Comparative Analysis of Fuels for Cooking:

LIFE CYCLE ENVIRONMENTAL IMPACTS AND ECONOMIC AND SOCIAL CONSIDERATIONS

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

ERG

ABOUT THIS GUIDE:

This study is an initiative of the Global Alliance for Clean Cookstoves, a public-private partnership with a mission to save lives, improve livelihoods, empower women, and protect the environment by creating a thriving global market for clean and efficient household cooking solutions. The Alliance is committed to providing resources that advance the work of its partners. In response to a request from our partners for country specific information on fuels, the Alliance undertook this research to provide an understanding of tradeoffs between fuel options and environmental impacts across the value chain, and to provide a guide to inform decisions regarding fuel choices for programs and investors. This study is meant to aid cookstove and fuel stakeholders to identify and prioritize opportunities, to remove barriers, and increase efficiency across the fuel supply chain while also increasing awareness of environmental, economic and gender and livelihood impacts of various fuel types.

The Global Alliance for Clean Cookstoves partnered with Eastern Research Group on this effort. Special thanks to the Alliance's many partners, staff, enterprises and fuel experts that provided inputs, insights, and review throughout the process.

EASTERN RESEARCH GROUP

ERG has over 30 years of experience serving federal, state, and local environmental agencies as well as nonprofit and educational organizations. ERG offers multidisciplinary skills in more than 20 specialized service areas, including: engineering, environmental/health science, economics, communications, information technology (IT), outreach and education,and training services. Our Franklin Associates division is a respected industry leader in conducting life cycle assessments (LCA). Our LCA practitioners apply modeling techniques across a full range of environmental media to understand the comprehensive life cycle impacts of various products and processes. We help our clients target their efforts to minimize environmental burdens and maximize resources.

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*The Detailed Analyses, Appendices, References and complementary resources can be viewed under the Resources tab of the Fuel Analysis, Comparison and Integration Tool (FACIT) webpage: **cleancookstoves.org/facit**

1. EXECUTIVE SUMMARY

1.1 OVERVIEW

Billions of people cook daily on traditional stoves and open fires with solid fuels like wood, which has far-reaching health, environmental, and socio-economic impacts. Much of the research on cooking fuels has focused on energy efficiency and emissions in the home. Fuel alternatives are often pursued to achieve benefits for the users, and are often marketed as being "renewable," "green," or "clean." The actual impacts of fuel alternatives for cooking are more complex than these terms imply, due to the multiple steps of fuel production, processing, distribution, and use, and because these steps touch on so many areas (e.g., energy use, agriculture, transportation, and manufacturing). A deeper investigation of the environmental impacts of fuels can contribute to strengthening the growing cookstoves and fuels sector as well as the trajectory of future research.

This study evaluates various cooking fuels using life cycle assessment (LCA), a method for comprehensive, quantified evaluations on the environmental benefits and tradeoffs for the entire life cycle of a product system, beginning with raw material extraction and continuing through the product's end-of-life. This effort also includes an initial assessment of various economic and social indicators to provide additional considerations to weigh when evaluating fuel choices. The results in this report and accompanying tool (*Fuel Analysis, Comparison & Integration Tool or FACIT*) can be used to interactively analyze and compare trade-offs of different cooking fuels (assuming representative cookstove efficiencies associated with each fuel); identify the steps in fuel production that have the largest impacts and, thus, present opportunities for improvements; and enhance investment in cleaner cooking fuels through increased awareness of the associated environmental, economic, and gender and livelihood benefits.

This study provides quantitative and qualitative information on previously identified areas of interest and information gaps for the fuel chain, including:

- Life cycle environmental impacts, including energy use, water consumption, emissions, and wastes.
- Quantified emission data on black carbon and short-lived climate pollutants sourced from solid, gaseous and liquid fuels.
- Benefits, challenges, and differences in impact for various processed biomass fuels such as bamboo, carbonized vs. non-carbonized briquettes.

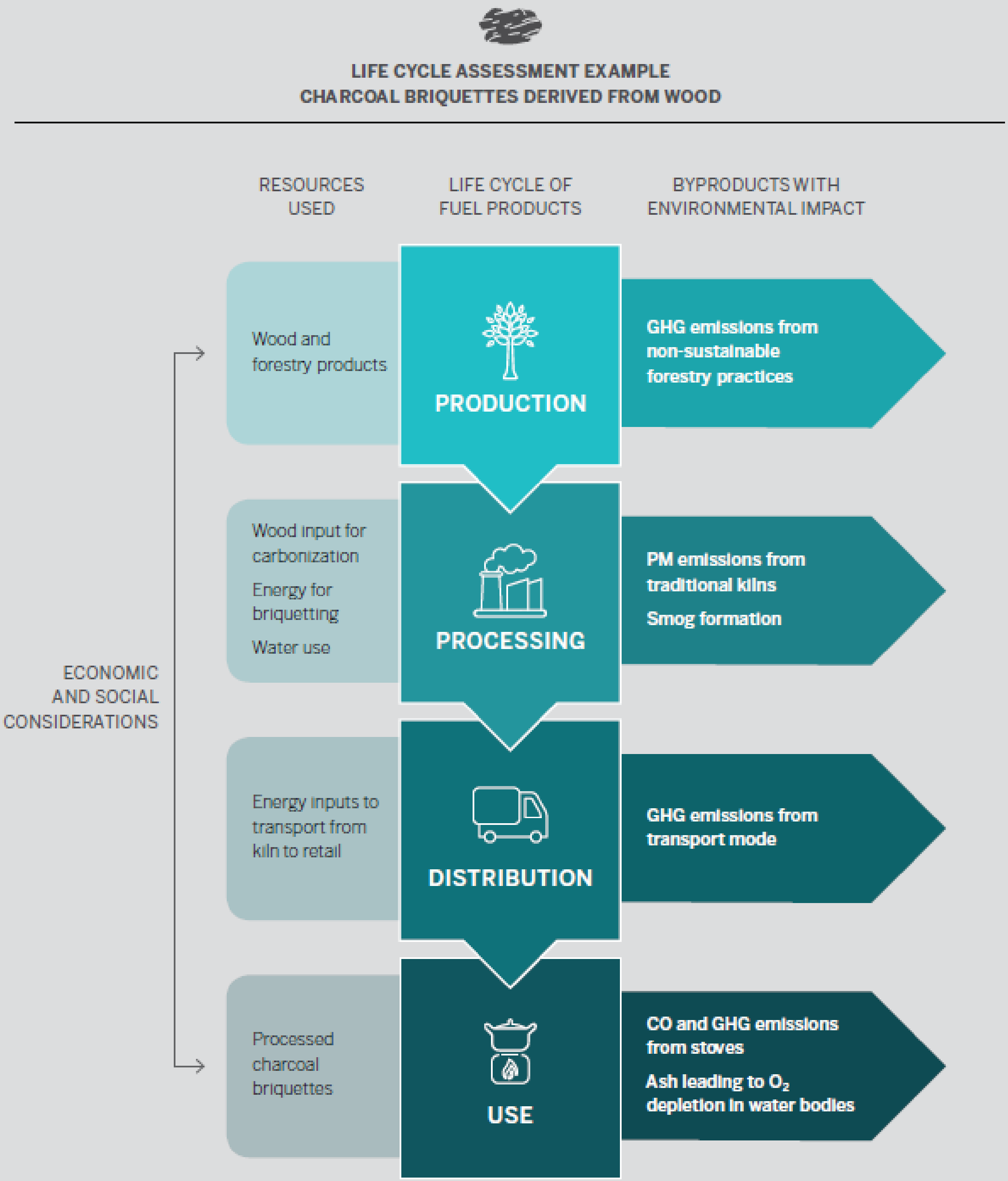
Audiences that may benefit from this study include, but are not limited to:

- Local and national governments, to guide policy development.
- Enterprises, to identify business opportunities for producing, optimizing processes, and marketing cooking fuels as well as attracting investment.
- Donors and investors, to make more informed choices about investments and projects to support.
- Researchers, to identify data gaps or opportunities to improve fuel technologies and performance.
- Marketing and behavior change communication experts, to better understand life cycle environmental and economic implications of cooking fuel choices.
- Global Alliance for Clean Cookstoves secretariat, to inform, guide, and prioritize future activities.

FIGURE 1-1: ILLUSTRATION OF LCA APPROACH TO EVALUATING FUEL IMPACTS

An LCA tracks the environmental effects of a product or a process from cradle (the resources used to create a product) to grave (the outputs/emissions to air, water, land), and include the inputs and outputs at each phase of production. The figure below shows examples of the types of resource inputs and byproduct outputs for the lifecycle of charcoal briquettes derived from wood.

