**Online Supplementary Material**

# Biomass availability, energy consumption and biochar production in rural households of Western Kenya

Dorisel Torres-Rojas[a], Johannes Lehmann[a]*, Peter Hobbs[a], Stephen Joseph[b], Henry Neufeldt[c]

[a] Department of Crop and Soil Sciences, Cornell University, Ithaca, New York 14853

[b] University of South Wales, NSW 2052, Australia

[c] World Agroforestry Center (ICRAF), Nairobi, Kenya

*corresponding author; phone: 607-254-1236; fax: 1-607-255-3207; email: CL273@cornell.edu

## Supplementary Materials and Methods

*1 Description of stoves*

### 1.1 Traditional stove

Cooking activities in the western part of Kenya are traditionally performed using an open fire surrounded by three stones (Figure S1). The three stones create a shield around the open fire and also serve as pot holders. The fire is started at the center of the three stones and it is usually allowed to burn uncontrolled, leading to incomplete combustion [1].

### 1.2 Improved Chepkube stove

The Chepkube stove was developed by women of the Kalenjin tribe and is considered a wood-saving stove. It is made out of bricks, stones and mud and has two or three burners (Figure S2). The stove also has an opening which serves as a warming oven. There are various models of the stove and they vary according to the design women prefer. According to local information, the stove is also known as “kuni mbili” (two pieces of wood) because a woman can cook an entire meal with only two pieces of wood.

### 1.3 Pyrolysis stove

The pyrolysis stove is an anila-type stove developed by U.N. Ravikumar, an environmentalist and engineer with the Director of the Centre for Appropriate Rural Technologies (CART) at India’s National Institute of Engineering. This stove is a first generation stove modified to suit the cooking conditions and feedstocks available in Kenya. The stove serves two purposes: cooking with biomass energy and the production

of biochar. The stove differs from traditional combustion stoves because it has two concentric cylinders of different diameters. The outer cylinder is the pyrolysis chamber while the inner cylinder is the combustion chamber (Figure S3). Biomass is placed in the pyrolysis chamber and wood fire is ignited in the combustion chamber. Heat from the fire in the combustion chamber pyrolyzes the biomass. Gases from the biomass escape to the combustion chamber where they add to the cooking flame as the ring of biomass turns to biochar.

