Supporting Online Material

Materials and Methods

<u>Household fuel use database (main text Fig 1)</u>

Estimating the greenhouse gas implications of current and future energy consumption in sub-Saharan Africa requires data on woodfuel (firewood and charcoal) production at the aggregate national-level; estimating its health effects requires data at the disaggregate household-level. To develop current estimates and future projections of household energy consumption, we integrated several data sources, described below.

Total biomass fuel production and consumption

As part of their international forest products database, the United Nations Food and Agriculture Organization (FAO) maintains annual production and trade data for fuelwood and charcoal at the national level based on information submitted by national governments or, in the absence of national submissions, based on their own estimates. This database includes recent wood production and trade estimates from nearly every country in the world, including 41 sub-Saharan African countries. The FAO data for 2000, including woodfuel and charcoal production, trade, and consumption are shown in Table S1.

Similarly, The International Energy Agency (IEA) maintains a database of national-level energy balances, which includes supply (production and trade) as well as transformation and final consumption (*S1* - *S3*). While the main focus of the IEA is on OECD countries, their database also covers many countries in the developing world, including 21 countries in sub-Saharan Africa as well as 26 additional countries aggregated into “other Africa”. The IEA data are disaggregated by sectors of the economy and include a category for residential consumers. These data include a category of “combustible renewables and waste”, which, in sub-Saharan Africa, consists almost exclusively of woodfuels. Unlike the FAO, the IEA also publishes data on commercial fuels like kerosene, LPG and electricity that are used within the residential sector. Table S2 shows national level woodfuel and charcoal data from the IEA including details of the sources for each entry and Table S3 shows the IEA’s estimates of wood and fossil-based fuels consumed solely within the residential sector in 21 individual countries and the aggregate group of "other African" countries. Like the FAO, approximately one third of the IEA data is derived from direct submissions from national sources with the remainder based on their own estimates.

Data were checked for (i) consistency of estimates for each fuel type from FAO and IEA; and (ii) consistency of estimates for across fuel types from IEA. When FAO and IEA estimates were consistent, we used FAO data for biomass fuels and IEA data for commercial fossil fuels. However, in a few cases where the FAO gave woodfuel estimates that were far lower than IEA estimates, and IEA data on consumption of petroleum-based fuels did not indicate a level of consumption consistent with lower woodfuel usage, we used IEA data [or, in the case of Kenya, reliable national survey data (*S4*)]. In these cases, relying on alternate data provided more realistic figures based on minimal household energy needs. In addition to Kenya, other countries where FAO data were not used, in favor of IEA data are: Angola, South Africa, Sudan, and Zambia. Together with Kenya, these countries constitute 20% of the region's population. By FAO estimations, they were responsible for only 10% of the region's firewood consumption and 14% of the region's charcoal consumption in 2000. With the IEA and Kenyan estimations the same countries constitute 24% of firewood and 30% of charcoal consumption. Thus, using IEA fuelwood data makes these countries more representative with respect to firewood consumption and gives higher weight to charcoal, which is consistent with our knowledge of the region and several national-level studies of woodfuel consumption that have been conducted (*S5 - S6*) showing that these countries should have disproportionately higher, rather than lower, charcoal consumption relative to the regional norm. Table S4 shows the final baseline estimates and the sources of the data for 41 countries in sub-Saharan Africa for which data was available.

Proportion of households

National-level data in Table S4 are sufficient to estimate aggregate impacts of woodfuel consumption, such as those on greenhouse gas emissions. However, estimating the health effects of household energy use (i.e. from exposure to indoor smoke from solid fuel consumption) requires household-level data. Data at the household scale also help develop projections of future patterns of fuel consumption based on the structure of the energy economy. For micro-scale (household) data, we relied on a information compiled by the World Bank, which publishes an annual compilation of African Development Indicators [see (*S7*) for the most recent edition]. This series contains socioeconomic, demographic and macroeconomic data on the entire region including some general data on energy consumption. It also includes the results of detailed household-level surveys for a subset of countries in the region. These data report the primary household cooking fuel in both rural and urban areas compiled from nationally representative welfare monitoring surveys since the early 1990s. The most recently available data presented in the World Bank's African Development Indicators series are shown in Table S5.

<u>Household energy scenarios (Main text Table 1 and Fig 2)</u>

Using the national-level consumption data in Table S4 and the household-level fuel choice data in Table S5 as common baselines for sub-Saharan Africa's residential energy consumption in the year 2000, we developed five scenarios based on divergent patterns of future household fuel consumption. Each scenario presents a possible path that the region might follow if similar policies were implemented in each country. In actuality, countries in the region may follow very different paths, in which case future emissions could be modeled by a linear combination of different scenarios.

The scenarios were designed around residential energy consumption for basic needs like cooking and space heating. These end-uses represent the largest fraction of household energy use in sub-Saharan Africa and have the largest consequences on health and environmental change. Thus, we focus on four main household fuels: firewood, charcoal, kerosene, and LPG. Although electricity can also be used for satisfying these needs, there is evidence showing that even when people in sub-Saharan Africa have access to electricity, they rarely use it for the bulk of their cooking or space heating needs, preferring to use it for lighting and running appliances while using cheaper, low quality fuels for cooking and heating. For example, in Kenya, roughly 15% of the population has access to electricity, but only 4% of the population use electricity for any cooking at all, and less than 1% consider it their "main" cooking fuel (*S4, S7*). Similarly, in Cameroon and Cote d'Ivoire, 50 and 65% of the population have access to electricity but no households report electricity as their primary cooking fuel (*S8*).

Population forecasts

We used the medium variant of the United Nations estimates of future population and urbanization (*S9, S10*). UN forecasts of total population extend to 2050, while the projections of the proportion of the population in urban areas extend only to 2030. In order to bring the urbanization projections forward to 2050 we extended the existing projections by extrapolating to 2050, for individual countries, then aggregated to the region by population-weighting (Main Text Fig 2, Panel 1). In all but 6 countries, a quadratic curve provided the best fit for extrapolating the 2000-2030 projections out to 2050. In these six countries, quadratic curves fit to the urban population projections peaked soon after 2030 and started to decline before 2050, which is an implausible outcome. For these countries, a logarithmic curve was used instead.

Fuelwood harvesting sustainability

Linking loss of forest cover to woodfuel consumption is not straightforward. Currently 3.6 million km^2 (15%) of SSA is forested land (based on ecosystem classifications defined by the International Geosphere-Biosphere Programme (IGBP)). “Forest” land is defined as land dominated by trees greater than 2 m in height and no less than 60% canopy cover. Africa’s forests are highly concentrated in the equatorial regions so that 92% of forested area is contained within only 10 countries constituting 36% of the region’s land area and only 28% of the population (*S11*). Although SSA has not experienced deforestation rates observed elsewhere, some countries in the region are losing forest cover at rapid rates. Between 1990 and 2000, the region as a whole lost natural forest area at a rate of approximately 0.7% per year (*S11*), but ten countries lost natural forests at rates larger than 2% of forested area each year, including Nigeria and Zambia, two of the region’s leading charcoal-producing nations. One study that considered proximate causes of deforestation in tropical regions identified fuel extraction as a likely contributor in 10 out of 19 cases analyzed in tropical regions of Africa. However, fuel extraction was rarely the sole factor identified. The authors found that land conversion to permanent or shifting agricultural cultivation and road expansion contribute to forest loss with roughly the same frequency as fuel extraction. Moreover, in two-thirds of the cases analyzed, two or more factors *in addition to* fuel extraction were identified as important co-contributors to forest loss (*S12*).

There is very little data on the sustainability of biomass harvesting at a national or regional level. Our estimates of regeneration rates in the BAU scenario are based on a recent nationwide biomass energy utilization survey from Kenya (*S4*), which provides estimates of sustainable yields from Kenya's multiple agro-ecological zones. The study found that 64-84% of wood consumed directly originates from on-farm tree resources. Other sources of wood included trust lands and forests. The study estimated that sustainable yields from these sources exceed the current rate of wood harvest however, not all woodlands are accessible for harvest; thus both they and we assume that some wood harvested for firewood is harvested unsustainably. If 90% of biomass productivity from farmlands and 50% from other sources is accessible as fuel, then 80% of the current fuelwood consumption and 20% of the wood harvested for charcoal are harvested sustainably (for the baseline year of 2000). The large difference between harvesting for wood and charcoal is because wood harvest and consumption are typically non-commercial activities that occur within a single location so that consumers can tailor their behavior to local production rates. Charcoal, on the other hand, is a commercial activity; it is typically transported long distances so that consumers are far-removed from production zones and pricing mechanisms are not in place to adequately reflect supply scarcity. In addition, charcoal is frequently associated with clearance for crop cultivation. The result is that charcoal is much less likely to be harvested on a sustainable basis than firewood, leading to permanent tree removal (*S13, S14*). The sensitivity of results to this these assumptions is discussed further below (see Figure S8 and Figure S9). Additional sensitivity analyses are also described below.

Forecasting future household fuel consumption

In every scenario, annual consumption of each fuel is a function of population growth and household fuel choice in both rural and urban areas, for each of the 42 sub-Saharan African countries. We used five-year time increments and estimate the increase in fuel consumption based on projected changes in these four variables. For any period t, the consumption of a given fuel Q_t can be described by the relationship:

$$Q_t = c_t\left(f_{R_t}R_t + f_{U_t}U_t\right) \quad (1)$$

Where:

Q_t is the consumption of the fuel in period t.

c_t is the per capita consumption among the population using the fuel in period t. This parameter is assumed to remain constant throughout the period of analysis given that the main use of the fuels in this analysis is for cooking.

f_{R_t} and f_{U_t} are the fractions of the population using that fuel in rural and urban areas respectively in period t.

R_t and U_t are the urban and rural populations in period t.

ΔQ_t is the change in consumption going from period t to t + 1.