To complement the environmental LCA, economic and social indicators were also included in the assessment to provide a more robust set of considerations for weighing the benefits and tradeoffs of cooking fuel options.



While health impacts were not were not a focus of this study, data from research on indoor air pollution was referenced. The results of this effort can inform the health research community, providing data to broaden the evaluation of the impacts of fuels used for cooking**.**

Sections 1.2 through 1.5 summarize the study scope and methodology, results, insights, recommendations and data gaps specific to the environmental analyses gained as a result of this study. Subsequent report sections offer more detail on the methodology and assumptions (Section 2), indicator definitions (Table 2-2), and country-specific results (Section 3).

Country-specific results are organized by region (Asia, Latin America, and Africa), and each country section includes a summary table of the environmental LCA modeling impacts for each fuel and indicator selected for this study, as well as an in-depth discussion for indicators particularly relevant to the cooking sector.

Companion Appendices provide the detailed environmental analyses and include economic and social considerations (Appendix A), descriptions of methodology considerations and process descriptions for each fuel life cycle (Appendix B), as well as complete references for literature and other information cited throughout the study (Appendix C).

The results of this report are meant to provide a snapshot of “fuel profiles” for several countries and provide directional guidance for stakeholder audiences. The output of this LCA is an assessment of the environmental impacts of cooking fuels over one set of different categories/indicators. Uncertainty and assumptions exist within all LCAs. The results reveal insights for a range of fuels, highlighting general trends and shed light on primary drivers of impacts to inform where additional research could be beneficial. The findings should not be used in isolation to make absolute determinations about one fuel type over another but rather to complement other resources, research, policies, and contextual factors to make more informed decisions.

To access the Detailed Analyses and Appendices online, visit:
cleancookstoves.org/facit under the Resources tab.

1.2 METHODOLOGY SUMMARY

LCA results are an instrument in evaluating different environmental tradeoffs between alternate options for providing a household's energy needs. This study uses a life cycle assessment methodology to evaluate fuels considering steps that occur prior to and including combustion in a stove, for example fuel extraction and processing. For each life cycle stage, this study quantifies the use of energy, water, and other materials, and wastes released to air, water, and land.

The analysis focused on the Alliance's eight focus countries (Box 1-1) and 11 cooking fuels (Box 1-2) derived from eight feedstocks. A number of additional fuels were assessed for India and China as part of a simultaneous study that was conducted by the U.S. Environmental Protection Agency (EPA).[1] Those additional fuels were only assessed for environmental (not social and economic) impacts and the results of that study are included in this report. It was not possible to find all the needed information specific to each country and therefore, results of similar studies in other developing countries were substituted where country-specific data gaps existed.

The environmental, economic, and social indicators assessed are presented in Table 1-1and defined in Section 2.1.5.

BOX 1-1: ALLIANCE FOCUS COUNTRIES

ASIA
China
India
Bangladesh

AFRICA
Ghana
Kenya
Nigeria
Uganda

LATIN AMERICA
Guatemala

BOX 1-2: FUEL AND PROCESSING METHOD COMBINATIONS

UNPROCESSED SOLID BIOMASS

- Firewood [A]
- Crop residue [B,C]
- Dung cake [C]

PROCESSED SOLID BIOMASS

- Charcoal briquettes
  - From wood
  - From bamboo
- Non-carbonized briquettes
  - From sawdust
  - From crop residues
- Wood pellets
- Other processed biomass
  - Wood chips

LIQUID/GAS

- Ethanol
  - From sugarcane
  - From wood
- Biogas from dung
- Liquefied petroleum gas (LPG) [D]
- Kerosene [B,C]
- Dimethyl ether (DME) [B,E]
- Natural gas [B,F]

OTHER

Electricity [B,C]

Hard coal [B,C]

A. Covers all types of whole wood including fuelwood and brushwood.
B. Environmental LCA data are included for these fuels for China through a companion study conducted by the U.S. Environmental Protection Agency (EPA).
C. Environmental LCA data are included for these fuels for India through a companion study conducted by the U.S. EPA.
D. Stored in cylinders.
E. Dimethyl ether is a gaseous fuel type derived from coal and was evaluated as part of the U.S. EPA study.
F. Natural gas is modeled as piped to the household in China.

[1] The EPA fuels analysis study was published in August 2016.

TABLE 1-1: ENVIRONMENTAL, ECONOMIC, AND SOCIAL INDICATORS

INDICATOR CATEGORY	INDICATORS	
ENVIRONMENTAL	• Total energy demand • Net energy demand • Global climate change potential (100a) • Black carbon and short-lived climate pollutants • Particulate matter formation potential	• Fossil fuel depletion • Water depletion • Terrestrial acidification potential (i.e., acid rain) • Freshwater eutrophication potential (i.e., excess nutrients to water bodies) • Photochemical oxidant formation potential (i.e., smog)
ECONOMIC	• Fuel use • Imports, exports, production and demand • Fuel cost	
SOCIAL	• Government policies/programs • Supply and access challenges • Distribution and adoption challenges • Protection and safety	• Time and drudgery • Income earning opportunities • Opportunities for women along the value chain

1.3 SUMMARY OF RESULTS

While this analysis focuses on fuels, it is recognized that the overall impacts will depend on both the fuel *and* the stove. Some of these findings are new insights, while others are consistent with commonly-held ideas in the sector, but we can now offer more quantitative evidence and guidance.

A summary of environmental modeling results per country by fuel is provided in Table 1-2 (see page 1-8). This table includes the *total* impacts for each fuel, summed across the entire life cycle, rather than by phase as presented elsewhere in the report results. To see the individual contributions at each life cycle stage, it is recommended to view the country-specific sections and in the FACIT resource (www.cleancookstoves.org/facit) and also to reference the detailed Appendices.

For each country (within each row) in Table 1-2, results are color coded to indicate fuels that tend to have more (shades of green) or less (shades of red) favorable results for a given environmental indicator. By reading the across the rows, you can compare one indicator across all fuels for that country. The color coding thresholds were determined by categorizing the overall impact contributions for each fuel by country into percentiles. These thresholds highlight broad trends and do not indicate statistically significant differences in results.

Each indicator is individually modeled for each fuel within each country. There is no single aggregated indicator of overall environmental impact for each fuel. Another reason that the indicators are not aggregated is that the importance of specific indicators is expected to vary among stakeholders. Variability seen for the same fuel across countries is the result of the composition of country-specific feedstocks, fuel production methods, variability in country specific distribution distances and modes, and ranges in stove efficiency.

A subset of observations from these results are discussed in Table 1-3 (see page 1-13).

In each country summary in Chapter 3, the environmental profile of each fuel is discussed, followed by a more in-depth discussion of several environmental indicators that were designated as of particular interest for the cooking sector, including *Total Energy Demand (TED), Global Climate Change Potential (GCCP), Black Carbon and Short-lived Climate Pollutants (BC),* and *Particulate Matter Formation Potential (PMFP)*. The online FACIT tool also displays impacts by each life cycle phase, providing more granularity with which to understand these observations.

To access the Detailed Analyses and Appendices online, visit:
cleancookstoves.org/facit under the Resources tab.

TABLE 1-2: SUMMARY OF ENVIRONMENTAL IMPACTS ACROSS ALL COUNTRIES (IMPACT PER HOUSEHOLD PER YEAR)

COLOR KEY:	LESS THAN 5TH PERCENTILE	BETWEEN 5TH PERCENTILE AND 25TH PERCENTILE	BETWEEN 25TH PERCENTILE AND 75TH PERCENTILE	BETWEEN 75TH PERCENTILE AND 95TH PERCENTILE	GREATER THAN 95TH PERCENTILE