Figure S1. Traditional three-stone fire cookstove

Figure S2. Improved Chepkube cookstove

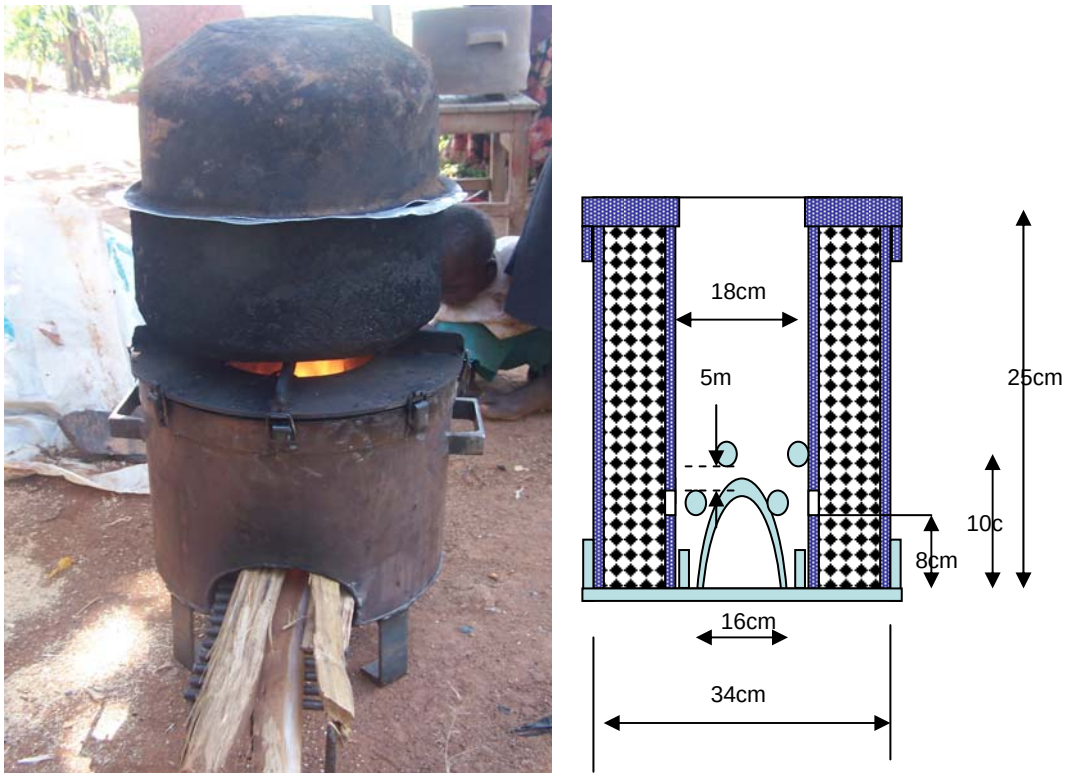


Figure S3. First generation pyrolysis stove and cross sectional diagram

## Supplementary Results

Table S1. Published wood density, standing stock biomass totals and mean annual increments for a single species stand.

| Species | Wood density (g $cm^{-3}$) | Standing biomass for each species from literature (Mg $ha^{-1}$) | Mean annual increment from literature (Mg $ha^{-1}$ $y^{-1}$) | Reference |
|---|---|---|---|---|
| *Acacia abyssinica* | 0.62 [2] | 87.6 | 16.5 | [3] |
| *Acacia nilotica* | 0.68 [4] | 23.2 | 4.6 | [5] |
| *Acrocarpus fraxinisfolius* | 0.50 [6] | 3.4 | 1.0 | [7] |
| *Afrocarpus falcatus* | 0.62 [2] | 21.0 | 1.9 | [8] |
| *Albizia spp.* | 0.56 [6] | 37.1 | 6.8 | [9] |
| *Azadirachta indica* | 0.62 [2] | 86.9 | 14.5 | [10] |
| *Calliandra calothyrsus* | 0.58 [6] | 3.5 | 1.0 | [7] |
| *Cassia siamea* | 0.62 [2] | 121.0 | 12.1 | [11] |
| *Casuarina equisetifolia* | 0.62 [2] | 199.9 | 36.2 | [12] |
| *Cedrela odorata* | 0.45 [6] | 1.0 | 0.3 | [7] |
| *Cordia africana* | 0.47 [6] | 33.0 | 6.2 | [3] |
| *Croton megalocarpus* | 0.53 [6] | 64.9 | 5.9 | [4] |
| *Cupressus lusitanica* | 0.39 [6] | 47.0 | 8.3 | [13] |
| *Eucalyptus citriodora* | 0.62 [2] | 106.0 | 11.8 | [11] |
| *Eucalyptus saligna* | 0.62 [2] | 107.0 | 11.8 | [11] |
| *Grevillea robusta* | 0.51 [6] | 9.8 | 2.8 | [7] |
| *Jacaranda mimosifolia* | 0.33 [6] | 105.1 | 9.0 | [14] |
| *Leucaena leucocephala* | 0.62 [2] | 46.3 | 6.6 | [15] |
| *Markhamia lutea* | 0.47 [6] | 30.6 | 15.3 | [16] |
| *Measopsis eminii* | 0.40 [6] | 75.4 | 3.8 | [17] |
| *Melia azedarach* | 0.42 [6] | 150.1 | 25.0 | [10] |
| *Milicia excelsa* | 0.58 [6] | 0.3 | 0.1 | [18] |
| *Olea capensis* | 0.77 [6] | 395.0 | 15.8 | [4] |
| *Polycias fulva* | 0.24 [6] | 51.9 | 1.5 | [19] |
| *Prunus africanum* | 0.60 [6] | 212.3 | 6.1 | [19] |
| *Senna spectabilis* | 0.62 [2] | 43.6 | 21.8 | [20] |
| *Sesbania sesban* | 0.43 [6] | 85.9 | 16.1 | [3] |
| *Tamarindus indica* | 0.62 [2] | 32.5 | 3.0 | [4] |
| *Tephrosia spp.* | 0.62 [2] | 25.6 | 17.0 | [21] |
| *Terminalia superba* | 0.46 [6] | 77.0 | 5.9 | [22] |
| *Xanthophyllum gillettii* | 0.69 [6] | 231.1 | 6.6 | [19] |
| *Spathodea campanulata* | 0.23 [6] | 187.5 | 7.5 | [23] |
| *Bridellia micrantha* | 0.51 [6] | 88.4 | 10.1 | [4] |
| *Ricinus spp.* | 0.62 [2] | 16.3 | 16.3 | [24] |