With c_t held constant, ΔQ_t may be written:

$$\Delta Q_t = c_t\left(f_{R_t}\Delta R_t + R_t\Delta f_{R_t} + f_{U_t}\Delta U_t + U_t\Delta f_{U_t}\right) \qquad (2)$$

In addition, from (1) c_t can be written as the ratio of the total consumption Q_t and the population using the fuel in question during period t:

$$c_t = \frac{Q_t}{\left(f_{R_t}R_t + f_{U_t}U_t\right)} \qquad (3)$$

Thus, consumption in the period Q_{t+1} is expressed in terms of consumption during the prior period Q_t, the change in the rural and urban populations, and the change in rural and urban fuel choice between the two periods:

$$Q_{t+1} = Q_t + \Delta Q_t = c_t\left(f_{R_t}R_t + f_{U_t}U_t + f_{R_t}\Delta R_t + R_t\Delta f_{R_t} + f_{U_t}\Delta U_t + U_t\Delta f_{U_t}\right) \text{ or}$$

$$Q_{t+1} = \frac{Q_t}{\left(f_{R_t}R_t + f_{U_t}U_t\right)}\left(f_{R_t}R_t + f_{U_t}U_t + f_{R_t}\Delta R_t + R_t\Delta f_{R_t} + f_{U_t}\Delta U_t + U_t\Delta f_{U_t}\right) \text{ and}$$

$$Q_{t+1} = Q_t\left(1 + \frac{f_{R_t}\Delta R_t + R_t\Delta f_{R_t} + f_{U_t}\Delta U_t + U_t\Delta f_{U_t}}{\left(f_{R_t}R_t + f_{U_t}U_t\right)}\right) \qquad (4)$$

In charcoal and fossil fuel (C and F) scenarios f_{R_t} and f_{U_t} change with time so that the equation (4) must be used. In the BAU scenarios, f_{R_t} and f_{U_t} are assumed to be constant and (4) may be simplified to:

$$Q_{t+1} = Q_t\left(1 + \frac{f_{R_t}\Delta R_t + f_{U_t}\Delta U_t}{\left(f_{R_t}R_t + f_{U_t}U_t\right)}\right) \qquad (5)$$

Life-cycle assessment (LCA) models for greenhouse gas emissions

To compare the GHG emissions resulting from current and future household energy options, we use a life-cycle assessment approach that considers emissions from production (upstream) and consumption (downstream) (*S15*).

End-use emissions

To quantify GHG impacts, we rely on published empirical measurements of emissions from production and end-use of woodfuels and fossil fuels. For end-use emissions we draw on research conducted in Africa and elsewhere (*S16 - S18*). Figure S1 shows emission factors for a range of pollutants from common household stoves presented in the literature. In this figure emissions are in terms of mass per unit useful energy released by combustion of the fuel. Figure S2 shows the net climate impact for the same stove/fuel combinations in the same order, for gases that are targeted for limits and reductions within the Kyoto Protocol: CO_2, CH_4, and N_2O. Each GHG has been weighted by its 100-year Global Warming Potential (GWP – see below). The impact of biomass fuels is shown with CO_2 (thick line read on left-hand axis) and without CO_2 (thin line read on right-hand axis) to reflect two extreme possibilities: completely unsustainable harvest and completely sustainable harvest. For each figure, the locations of measurement and sources of data are listed on the horizontal axis.

These figures compare emissions per unit energy delivered. The calculations estimating regional GHG emissions use the corresponding emission factors with respect to mass of fuel consumed, because national consumption data and future projections of fuel consumption are defined in that way.

Upstream emissions

Firewood is not typically associated with “upstream” emissions; however, the production of charcoal, which is a process of intentional incomplete combustion, and fossil fuels both lead to substantial emissions. For charcoal, we estimate upstream emissions using published empirical measurements (*S16, S18, S19*).

Most charcoal is also associated with GHGs emitted during transportation of the end-product from the point of production to markets where it is sold. However, these emissions are difficult to quantify on a regional basis because there is very little data indicating where the fuels are produced and the distance they are transported to consumers. Moreover, in the case of Kenya, for which the authors do have reliable data, transportation emissions are negligible, contributing less than one percent of total emissions over the charcoal life cycle (*S20*). Thus, we did not include emissions from charcoal transport in the analysis.

For upstream emissions associated with fossil fuel production we relied on a GHG emissions model that accounts for the sum of emissions from all upstream activities: extraction, transportation and storage of feedstock, as well as refining, transportation, and distribution of the final product. The GREET model (Greenhouse gases, Regulated Emissions, and Energy use in Transportation), developed by the Argonne National Laboratory as a tool to evaluate the climate impacts of the life cycle of transportation fuels in the US (*S21*), has been used in similar analyses elsewhere (*S22*). Following previous models, we used the model to evaluate upstream emissions associated with LPG and kerosene. Kerosene is not included as a fuel in the GREET model, so diesel fuel was used because it is a similar petroleum distillate, associated with similar upstream emissions (*S22*). The model calculates emissions from LPG based on different sources of feedstock: crude oil or natural gas. Our model assumes LPG in sub-Saharan Africa originates from 100% crude oil. This model is tailored to emissions patterns that are specific to the United States. Assuming that US production, transportation and distribution is less polluting than similar activities in sub-Saharan Africa, these figures should be considered a lower bound of what is likely to occur there. However, because the products in question are fossil fuels, 69 and 76 percent of emissions occur during final consumption for kerosene and LPG respectively, which makes the end results robust to these assumptions about production. Estimates of upstream GHG emissions from several different measurements of charcoal production as well as LPG and kerosene are illustrated in Figure S3 (note this figure shows emissions in terms of fuel mass produced rather than energy consumed as in Figure S1 and Figure S2).

Total emissions: combining upstream and downstream emissions

To assess potential climate change impacts, both upstream and end-use emissions were converted into CO_2 equivalent units using 100-year Global Warming Potential (GWP). These factors account for the differential warming effect (radiative forcing) that each type of GHG has on the atmosphere.

The life-cycle analysis shows that fuel transitions have substantial effects on GHG emissions. Figure S4 shows the combined emissions of Kyoto Protocol GHGs from both *production* and *consumption* per unit mass of household fuels expressed in terms of g-C in CO_2 equivalent units weighted by 100-yr Global Warming Potential (GWP) based on recent empirical measurements and the GREET model described above (*S16 - S18, S22, S23*). Wood and charcoal emissions from 3 studies are shown with full regeneration (solid bars) of harvested biomass and no regeneration (shaded bars) of harvested biomass.

This analysis used emission factors from Zambia (*S16*) for firewood and charcoal consumption and traditional charcoal production. We chose these factors because the sum of upstream and downstream emissions from that study is the median of the three studies available. For improved charcoal production, we use emission factors from Brazil (*S19*). As Figure S4 illustrates, for charcoal, upstream emissions constitute the majority of emissions in all cases except the most efficient production method. Production emissions for kerosene and LPG result from exploration, extraction, refining and storage. Consumption emissions in the case of each fuel are simply the gases released from the final combustion of the fuel.

As discussed in the main text, the majority of people in SSA currently use firewood for their cooking needs and charcoal is the second most popular cooking fuel. The impact of transitions between firewood, charcoal and fossil fuels depend on several factors: the nature of the fuel itself, the sustainability of woodfuel harvesting, and the production method of charcoal. For example, for each unit of useful energy obtained from the fuel, a switch from wood to charcoal increases GHG emissions in CO_2 equivalent units based on 100-yr GWP between 67-175% (the range depends on the regeneration rate of wood harvested). Currently, nearly all charcoal is made in traditional earth-mound kilns. Switching from these kilns to improved kilns increases production efficiency by over 50% and reduces life-cycle emissions by 26-29% (*S19*). A review of charcoal production technologies is available online (*S24*). Shifting from unsustainable harvesting of fuels, in which none of the harvested trees regenerate, to fully sustainable harvesting reduces GHG emissions by 76% for charcoal and 85-97% for firewood.

Thus, the effect of a complete household energy transition from firewood or charcoal to fossil fuels depends strongly on the sustainability of the wood harvest. If trees are harvested sustainably, a transition to fossil fuels can result in a large increase in GHG emissions per unit of energy obtained from the fuel 155-674%. If the trees are not harvested sustainably, a transition to fossil fuels results in a decrease of net GHGs by 2-41%.

Results of GHG forecasts (Main text Fig 3) and sensitivity analyses

Main text figure 3 shows the cumulative GHG emissions estimated from each scenario. Figure S5 shows how emissions in each scenario evolve throughout the period of analysis. Each scenario was also tested for sensitivity to various parameters: GHGs not included in the Kyoto Protocol; time-scale of GWPs; and sustainability of wood harvest for both firewood and for charcoal.

Sensitivity analysis 1: Non-Kyoto Protocol GHGs

Combustion of both biofuels and fossil fuels releases hundreds of chemical species including long-lived greenhouse gases like CO_2, CH_4 and N_2O. Many short-lived chemical species are also released like carbon monoxide (CO), volatile organic compounds (VOCs), and aerosols. Long lived compounds mix fully in the atmosphere and their climate impact is well understood. Short-lived species do not mix evenly and their impact on the climate is much less certain. Nevertheless, estimates of GWPs for CO and VOCs have been calculated (*S23 - S28*), and we used these values in our comparison. The effect of aerosols is still more complex as combustion processes release both black carbon (BC) and organic carbon (OC) aerosols. The former have a net warming effect and the latter have a net cooling effect (*S29, S30*). Bond and colleagues have estimated a GWP for both BC and OC aerosols (*S23*). Nevertheless, we limited sensitivity analysis to CO and NMHCs and did not include aerosols for three reasons: (i) high degree of uncertainty in estimates of GWP for aerosols; (ii) other unknown factors such as the ratio of BC to OC released by household fuel combustion; and (iii) the degree to which these aerosols are deposited indoors rather than released to the atmosphere.

If climate impacts are assessed for CO and NMHCs, the net impact of each scenario increases between 42 and 106%, with the additional impact smallest for fossil fuel intensive scenarios (F and RF) and the unsustainable woodfuel scenarios (BAU, C, and RC) (42 - 58% increase over KP GHGs). In these cases, CO_2 remains the most influential gas and including non-KP gases only has a moderate effect. However, in sustainable woodfuel cases (BAU-S, C-S, and RC-S) where CO_2 plays a minor role and the majority of the climate impact results from non-CO_2 gases, the additional impact of non-KP gases like CO and NMHCs is larger, resulting in a 75 - 106% increase in climate impact over KP GHGs. These effects are shown in Figure S6.

The relative impact of non-KP GHGs is then largest in the sustainable woodfuel scenarios (C-S, RC-S, and BAU-S), in which CO_2 is absorbed during regeneration and plays a relatively small role; in these scenarios GHG impacts are driven by products of incomplete combustion and give a larger relative role to non-CO_2 greenhouse gases. Note that the largest absolute increase in warming impact from non-KP GHGs continues to occur in those scenarios C and RC, despite lower relative increases.

