, followed by the fraction acquired by different means averaged over households who used charcoal.

| | Fraction of households who used charcoal at all | Purchased | Made by the household from wood collected by the household[1] | All other sources |
|---|---|---|---|---|
| Bonsaaso (GHA) | 0.14 | 0.48 | 0.16 | 0.36 |
| Dertu (KEN) | 0.02 | 0.41 | 0.26 | 0.32 |
| Ikaram (NGA) | 0.30 | 0.40 | 0.53 | 0.06 |
| Mayange (RWA) | 0.07 | 0.97 | 0.00 | 0.03 |
| Mbola (TZA) | 0.18 | 0.56 | 0.29 | 0.16 |
| Mwandama (MWI) | 0.22 | 0.71 | 0.22 | 0.07 |
| Pampaida (NGA) | 0.23 | 0.09 | 0.83 | 0.07 |
| Potou (SEN) | 0.60 | 0.99 | 0.01 | 0.00 |
| Ruhiira (UGA) | 0.07 | 0.86 | 0.14 | 0.00 |
| Tiby (MLI) | 0.26 | 0.55 | 0.33 | 0.12 |
| **Average (all sites)** | **0.21** | **0.60** | **0.28** | **0.12** |

1) i.e. charcoal remaining from cooking fires (not produced in a kiln).

*Candles*

Candles were used by approximately one-fifth of the households surveyed, and virtually all use is assumed to be for lighting (Table 12). This is because the overwhelming majority of use was for domestic lighting while the second most common use ("income generation"), as well as other uses, are not exclusive with lighting.

*Farm residue and dung/manure*

While use of farm residue as a fuel was common (reported by 47% of households, on average, across all sites), use of dung/manure was rare (reported by less than 5%, on average). Both farm residue and dung/manure were predominantly used for cooking for the household in all villages, except Tiby (MLI), where this was not true for dung/manure. The use of dung/manure for cooking is also comparatively low in Mayange (RWA) and Mbola (TZA) (Tables 13 and 14).

*Electricity*

At the time of the survey, as the national electricity grid did not reach most of the research villages, very few households surveyed were connected to the electric grid. The exceptions are the village of Ikaram (NGA), where a full 85% of households had a grid connection (Table 15); as well as Potou (SEN), Mwandama (MWI) and Bonsaaso (GHA), where the grid did reach the sites, but still very small numbers of households were connected.

**Table 11**
Fraction of households who reported any kerosene use, followed by the fraction used for different purposes averaged over all households who reported kerosene use.

| | Fraction of households who used kerosene at all this season | Fraction of kerosene used for each of the following purposes | | | | |
|---|---|---|---|---|---|---|
| | | Domestic lighting | Cooking in kerosene stove | Starting fire in non-kerosene stove | Income generation | All other uses |
| Bonsaaso (GHA) | 1.00 | 0.85 | 0.02 | 0.07 | 0.03 | 0.02 |
| Dertu (KEN) | 0.43 | 0.70 | 0.11 | 0.10 | 0.08 | 0.01 |
| Ikaram (NGA) | 0.96 | 0.49 | 0.46 | 0.05 | 0.00 | 0.01 |
| Mayange (RWA) | 0.86 | 0.93 | 0.06 | 0.00 | 0.01 | 0.00 |
| Mbola (TZA) | 0.99 | 0.94 | 0.02 | 0.04 | 0.01 | 0.00 |
| Mwandama (MWI) | 0.97 | 0.92 | 0.01 | 0.05 | 0.02 | 0.00 |
| Pampaida (NGA) | 0.88 | 0.62 | 0.04 | 0.27 | 0.01 | 0.06 |
| Potou (SEN) | 0.53 | 0.72 | 0.01 | 0.27 | 0.01 | 0.00 |
| Ruhiira (UGA) | 0.99 | 0.95 | 0.03 | 0.00 | 0.02 | 0.00 |
| Tiby (MLI) | 0.99 | 0.87 | 0.01 | 0.07 | 0.03 | 0.02 |
| **Average (all sites)** | **0.86** | **0.80** | **0.08** | **0.09** | **0.02** | **0.01** |

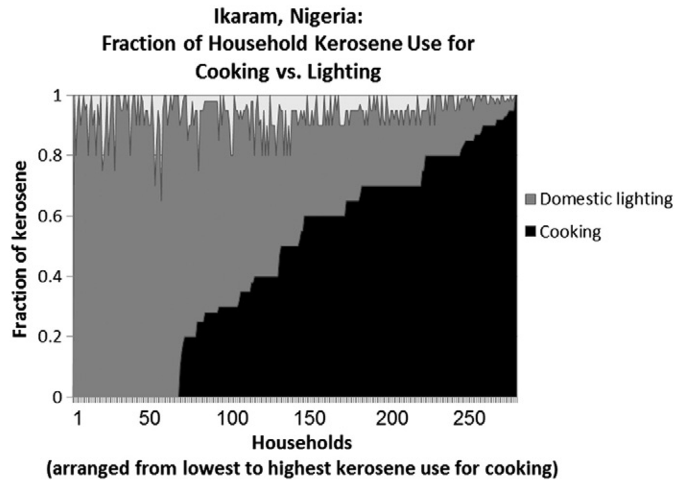


**Fig. 1.** Fraction of kerosene used for lighting versus cooking for all households in Ikaram (NGA) who reported using kerosene (gray areas represent use of kerosene for other purposes).