	UNPROCESSED SOLID BIOMASS			PROCESSED SOLID BIOMASS						LIQUID/GAS							OTHER	
	FIREWOOD	CROP RESIDUE	DUNG CAKE	CHARCOAL BRIQUETTES FROM WOOD	CHARCOAL BRIQUETTES FROM BAMBOO	NON-CARBONIZED BRIQUETTES FROM SAWDUST	NON-CARBONIZED BRIQUETTES FROM CROP RESIDUES	WOOD PELLETS	WOOD CHIPS	ETHANOL FROM SUGARCANE	ETHANOL FROM WOOD	BIOGAS FROM DUNG	LPG	KEROSENE*	NATURAL GAS*	DME*	HARD COAL*	ELECTRICITY*
TOTAL ENERGY DEMAND (MJ/HH/YR)																		
CHINA	32,391	39,159		52,177	56,042	52,194	15,638	12,434	14,339	32,318	12,548	9,014	13,794	14,577	10,150	31,681	44,249	30,023
INDIA	30,981	9,670	51,628	40,989	47,704	37,110	13,098	8,362	12,976	26,127	8,507	7,306	7,852	10,373			55,317	21,853
BANGLADESH	16,742			23,441	23,441	16,965	6,733	5,150	7,338	14,663	4,787	4,111	4,702					
GUATEMALA	104,300			211,088	207,685	117,412	52,361	40,199	51,041	42,721	33,129	28,453	48,630					
NIGERIA	114,855			322,267	314,079	122,583	58,145	43,160	52,343	43,912	34,080	28,483	111,077					
GHANA	35,444			99,451	96,924	37,657	15,898	12,749	16,153	13,532	10,517	8,790	34,245					
KENYA	30,433			59,871	58,906	34,609	14,610	11,472	14,785	29,687	9,667	8,079	29,995					
UGANDA	39,705			78,111	76,858	45,211	21,616	14,775	19,289	38,731	12,611	10,540	39,125					
NET ENERGY DEMAND (MJ/HH/YR)**																		
CHINA	27,437	34,205		47,223	51,088	47,240	10,685	7,480	9,385	27,364	7,594	4,061	8,840	9,623	5,196	26,727	39,295	25,069
INDIA	26,966	5,655	47,613	36,974	43,689	33,095	9,083	4,347	8,961	22,112	4,492	3,291	3,837	6,358			51,302	17,838
BANGLADESH	14,483			21,182	21,182	14,706	4,474	2,890	5,078	12,404	2,528	1,852	2,443					
GUATEMALA	88,663			195,451	192,049	101,776	36,724	24,563	35,405	27,084	17,492	12,817	32,993					
NIGERIA	98,770			306,181	297,991	106,498	42,059	27,075	36,257	27,827	17,995	12,397	94,992					
GHANA	30,480			94,487	91,960	32,693	10,934	7,785	11,189	8,568	5,553	3,826	29,281					
KENYA	25,870			55,309	54,344	30,046	10,048	6,909	10,222	25,124	5,104	3,516	25,432					
UGANDA	33,752			72,159	70,905	39,259	15,664	8,823	13,337	32,779	6,659	4,588	33,173					

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TABLE 1-2: SUMMARY OF ENVIRONMENTAL IMPACTS ACROSS ALL COUNTRIES (IMPACT PER HOUSEHOLD PER YEAR), *CONTINUED*

COLOR KEY: 0 - 5TH PERCENTILE | 5TH - 25TH PERCENTILE | 25TH - 75TH PERCENTILE | 75TH - 95TH PERCENTILE | 95TH - 100TH PERCENTILE

	UNPROCESSED SOLID BIOMASS			PROCESSED SOLID BIOMASS						LIQUID/GAS							OTHER	
	FIREWOOD	CROP RESIDUE	DUNG CAKE	CHARCOAL BRIQUETTES FROM WOOD	CHARCOAL BRIQUETTES FROM BAMBOO	NON-CARBONIZED BRIQUETTES FROM SAWDUST	NON-CARBONIZED BRIQUETTES FROM CROP RESIDUES	WOOD PELLETS	WOOD CHIPS	ETHANOL FROM SUGARCANE	ETHANOL FROM WOOD	BIOGAS FROM DUNG	LPG	KEROSENE*	NATURAL GAS*	DME*	HARD COAL*	ELECTRICITY*
GLOBAL CLIMATE CHANGE POTENTIAL (KG CO 2 EQ/ HOUSEHOLD/ YEAR)																		
CHINA	1,390	271		2,824	1,496	264	198	949	754	439	40.4	52.1	930	1,027	1,056	1,711	3,885	2,458
INDIA	2,166	530	765	2,298	1,132	277	215	683	644	384	43.3	42.2	1,206	728			3,865	1,665
BANGLADESH	1,875			2,279	470	204	103	860	820	195	18.5	23.8	671					
GUATEMALA	11,728			19,682	5,616	1,380	349	5,720	5,714	236	123	164	4,768					
NIGERIA	12,929			24,512	4,976	1,428	737	6,010	5,851	241	126	48.0	6,214					
GHANA	3,990			7,595	1,536	470	226	1,826	1,805	72.9	43.7	14.8	1,915					
KENYA	3,422			5,400	1,686	505	208	1,649	1,663	399	35.7	13.6	1,529					
UGANDA	4,464			7,027	2,200	508	271	2,121	2,170	540	43.7	17.8	2,007					
BLACK CARBON AND SHORT-LIVED CLIMATE POLLUTANTS (KG BC EQ/HOUSEHOLD/YEAR)																		
CHINA	1.48	3.43		21.2	4.32	0.63	0.71	0.053	1.09	-0.038	0.023	0.034	-0.087	-0.16	-0.011	0.27	0.23	-0.60
INDIA	4.19	9.72	20.1	17.2	9.58	1.78	3.37	0.080	1.79	-0.022	0.019	0.027	0.045	0.045			15.7	-0.076
BANGLADESH	1.70			1.28	1.28	1.20	1.90	0.045	0.74	-0.014	0.010	0.015	0.0028					
GUATEMALA	9.97			68.1	68.1	7.49	2.30	0.33	4.84	0.023	0.072	0.11	-0.40					
NIGERIA	11.0			27.2	26.6	7.70	13.5	0.34	4.97	0.025	0.074	0.16	0.27					
GHANA	3.39			8.40	8.22	2.37	4.17	0.10	1.53	0.0084	0.023	0.051	0.083					
KENYA	2.91			7.66	7.51	2.19	3.83	0.093	0.50	-0.032	0.021	0.047	0.031					
UGANDA	3.80			10.0	9.79	2.84	5.00	0.12	0.65	-0.040	0.027	0.061	0.042					

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TABLE 1-2: SUMMARY OF ENVIRONMENTAL IMPACTS ACROSS ALL COUNTRIES (IMPACT PER HOUSEHOLD PER YEAR), *CONTINUED*

COLOR KEY: 0 - 5TH PERCENTILE | 5TH - 25TH PERCENTILE | 25TH - 75TH PERCENTILE | 75TH - 95TH PERCENTILE | 95TH - 100TH PERCENTILE

	UNPROCESSED SOLID BIOMASS			PROCESSED SOLID BIOMASS						LIQUID/GAS							OTHER	
	FIREWOOD	CROP RESIDUE	DUNG CAKE	CHARCOAL BRIQUETTES FROM WOOD	CHARCOAL BRIQUETTES FROM BAMBOO	NON-CARBONIZED BRIQUETTES FROM SAWDUST	NON-CARBONIZED BRIQUETTES FROM CROP RESIDUES	WOOD PELLETS	WOOD CHIPS	ETHANOL FROM SUGARCANE	ETHANOL FROM WOOD	BIOGAS FROM DUNG	LPG	KEROSENE*	NATURAL GAS*	DME*	HARD COAL*	ELECTRICITY*
PARTICULATE MATTER FORMATION POTENTIAL (KG PM10 EQ/HOUSEHOLD/YEAR)																		
CHINA	7.36	16.9		96.6	13.6	29.2	3.25	1.10	4.65	0.83	1.01	0.38	0.98	1.15	0.28	3.73	3.37	6.61
INDIA	19.0	45.4	94.9	78.3	41.2	19.8	15.9	0.85	8.27	0.67	0.28	0.31	0.62	1.24			77.5	6.77
BANGLADESH	6.84			2.69	2.69	4.92	8.86	0.31	2.99	0.34	0.15	0.17	0.26					
GUATEMALA	34.0			305	305	25.8	9.51	2.49	16.6	0.76	1.01	1.21	1.47					
NIGERIA	37.4			102	99.0	29.6	63.1	2.02	17.0	0.76	1.04	0.84	1.92					
GHANA	11.5			31.6	30.6	9.08	19.5	0.68	5.25	0.23	0.33	0.26	0.59					
KENYA	9.93			28.9	28.1	8.47	17.9	0.61	4.82	0.73	0.29	0.24	0.89					
UGANDA	12.9			37.6	37.0	10.7	23.3	0.73	6.29	0.98	0.38	0.31	1.18					
FOSSIL FUEL DEPLETION (KG OIL EQ/HOUSEHOLD/YEAR)																		
CHINA	0.012	0.076		0.97	1.09	12.4	16.9	41.2	4.07	78.5	2.62	0	319	335	241	550	782	474
INDIA	0.026	0.030	0.62	0.47	0.50	5.29	7.21	25.1	0.54	73.4	4.30	0	201	264			974	367
BANGLADESH	0.015			0.036	0.057	0.018	0.0060	22.2	1.01	34.0	2.42	0	111					
GUATEMALA	0.079			0.16	0.30	0.12	0.0094	59.8	12.7	41.6	16.7	0	1,667					
NIGERIA	0.11			0.25	0.19	2.01	2.41	128	4.60	42.0	17.2	0	2,605					
GHANA	0.033			0.067	0.038	0.33	0.40	21.6	1.42	12.5	5.31	0	803					
KENYA	0.025			0.046	0.045	0.26	0.27	14.8	1.15	70.4	4.88	0	708					
UGANDA	0.033			0.047	0.11	0.18	0.24	12.8	1.50	91.9	6.36	0	923					