Table S2. Total standing biomass and usable biomass for pyrolysis for each type of feedstock in the farm (N=50)

| | | Standing Biomass | | | | Usable Biomass for Pyrolysis | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Farmer** | **Farm Size (ha)** | **Tree Standing Weight (Mg ha$^{-1}$)** | **Maize Residue (Mg ha$^{-1}$)** | **Banana Biomass (Mg ha$^{-1}$)** | **Collard Stalks Biomass (Mg ha$^{-1}$)** | **Tree Biomass (Mg ha$^{-1}$)** | **Usable Maize Residue (Mg ha$^{-1}$)** | **Usable Banana (Mg ha$^{-1}$)** | **Usable Collard Stalks Biomass (Mg ha$^{-1}$)** | **Total Biomass (Mg ha$^{-1}$)** | **Total Usable Biomass (Mg ha$^{-1}$)** | **% of Total** |
| 1 | 0.57 | 6.94 | 5.81 | 0.65 | 0.03 | 3.87 | 5.03 | 0.65 | 0.03 | 13.43 | 9.58 | 71.4 |
| 2 | 0.75 | 6.97 | 10.42 | 0.00 | 0.29 | 0.72 | 10.42 | 0.00 | 0.29 | 17.67 | 11.43 | 64.7 |
| 3 | 1.00 | 1.56 | 5.81 | 0.00 | 0.00 | 0.26 | 5.81 | 0.00 | 0.00 | 7.38 | 6.08 | 82.4 |
| 4 | 1.72 | 4.14 | 6.01 | 0.38 | 0.28 | 0.41 | 5.11 | 0.30 | 0.28 | 10.81 | 6.10 | 56.5 |
| 5 | 2.87 | 4.09 | 3.67 | 0.00 | 0.09 | 0.49 | 3.42 | 0.00 | 0.09 | 7.85 | 4.00 | 51.0 |
| 6 | 0.66 | 3.17 | 7.48 | 0.00 | 0.00 | 0.33 | 6.38 | 0.00 | 0.00 | 10.65 | 6.71 | 63.1 |
| 7 | 2.03 | 0.11 | 2.61 | 0.00 | 0.00 | 0.01 | 2.35 | 0.00 | 0.00 | 2.72 | 2.37 | 87.0 |
| 8 | 0.25 | 21.92 | 7.49 | 0.00 | 0.00 | 5.44 | 6.55 | 0.00 | 0.00 | 29.41 | 12.00 | 40.8 |
| 9 | 0.57 | 2.31 | 6.60 | 0.00 | 0.00 | 0.28 | 5.65 | 0.00 | 0.00 | 8.91 | 5.93 | 66.6 |
| 10 | 1.08 | 1.20 | 7.62 | 0.77 | 0.00 | 0.10 | 6.53 | 0.62 | 0.00 | 9.59 | 7.24 | 75.5 |
| 11 | 0.31 | 0.00 | 5.88 | 2.00 | 0.00 | 0.00 | 5.04 | 1.60 | 0.00 | 7.87 | 6.63 | 84.2 |
| 12 | 1.31 | 2.50 | 4.85 | 0.00 | 0.12 | 0.32 | 4.16 | 0.00 | 0.12 | 7.48 | 4.60 | 61.5 |
| 13 | 2.78 | 0.62 | 0.54 | 0.07 | 0.00 | 0.07 | 0.46 | 0.06 | 0.00 | 1.23 | 0.59 | 47.7 |
| 14 | 3.11 | 2.39 | 2.55 | 0.00 | 0.00 | 0.50 | 2.18 | 0.00 | 0.00 | 4.93 | 2.69 | 54.5 |
| 15 | 1.01 | 23.84 | 1.47 | 0.00 | 0.16 | 3.15 | 1.47 | 0.00 | 0.16 | 25.47 | 4.77 | 18.7 |
| 16 | 2.17 | 11.12 | 0.59 | 0.44 | 0.00 | 1.26 | 0.52 | 0.36 | 0.00 | 12.16 | 2.13 | 17.5 |
| 17 | 5.33 | 7.45 | 0.28 | 0.14 | 0.00 | 0.88 | 0.24 | 0.12 | 0.00 | 7.87 | 1.24 | 15.8 |
| 18 | 0.81 | 2.37 | 4.89 | 0.19 | 0.00 | 0.34 | 4.34 | 0.15 | 0.00 | 7.45 | 4.83 | 64.8 |
| 19 | 2.78 | 4.90 | 0.66 | 0.17 | 0.10 | 0.58 | 0.59 | 0.13 | 0.10 | 5.83 | 1.40 | 23.9 |
| 20 | 2.87 | 1.49 | 0.71 | 0.00 | 0.00 | 0.17 | 0.63 | 0.00 | 0.00 | 2.20 | 0.80 | 36.6 |