Instead, to obtain services derived from electricity such as mobile phone recharging, radio, and electric lighting, villagers typically spent a substantial amount of the household energy budget on the recharging of batteries, primarily mobile phone batteries, and purchase of dry-cell batteries. Table 16 shows the households' average annual expenditure on different types of batteries. Disposable, dry cell batteries made up the largest part of the households' battery expenses which totaled, on average, USD 19 per year. It is notable that in Ikaram (NGA), the only site with a very high rate of household grid connections, expenditures on batteries were lower than in all other sites.

Tables 17 and 18 show the primary charging sources for cell phone batteries and large rechargeable batteries. Home charging of cell phone batteries is much more prevalent in Ikaram (NGA) and to some extent in Potou (SEN) than in other villages. In these sites, relatively high prevalence of grid connections not only increased home charging, but also – particularly in Potou (SEN) – the availability of commercial and community charging stations. Data regarding the distance to charging sources is important because anecdotal reports suggest that, in many cases, limited opportunity to charge phones locally can be a substantial hurdle to villagers' use of mobile phones, even where a mobile phone signal can be found.

**Table 12**
Fraction of households who reported any candle use, followed by the fraction used different purposes averaged over all households who reported candle use.

| | Fraction of households who used candles at all this season | Fraction of candles used for each of the following purposes | | |
|---|---|---|---|---|
| | | Domestic lighting | Income generation | All other uses |
| Bonsaaso (GHA) | 0.34 | 0.71 | 0.05 | 0.24 |
| Dertu (KEN) | 0.00 | N/A | N/A | N/A |
| Ikaram (NGA) | 0.10 | 0.91 | 0.04 | 0.05 |
| Mayange (RWA) | 0.15 | 0.84 | 0.11 | 0.05 |
| Mbola (TZA) | 0.00 | N/A | N/A | N/A |
| Mwandama (MWI) | 0.52 | 0.99 | 0.01 | 0.00 |
| Pampaida (NGA) | 0.02 | 0.83 | 0.17 | 0.00 |
| Potou (SEN) | 0.68 | 0.98 | 0.02 | 0.00 |
| Ruhiira (UGA) | 0.25 | 0.96 | 0.04 | 0.00 |
| Tiby (MLI) | 0.03 | 0.79 | 0.08 | 0.13 |
| **Average (all sites)** | **0.21** | **0.88** | **0.06** | **0.06** |

**Table 13**
Fraction of households who reported any use of farm residue, followed by the fraction used for different purposes averaged over all households who reported use of farm residue.

| | Fraction of households who used farm residue at all this season | Fraction of farm residue used for each of the following purposes | | |
|---|---|---|---|---|
| | | Cooking | Income generation | All other uses |
| Bonsaaso (GHA) | 0.43 | 0.81 | 0.05 | 0.14 |
| Ikaram (NGA) | 0.01 | 1.00 | 0.00 | 0.00 |
| Mayange (RWA) | 0.28 | 0.54 | 0.03 | 0.43 |
| Mbola (TZA) | 0.61 | 0.62 | 0.00 | 0.38 |
| Mwandama (MWI) | 0.68 | 0.88 | 0.03 | 0.09 |
| Pampaida (NGA) | 0.97 | 0.85 | 0.01 | 0.14 |
| Potou (SEN) | 0.15 | 0.84 | 0.04 | 0.12 |
| Ruhiira (UGA) | 0.77 | 0.98 | 0.01 | 0.00 |
| Tiby (MLI) | 0.32 | 0.54 | 0.05 | 0.41 |
| **Average (all sites)** | **0.47** | **0.79** | **0.02** | **0.19** |

*Energy expenditures*

Kerosene accounted for the largest share of fuel expenses on average across the villages, followed by fuelwood and charcoal (Table 19). The total annual energy expenses per household ranged from USD 25 in Ruhiira (UGA) and USD 26 in Mwandama (MLI) to USD 112 in Tiby (MLI), with an average of USD 58 across all sites. While Tiby shows above average household expenditures throughout, this is likely due, at least in part, to the unusually high household size.

Reported annual expenses on cooking are shown in Table 20, and expenses on lighting and electricity are shown in Table 21. On average, households spent more on lighting and electricity than on cooking. Across all villages, households spent on average USD 48 per year on lighting and electricity and USD 21 per year on cooking.