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TABLE 1-2: SUMMARY OF ENVIRONMENTAL IMPACTS ACROSS ALL COUNTRIES (IMPACT PER HOUSEHOLD PER YEAR), *CONTINUED*

COLOR KEY: 0 - 5TH PERCENTILE | 5TH - 25TH PERCENTILE | 25TH - 75TH PERCENTILE | 75TH - 95TH PERCENTILE | 95TH - 100TH PERCENTILE

	UNPROCESSED SOLID BIOMASS			PROCESSED SOLID BIOMASS						LIQUID/GAS							OTHER	
	FIREWOOD	CROP RESIDUE	DUNG CAKE	CHARCOAL BRIQUETTES FROM WOOD	CHARCOAL BRIQUETTES FROM BAMBOO	NON-CARBONIZED BRIQUETTES FROM SAWDUST	NON-CARBONIZED BRIQUETTES FROM CROP RESIDUES	WOOD PELLETS	WOOD CHIPS	ETHANOL FROM SUGARCANE	ETHANOL FROM WOOD	BIOGAS FROM DUNG	LPG	KEROSENE*	NATURAL GAS*	DME*	HARD COAL*	ELECTRICITY*
WATER DEPLETION (M 3 /HOUSEHOLD/YEAR)																		
CHINA	0.093	0.58		5.88	5.70	74.9	103	275	4.24	343	23.3	5.16	283	358	28.6	136	378	2,598
INDIA	0.20	0.23	4.76	2.53	2.45	29.6	40.6	143	0.63	356	1.12	4.18	123	146			66.7	2,066
BANGLADESH	0.11			0.20	0.20	0.061	0.046	15.8	1.08	155	0.63	2.36	44.7					
GUATEMALA	0.60			0.74	0.74	0.42	0.069	1,961	13.4	255	4.35	16.3	139					
NIGERIA	0.82			1.23	1.21	12.1	15.0	789	5.08	262	4.48	51.5	151					
GHANA	0.25			1.14	1.14	13.2	18.1	953	1.57	80.6	1.38	15.9	73.8					
KENYA	0.19			0.77	0.76	8.65	11.9	627	1.26	315	1.27	14.6	276					
UGANDA	0.25			1.52	1.37	16.4	24.7	1,304	1.65	411	1.66	19.0	379					
TERRESTRIAL ACIDIFICATION POTENTIAL (KG SO2 EQ/HOUSEHOLD/YEAR)																		
CHINA	1.43	1.49		1.50	1.62	1.44	1.13	2.02	0.58	2.57	0.61	0.53	3.38	4.30	0.84	5.86	7.92	21.2
INDIA	1.60	2.47	3.01	1.34	1.34	1.49	1.17	1.17	0.72	2.00	0.37	0.43	1.29	1.60			7.51	16.1
BANGLADESH	3.55			0.59	0.59	2.04	0.48	0.29	1.57	1.05	0.19	0.24	0.66					
GUATEMALA	8.06			3.93	4.00	6.80	1.22	2.61	4.20	3.35	1.27	1.66	3.63					
NIGERIA	8.81			3.27	3.25	7.01	3.45	1.50	4.11	3.39	1.30	0.25	4.13					
GHANA	2.72			1.14	1.13	2.29	1.07	0.66	1.27	1.01	0.42	0.076	1.26					
KENYA	2.35			0.72	0.72	2.41	0.98	0.54	1.16	2.24	0.37	0.070	2.26					
UGANDA	3.07			0.87	1.76	2.51	1.28	0.54	1.51	3.00	0.47	0.091	2.99					

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TABLE 1-2: SUMMARY OF ENVIRONMENTAL IMPACTS ACROSS ALL COUNTRIES (IMPACT PER HOUSEHOLD PER YEAR), *CONTINUED*

COLOR KEY: 0 - 5TH PERCENTILE | 5TH - 25TH PERCENTILE | 25TH - 75TH PERCENTILE | 75TH - 95TH PERCENTILE | 95TH - 100TH PERCENTILE

	UNPROCESSED SOLID BIOMASS			PROCESSED SOLID BIOMASS						LIQUID/GAS							OTHER	
	FIREWOOD	CROP RESIDUE	DUNG CAKE	CHARCOAL BRIQUETTES FROM WOOD	CHARCOAL BRIQUETTES FROM BAMBOO	NON-CARBONIZED BRIQUETTES FROM SAWDUST	NON-CARBONIZED BRIQUETTES FROM CROP RESIDUES	WOOD PELLETS	WOOD CHIPS	ETHANOL FROM SUGARCANE	ETHANOL FROM WOOD	BIOGAS FROM DUNG	LPG	KEROSENE*	NATURAL GAS*	DME*	HARD COAL*	ELECTRICITY*
FRESHWATER EUTROPHICATION POTENTIAL (KG P EQ/HOUSEHOLD/YEAR)																		
CHINA	0.30	1.88		1.38	0.81	0.40	0.082	0.043	0.10	0.17	0.023	0	0.040	0.051	0.0034	0.31	0.44	0.31
INDIA	0.63	0.75	15.3	1.12	0.86	0.30	0.26	0.014	0.27	0.15	1.3E-05	0	0.011	0.013			0.0086	0.014
BANGLADESH	0.37			0.64	0.64	0.20	0.15	0.0073	0.16	0.079	7.4E-06	0	0.0056					
GUATEMALA	1.95			2.36	2.36	1.36	0.22	0.064	0.94	0.13	5.1E-05	0	0.024					
NIGERIA	2.65			1.26	1.23	1.48	1.05	0.049	1.20	0.13	5.3E-05	0	0.019					
GHANA	0.82			0.39	0.38	0.42	0.32	0.016	0.37	0.040	1.6E-05	0	0.0059					
KENYA	0.62			0.31	0.31	0.39	0.30	0.015	0.30	0.16	1.5E-05	0	0.036					
UGANDA	0.81			0.41	0.40	0.48	0.39	0.018	0.39	0.21	1.9E-05	0	0.047					
PHOTOCHEMICAL OXIDANT FORMATION POTENTIAL (KG NMVOC EQ/HOUSEHOLD/YEAR)																		
CHINA	8.96	12.5		51.9	120	5.61	5.49	1.37	9.77	1.61	0.53	0.56	1.98	2.10	1.12	9.97	5.94	9.26
INDIA	24.2	35.1	74.9	42.3	71.9	12.4	12.3	0.95	10.5	1.37	0.90	0.46	2.92	4.65			31.6	8.08
BANGLADESH	8.96			61.4	61.4	39.3	6.86	0.50	26.1	0.64	0.46	0.51	1.48					
GUATEMALA	362			287	287	273	16.3	3.43	176	13.5	3.16	1.78	9.27					
NIGERIA	399			455	452	280	48.9	3.13	180	13.8	3.25	1.31	34.9					
GHANA	123			141	140	86.5	15.1	0.53	55.7	4.24	1.04	0.40	10.8					
KENYA	106			129	129	80.1	13.9	0.88	51.1	1.38	0.92	0.37	7.42					
UGANDA	138			168	169	103	18.1	0.98	66.7	1.94	1.18	0.48	9.77					

NOTES FOR TABLE 1-2:

Calculated values in the table are rounded and displayed to atleast two significant figures. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently. Cells filled with diagonal lines denote that those fuels were not assessed for that country.

* These fuels are included in the study scope only for India and/or China through a companion study conducted by the U.S. EPA.