Sensitivity analysis 2: 20-year GWPs

A second sensitivity analysis was performed to assess the effect of using different global warming potentials (GWPs), which are time-dependent ratios of each GHG's radiative forcing relative to the radiative forcing of CO_2 (*S29, S31*). The principle analysis was done using 100-year GWPs, which matches most closely the 50-year time-scale of the projections. Using 20-year GWP rather than 100-year GWP increases the impact of short-lived GHGs like CH_4, which is the most prevalent GHG after CO_2 because, it has much greater radiative forcing than CO_2, but it exits the atmosphere faster. Thus, if the analysis is done using KP-GHGs with 20-year GWPs, net emissions increase across all scenarios due to the larger influence of CH_4, without changing the ranking of scenarios.

The relative increases of emissions resulting from using 20 rather than 100-year GWPS range from 38 to 117 percent, with the largest relative increase occurring in the sustainable wood and/or charcoal scenarios (C-S, BAU-S, and RC-S). This is because sensitivity to the choice of GWP arises from the same mechanism as sensitivity to non-KP GHGs: incomplete combustion, which releases large quantities of heat-trapping greenhouse gases. Figure S7 shows the cumulative emissions that result from using either 100-year or 20-year GWPs. The scenarios in this figure are ordered identically as in Figure S6.

Sensitivity analysis 3: baseline firewood regeneration rates (sustainability)

In the baseline year, 91% of rural and 39% of urban dwellers (76% of the total population) used firewood as their primary source of household fuel. In the BAU scenario, this fraction decreases over time, but remains significant in some scenarios, especially for scenarios C and F, with slower rates of household energy transitions,(see Main Text, Fig 2).

The extent to which firewood is harvested on a sustainable basis, particularly in sub-Saharan Africa, is uncertain. Early assessments of wood consumption in the region posited a "fuelwood crisis" that largely blamed loss of forest cover on household wood-energy consumption (*S32, S33*). However, later analyses revealed that, in most cases, rural firewood consumers were not the main drivers of deforestation although they are impacted by it. Rather, permanent loss of tree cover in sub-Saharan Africa is usually caused by other factors such as timber production, expansion of agricultural land, and expansion of infrastructure like road networks. Moreover, when demand for firewood is a contributing factor, it usually acts in combination with one or more of these other factors (*S11 - S14, S34, S35*). As discussed above, we used data from a recent study from Kenya (*S4*) that quantified household consumption of wood and charcoal and estimated the productivity of woody biomass in areas accessible to the rural population to estimate that 80% of firewood and 20% of wood for charcoal is currently harvested sustainably. Our sensitivity analysis finds that shifting the sustainability of the firewood harvest up to 100% sustainability (or down to 60%) results in decreased (increased) emissions ranging from 2-32% in relative terms or an additional 0.1-2.1 Gt-C in absolute emissions (Figure S8). The largest relative change occurred in scenarios where firewood plays a more prominent role than charcoal in future household fuel choice (BAU, BAU-S, F and RF). The scenarios that envisage charcoal in a more prominent role were relatively unaffected by the changes in sustainability of the firewood harvest (C, RC, C-S, and RC-S).

Similarly, we examined the sensitivity of outcomes to our baseline assumption that charcoal harvest occurs with a 20% rate of regeneration. We examined outcomes with baseline sustainability of charcoal production decreased to 0% (and increased to 40%) replacement of harvested trees, which increased (decreased) cumulative emissions by 1-17% in relative terms or 0.07-3.28 Gt-C in absolute terms Figure S9. The smallest change is observed in the scenario with a fast transition to sustainable charcoal (RC-S). In this model, charcoal production shifts to 80% sustainability within only 10 years and the choice of the baseline has little impact. Other scenarios showing little sensitivity are those in which charcoal plays a small role (F and RF). In addition, BAU-S has little sensitivity to these changes because, although charcoal gains in importance as a household fuel in this scenario (see Fig 2 in main text), tree regeneration increases as charcoal gains in popularity. The largest sensitivity to ±20% changes in baseline regeneration of trees harvested for charcoal occurs in charcoal intensive scenarios with no transition to sustainable production (C and RC).

As a benchmark, note that the proportional changes in cumulative emissions resulting from the ±20% change in baseline regeneration of trees harvested for charcoal are all smaller than those resulting from the ±20% changes in baseline firewood regeneration. This is because the relative contribution of CO_2 to net life-cycle emissions of charcoal is smaller than the relative contribution of CO_2 to net life-cycle emissions of firewood. However, the range and magnitude of *absolute changes* in cumulative emissions resulting from ±20% changes in baseline regeneration of trees harvested for charcoal is larger. This is because the scenarios with the largest absolute emissions (C and RC) are heavily charcoal-dependent and have no forecast changes in the fraction of trees harvested for charcoal production allowed to regenerate in later years so that they are sensitive to assumptions concerning baseline tree regeneration.

GHG emissions from scenarios as a fraction of global and regional emissions projections (Main Text Fig 3)

Future global and regional emissions used in this analysis were from the median emissions scenario introduced by the IPCC in their Special Report on Emissions Scenarios (SRES) to inform policy makers during the IPCC's Third Assessment period (*S36*). The SRES consists of four families of scenarios that project emissions in four world regions from 1990 to 2100 based on ranges of population growth, GDP growth, energy consumption, land-use change, resource availability, and the pace and direction of technological change. To convert the results of this analysis to fraction of African/Global emissions, we used the SRES scenario with the median cumulative emissions: A1 AIM. Between 2000 and 2050, this scenario forecasts cumulative global CO_2 emissions of 655 Gt-C. It also forecasts emissions of non-CO_2 greenhouse gases: CH_4, N_2O, halocarbons and other halogenated compounds, which are included within the Kyoto Protocol as well as "criteria pollutants" such as SO_x, CO, NMVOC, and NO_x. If the non-CO_2 GHGs are added to the cumulative CO_2 emissions in the period of analysis, the net global emissions in the median SRES scenario between 2000 and 2050 is 917 Gt-C. This is the magnitude used in Fig 3 of the main text.

We also disaggregated the SRES A1-AIM outcome in order to compare cumulative emissions from our scenarios to the forecast emissions originating specifically from the Africa region. The SRES exercise divided the world into four large regions. Countries of sub-Saharan Africa fall within the SRES-ALM (Africa, Latin America, and Middle East) region. To separate Africa from the balance of the ALM region, we multiplied the regional emissions by the SSA share of the region's population. The projected global, regional and sub-regional emissions are shown in Table S6.

<u>Mortality impacts (main text Fig 4)</u>

The proportional contribution of exposure to a risk factor (e.g. distribution of fuel use in a population) to disease or mortality relative to some alternative exposure scenario (e.g. another fuel use distribution) is referred to as the population attributable fraction, PAF, calculated by the generalized "potential impact fraction" relationship in Equation 1 (*S37 - S40*).

$$PAF = \frac{\sum_{i=1}^{n} P_i \, RR_i - \sum_{i=1}^{n} P_i' \, RR_i}{\sum_{i=1}^{n} P_i \, RR_i} \qquad (6)$$

RR_i: relative risk of disease or mortality for the i[th] exposure category

P_i: proportion of population in the i[th] exposure category (in BAU)

P'_i: proportion of population in the i[th] exposure category (in alternative exposure scenarios as defined in Table 1: C, RC, F, RF)

n: number of exposure categories; $n = 3$ in this work with the 3 categories consisting of wood, charcoal, and fossil fuels.

Consistent with all current epidemiological studies (*S41, S42*), fossil fuels (kerosene and LPG) which result in the lowest levels of indoor air pollution, together with other "clean fuels" such as electricity, were the baseline for relative risks (RR_i) (Table S7).

Equation 6 was used to estimate: (i) the fraction of LRI and COPD mortality attributable to current and BAU household fuel use (relative to a universal switch to clean fuels) and (ii) the fraction avoidable with a shift to other fuel use patterns as defined in the household fuel use scenarios (C, RC, F, and RF). In estimating future avoidable mortality under various scenarios, LRI and COPD must be treated differently. Transition to cleaner fuels has immediate benefits for child LRI mortality, because LRI is an acute disease. Therefore in estimating the avoidable fraction, the full range of benefits (i.e. change in relative risk from one fuel to the other in Table S7) is immediately realized for LRI. Because COPD is a chronic disease, the health benefits of cleaner fuels occur gradually over time. In other words, the change in relative risks from a higher level to a lower level after transitions to cleaner fuels occurs gradually. Time pattern of relative risk reduction for COPD was obtained from the re-analysis of COPD risk reduction after smoking cessation in the American Cancer Society's Cancer Prevention Study, Phase II (Figure S10) (*S43*).

<u>Uncertainty and research needs</u>

Estimating population health and greenhouse gas impacts of alternative energy futures requires combining fuel use data with relative risks or emission factors that are obtained from epidemiological and environmental studies. These estimates are subject to uncertainty both of because of statistical (random) uncertainty in individual data sources, and more importantly because of extrapolation of parameters from fuel use, epidemiological, and environmental studies to the whole continent. Important sources of uncertainty in risk assessment are described in detail by Murray et al. (S39). Specific sources for estimating the health and greenhouse gas impacts future energy use include:

- current woodfuel and charcoal production, and household fuel use levels;
- current mortality from various diseases, especially because many nations in the sub-Saharan Africa do not have complete vital registration systems (S47);
- business-as-usual projections of fuel use;
- business-as-usual projections of mortality. Mortality projections are particularly uncertain because large unexpected changes in disease epidemiology (e.g. new infectious diseases) or in interventions (e.g. new vaccines) can change future mortality;
- emission factors for each fuel type (upstream and end-use);
- relative risks for each disease; and
- heterogeneity of energy use patterns, and the associated GHG emissions and health hazards, across the region. Heterogeneity results in additional uncertainty when extrapolating emission factors and relative risks.

Despite uncertainty in individual numerical estimates, the overall findings of the analysis, the ordinal magnitudes of the alternative future energy scenarios, are relatively robust to these uncertainties. A number of important health research topics are also important for better quantification of the benefits of various interventions. First, many indoor air pollution intervention options, including those analyzed in this work, provide partial exposure reduction. This requires quantifying hazard along a continuum of exposures, very rare in current research, to determine the effectiveness of a range of interventions. Continuous exposure-response relationship in turn requires technologies and methods for exposure measurement which can be used in community studies. Second, there is a need to establish the temporal dimensions of exposure and hazard. Specific questions include the effects of exposure during pregnancy, young ages, and adults on hazards of various diseases outcomes, and risk reversibility after exposure reduction. Third, because the health outcomes caused by indoor air pollution also have other common risk factors (e.g. childhood and maternal undernutrition for low birth weight and LRI, and smoking for COPD and lung cancer) the hazards of multiple exposures and benefits of individual and combined interventions must be studied.”