*Energy services*

*Cooking*

Fuels were mostly used for cooking, and the predominant cooking fuel was fuelwood, which accounted for 74% of all cooking fuel across all sites (Table 22). The next most important cooking fuels were farm residue, accounting 11% across the villages; kerosene, accounting for 7%; and charcoal, accounting for only 4% across all sites. No LPG use was reported in any of the villages except Potou, where it was used by 97% of households and 12% of all cooking was done with LPG. The high level of LPG use in Potou is linked to Senegal's national policy promoting LPG, which was initiated in 1974 with the aim of replacing 50% of charcoal consumption with LPG in major urban areas through subsidies and promotional campaigns (Sokona et al., 2003). All other fuels, including dung, accounted for no more than 3% of fuels used for cooking in any of the villages.

**Table 14**
Fraction of households who reported use of dung/manure, followed by the fraction used for different purposes averaged over all households who reported use of dung/manure.

| | Fraction of households who used dung/manure at all this season | Fraction of dung/manure used for each of the following purposes | | |
|---|---|---|---|---|
| | | Cooking | Income generation | All other uses |
| Bonsaaso (GHA) | 0.06 | 0.83 | 0.01 | 0.16 |
| Ikaram (NGA) | 0.00 | N/A | N/A | N/A |
| Mayange (RWA) | 0.04 | 0.51 | 0.08 | 0.41 |
| Mbola (TZA) | 0.02 | 0.50 | 0.50 | 0.00 |
| Mwandama (MWI) | 0.01 | 0.80 | 0.20 | 0.00 |
| Pampaida (NGA) | 0.16 | 0.75 | 0.04 | 0.21 |
| Potou (SEN) | 0.01 | 0.97 | 0.00 | 0.03 |
| Ruhiira (UGA) | 0.02 | 1.00 | 0.00 | 0.00 |
| Tiby (MLI) | 0.04 | 0.45 | 0.20 | 0.35 |
| **Average (all sites)** | **0.04** | **0.73** | **0.13** | **0.15** |

**Table 15**
Number of households connected to the electric grid at the time of the baseline survey.

| | |
|---|---|
| Bonsaaso (GHA) | 1 |
| Dertu (KEN) | 0[1] |
| Ikaram (NGA) | 253 |
| Mayange (RWA) | 0[1] |
| Mbola (TZA) | 0[1] |
| Mwandama (MWI) | 6 |
| Pampaida (NGA) | 0[1] |
| Potou (SEN) | 16 |
| Ruhiira (UGA) | 0[1] |
| Tiby (MLI) | 0[1] |

1) The national electricity grid either did not reach the MRV (research village) for this site at baseline, or connections were limited to public institutions (schools, clinics) with no connections to households or shops.

Table 23 shows the amount of fuelwood used per capita per day for cooking. The average, of around 2.2 kg per capita per day agrees closely with data from the Republic of Kenya Ministry of Energy (2002), which gives an average fuelwood consumption per household for rural areas of 741 kg/year, which gives a daily average of 2.0 kg (Republic of Kenya Ministry of Energy, 2002). This would result in about 4 t of fuelwood consumed per year for a household of 5.

Cooking with biomass using a traditional three-stone fire is a major cause of indoor air pollution and respiratory problems (Smith et al., 2000). This is the practice in the vast majority of households in all MVP sites, except in Ikaram and Mayange, where traditional and improved charcoal stoves are relatively common. In these sites, as well as to a lesser degree in Dertu, “other” stove types, a category consisting primarily of local clay fuelwood stoves and LPG stoves, were relatively common (Table 24).

Cooks reported spending many hours per week cooking, generally 30 or more per week, when both primary and secondary cooks were considered together (Table 25). However, in some of the villages – Pampaida (NGA), Potou (SEN), and Tiby (MLI) – people's exposure to harmful smoke was limited by the fact that cooking was usually done outdoors by most households. In Dertu (KEN), Mbola (TZA), Ruhiira (UGA), Ikaram (NGA), and Mayange (RWA), most households usually cooked in a structure separate from the main living area. This limited smoke exposure experienced by non-cooking family members, including small children who are believed to be most at-risk for related adverse health impacts.

Also, in most households, the kitchen was a separate room, defined as a room where cooking is kept separate from all other living activities and with no shared airspace between the kitchen and other rooms in

**Table 16**
Expenditures on batteries per household per year (USD), averaged over all households (with number of households who reported expenditures for each battery type in parentheses). Expenditures on disposable batteries reflect cost of purchase. Expenditures on other battery types reflect cost of recharging.

| | Disposable/dry cell batteries | Battery in cell phone | Other | Sum of battery expenses |
|---|---|---|---|---|
| Bonsaaso (GHA) | 28.06 (250) | 3.24 (10) | 0.33 (2) | 31.63 |
| Ikaram (NGA) | 4.71 (213) | 0 (145) | 0.73 (133) | 5.45 |
| Mayange (RWA) | 12.8 (132) | 0.49 (11) | 0.19 (4) | 13.49 |
| Mwandama (MWI) | N/A | 0.52 (12) | 1.73 (51) | N/A |
| Pampaida (NGA) | 19.07 (292) | 0.75 (7) | 0.03 (1) | 19.85 |
| Potou (SEN) | 19.69 (184) | 9.05 (154) | 2.93 (35) | 31.67 |
| Ruhiira (UGA) | 6.05 (202) | 1.43 (29) | 1.10 (14) | 8.58 |
| Tiby (MLI) | 16.54 (224) | 0.36 (15) | 5.03 (40) | 21.94 |
| **Average (all sites)** | **15.27** | **1.98** | **1.51** | **18.94** |