** Net Energy Demand is Total Energy Demand minus the final energy actually delivered to the cooking pot.

TABLE 1-3: OBSERVATIONS BY FUEL TYPE

FUEL TYPE	KEY OBSERVATIONS
UNPROCESSED SOLID BIOMASS	Solid biomass fuels show higher impacts compared to liquid and gas fuels across almost all indicators, with the exception of *Water Depletion* and *Fossil Fuel Depletion*.
FIREWOOD **CROP RESIDUES** **DUNG CAKES**	• For this study, any country with decreasing forest land was assumed 100% non-renewable, with the exception of India and China (41% and 42.5% respectively).* In cases with high forestry product demand and limited supply, in part due to reduced tree planting and growth to absorb CO_2, *Global Climate Change Potential* impacts tend to be higher and should be factored into the interpretation of the results. • For Guatemala and Nigeria, higher values are seen for *GCCP* for firewood because household energy use in these countries is higher (Appendix B, Table B-28). • In addition to high emissions of particulate matter and carbon monoxide relative to other fuel alternatives, firewood use also has higher impacts for: - *Freshwater Eutrophication*. Ash from burning firewood contains phosphorous and when applied to the land as a fertilizer, can lead to soil emissions and runoff into freshwater. - *Terrestrial Acidification Potential*. SOx and NOx are produced when firewood is combusted, which leads to acid rain. Therefore, firewood also has higher impacts for this indicator. • Despite being renewable, crop residues and dung cake show high impacts across a number of indicators. • Dung cake, though only assessed for India, has the highest *BC* and *PMFP* emissions of all fuels namely due to having the lowest stove thermal efficiency of all the fuels assessed.
PROCESSED SOLID BIOMASS	Processed biomass that is non-carbonized shows low to mid-level environmental impacts. Exceptions are *Water Depletion* and *Fossil Fuel Depletion* impacts for pellets due to the input requirements for pellet processing and production. Processed biomass that is carbonized shows higher impacts overall namely due to impacts resulting from inefficient processing steps.
CHARCOAL BRIQUETTES *(FROM WOOD OR BAMBOO)*	• While the carbonization process creates a higher quality of fuel than firewood, charcoal briquettes demonstrate high impacts across a number of indicators compared to other fuel types and other processed biomass pathways. This is generally resulting from the estimated use of inefficient traditional earth mound kilns during the carbonization process. - Earth mound kilns, used during the processing step, are the greatest contributor to *Total and Net Energy Demand*, *Photochemcial Oxidant Formation Potential*, *GCCP*, *Black Carbon and SLCPs*, and *PM Formation Potential*. - *Freshwater Eutrophication*. Higher impacts result mainly from ash from the wood combustion at the kiln. • Utilizing bamboo for charcoal briquettes avoids some of the wood feedstock GHG emissions associated with deforestation (bamboo growing practices are estimated to be 100% renewable and hence carbon neutral). However, similar to utilizing wood for charcoal briquettes, bamboo has significantly large processing energy requirements than other fuels, which cancel out benefits from its renewability.
NON-CARBONIZED BRIQUETTES *(FROM CROP RESIDUES)*	• Non-carbonized briquettes from crop residues have generally lower environmental impacts compared to charcoal briquettes namely due to lack of a carbonization step.

TABLE 1-3: OBSERVATIONS BY FUEL TYPE, *CONTINUED*

FUEL TYPE	KEY OBSERVATIONS
NON-CARBONIZED BRIQUETTES FROM SAWDUST, WOOD PELLETS, OR WOOD CHIPS	• Different levels of manual vs. commercialized processing were estimated based on the literature cited for each country. In commercially made non-carbonized sawdust briquettes, the wood is combusted during the drying process to remove the moisture content, resulting in higher *Energy Demand* impacts compared to non-carbonized briquettes from crop residues. However, the *Black Carbon and SLCPs*, and *PM Formation* impacts are generally lower for non-carbonized briquettes from sawdust. • Non-carbonized briquettes from crop residues show lower Energy Demand when compared to firewood and carbonized briquettes, namely due to lower energy processing requirements. • In addition to efficiency benefits from a smaller, denser, and more uniform fuel, the stoves used to burn wood chips and wood pellets (30-53% efficiency) are generally more efficient than stoves used to burn unprocessed solid biomass (8.5-13.5%). As a result, more of the energy content of the chips and pellets is converted into useful cooking energy, which is a contributing factor to its overall favorable environmental impacts, outweighing the energy inputs needed for processing. - The *Water Depletion* indicator for wood pellets tend to be high as a result of electricity usage during pelletization in countries where the electricity grid mix is primarily hydropower. - Stove thermal efficiencies for wood pellets (~53%) tend to be higher than for wood chips (~31%) resulting in lower impacts for pellets even though they consume more energy in the processing stage.
LIQUID/GAS	Liquid and gas fuels that are combusted in higher efficiency stoves lead to less fuel combusted and therefore less air emissions, especially particulate matter and black carbon. Liquid and gas fuels also tend to have lower overall life cycle environmental impacts, with some exceptions. More of the heating value of the fuel is converted into useful cooking energy and therefore less fuel must be produced, transported, and burned to deliver the same amount of cooking energy resulting in lower *Total* and *Net Energy Demand* impacts. Categories such as *Fossil Fuel Depletion* and *Water Depletion* show higher impacts as liquid/gas fuels such as LPG and ethanol often require more complex upstream processing components, i.e. the cultivation and processing of the sugarcane, and electricity requirements.
ETHANOL *(FROM SUGARCANE OR WOOD)*	• Ethanol produced from cellulosic/non-food feedstocks (wood, agricultural residue) has lower life cycle impacts compared to ethanol produced from sugar and starch materials. - *Water Depletion*. Sugarcane undergoes more agricultural and pre-processing steps and requires more irrigation than wood residues which can be directly converted to ethanol. - *Fossil Fuel Depletion*. These impacts are higher for sugarcane ethanol mainly from fertilizer use during cane production as well as diesel use for farm operations and distribution of the feedstock and fuel. - *Terrestrial Acidification*. Ammonia is a main emission that leads to acidification and is emitted from fertilizers applied during sugarcane cultivation. • Ethanol from sugarcane has lower impacts compared to solid fuels in many categories, especially on air emission indicators such as *Global Climate Change Potential*, *Black Carbon and SLCPs*, and *Particular Matter Formation*.

TABLE 1-3: OBSERVATIONS BY FUEL TYPE, *CONTINUED*

FUEL TYPE	KEY OBSERVATIONS
BIOGAS *(FROM DUNG)*	• Biogas from dung shows low overall life cycle environmental impacts for all countries in this study. As it uses a local byproduct and does not require upstream processing, impacts are vastly reduced. - One exception is the *Water Depletion* indicator which shows some impacts due to the water needed to maintain the digester. - Application of digested sludge from the biogas system could lead to some *Eutrophication* impacts, but as utilization of this co-product is outside the system boundaries of this study, *Freshwater Eutrophication* impacts display as zero.
LPG	• Despite being a fossil fuel, when considering the energy density of the fuel, use of higher efficiency stoves, and non-renewability of biomass in many situations, LPG is comparable to other fuel alternatives and in some cases, shows lower impacts. - The *Energy Demand* of LPG is low compared to many other fuels. However, *Energy Demand* was found to be higher in African and Latin American countries mainly due to less efficient refineries and practices, hence requiring more energy inputs. - Not capturing the flared gas for reuse leads to lower efficiency and yield at the refinery resulting in notable *Net Energy Demand* burdens. • LPG shows more favorable performance for indicators such as *Global Climate Change Potential*, *Particulate Matter Formation*, and *Black Carbon and Short-lived Climate emissions* when compared to solid biomass (especially from non-renewable sources), kerosene, natural gas and electricity. • *Water Depletion* impacts trend higher generally due to the water inputs needed for the production of LPG during crude oil extraction and petroleum refining.
KEROSENE	• *Fossil Fuel Depletion* impacts are high for kerosene** as it is a fossil fuel derived from crude oil, but it also displays high impacts for *Water Depletion*. - Existing evidence shows that household use of kerosene can lead to levels of particulate matter and other pollutants that exceed WHO guidelines and is also a concern in terms of risk of burns, fires and poisoning.***
NATURAL GAS	• Natural gas has low environmental impacts across the majority of life cycle impacts.****
DME	• While DME is produced from coal feedstock via gasification, slightly lower *Total Energy Demand* impacts are seen for DME as compared to coal due to its ability to be transported in lighter weight bottles and its application in more efficient gas stoves.****
OTHER	
ELECTRICITY	• Electricity-related fuel combustion emissions do not occur at the household level. But for consistency with other fuels, the fuel combustion emissions associated with electricity generation have been allocated to the use stage in this LCA. - While household air pollution will not occur with electricity, ambient air pollution will result near the power plants generating the electricity due to the energy sources supplying the grid. - For countries like China and India** where electricity is primarily generated from coal, its life cycle impacts for indicators such as *Global Climate Change Potential*, *Fossil Fuel Depletion*, *Water Depletion* (due to hydropower in the electricity mix), and *Terrestrial Acidification Potential* are notable.

TABLE 1-3: OBSERVATIONS BY FUEL TYPE, *CONTINUED*

FUEL TYPE	KEY OBSERVATIONS
HARD COAL	• Hard coal** consistently emerged as having the largest overall negative impacts since it is derived from non-renewable carbon and because thermal efficiency of coal stoves is relatively low compared to stoves for the other fossil fuel options. • Coal has high *Total Energy Demand* results because of high energy requirements for coal mining and distribution.