Supporting Figures

Figure S1: Pollution emissions for common household fuels reported in the literature

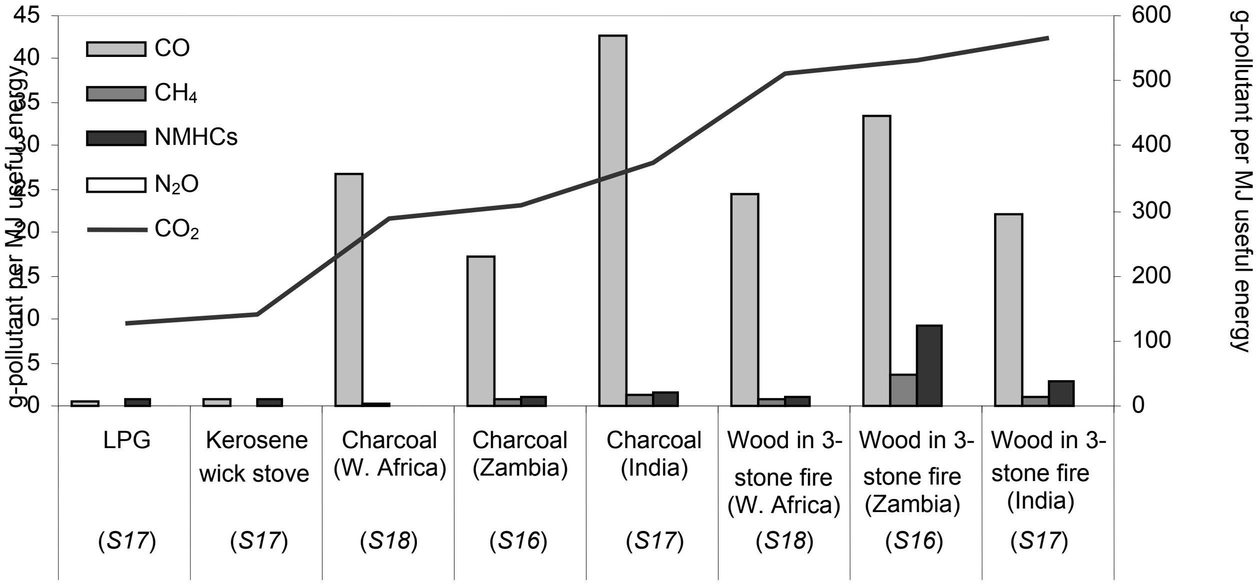


Figure S2: Global warming impact of emissions from Figure S1 in 100 yr CO_2 equivalent units for Kyoto Protocol gases

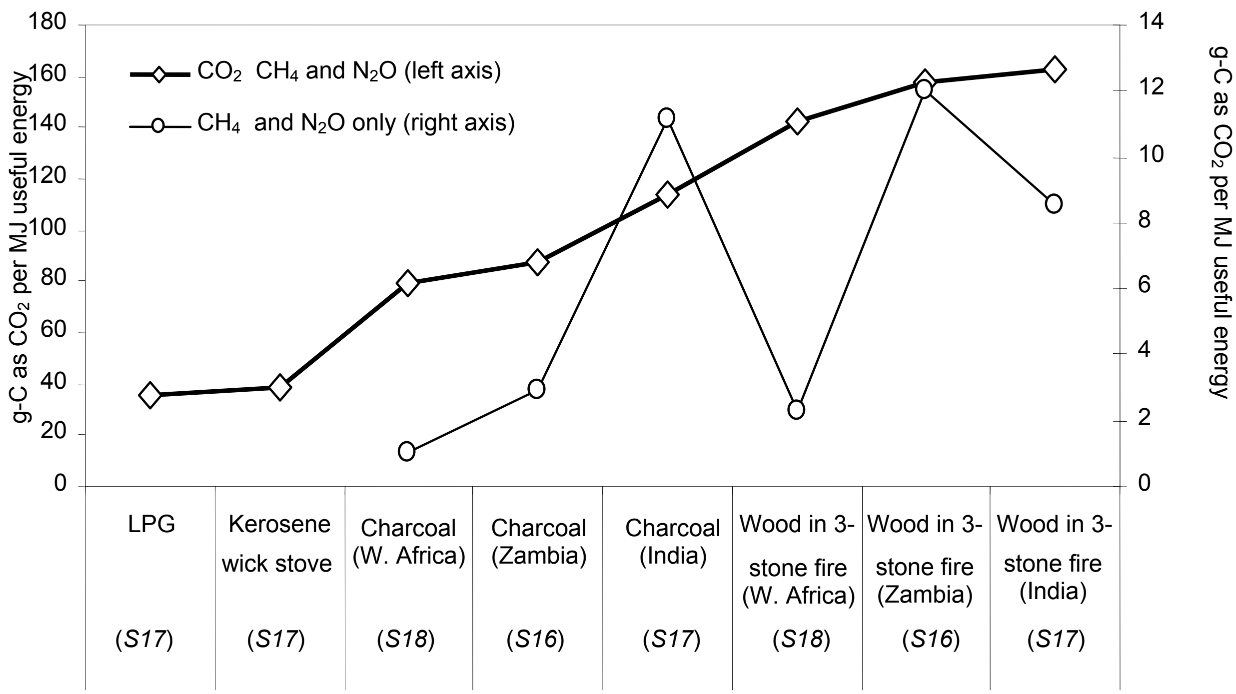


Figure S3: Upstream GHG emissions of household fuels: charcoal production measured in three Earth-mound kilns in sub-Saharan Africa and one improved kiln in Brazil as well as LPG and kerosene production

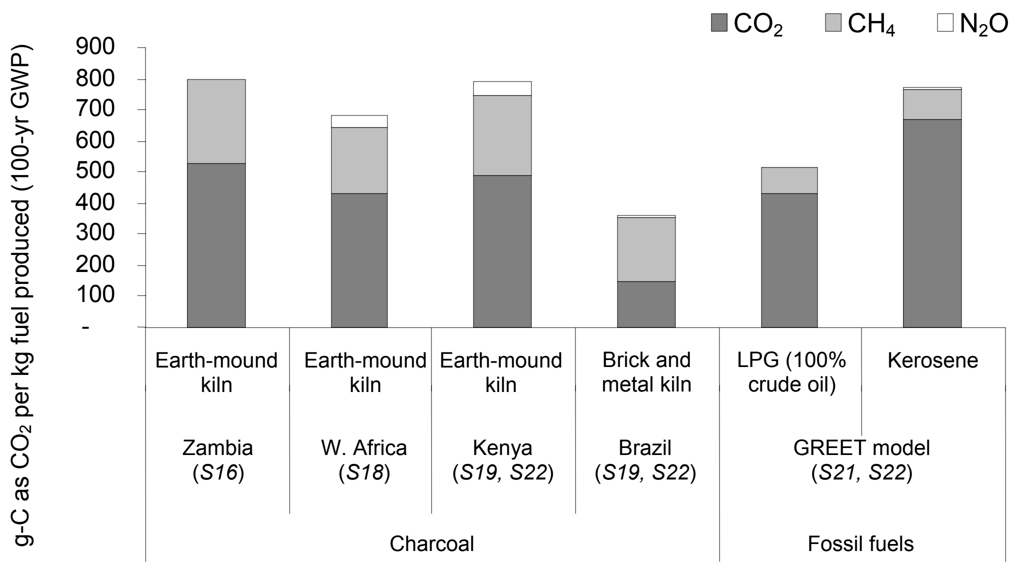


Figure S4: Emissions of Kyoto Protocol GHGs from both production and consumption of household fuels expressed in terms of g-C in CO_2 equivalent units weighted by 100-yr Global Warming Potential (GWP)

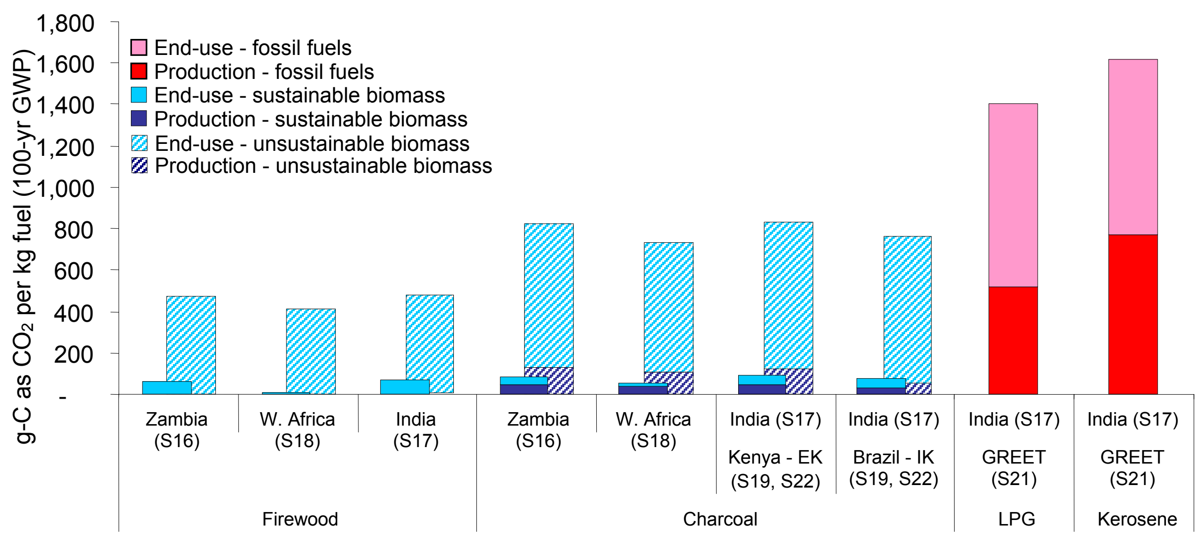


Figure S5: GHG emissions from 2000 and 2050 from CO_2, CH_4, and N_2O converted to CO_2 equivalent units weighted by 100-year-GWP for each scenario of SSA household energy futures.