**Table 17**
Primary cell phone charging sources and distances from households.

| | Number of households reporting each mobile phone charging source as "primary" | | | | | Sum (households reporting a "primary" source) | Average distance to the primary source (km) |
|---|---|---|---|---|---|---|---|
| | Home charger | Commercial | Community charging station | Solar panel | Other | | |
| Bonsaaso (GHA) | 4 | 3 | 2 | | 1 | 10 | 3.2 |
| Dertu (KEN) | | 2 | | | 1 | 3 | 52.5 |
| Ikaram (NGA) | 153 | | | | 1 | 154 | 0.02 |
| Mayange (RWA) | 2 | 8 | 1 | | 2 | 13 | 40.9 |
| Mwandama (MWI) | 5 | 3 | 3 | | 1 | 12 | 1.6 |
| Pampaida (NGA) | | 4 | 3 | | | 7 | 2.7 |
| Potou (SEN) | 35 | 112 | 11 | 14 | 23 | 195 | 3.3 |
| Ruhiira (UGA) | 4 | 25 | | | | 29 | 1.5 |
| Tiby (MLI) | 9 | 4 | 5 | 1 | 1 | 20 | 7.3 |
| **Average (all sites)** | | | | | | | **12.6** |

**Table 18**
Primary larger rechargeable battery charging sources and distances from households.

| | Number of households reporting each large rechargeable battery charging source as "primary" | | | | | Sum (households reporting a "primary" source) | Average distance to the primary source (km) |
|---|---|---|---|---|---|---|---|
| | Home charger | Commercial | Community charging station | Solar panel | Other | | |
| Bonsaaso (GHA) | | 1 | 1 | | | 2 | 1.5 |
| Dertu (KEN) | | | | | | 0 | N/A |
| Ikaram (NGA) | 1 | 2 | | | | 3 | 5.3 |
| Mayange (RWA) | | 2 | | | | 2 | 7 |
| Mwandama (MWI) | 1 | 22 | 22 | | 1 | 46 | 4.5 |
| Pampaida (NGA) | | 1 | | | | 1 | 15 |
| Potou (SEN) | | 31 | 11 | 2 | | 44 | 4.8 |
| Ruhiira (UGA) | | 13 | | | | 13 | 12.7 |
| Tiby (MLI) | 1 | 21 | 1 | 3 | | 26 | 11.0 |
| **Average (all sites)** | | | | | | | **7.7** |

the house. However, the use of smoke removal devices (including a chimney, smoke hood, fan or other removal device) was low in all villages except Ikaram where additional ventilation in local kitchen structures was considered a smoke removal device (Table 26).

*Lighting*

The most commonly used energy source for lighting was kerosene, which was reported as the primary or secondary energy source by 85% of the households on average across the sites, followed by dry cell batteries, at 39%, and candles, at 21% (Table 27). Use of all other energy sources for lighting was low in all sites, except in Ikaram, where grid electricity was the primary or secondary source for 87% of households. Use of solar photovoltaic systems was reported only in Potou, where it was the primary or secondary source for 12% of households.

Data presented so far show the expenditures on different energy sources used for lighting and which lighting sources were the households' primary or secondary lighting sources. We do not have precise information on the physical quantities of fuel (e.g. liters of kerosene), and while most households use wick lamps – either of the type made from recycled food cans or the "hurricane" type – we do not have technical information on the lighting devices utilized (e.g. their luminous efficacy), so we are unable to quantitatively look at the differences in the level of lighting "service". We do however have information on the hours of lighting obtained from each source. This is shown in Table 28 in the form of both total hours of lighting (self-reported) from each source and the fractional use of that particular source for each site. For all sites in Eastern and Southern Africa, lighting hours are low, which is consistent with the generally lower income levels at these sites compared to the West African sites. Given the typical kerosene prices in these sites at the time of the survey, kerosene lighting hour data in the East African sites reflect the fuel use consumption rates of a simple kerosene wick lamp. Kerosene is clearly the dominant lighting technology of the poor. The exceptions are Dertu (KEN), where households also relied heavily on energy from dry cell batteries, which might reflect a reliance on flashlights consistent with a pastoralist nature of the population, and Ikaram (NGA), which had significant grid coverage. In Ikaram, households with grid connections reported using nearly twice as many total hours per week of light in the home than those without: 109 total average hours per week from all sources (separate bulbs and lamps are counted cumulatively), versus 62 hours per week from all sources for those households relying on non-grid lighting. We do not have an explanation for the high use of dry cell batteries in Pampaida (NGA), Potou (SEN) and Tiby (MLI).