NOTES FOR TABLE 1-3:

* At the time the modeling for this analysis was initiated, more up to date numbers on the fraction of non-renewable biomass (fNRB) (Bailis et al) were not released.

** Was only evaluated for 2 of 8 of the Alliance focus countries as part of the study conducted by the U.S. EPA.

*** WHO Guidelines for Indoor Air Quality: Household Fuel Combustion

**** Was only evaluated for 1 of 8 of the Alliance focus countries as part of the study conducted by the U.S. EPA.

1.4 RECOMMENDATIONS

Although cooking consumes most of the energy across the life cycle, results of the analysis show that other parts of the value chain contribute a high proportion of the total environmental burden. In addition to high efficiency stoves and high calorific value fuels that can reduce these energy losses, there are additional environmental, economic, and social factors to consider when prioritizing and developing policies about fuel types. Based on the results of the fuel impact study, country-specific policy considerations, available literature, and insights from the Alliance Secretariat, partners and enterprises, the next section outlines enterprise- and policy-level recommendations to scale up cleaner fuel options.

1.4.1 *Enterprise-Level Recommendations*

Enterprises can use the information in this study and FACIT to improve their value proposition for customers and potential investors while producing non-traditional fuels in a more cost-effective way. A reduction in the use of environmentally and health harming fuels and practices can be realized as clean fuel enterprises increase their market share. The following fuel opportunities, if taken up by more fuel entrepreneurs, could lead to positive environmental impacts. (Appendix A provides a more in depth discussion for each country):

- Fuels produced from locally available feedstocks, including waste materials, have lower environmental impacts across many indicators, particularly when combusted in high-performing efficient stoves and when locating production and distribution in close proximity to the raw material supply. Additionally, using waste materials for productive fuel use at scale would reduce the amount available for direct combustion in traditional, inefficient stoves.

    - **Biogas** can be produced from locally available dung in rural conditions and its resultant bioslurry can be a substitute for chemical fertilizers.

    - **Ethanol** from cellulosic and/or non-food feedstocks can be produced from wastes such as wood or agricultural residues.

    - **Pellets** can be sourced from locally produced wood and agricultural residue. Environmental impacts could be further reduced by utilizing waste material from other industries such as sawdust from timber companies.

- Fuels that governments already support/promote via subsidies or consumer education programs.

    - **LPG** is largely subsidized in many focus countries. While it has higher fossil fuel depletion impacts, it has moderate or low impacts compared to traditional fuels in many environmental indicators associated with air emissions as illustrated in Table 1-2 (see page 1-8).

- **Biogas and pellets** in countries like China have received various levels of government support over the years for distribution or technology procurement. Both demonstrate favorable environmental impacts across the value chain.

- Fuel types that tend to be more readily accepted by consumers (e.g., fuels that can be purchased and transported to consumers in convenient quantities, or that do not require learning to use a significantly different type of stove).

  - **Non-carbonized briquettes from crop residues** can be used with existing wood charcoal briquette stoves, and are derived from renewable agricultural wastes. This fuel has consistently lower environmental impacts compared to charcoal (i.e., carbonized) briquettes.

Other potential consideration for enterprises when starting up or scaling a fuel business in a sustainable manner include the following[1]:

- **Production Technology**: For charcoal briquettes, emission impacts from the carbonization process when using traditional kilns show high environmental impacts across a number of indicators. Though inexpensive and mobile, the efficiency rates of traditional of kilns are typically low. Improvements in the conversion efficiency of biomass to briquettes would show potential for reductions in emissions. And when paired with incentives or financing programs, communities would be enabled to construct, purchase and/or utilize improved kilns.

- **Distribution Logistics**: Over two-thirds of the *Total Energy Demand* impact for LPG and ethanol from sugarcane results from the importation and distribution phase. Local production of fuels could reduce the *Total Energy Demand* impacts. Additionally, enterprises have found that locating upstream production facilities significant distances away from their downstream operations makes their business vulnerable to transportation disruptions and can jeopardize supply meeting demand.

1.4.2 *Policy-Level Recommendations*

While not a primary focus on this analysis, presented below are a brief sampling of fuel-related policies and initiatives across Alliance focus countries. Notable tradeoffs between fuels' LCA results, used in conjunction with other resources, research, policies, and contextual factors can inform energy and environmental policy. These cases are meant to show a few examples of policies that could support or inhibit the effectiveness of various fuel value chain-related interventions. While Table 1-4 (see page 1-21) is not a comprehensive list, it begins to show a range of polices and regulations to consider in conjunction with using an LCA as a decision-support tool.

Current fuel use patterns in each country have evolved due to availability of resources; cultural preferences; geographic dispersion of the population; poverty and awareness; existing subsidies, taxes, and trade policy; and more. Presented below are recommendations to further expand affordability, accessibility, and adoption of cleaner fuel options based on the results of the LCA as well as stakeholder insights. Policy makers can use the results of this LCA to guide decisions on legislative and economic policy instruments, strategic planning and procurement.

Agricultural and Forest Management

- Biomass will continue to be a dominant fuel in the household energy mix, and should be incorporated into policy planning. Zoning land for sustainable woodlots or for growing annually renewable biomass fuels should be incorporated into forest management plans. Increased growth of trees leads to greater absorption of CO2 and therefore reduction in *Global Climate Change Potential* as shown in the LCA results.

- To complement this, governments should increase regulatory involvement in informal markets for purchased firewood and traditional charcoal. This would contribute to the reduction of environmental impacts overall.

- Agricultural management practices, e.g. irrigation and fertilizer application as seen in the results for fuels such as ethanol from sugarcane, have an effect on the cooking fuel supply chain and should be considered when developing policies related to biomass-derived cooking fuels.

- Policy mechanisms should take into account shifts in cooking fuel needs by season. For example, rural families in India often used fuels like LPG as a stopgap measure when firewood was too expensive during the monsoon season[2] and moisture content in fuel sources such as wood and agricultural residues can affect combustion performance and emissions of the fuel.

Financing Programs

- Government financing programs should look across the fuel value chain to identify who should receive the support (consumers, producers, or both), which part(s) of the value chain should financial support target (collection, storage, transportation, manufacturing, distribution/sales), and if financial support should be based on outcomes. As seen from the LCA results, many environmental impacts result from the process of producing the fuels.

- In countries where waste residues can and are being used productively and where higher efficiency combustion technologies exist, national governments should provide unified policies and financial support for fuel production. This could open up more opportunities for the cleaner fuel markets to scale and reach more consumers.

- Biogas shows low overall environmental impacts across most indicators. Policy makers should consider providing financing options for biogas digesters and biogas stoves to improve affordability for consumers, which is often a barrier to adopting this fuel type. Different government subsidy schemes could be explored including performance-based subsidies linking the payment of subsidies to the performance of the digester or use-based subsidies to incentivize biogas users.

- Economic incentives, credit facilities or barriers (i.e., payment for natural resources) could be considered to enhance the procurement, construction and adoption of advanced kiln technologies to improve the conversion efficiency of wood resources. As seen in the results, traditional kilns are a major contributor to negative environmental impacts across a number of indicators. If paired with strong forest management policies, improving charcoal production could have significant environmental benefits.

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cleancookstoves.org/facit under the Resources tab.

TABLE 1-4: FUEL-RELATED POLICIES IN ALLIANCE FOCUS COUNTRIES

INDIA	• Through the PAHAL Scheme in India, LPG cylinders purchased through participating oil companies are tracked and a partial refund credit is provided to the consumer's bank account for the number of cylinders purchased (with a maximum of nine cylinders per year).[2,3] • India currently places high taxes on ethanol as a cooking fuel to discourage alcohol consumption.[4]
BANGLADESH	• In 2008, Bangladesh's 2008 Renewable Energy Policy created an independent agency (SREDA) to focus on sustainable energy development and promotion within the country.[5] • Grameen Shakti has installed over 30,000 biogas systems in Bangladesh since 2005, thanks in part to its innovative microfinance solutions that help buyers overcome the upfront costs of new biogas systems.[6,7]
GUATEMALA	• Guatemala's National Strategy for the Sustainable Production and Consumption of Woodfuels (2013-2024), which calls for the establishment and management of at least 48,000 hectares of plantations and agroforestry systems and distribution of 100,000 improved cookstoves.[8] • In 2013, the Government of Guatemala enacted a new National Energy Policy, which promotes energy sources other than wood.[9] One goal is to replace firewood with other energy sources in 25 percent of Guatemalan households by 2027.
NIGERIA	• Nigeria has experienced a weak legal framework, which has led to the loss of cylinder control, poor management of refilling practices and inconsistent license approvals for LPG retailers and suppliers.[10,11]
GHANA	• The government of Ghana has committed to implementing a nationwide LPG accelerated promotion program including a Cylinder Recirculation Model to ensure safety and increase access to LPG. The policy goal is to ensure at least 50% of Ghanaians have access to safe LPG for commercial, industrial and domestic use by 2020.
KENYA	• The LPG industry in Kenya is fragmented and illegal practices are widespread, often from smaller LPG operators. The impact is damaging to the growth of the industry.
UGANDA	• Uganda's 2011/12 - 2021/22 National Forest Plan, which seeks to re-orient Uganda's forestry sector with a "business approach" aimed at using public and private funding to develop forestry-related enterprises and to sustainably manage resources.[12] • Through the Promotion of Renewable Energy and Energy Efficiency Programme (PREEP), the Uganda Ministry of Energy and Minerals and local NGOs promoted sustainable charcoal briquette production, increased access to modern biomass energy technologies, and more from 2007 to 2014. The program, however, struggled to develop markets in rural areas where households found modern cooking methods too expensive.[13] • Producers of wood-based charcoal briquettes in Uganda are subject to value-added taxes, employment taxes, and more. Producers are forced to pass these costs on to buyers, reducing their competitiveness in a marketplace that includes informal producers of charcoal briquettes who are not subject to regulation.[14] • Due to lack of infrastructure in Uganda, LPG is imported from Kenya.[15] LPG is usually sold in 13 kg cylinders, which are expensive to purchase and difficult to transport.