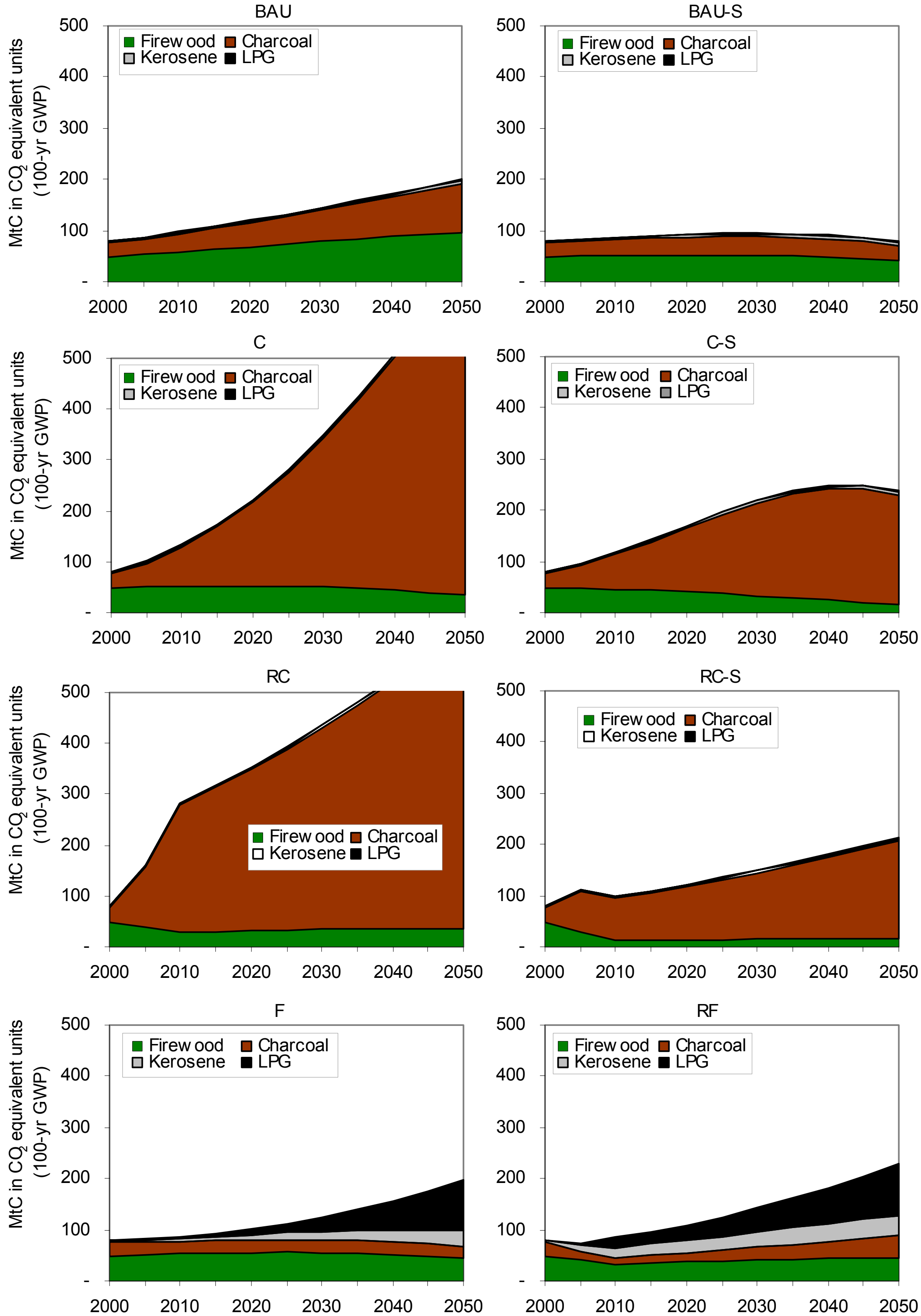


Figure S6: Cumulative emissions and additional impacts of CO and NMHCs (2000-2050)

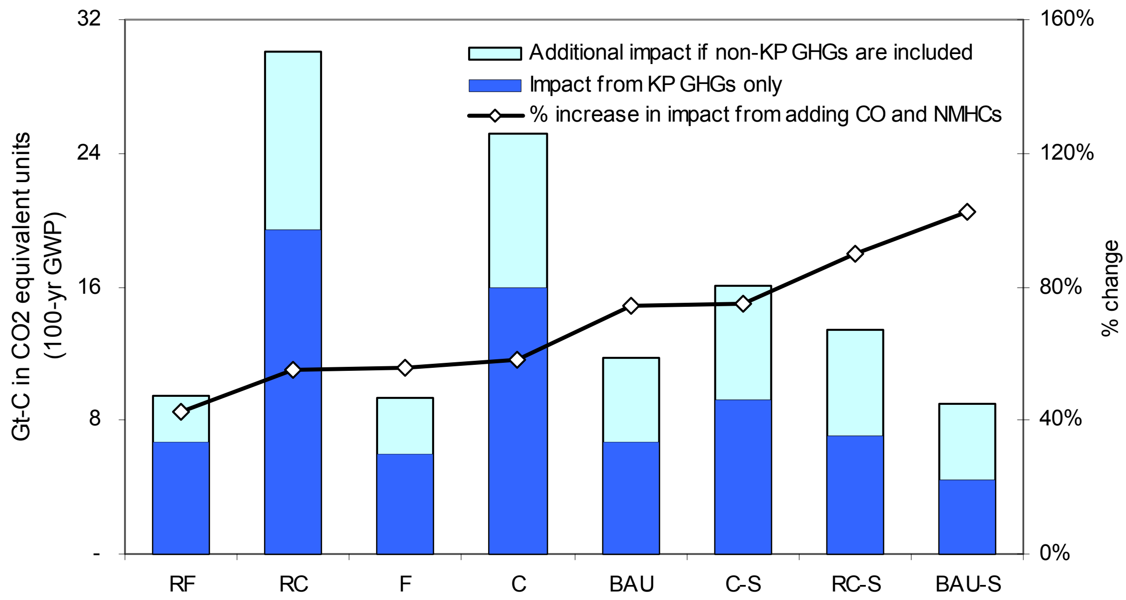


Figure S7: Cumulative emissions for both 100-yr and 20-yr GWPs (2000-2050)

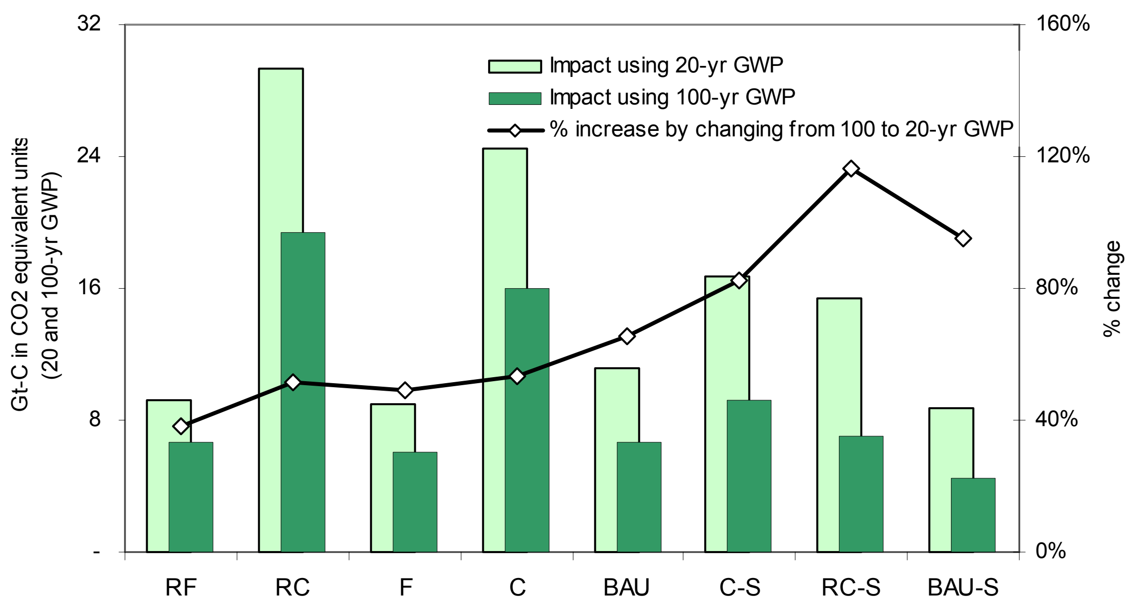


Figure S8: Cumulative emissions for 60%, 80%, and 100% sustainability in baseline firewood harvest (2000-2050)

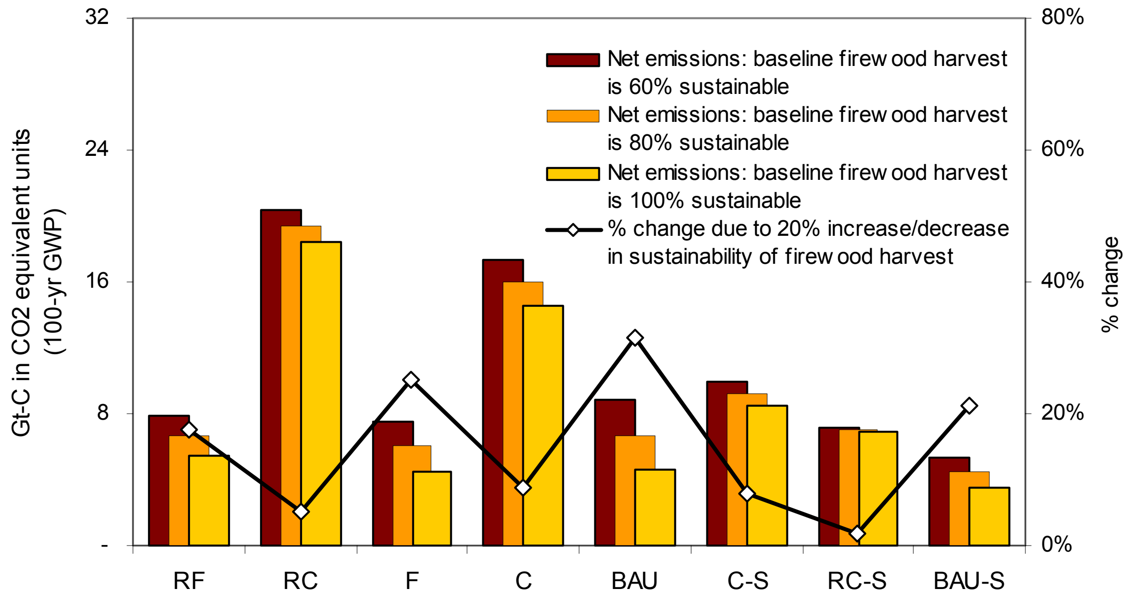


Figure S9: Cumulative emissions for 0%, 20%, and 40% sustainability in baseline charcoal harvest (2000-2050)