## Discussion

This section summarizes some of the energy use patterns the Millennium Villages sites on a site-by site basis, starting with the sites

**Table 19**
Total fuel expenses per household per year (USD) (average over all households, does not include electricity expenditures).

| | Kerosene | Fuelwood | Charcoal | Candles | All other fuels | Sum |
|---|---|---|---|---|---|---|
| Bonsaaso (GHA) | 51.37 | 5.69 | 2.93 | 18.53 | 1.52 | 80.04 |
| Ikaram (NGA) | 48.81 | 15.35 | 6.98 | 1.90 | 0.00 | 73.04 |
| Mayange (RWA) | 11.66 | 24.22 | 0.00 | 1.69 | 0.59 | 38.16 |
| Mbola (TZA) | 33.10 | 5.45 | 4.47 | 0.35 | 0.59 | 43.97 |
| Mwandama (MWI) | 12.08 | 3.97 | 1.88 | 7.31 | 0.40 | 25.64 |
| Pampaida (NGA) | 48.62 | 16.44 | 0.25 | 0.48 | 2.17 | 67.95 |
| Ruhiira (UGA) | 15.10 | 4.83 | 2.09 | 2.44 | 0.70 | 25.16 |
| Tiby (MLI) | 55.80 | 41.66 | 9.39 | 1.16 | 4.10 | 112.11 |
| **Average (all sites)** | **34.57** | **14.70** | **3.50** | **4.23** | **1.26** | **58.26** |

**Table 20**
Total cooking expenses[1] per household per year (USD) (average over all households).

| | Kerosene | Fuelwood | Charcoal | Sum |
|---|---|---|---|---|
| Bonsaaso (GHA) | 4.76 | 4.80 | 1.34 | 10.90 |
| Ikaram (NGA) | 24.67 | 12.95 | 5.94 | 43.57 |
| Mayange (RWA) | 0.51 | 23.63 | 0.00 | 24.14 |
| Mbola (TZA) | 1.86 | 4.32 | 2.97 | 9.16 |
| Mwandama (MWI) | 0.72 | 3.31 | 0.66 | 4.70 |
| Pampaida (NGA) | 15.22 | 14.33 | 0.03 | 29.57 |
| Ruhiira (UGA) | 0.53 | 4.07 | 1.27 | 5.87 |
| Tiby (MLI) | 4.58 | 35.68 | 2.20 | 42.46 |
| **Average (all sites)** | **6.61** | **12.89** | **1.80** | **21.30** |

1) Values in this table are calculated using the expenses per fuel and the fraction of each fuel that was used for cooking.

that are arguably most different from the others. Not all sites stood out in important ways, and therefore not all sites are discussed under a separate heading.

*Ikaram*

Ikaram in Nigeria on the Guinea savanna is a peri-urban site, with higher average income than in all other sites and pre-existing road and electricity infrastructure that is better than that in all other sites. Unlike in any other site, most households had access to the electric grid. Across the sites, the fraction of lighting obtained from grid electricity was the highest in Ikaram, and households here utilized lighting for more hours per day than in any other site. It is possible that the continued use of kerosene for lighting in Ikaram can be explained by the unreliable nature of the electric grid. Unlike in any other site, a large fraction of kerosene was used for cooking, although the majority of cooking was still done with fuelwood. A higher fraction of households than in other sites also cooked in kerosene-powered stoves. The higher incomes in Ikaram may explain the higher fraction of kerosene used for cooking, including starting fires in non-kerosene powered stoves.

**Table 21**
Total lighting and electricity expenses[1] per household per year (USD) (average over all households).

| | Kerosene | Candles | Batteries | Sum |
|---|---|---|---|---|
| Bonsaaso (GHA) | 43.74 | 13.17 | 31.68 | 85.75 |
| Ikaram (NGA) | 23.71 | 1.74 | 5.45 | 30.89 |
| Mayange (RWA) | 10.79 | 1.42 | 13.49 | 25.87 |
| Mbola (TZA) | 30.98 | N/A | N/A | N/A |
| Mwandama (MWI) | 11.10 | 7.22 | N/A | N/A |
| Pampaida (NGA) | 30.12 | 0.40 | 19.85 | 50.32 |
| Potou (SEN) | N/A | N/A | 31.67 | N/A |
| Ruhiira (UGA) | 14.34 | 2.34 | 8.58 | 25.29 |
| Tiby (MLI) | 48.63 | 0.91 | 21.94 | 71.48 |
| **Average (all sites)** | **26.68** | **3.89** | **18.95** | **48.27** |

1) Values in this table are calculated using the expenses per energy type and the fraction of each energy type that was used for lighting and electricity.