| | | Standing Biomass | | | | Usable Biomass for Pyrolysis | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 2.66 | 4.34 | 2.22 | 0.77 | 0.00 | 0.56 | 1.97 | 0.61 | 0.00 | 7.32 | 3.15 | 43.0 |
| 22 | 0.99 | 12.10 | 5.84 | 0.52 | 0.06 | 1.49 | 5.18 | 0.41 | 0.06 | 18.52 | 7.13 | 38.5 |
| 23 | 2.10 | 13.28 | 0.24 | 0.25 | 0.00 | 1.88 | 0.22 | 0.20 | 0.00 | 13.77 | 2.30 | 16.7 |
| 24 | 4.05 | 7.71 | 1.14 | 0.11 | 0.00 | 0.89 | 1.01 | 0.08 | 0.00 | 8.96 | 1.99 | 22.2 |
| 25 | 4.63 | 12.91 | 0.28 | 0.14 | 0.08 | 2.10 | 0.26 | 0.11 | 0.08 | 13.42 | 2.55 | 19.0 |
| 26 | 1.16 | 2.60 | 3.13 | 1.12 | 0.00 | 0.48 | 2.34 | 1.12 | 0.00 | 6.84 | 3.94 | 57.6 |
| 27 | 1.49 | 7.53 | 1.12 | 0.35 | 0.00 | 0.64 | 0.99 | 0.28 | 0.00 | 8.99 | 1.91 | 21.2 |
| 28 | 1.08 | 8.99 | 1.51 | 0.00 | 0.00 | 1.00 | 1.06 | 0.00 | 0.00 | 10.50 | 2.06 | 19.6 |
| 29 | 1.41 | 21.05 | 3.39 | 0.00 | 0.00 | 3.70 | 2.20 | 0.00 | 0.00 | 24.44 | 5.90 | 24.1 |
| 30 | 1.71 | 8.92 | 2.70 | 0.20 | 0.08 | 1.00 | 2.37 | 0.16 | 0.08 | 11.90 | 3.60 | 30.3 |
| 31 | 1.37 | 14.21 | 1.65 | 0.21 | 0.00 | 1.58 | 1.47 | 0.17 | 0.00 | 16.08 | 3.21 | 20.0 |
| 32 | 1.44 | 12.98 | 3.23 | 0.64 | 0.12 | 1.71 | 2.87 | 0.51 | 0.12 | 16.97 | 5.21 | 30.7 |
| 33 | 0.83 | 1.91 | 2.50 | 0.50 | 0.00 | 0.18 | 2.22 | 0.40 | 0.00 | 4.91 | 2.80 | 57.1 |
| 34 | 1.74 | 4.61 | 2.89 | 0.80 | 0.01 | 0.30 | 2.89 | 0.80 | 0.01 | 8.32 | 4.01 | 48.2 |
| 35 | 1.55 | 14.23 | 0.00 | 0.00 | 0.00 | 2.28 | 0.00 | 0.00 | 0.00 | 14.23 | 2.28 | 16.0 |
| 36 | 1.33 | 1.31 | 0.59 | 0.68 | 0.07 | 0.09 | 0.52 | 0.54 | 0.07 | 2.64 | 1.22 | 46.2 |
| 37 | 5.67 | 3.87 | 0.77 | 0.15 | 0.01 | 0.58 | 0.77 | 0.15 | 0.01 | 4.80 | 1.52 | 31.5 |
| 38 | 2.23 | 7.83 | 4.26 | 0.13 | 0.09 | 0.82 | 3.94 | 0.10 | 0.09 | 12.30 | 4.95 | 40.2 |
| 39 | 1.40 | 3.46 | 3.03 | 0.34 | 0.00 | 0.38 | 2.80 | 0.34 | 0.00 | 6.83 | 3.52 | 51.6 |
| 40 | 2.71 | 3.52 | 0.10 | 0.60 | 0.00 | 0.37 | 0.09 | 0.48 | 0.00 | 4.23 | 0.95 | 22.5 |
| 41 | 1.79 | 9.99 | 2.72 | 0.13 | 0.08 | 2.31 | 1.61 | 0.10 | 0.08 | 12.93 | 4.11 | 31.8 |
| 42 | 0.75 | 12.91 | 0.85 | 1.43 | 0.00 | 2.23 | 0.64 | 1.29 | 0.00 | 15.19 | 4.15 | 27.3 |
| 43 | 3.11 | 5.89 | 1.30 | 0.17 | 0.00 | 0.51 | 1.15 | 0.13 | 0.00 | 7.35 | 1.80 | 24.5 |
| 44 | 0.66 | 2.90 | 1.99 | 0.85 | 0.00 | 0.42 | 1.75 | 0.68 | 0.00 | 5.74 | 2.85 | 49.6 |
| 45 | 0.93 | 2.36 | 0.83 | 0.00 | 0.00 | 0.32 | 0.74 | 0.00 | 0.00 | 3.19 | 1.06 | 33.2 |
| 46 | 0.98 | 22.18 | 1.96 | 0.24 | 0.00 | 2.39 | 1.70 | 0.19 | 0.00 | 24.38 | 4.28 | 17.5 |
| 47 | 1.70 | 5.69 | 0.76 | 0.00 | 0.00 | 0.94 | 0.68 | 0.00 | 0.00 | 6.46 | 1.62 | 25.0 |
| 48 | 0.84 | 9.27 | 1.60 | 2.21 | 0.00 | 1.47 | 1.42 | 1.76 | 0.00 | 13.08 | 4.65 | 35.6 |
| 49 | 1.40 | 0.00 | 2.20 | 0.34 | 0.00 | 0.00 | 2.02 | 0.27 | 0.00 | 2.54 | 2.29 | 90.2 |
| 50 | 0.77 | 2.92 | 1.28 | 0.31 | 0.03 | 0.32 | 1.09 | 0.25 | 0.03 | 4.54 | 1.70 | 37.4 |