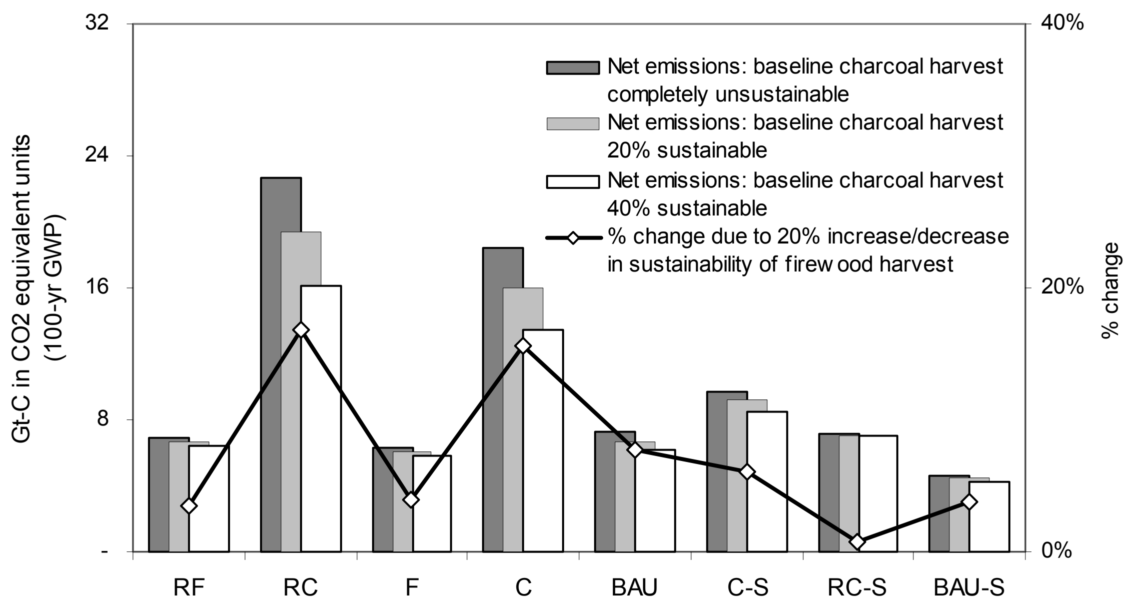


Figure S10: Proportion of COPD excess risk (excess risk = relative risk – 1) remaining after cessation of exposure over time, used for estimating avoidable COPD deaths as a result of shift to cleaner fuels (C, RC, F, RF)

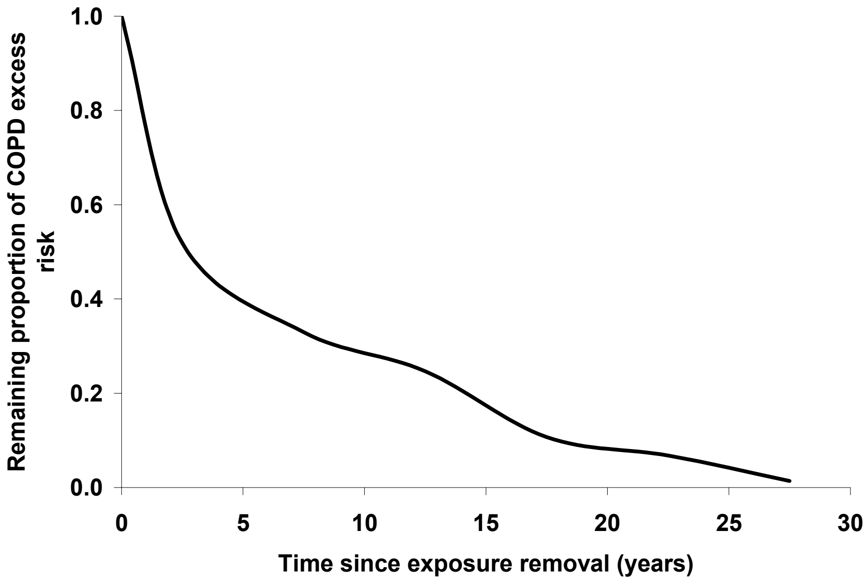
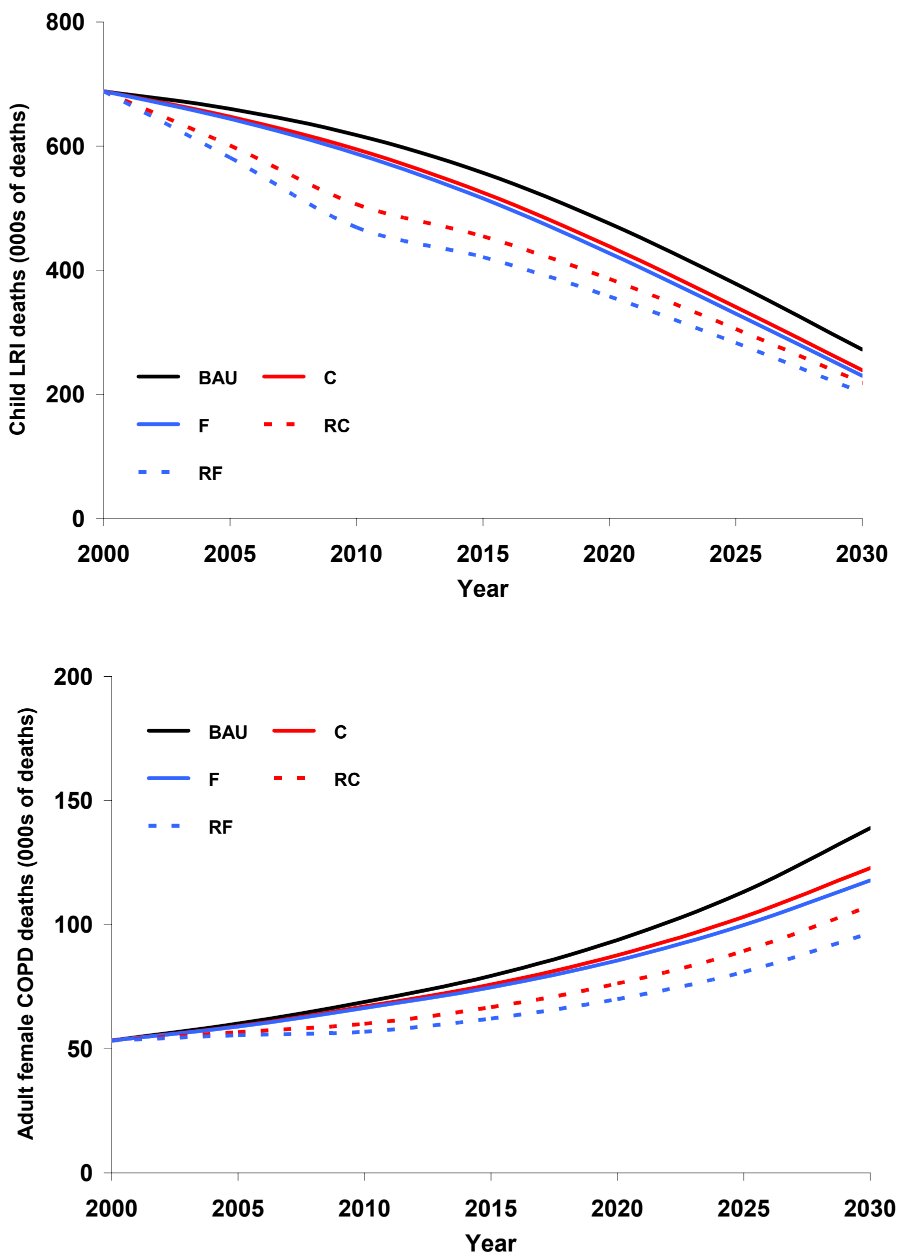


Figure S11: Estimated mortality for scenarios of household energy futures in SSA, separately for childhood LRI and COPD among adult women



Supporting Tables

Table S1: African woodfuel production and trade statistics for 2000 from the FAO database (*S1*). Woodfuel includes both wood used directly as firewood and wood processed into charcoal before final consumption.

Country	WOODFUEL (m^3)			CHARCOAL (tons)		
	Production	Import	Export	Production	Import	Export
Sub-Saharan Africa						
Angola	3,163,217	141	0	205,061	21	97
Benin	5,910,329	1	0	183,197	637	110
Botswana	635,448	400	0	58,703	300	0
Burkina Faso	7,402,000	0	0	112,000	0	0
Burundi	5,420,000	0	0	60,000	0	0
Cameroon	9,111,347	0	0	21,000	0	0
Central African Republic	2,000,000	0	0	21,000	0	0
Chad	5,885,198	0	0	310,971	0	0
Democratic Republic of the Congo	64,902,848	0	24	1,431,274	0	0
Congo	1,153,140	0	0	1,000	0	0
Côte d'Ivoire	8,529,021	0	0	327,000	0	0
Djibouti	0	3,370	0	0	0	0
Equatorial Guinea	447,000	0	0	0	0	0
Eritrea	2,244,341	0	0	145,609	1,000	0
Ethiopia	87,471,092	0	0	2,908,485	0	0
Gabon	515,409	0	0	15,466	0	0
Gambia	602,682	0	0	46,802	0	0
Ghana	20,678,000	0	0	752,000	0	0
Guinea	11,444,377	0	0	276,593	0	0
Guinea-Bissau	422,000	0	0	0	0	0
Kenya	19,658,247	0	0	640,501	0	2
Lesotho	2,022,018	0	0	78,483	0	0
Liberia	4,725,361	0	0	152,604	0	0
Madagascar	9,637,458	0	0	645,000	0	19,700
Malawi	4,964,075	0	37	391,746	1	0
Mali	4,730,585	0	0	96,317	0	0
Mauritania	1,428,069	0	0	130,904	0	0
Mauritius	10,000	41	0	100	20	0
Mozambique	16,724,000	6	19	100,000	15	478
Niger	7,805,433	0	0	423,613	0	13
Nigeria	59,348,652	0	1,060	3,085,072	0	28,000
Rwanda	7,500,000	0	0	48,000	0	0
Réunion	31,000	0	0	0	0	0
Senegal	5,113,579	0	0	110,208	0	500
Sierra Leone	5,357,763	0	0	296,908	283	0
Somalia	9,228,017	0	0	651,062	0	0
South Africa	12,000,000	0	0	41,000	7,500	44,500
Sudan	16,680,060	0	38	743,342	16	432
Swaziland	560,000	0	0	0	0	0
Togo	5,499,189	0	0	281,000	0	0
Uganda	34,090,320	0	0	713,381	0	0
Zambia	7,219,000	27	0	1,041,000	1	0
Zimbabwe	8,115,200	0	0	10,500	0	0
Tanzania	20,786,647	3	19	1,164,705	0	0
Sub-Saharan Africa regional total	**501,172,122**	**3,989**	**1,197**	**17,721,607**	**9,794**	**93,832**
North Africa						
Algeria	7,074,136	0	0	547,352	0	0
Egypt	16,181,909	200	0	1,200,542	0	4,400
Libya	536,000	0	0	0	0	0
Morocco	487,000	0	0	90,178	0	0
Tunisia	2,094,053	0	0	195,188	600	0
North Africa regional total	**26,373,098**	**200**	**0**	**2,033,260**	**600**	**4,400**
Africa Total	**527,545,220**	**4,189**	**1,197**	**19,754,867**	**10,394**	**98,232**