**Table 22**
Fraction of cooking done with each fuel (average over all seasons and all households).

| | Fuelwood | Farm residue | Kerosene | Charcoal | Gas/ LPG | All other fuels |
|---|---|---|---|---|---|---|
| Bonsaaso (GHA) | 0.76 | 0.09 | 0.12 | 0.02 | 0.00 | 0.01 |
| Ikaram (NGA) | 0.74 | 0.00 | 0.19 | 0.06 | 0.00 | 0.01 |
| Mayange (RWA) | 0.92 | 0.04 | 0.01 | 0.03 | 0.00 | 0.00 |
| Mbola (TZA) | 0.64 | 0.19 | 0.11 | 0.05 | N/A | 0.00 |
| Mwandama (MWI) | 0.66 | 0.30 | 0.03 | 0.02 | 0.00 | 0.00 |
| Pampaida (NGA) | 0.61 | 0.20 | 0.15 | 0.03 | 0.00 | 0.01 |
| Potou (SEN) | 0.71 | 0.04 | 0.03 | 0.07 | 0.12 | 0.03 |
| Ruhiira (UGA) | 0.84 | 0.13 | 0.01 | 0.02 | 0.00 | 0.00 |
| Tiby (MLI) | 0.77 | 0.08 | 0.10 | 0.02 | 0.00 | 0.03 |
| **Average (all sites)** | **0.74** | **0.12** | **0.08** | **0.04** | **0.02** | **0.01** |

**Table 23**
Amount of fuelwood used for cooking per capita per day (kg)[1].

| | Fuelwood (kg) |
|---|---|
| Bonsaaso (GHA) | 2.08 |
| Ikaram (NGA) | 4.52 |
| Mayange (RWA) | 1.34 |
| Mbola (TZA) | 2.20 |
| Mwandama (MWI) | 2.05 |
| Pampaida (NGA) | 4.01 |
| Potou (SEN) | 1.05 |
| Ruhiira (UGA) | 1.48 |
| Tiby (MLI) | 1.14 |
| **Average (all sites)** | **2.21** |

1) Values in this table are calculated using the fuelwood use per household per day, the number of people per household, and the fraction of households' fuelwood used for cooking.

Ikaram was also the only site with a fairly high use of smoke removal devices for household cooking. Unlike in other sites, there was virtually no use of farm residue in Ikaram for any purpose. The fraction of households who used cell phones was high, and data show that grid access enabled households to charge their cell phone batteries in their homes.

*Dertu*

Dertu in Kenya is characterized by having a population that is partly pastoral, although it is not clear if our surveys reached a representative fraction of pastoral households. The site has low rainfall and low overall population density. At the time when the baseline survey was fielded, access to energy sources was difficult, and the use of any energy sources other than biomass was comparatively low. Compared to other sites, the fraction of fuelwood which was collected was low, and the fraction of households who used kerosene and charcoal was low. Candle use was non-existent. No households had access to the electric grid. Cell phone coverage was also non-existent, and charging sources for cell phone batteries were very distant. Disposable batteries contributed to a high fraction of lighting hours.

*Potou*

Potou in Senegal has low rainfall, below average population density, and a high mean household size. Successful production of onions and other vegetables in the community, ready access to markets in the nearby cities of Dakar and St. Louis, and a government program to bottle LPG in smaller containers and develop distribution chains for LPG, might explain why this was the only site with any LPG use and any solar PV use to speak of. Cell phone use was also high in spite of low household grid access at the time of the survey. Household expenditure on battery purchases was high compared to other sites, and the expenditure on cell phone battery recharging was higher than in any other site. Expenses on cooking fuels were also

**Table 24**
Fraction of all households who named each stove type as their primary stove.

| | Three stone fire | Traditional charcoal stove | Improved charcoal stove | Kerosene stove | Other stove |
|---|---|---|---|---|---|
| Bonsaaso (GHA) | 0.99 | 0.01 | 0.00 | 0.00 | 0.00 |
| Dertu (KEN) | 0.87 | 0.01 | 0.00 | 0.01 | 0.11 |
| Ikaram (NGA) | 0.46 | 0.23 | 0.00 | 0.09 | 0.22 |
| Mayange (RWA) | 0.12 | 0.27 | 0.41 | 0.00 | 0.19 |
| Mbola (TZA) | 0.98 | 0.01 | 0.01 | 0.00 | 0.00 |
| Mwandama (MWI) | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pampaida (NGA) | 0.97 | 0.01 | 0.00 | 0.01 | 0.01 |
| Potou (SEN) | 0.85 | 0.10 | 0.01 | 0.00 | 0.04 |
| Ruhiira (UGA) | 0.96 | 0.00 | 0.01 | 0.02 | 0.01 |
| Tiby (MLI) | 0.83 | 0.09 | 0.00 | 0.00 | 0.08 |
| **Average (all sites)** | **0.80** | **0.07** | **0.05** | **0.01** | **0.06** |

**Table 25**
Total hours spent cooking by primary and secondary cooks in the household per week, (average over all households; number of households in brackets).