Supportive Energy Policy Development

- Switching from traditional solid fuels to electricity powered by coal shifts emissions to other points in the fuel supply chain, i.e. near the power plants. Electric/induction stoves could help reduce indoor air pollution but national energy plans should closely evaluate opportunities to move their electricity grid mix towards renewables.

- Policy makers and private partners should perform holistic assessments of key supply and demand drivers and identify critical investment needs to improve the market penetration of the fuels as well as address environmental inefficiencies.

- Advocacy and partnerships should focus on working with the government to reform tax/tariff/Value Added Tax (VAT) policies for both fuels, efficient stoves, and efficient production technologies and materials.

- In the case of LPG, strict enforcement of regulations to maintain cylinders and prevent illegal refilling and cross-filling of LPG cylinders are needed.

- Governments should take care that actions with other goals do not have unintended consequences that could affect access to cleaner burning and more efficient fuels. The policies should ensure the target demographic is the primary and actual beneficiary of the program to avoid the challenges faced with misuse of LPG.

Local Government and Agency Involvement

- Provincial and state governments should play a key role in informing and enforcing supportive fuel policies, fostering clean fuel businesses, financing and distribution programs. Designing solutions (policy and business model designs) should take into account the unique features of each province or state. This includes feedstock availability, seasonality, infrastructure, available production technologies, performance of available combustion technologies, transportation distances, rural/urban profile, income level, market development, and prior policy implementation.

- Independent agencies should be recruited to serve as strong advocates for promoting new, cleaner pathways in cooking fuel markets alongside the Government. Independent agencies can also bridge the gap between stove technology providers and fuel providers to ensure the technologies are available that optimize the performance of the available fuels.

Infrastructure Improvements

- Governments should focus on establishing more reliable, modern, cost-effective infrastructure for distributing LPG cylinders with more private sector suppliers entering the market. Additionally, the development of domestic LPG processing infrastructure would reduce the sector’s dependence on imports. Reducing/optimizing the distance between the various parts of the fuel supply chain can help to reduce the environmental footprint of the fuel production and distribution processes while also expanding the reach to consumers.

- As seen in the detailed LCA results, less efficient refineries and practices in certain countries leads to higher energy demand impacts, and not capturing flared gas for reuse leads to lower efficiency and yield at the refinery resulting in high energy demand impacts. Focusing investments in improving these areas could lead to lower energy demand burdens and more positive environmental profiles for fuels such as LPG

1.5 DATA GAPS AND RESEARCH NEEDS

This study demonstrates that there is potential to optimize fuel value chains from an environmental standpoint. However, to gain a comprehensive view of the cooking fuel opportunities, the results of this LCA study should be used in conjunction with social, economic and policy considerations, while being aware that gaps exists in all three dimensions. Through this analysis, data gaps and research needs were identified that can potentially guide future research.

1.5.1 *Environmental Data*

For the environmental assessment, data on combustion emissions for some fuels and countries were limited and therefore had to be adapted from data for corresponding types of fuels in other countries. Energy and combustion emissions for firewood and crop residues vary depending on the type of wood or biomass being burned and their moisture content. Next steps to build upon the work completed for this study could be:

- Expand data on heating values and emission factors for local biomass resources in each country to provide a more representative assessment of available biomass fuel options.
- Develop a database with improved regional data on agricultural practices (e.g., use of large-scale mechanized agricultural methods, sustainable use of fertilizer, and irrigation requirements) that could support more accurate country-specific assessments.
- Conduct sensitivity analyses to understand the overall impact of LCA modeling choices on the environmental results. For examples, for crop residues, the environmental burdens for primary cultivation of the crop is assigned to the primary product, not the residues. Impacts may notably increase if conducting a sensitivity analysis that partitions some of these burdens to the residue.[2]
- Evaluate additional advanced processing technologies to understand further opportunities to improve impacts, e.g. improved kiln technologies for charcoal briquettes or capturing of flared gas in petroleum production for LPG.

While biogas and ethanol consistently showed lower life cycle impacts in many results categories across all countries, there are additional implications to consider. For example, sugarcane ethanol requires energy inputs for agricultural and manufacturing. Impacts related to fertilizer production and emissions from application as well as impacts resulting from the importation and distribution can also be notable. Biogas users must have sufficient livestock to support a digester and the units are often only affordable if upfront cost of the digester can be financed. As a result, additional research and development in the following areas would be beneficial:

[2] The U.S. EPA is undertaking a second study to extend this research, including assessing a range of stove types and efficiencies, updating stove emissions based on updated research, updating non-renewable forestry values, and conducting uncertainty analyses. Phase 2 data are expected be be available in the summer of 2017.

- Investigate the economic feasibility to scale up technology for local ethanol production from readily available non-food and other residues (e.g., cassava and cashew wastes) feedstocks.

- Improve the reliability of household biogas digesters. More research could improve the understanding of effects of climate and feedstock choice on household-level biogas digester performance.

- Improve the feasibility of larger biogas digesters for urban areas that could utilize food waste or other municipal wastes as feedstock (not only providing biogas fuel, but also reducing the amount of municipal waste to be disposed).

- For biogas, ethanol, and LPG conduct a quantitative analysis of historical demand of these fuels for cooking as well as existing infrastructure, supportive policies and financing options to provide an understanding of where these cooking fuels can reasonably be brought to scale. The analysis would evaluate the economic costs and benefits, to confirm whether government subsidies are justified and make recommendations for subsidies to be more cost-effective.

1.5.2 *Economic Data*

Data on cost, affordability, and use of different fuels (for cooking, heating, or other households) are among the most important criteria for determining which fuel options can be adopted, but the data were incomplete. Complete data on fuel imports, exports, and demand is needed to to assess whether a country can be self-sufficient in producing an adequate supply of fuels.

- Improve detailed accounting of fuel costs to the consumer (i.e., average fuel collection distances, price paid, and frequency of purchase), including for fuels that are currently used at low levels and generate more thorough data on fuel imports, exports, and demand, differentiated by use.

- Conduct a life cycle cost (LCC) analysis. This would estimate the total cost of each fuel from fuel feedstock acquisition through final use, including agricultural or forestry operations to produce fuel feedstock, harvest or collection of fuel materials, processing into the fuel product, distribution, use in a cookstove, and any waste disposal (e.g., of ash).

1.5.3 *Social and Gender Data*

Recent efforts by the Global Alliance for Clean Cookstoves and the International Center for Research on Women (ICRW) has created a set of indicators for measuring the diverse social impacts of cookstove and fuel initiatives at the global and local program levels. However, information gaps still exist in collecting and consolidating the research and assessing the impacts across the fuel value chain before the consumer uses the fuel product.

- Commission research, collect data and develop case studies on socioeconomic impacts (i.e., time, cost savings, safety and protection, income-earning opportunities, women's empowerment and gender equality) of fuel related projects or interventions in conjunction with use of the Alliance's Social Impact Monitoring and Evaluation framework and guidance.

- Develop a framework for collection of challenges and successes encountered during distribution, fuel reliability, and other parts of the fuel supply chain, as projects are being implemented so that best practices and lessons learned can be used to inform strategies to drive adoption, build effective distribution channels and increase reliability.