Table S2: Woodfuel and charcoal production data for a selection of sub-Saharan African countries reported for 2000 [from (*S2, S3*)]. Woodfuel includes wood used directly as firewood and wood processed into charcoal before final consumption.

Country	Woodfuel (ktoe)	Charcoal (1000 tons)	Original source of data as reported in (S2)
Angola	5,641	851	Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Benin	1,406	174	WEC-IEA Joint Energy Reporting Format for Africa, 1999-2000.
Cameroon	4,985	99	The IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Congo (Dem Rep)	13,609	283	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Congo (Rep)	588	123	Direct communication to the IEA Secretariat from the Ministère de l'Energie et de l'Hydraulique, 2000, 2001
Côte d'Ivoire	4,224	714	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Eritrea	511	18	Direct communication to the IEA Secretariat from the Ministry of Energy and Mines, State of Eritrea
Ethiopia	17,424	195	IEA Secretariat estimates based on 1992 data from Eshetu, L. and Bogale, W., *Power Restructuring in Ethiopia*, AFREPREN, Nairobi, 1996.
Gabon	925	--	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Ghana	5,315	587	Ministry of Mines and Energy, the UN Energy Statistics Database, and IEA secretariat estimates
Kenya	7,172	1,511	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Mozambique	6,610	338	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Namibia	173	--	IEA Secretariat estimates
Nigeria	72,327	870	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Senegal	1,722	140	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996 and from direct communication with ENDA, Senegal.
South Africa	12,439	1,447	Direct submissions to the IEA secretariat from the Department of Minerals and Energy and related institutions, 2001, 2002, 2003.
Sudan	13,803	2,411	IEA Secretariat estimates based on 1990 Bhagavan, M.R., Editor, *Energy Utilities and Institutions in Africa*, AFREPREN, Nairobi, 1996.
Tanzania	12,458	950	IEA Secretariat estimates based on 1990 data from *Energy Statistics Yearbook 1990*, SADC, Luanda, 1992.
Togo	1,034	165	UN and direct communication to the IEA Secretariat from the Ministère de l'Equipement, des Mines, de l'Energie et de Postes et Télécommunications, 2003.
Zambia	5,135	793	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Zimbabwe	5,591	--	IEA Secretariat estimates based on 1991 data from African Energy Programme of the African Development Bank, *Forests and Biomass Sub-sector in Africa*, Abidjan, 1996.
Other Africa [b]	47,030	1,052	IEA Secretariat estimates based on information about component countries

[b] Other Africa includes Botswana, Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Djibouti, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Niger, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Swaziland and Uganda.

Table S3: Residential consumption of household fuels in sub-Saharan African countries (S3)

Country	Liquified Petroleum Gas (kton)	Kerosene (kton)	Electricity (GWh)	Coal (kton)	Residential Biomass[a] (ktoe)
Angola	58	0	877		4,058
Benin	2	98	169		945
Cameroon	28	166	391		3,941
Congo, Dem Republic of	0	8	1,160	90	10,241
Congo, Republic of	2	20	132		403
Côte d'Ivoire	29	47	0		2,301
Eritrea	2	21	69		391
Ethiopia	1	172	529		16,639
Gabon	19	30	544		740
Ghana	32	91	2,138		3,650
Kenya	13	275	898		11,777
Mozambique	7	33	442		5,020
Namibia	0	0	NR		173
Nigeria	13	1671	5,448		63,279
Senegal	103	18	436		1,139
South Africa	64	441	33,118	1,516	7,531
Sudan	55	7	1,033		6,123
Tanzania, United Rep of	4	116	1,048		9,164
Togo	0	35	228		685
Zambia	0	15	1,131		3,321
Zimbabwe	1	55	2,349	1	5,203
Other Africa[b]	142	465	2,125		4,703

[a] This is presented in terms of final consumption, thus it accounts for losses resulting from conversion of a portion of harvested woodfuel to charcoal. The amount of wood converted to charcoal varies on a country-by-country basis.

[b] Other Africa includes Botswana, Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Djibouti, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Niger, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Swaziland and Uganda.

Table S4: Baseline population and household fuel consumption for 41 sub-Saharan African countries in 2000 (all fuels are measured in metric tons)

Country	Population	Woodfuel* (ktons)	Fuelwood (ktons)	Charcoal (ktons)	Kerosene (ktons)	LPG (ktons)	Coal (ktons)	Source for woodfuels	Source for charcoal
Angola	12,386,000	17,198	12,372	851	-	58	-	a	a
Benin	6,222,000	4,285	3,488	183	98	2	-	b	b
Botswana	1,725,000	461	205	59	5	0	-	b	b
Burkina Faso	11,905,000	5,366	4,879	112	38	5	-	c	c
Burundi	6,267,000	3,930	3,669	60	20	4	-	c	c
Cameroon	15,117,000	6,606	6,514	21	166	28	-	b	b
Central African Rep	3,715,000	1,450	1,359	21	12	1	-	c	c
Chad	7,861,000	4,267	2,914	311	25	4	-	b	b
Congo, Dem Rep	48,571,000	47,055	40,829	1,431	8	-	90	b	b
Congo, Republic of	3,447,000	836	832	1	20	2	-	b	b
Côte d'Ivoire	15,827,000	6,184	4,761	327	47	29	-	b	c
Equatorial Guinea	456,000	324	324	-	1	0	-	b	NA
Eritrea	3,712,000	1,627	994	146	21	2	-	b	b
Ethiopia	65,590,000	63,417	50,765	2,908	172	1	-	b	b
Gabon	1,258,000	374	306	15	30	19	-	b	b
Gambia	1,312,000	437	233	47	4	0	-	b	b
Ghana	19,593,000	14,992	11,720	752	91	32	-	b	b
Guinea	8,117,000	8,297	7,094	277	26	8	-	b	b
Guinea-Bissau	1,367,000	306	306	-	4	0	-	b	NA
Kenya	30,549,000	35,120	15,730	2,176	275	13	-	d	d
Lesotho	1,785,000	1,466	1,125	78	6	1	-	b	b
Liberia	2,943,000	3,426	2,762	153	9	3	-	b	b
Madagascar	15,970,000	6,987	4,181	645	50	7	-	b	c
Malawi	11,370,000	3,599	1,895	392	36	3	-	b	b
Mali	11,904,000	3,430	3,011	96	38	3	-	b	b
Mauritania	2,645,000	1,035	466	131	8	1	-	b	b
Mozambique	17,861,000	12,125	11,690	100	33	7	-	b	b
Niger	10,742,000	5,659	3,816	424	34	5	-	b	b
Nigeria	114,746,000	43,028	29,608	3,085	1,671	13	-	b	b
Rwanda	7,724,000	5,438	5,229	48	24	5	-	b	b
Senegal	9,393,000	3,707	3,228	110	18	103	-	b	b
Sierra Leone	4,415,000	3,884	2,593	297	14	4	-	b	b
Somalia	8,720,000	6,690	6,690	-	28	6	-	b	NA
South Africa	44,000,000	37,924	22,960	1,447	441	64	1,516	b	b
Sudan	31,437,000	42,082	18,668	2,411	7	55	-	a	a
Swaziland	1,044,000	406	406	-	3	0	-	b	NA
Tanzania	34,837,000	15,070	10,004	1,165	116	4	-	b	b
Togo	4,562,000	3,987	2,765	281	35	-	-	b	c
Uganda	23,487,000	24,715	21,612	713	74	2	-	b	b
Zambia	10,419,000	15,655	10,125	793	15	-	-	a	a
Zimbabwe	12,650,000	5,884	5,838	11	55	1	1	b	c

Notes:

* Woodfuel includes wood used directly as firewood and wood that is converted into charcoal.

a) IEA estimate
b) FAO estimate
c) Country data reported in FAO database
d) National level survey not reported by either IEA or FAO

Table S5: Primary household fuel choice compiled by the World Bank based on national Welfare Monitoring Surveys [a]

Country (year of survey)	Sector	Firewood	Charcoal	Kerosene	Electricity	Gas	Other	Notes
Burkina Faso (1998)	Rural	91	5	1	-	1	3	
	Urban	74	6	2	1	10	8	
Burundi (year NA)	Rural	97	1	2	0	0	0	b
	Urban	15	74	0	2	10	0	
Cameroon (1996)	Rural	94	1	1	0	0	3	
	Urban	42	9	17	0	17	14	
Côte d'Ivoire (1998)	Rural	90	3	1	0	0	6	c
	Urban	32	51	0	0	8	9	
Ethiopia (2000)	Rural	85	0	2	0	0	13	d
	Urban	78	13	2	1	4	1	
Ghana (1998/9)	Rural	81	16	1	0	1	1	
	Urban	23	62	2	0	11	1	
Guinea (1994/5)	Rural	99	1	0	0	0	0	e
	Urban	42	52	1	1	4	0	
Kenya (1997)	Rural	91	5	3	0	0	1	
	Urban	5	21	62	3	9	0	
Madagascar (1999)	Rural	92	7	2	0	0	0	f
	Urban	40	55	1	1	3	0	
Malawi (1997/8)	Rural	97	0	1	0	0	2	g
	Urban	47	18	5	27	4	0	
Mali (1994)	Rural	97	0	0	0	0	2	
	Urban	85	13	1	0	2	0	h
Mauritania (1995)	Rural	76	10	13	0	0	1	
	Urban	14	30	46	1	6	2	i
Mozambique (1996)	Rural	99	0	1	0	1	0	j
	Urban	50	37	2	8	3	0	
Niger (1995)	Rural	90	0	1	0	0	9	
	Urban	90	0	4	1	5	1	k
Senegal (1994/5)	Rural	84	12	2	0	0	2	l
	Urban	18	34	8	0	40	0	
South Africa (1999)	Rural	56	0	40	23	6	11	m
	Urban	5	0	29	73	8	10	
Swaziland (1994)	Rural	2	93	2	1	0	2	
	Urban	34	16	14	14	3	19	n
Tanzania (1993)	Rural	96	3	0	0	0	0	
	Urban	42	47	6	3	1	0	o
Uganda (1999/2000)	Rural	95	4	1	0	0	0	
	Urban	20	69	5	3	3	0	p