| | Hours spent cooking per week by… | | |
|---|---|---|---|
| | …primary cook | …secondary cook | …sum (primary and secondary cook) |
| Bonsaaso (GHA) | 27.4 (292) | 15.4 (172) | 36.5 (292) |
| Ikaram (NGA) | 22.5 (290) | 13.5 (153) | 29.6 (290) |
| Mayange (RWA) | 18.3 (242) | 3.1 (101) | 22.1 (242) |
| Pampaida (NGA) | 27.4 (292) | 17.5 (157) | 37.3 (292) |
| Potou (SEN) | 24.3 (291) | 15.9 (186) | 34.5 (291) |
| Ruhiira (UGA) | 23.5 (299) | 10.9 (152) | 29.0 (299) |
| Tiby (MLI) | 36.0 (284) | 18.1 (88) | 41.6 (284) |
| **Average (all sites)** | **25.6** | **13.5** | **32.9** |

**Table 26**
Smoke exposure; prevalence of separate kitchens and use of smoke removal devices.

| | Fraction of all households where the primary indoor kitchen was an entirely separate room | Fraction of all households who used a smoke removal device while cooking |
|---|---|---|
| Bonsaaso (GHA) | 0.69 | 0.01 |
| Ikaram (NGA) | 0.90 | 0.50* |
| Mayange (RWA) | 0.80 | 0.20 |
| Mbola (TZA) | 0.78 | 0.00 |
| Mwandama (MWI) | 0.70 | 0.05 |
| Pampaida (NGA) | 0.85 | 0.16 |
| Potou (SEN) | 0.75 | 0.02 |
| Ruhiira (UGA) | 0.91 | 0.03 |
| Tiby (MLI) | 0.87 | 0.10 |
| **Average (all sites)** | **0.80** | **0.12** |

* This value is unusually high for Ikaram largely because of a location-specific interpretation of "smoke removal device." Local kitchen construction practices numerous extra vertical spaces, or "slots", between bricks in kitchen walls. This was very common in the site, but rare in others, and Ikaram-based researchers included this design within the definition of "smoke removal device." Thus, for the Ikaram site, the data for this question is not strictly comparable to the other sites. Moreover, the high positive response rate for these slotted kitchen walls effectively masks the data for chimneys and similar devices, though anecdotal reports from local researchers are that chimneys and similar smoke removal devices are rare.

higher than in any other site. The fraction of households who used charcoal was high and the fraction of households who used kerosene was low. Possibly due to the large average household size, fuelwood use per capita was low.

*Tiby*

Tiby, Mali, in the Sahel is characterized by low rainfall and a large average household size. Expenditures on energy were high; households in Tiby spent more than households in almost all other sites on purchases of fuelwood, charcoal, and kerosene. Although the majority of fuelwood collection was done by women, male fuelwood collection in Tiby was high compared to most other Millennium Villages sites, both in terms of number of male gatherers and in terms of the fraction of households' fuelwood gathered by adult males. The fraction of households who used charcoal was high compared to other sites. Like in Potou, fuelwood use per capita was low, possibly due to the large average household size. This was the only site with any use of pack animals to gather fuelwood, which allowed households to go farther to gather fuelwood without an inordinately high amount of time spent.

*Pampaida*

Both the fraction of households who used farm residue and the fraction that used dung/manure were higher in Pampaida, Nigeria, than in any other site. Like in Tiby, male fuelwood collection was high in Pampaida, both in terms of number of male gatherers and in terms of the fraction of households' fuelwood gathered by adult males. The fraction of lighting done with dry cell batteries was high compared to other sites.

*Bonsaaso*

Bonsaaso, Ghana, is the only Millennium Villages sites located in the rainforest. The population here grew more cash crops than those in other sites. Household expenditure on energy in Bonsaaso was one of the highest across the sites. Like in Tiby (MLI) and Pampaida (NGA), the number of male fuelwood gatherers in Bonsaaso was high, as was the fraction of households' fuelwood gathered by adult males. The ratio of energy expenses for electricity compared to expenses for cooking was much higher in Bonsaaso than in other sites.

*Mayange (RWA), Mbola (TZA), Ruhiira (UGA), Mwandama (MWI)*

All these sites are located in East and South Africa, rely on maize as a staple food, and, with the exception of Mayange, are far from any urban centers. None of these sites had any significant presence of grid electricity, solar PV, or any significant use of LPG. The generally lower incomes in these sites compared to those in West Africa might explain the low total expenditures on lighting, disposable batteries and battery charging. Three of these sites – Mayange, Ruhiira, and Mwandama – show between USD 12 and USD 20 annual expenditure on kerosene and candles for lighting. In the absence of any modern lighting sources, these are amongst the lowest expenditures reported in any of the recent literature in the world.