Table S3. High heating value (HHV), low heating value (LHV) and hydrogen (H) content for feedstocks in the farm and biochar produced during cooking; LHV was calculated using the formula: LHV=HHV-23.96(9H) (means ±SD; N=3 for all samples; only for biochars, field replicates were taken, all others are means of triplicate analyses and therefore SD is not shown).

| | **Biomass** | | | **Biochar** | | |
|---|---|---|---|---|---|---|
| **Feedstock** | **HHV (MJ kg$^{-1}$)** | **LHV (MJ kg$^{-1}$)** | **H (%)** | **HHV (MJ kg$^{-1}$)** | **LHV (MJ kg$^{-1}$)** | **H (%)** |
| Bananas | 13.1[a] | ND | ND | ND | ND | ND |
| Mixed wood | 18.4 | 17.2 | 6.0 | 18.4 | 17.2 | 2.1±0.28 |
| Maize stover | 18.5 | 17.3 | 5.5 | 21.6±2.0 | 20.9±1.9 | 3.6±0.40 |
| Maize cobs | 18.2 | 16.9 | 6.1 | 24.1±1.7 | 23.3±1.6 | 3.9±0.30 |
| Sawdust | 18.6 | 17.4 | 5.6 | 21.8±2.1 | 20.9±2.0 | 4.0±0.30 |
| Collar green stalks | 16.8 | 15.5 | 6.0 | ND | ND | ND |

[a] data taken from Tock, JY et al. [25]

ND not determined

Table S4. Heating values and hydrogen content for wood char and biochar produced during cooking tests with the three stone traditional stove, an improved Chepkube stove and a pyrolysis stove (N=3; means ±SD).

| Type of Stove | N | Wood Char HHV (MJ $kg^{-1}$) | Biochar HHV (MJ $kg^{-1}$) | Wood Char LHV (MJ $kg^{-1}$) | Biochar LHV (MJ $kg^{-1}$) | H Wood Char (%) | H Biochar (%) |
|---|---|---|---|---|---|---|---|
| Three stone | 9 | 27.7±1.6 | N/A | 27.3±1.6 | N/A | 2.2±0.22 | N/A |
| Chepkube | 10 | 26.8±1.6 | N/A | 26.4±1.5 | N/A | 2.0±0.23 | N/A |
| Pyrolysis | 19 | 26.6±2.3 | 22.6±2.1 | 26.2±2.3 | 21.8±2.1 | 2.0±0.26 | 3.8±0.40 |

N/A not applicable; HHV high heating value; LHV low heating value

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