Zambia (1998)	Rural	90	9	0	1	0	0	
	Urban	12	48	0	40	0	0	
Population weighted average (excluding South Africa)	Rural	91	4	1	0	0	5	
	Urban	39	34	12	4	8	2	

Notes:

a) All data are from (*S7*) except South Africa, which is from (*S8*).

b) The data from Burundi was undated. In addition, the fraction of rural households using kerosene was increased from 1% to 2% to account for the country's kerosene consumption as estimated from IEA data for "Other Africa" based on Burundi's share of "Other Africa" population. Similarly, the fraction of urban households using gas in Burundi was increased from 1% to 10% (with an equivalent decrease in charcoal) in order to account for Burundi's domestic gas consumption, which was estimated from IEA data for "Other Africa" based on Burundi's share of "Other Africa" population. In the rural case, the 1% difference was taken from firewood users and in the urban case, the 9% difference was taken from charcoal users.

c) For Côte d'Ivoire, the fraction of rural and urban households using kerosene was increased from 0% to 1% and 2% respectively to account for kerosene consumed in the country country's residential sector according to IEA data. For rural households, the difference was not accounted for because original data only added to 99%. For urban households, the difference was taken from "other".

d) Rural households in Ethiopia were adjusted from 0% using kerosene to 2% in order to account for kerosene consumed in the country's residential sector according to IEA data. The difference was accounted for by subtracting from "other".

e) Households in Guinea using kerosene and gas were combined in the WB database, with the total using either fuel given as only 1%. We assume the fraction of urban households using gas is 4% in order to account for the quantity of LPG consumed according to Guinea's share of the population in "Other Africa". In addition, the fraction of households using kerosene was changed to 2% for urban areas and 1% for rural areas in order to account for the quantity of kerosene consumed according to Guinea's share of the population in "Other Africa". This additional increment was accounted for by subtracting from both "other" and firewood.

f) The fraction of rural households in Madagascar using kerosene was changed from 0% to 2% in order to account for the quantity of fuel consumed according to Madagascar's share of the population in "Other Africa". The change was accounted for by subtracting 1% from "other" and 1% from firewood. In addition, the fraction of urban households in Madagascar using gas was changed from 2% to 3% and the fraction using kerosene was changed from 0% to 1% in order to account for the quantity of each fuel consumed according to Madagascar's share of the population in "Other Africa". The urban changes were accounted for by subtracting 2% from "other".

g) The fraction of urban households in Malawi using gas was changed from 0% to 4% in order to account for the quantity of each fuel consumed in proportion to Malawi's share of population in "Other Africa". In addition, the fraction of rural households using kerosene was changed from 0% to 1%. The urban change was accounted for by subtracting from firewood and the rural change was not accounted for because the original data only added to 99%.

h) Households using kerosene and gas in Mali were combined in the WB database with only 1% of urban households and 0% of rural households shown to be using either fuel. In order to account for the quantity of both fuels consumed in proportion to Mali's share of the population in "Other Africa", the fraction of urban households in Mali using gas and kerosene separately was assumed to be 2% for each fuel and the fraction or rural households using kerosene was increased to 1%. The urban change was accounted for by subtracting 1% from "other" and 2% from firewood and the rural change was unaccounted for because the original data only added to 99%.

i) Households using kerosene and gas in Mauritania were combined in the WB database. The fraction of urban households using both fuels was 52%. We assume the fraction of households using each fuel is proportional to the quantities of fuel consumed in 2000 according to Mauritania's share of the population in "Other Africa", thus 6% was assumed to use gas and 46% was assumed to use kerosene.

j) The fraction of households using kerosene in Mozambique was changed from 0% for both rural and urban households to 2% and 1% respectively to account for the kerosene consumed in the residential sector according to IEA data. The change was accounted for by subtracting 1% from firewood for rural areas and 1% from "other" in urban areas, which only added to 99% in the original database.

k) In Niger, kerosene and gas were combined in the WB database with 4% of urban households using one or the other. We assume the fraction of households using kerosene was itself 4% and that an additional 5% of households use gas. This division accounts for the amount of each fuel consumed in 2000 according to Niger's share of gas and kerosene consumption, which was based on the country's share of population in "Other Africa". The additional percentage was compensated by subtracting from "other".

l) Households using kerosene and gas in Senegal were combined in the WB database. 48% of urban households use either fuel. We assume the fraction of urban households using each fuel was proportional to the quantities of fuel consumed in 2000 according to IEA country data for Senegal, thus 8% was assumed to use kerosene and 40% was assumed to use gas (see Table S3).

m) South African data reports the usage of any fuel for cooking, rather than primary cooking fuel thus the data add to more than 100% for both rural and urban areas.

n) Households using kerosene and gas in Swaziland were combined in the WB database. 15% of urban households use either fuel. For this study, the fraction of urban households using each fuel was assumed to be proportional to the quantities of fuel consumed in 2000, which was estimated by considering Swaziland's share of the population "Other Africa". Thus, 14% of urban households was assumed to use kerosene and 3% was assumed to use gas. The additional 2% was accounted for by subtracting from "other".

o) Households using kerosene and gas in Tanzania were combined in the WB database, with 7% of urban households using either fuel. For this study, the fraction of urban households using each fuel was assumed to be proportional to the quantities of fuel consumed in 2000 according to IEA country data for Tanzania, thus 6% was assumed to use kerosene and 1% was assumed to use gas.

p) The fraction of urban households in Uganda using gas was changed from 1% to 3% and the fraction of rural households using kerosene was changed from 0% to 1% to which account for the estimated residential consumption of each fuel, which was based on Uganda's share of the population in "Other Africa". The changes were accounted for by subtracting 1% from "other" and 2% from charcoal for urban areas. No change was required for rural areas, because the original data only added to 99%.

Table S6: Emissions projections for SRES A1-AIM scenario with sub-regional estimations for SSA [from (S36)]

World	Units	2000	2010	2020	2030	2040	2050	Cumulative (2000-2050)	GW Impact (Gt-C, 100-yr GWP)
CO_2	Gt-C	7.97	10.88	12.64	14.48	15.35	16.38	655	655
CH_4	$MtCH_4$	323	373	421	466	458	452	21,058	120
N_2O	MtN_2O-N	7.0	7.0	7.2	7.3	7.4	7.4	362	108
HFC [b]	MtC eq.	883	791	337	369	482	566	27,035	27
PFC [b]	MtC eq.	25	31	43	61	77	89	2,690	3
SF_6 [b]	MtC eq.	40	43	48	66	99	119	3,368	3
World total									**917**
ALM									
CO_2	GtC	1.83	2.93	3.80	4.52	5.20	5.99	204	204
CH_4	MtCH4	85	99	120	134	139	144	6,068	35
N_2O	MtN2O-N	1.3	1.3	1.3	1.3	1.4	1.4	66	20
HFC [b]	MtC eq.	2	15	39	81	139	184	3,678	4
PFC [b]	MtC eq.	4	5	9	14	19	23	609	1
SF_6 [b]	MtC eq.	5	10	14	19	32	40	969	1
ALM total									**263**
SSA[a]									
CO_2	GtC	0.82	1.32	1.71	2.03	2.34	2.70	92	92
CH_4	MtCH4	38.32	44.65	53.93	60.32	62.56	64.90	2,731	16
N_2O	MtN2O-N	0.58	0.57	0.58	0.59	0.62	0.64	30	9
HFC [b]	MtC eq.	0.99	6.97	17.61	36.38	62.67	82.78	1,655	2
PFC [b]	MtC eq.	1.59	2.36	4.04	6.36	8.58	10.49	274	0
SF_6 [b]	MtC eq.	2.05	4.36	6.42	8.36	14.50	17.87	436	0
SSA total									**118**

[a] Assuming SSA constitutes, on average, 45% of the ALM population during the 50-year period of analysis and emissions scale with population.

[b] HFC – Hydrofluorocarbon (Hydrogenated FluoroCarbon); PFC – Perfluorocarbon; SF_6 – Sulfur Hexaflouride

Table S7: Relative risks (RR) used in estimating mortality from lower respiratory infection (LRI) among children younger than 5 years of age and from chronic obstructive pulmonary disease (COPD) among adult women. All relative risks are with respect to a baseline of using fossil fuels (kerosene and LPG).

Fuel type	RR	Source
		LRI
Kerosene and LPG	1.0	By definition of baseline
Charcoal	1.3	Exposure-response relationship study in Kenya which included multiple exposure categories, and quantified the health benefits of charcoal relative to wood (*S44, S45*). Relative risk for wood relative to charcoal (1.77) converted to charcoal relative to Kerosene/LPG by definition of RR (2.3 / 1.77 = 1.3).
Wood	2.3	Systematic review and meta-analysis of epidemiological studies (*S41, S42*)
		COPD
Kerosene and LPG	1.0	By definition of baseline
Charcoal	1.5	Based on exposure-response relationship for cardiopulmonary diseases as a result of exposure to particulate matter in ambient air pollution (*S46*), with an exposure of 150 $\mu g/m^3$. The exposure estimates for charcoal users is in terms of PM_{10} (particulate matter smaller than 10 μm in aerodynamic diameter) and the exposure-response relationship in terms of $PM_{2.5}$. A conversion factor of 50% for converting PM_{10} to $PM_{2.5}$ was used (*S46*).
Wood	3.2	Systematic review and meta-analysis of epidemiological studies (*S41*)

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