## Conclusion

This study confirms and adds quantitative information to some accepted aspects of energy use in sub-Saharan Africa, including the heavy reliance on biomass as cooking fuel, the dominant use of kerosene for household lighting, and the very low rate of household

**Table 27**
Fraction of all households naming each source as primary or secondary energy source for lighting.

| | Kerosene | Dry cell batteries | Candles | Grid electricity connection in the home | Rechargeable batteries | Solar PV | Other |
|---|---|---|---|---|---|---|---|
| Bonsaaso (GHA) | 1.00 | 0.57 | 0.18 | 0.00 | 0.00 | 0.00 | 0.01 |
| Dertu (KEN) | 0.37 | 0.93 | 0.00 | 0.00 | 0.01 | 0.00 | 0.11 |
| Ikaram (NGA) | 0.95 | 0.01 | 0.01 | 0.87 | 0.05 | 0.00 | 0.01 |
| Mayange (RWA) | 0.94 | 0.02 | 0.14 | 0.00 | 0.00 | 0.00 | 0.04 |
| Mbola (TZA) | 1.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mwandama (MWI) | 0.97 | 0.00 | 0.52 | 0.02 | 0.00 | 0.00 | 0.11 |
| Pampaida (NGA) | 0.88 | 0.90 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Potou (SEN) | 0.38 | 0.57 | 0.60 | 0.05 | 0.05 | 0.12 | 0.01 |
| Ruhiira (UGA) | 1.00 | 0.03 | 0.25 | 0.00 | 0.00 | 0.00 | 0.02 |
| Tiby (MLI) | 0.98 | 0.83 | 0.00 | 0.00 | 0.01 | 0.00 | 0.05 |
| **Average (all sites)** | **0.85** | **0.39** | **0.21** | **0.09** | **0.01** | **0.01** | **0.04** |

**Table 28**
Total lighting hours per household per week provided by primary and secondary lighting sources together (average over all households) (fractions of total lighting hours in brackets).

| | Kerosene | Grid electricity | Dry cell batteries | Candles | Re-chargeable batteries | Solar PV | Other | Total hours all sources |
|---|---|---|---|---|---|---|---|---|
| Bonsaaso (GHA) | 74 (0.82) | 0 (0.00) | 12 (0.13) | 4 (0.05) | 0 (0.00) | 0 (0.00) | 0 (0.00) | 90 |
| Dertu (KEN) | 14 (0.44) | 0 (0.00) | 15 (0.49) | 0 (0.00) | 0 (0.00) | 0 (0.00) | 2 (0.07) | 31 |
| Ikaram (NGA) | 22 (0.19) | 95 (0.80) | 0 (0.00) | 0 (0.00) | 1 (0.00) | 0 (0.00) | 0 (0.00) | 118 |
| Mayange (RWA) | 15 (0.87) | 0 (0.00) | 0 (0.00) | 2 (0.10) | 0 (0.00) | 0 (0.00) | 0 (0.02) | 18 |
| Mwandama (MWI) | 15 (0.72) | 1 (0.05) | 0 (0.00) | 4 (0.21) | 0 (0.00) | 0 (0.00) | 0 (0.02) | 21 |
| Pampaida (NGA) | 44 (0.50) | 0 (0.00) | 43 (0.49) | 0 (0.01) | 0 (0.00) | 0 (0.00) | 0 (0.00) | 88 |
| Potou (SEN) | 7 (0.25) | 1 (0.05) | 8 (0.29) | 7 (0.28) | 1 (0.04) | 2 (0.09) | 0 (0.00) | 27 |
| Ruhiira (UGA) | 20 (0.89) | 0 (0.00) | 0 (0.01) | 2 (0.10) | 0 (0.00) | 0 (0.00) | 0 (0.01) | 22 |
| Tiby (MLI) | 35 (0.79) | 0 (0.00) | 7 (0.16) | 0 (0.00) | 0 (0.01) | 0 (0.00) | 2 (0.04) | 44 |
| **Average (all sites)** | **27 (0.61)** | **11 (0.10)** | **10 (0.18)** | **2 (0.08)** | **0 (0.01)** | **0 (0.01)** | **1 (0.02)** | **51** |

connections to the electricity grid. Given the negative effects of using biomass as fuel – stress on local biomass resources, health problems caused by indoor smoke, and the burden of fuel gathering – and the importance of energy access for economic development, it would be desirable to move towards more modern, more efficient and cleaner sources of energy. Unfortunately, programs for expansion of use of modern cooking fuels and electricity connections are unlikely to keep pace with rapid population growth in the region, and the number of people relying on traditional biomass for cooking is expected to increase over the next 25 years (Brew-Hammond, 2010).

The Millennium Villages Project has implemented development interventions to address multiple energy issues, including programs to extend the national electricity grid and support local connections to households and businesses; programs to introduce improved biomass cookstoves and portable LED lanterns for light and other household energy services (such as phone charging); and programs to support various applications of mechanical power and other energy systems for income generation, particularly agriculture and related processing (Adkins et al., 2010a, 2010b, 2010c). As part of the Millennium Villages Project, follow-up surveys will be conducted in the villages at years 3 and 5 of the project in part to assess changes in the key metrics surveyed in this study, as well as other metrics relevant to the energy sector.

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