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2. SCOPE AND METHODOLOGY

2.1 SCOPE OF STUDY

2.1.1 *Functional Unit*

To provide a basis for comparing different products, a common reference unit, or functional unit, must be defined based on the end performance of the product. Results of the LCA are then expressed in terms of this functional unit. As this analysis compares different fuels used to provide cooking energy, and that depends on both the energy content of the fuel as well as the thermal efficiency of the stove, the LCA results (and the cost results discussed in Table 2-2) are based on **energy delivered for cooking per household per year**. Energy delivered for cooking is what is directly used for heating the pot. In contrast, the total energy demand impact category evaluates the energy needs for feedstock production, fuel processing, transportation to households and retail locations, and heat losses during cooking. Table 2-1 provides the sources used to determine household energy needs for each country, which are influenced by country-specific household size, meal type, and other traditions or cultures centered on the use and preference of fuels for cooking.

Table 2-1. Household Energy Cooking Use per Year for Each Focus Country

Country	GJ/household/year	Sources
India	4.02	Habib et al., 2004
China	4.95	Zhou et al., 2007
Bangladesh	2.26	USAID, 2013
Kenya	4.56	IEA, 2014; GVEP International, 2012a
Uganda	5.95	BMWi, 2009; Uganda Bureau of Statistics, 2014
Ghana	4.96	IEA, 2014; GVEP International, 2012c
Nigeria	16.1	IEA, 2014; Accenture, 2011
Guatemala	15.6	ESF, 2013

GJ= gigajoules

2.1.2 *Geographic Scope*

See Box 1-1 for detail on the geographic scope of the project.

2.1.3 *Fuel Systems Studied*

See Box 1-2 for cooking fuel systems studied in the analysis.

2.1.4 *System Boundaries*

An LCA quantifies and characterizes the use of energy and materials and the releases to the air, water, and land for each step from raw material extraction through end-of-life management. As illustrated in Figure 2-1, the following four fuel life cycle stages are covered in the environmental portion of this study:

1. **Feedstock Production**: Includes all stages from extraction or acquisition of the fuel feedstock from nature through production into a form ready for processing into cooking fuel (e.g., harvesting sugarcane, extracting crude oil from wells).

2. **Processing**: Comprises steps to convert the fuel feedstock into a cooking fuel.

3. **Distribution**: Covers the transportation of the fuel to the processing location and then to the consumer.

4. **Use**: Comprises steps associated with combustion of the fuel in the cookstove and disposal of any combustion wastes or residues (e.g., ash).

Additional considerations related to modeled system boundaries include:

- For primary agricultural products (i.e., sugarcane for use in ethanol production), the system boundaries start at biomass cultivation. For agricultural residues used as a feedstock for unprocessed or processed solid and liquid cooking fuels (i.e., maize, wheat or rice residues and including dung), the system boundaries begin at residue collection. A description of the LCA modeling method for residues and other multi-product output process is described in Section 2.2.1.

- Similarly, limited material and fuel inputs are required for production of forestry products as these grow naturally; therefore, the system boundaries for wood-based fuels start at wood collection.

- LPG production includes extraction of the natural gas and crude oil.

- Processing includes energy inputs and emission outputs for converting the fuel from its feedstock form to the form ready to be used for cooking.

- Distribution, which is included for all processes in the life cycle where applicable, is based on typical mode(s) of transportation (e.g., truck, rail) and average distance travelled for each fuel and country combination.

- Use phase air pollution levels and constituents are based on the fuel’s composition (i.e., average fixed carbon, ash content, and volatile matter) and the average cookstove technology or average technology mix (i.e., thermal efficiency).

- The end-of-life (EOL) fuel wastes and residues are included in the use phase. At the fuel EOL, solid residues from the combustion of cooking fuels (bottom ash and carbon char) must be disposed of or re-used. Disposal typically involves scattering on land around the home or using them as soil amendments to benefit household-level crop production.

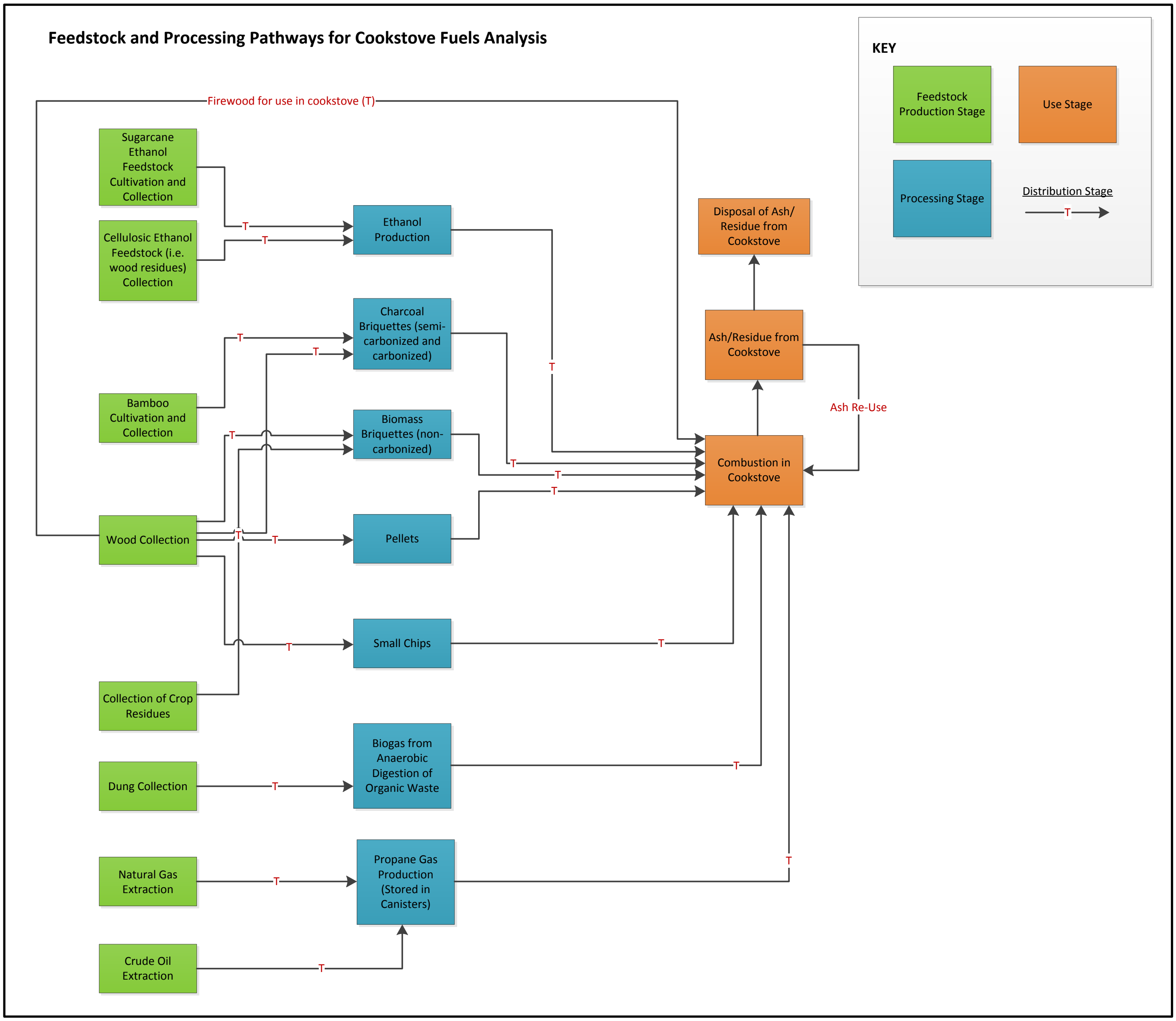


Figure 2-1. System Boundaries for Cookstove Fuel Production, Distribution, and Use in the Alliance Focus Countries

2.1.5 *Indicator Descriptions*

The term “indicator” is used throughout this report to describe the key considerations or impact areas addressed in the environmental, economic, and social sections. Table 2-2 provides descriptions of each indicator assessed.

Environmental and economic indicators are primarily quantitative, whereas social indicators are a combination of quantitative data and qualitative insights. The environmental indicators are specifically assessed through application of standard LCA methodology (described in detail in Section B.2.7 in Appendix B). The inventory of emissions from the different pathways is first classified by emissions’ contributions to impacts on human health or the environment. Most environmental indicators are expressed based on the “potential” to cause damage. Within each impact category, the emissions are then normalized to a common reporting basis.

Table 2-2. Indicators and Descriptions

Indicator	Unit	Description
Environmental Indicators		
Total Energy Demand	MJ/Household per year	Total energy demand quantifies the primary energy usage through the life cycle of a product. The total energy demand indicator accounts for the total usage of non-renewable fuels (natural gas, petroleum, coal, and nuclear) and renewable fuels (such as biomass and hydro) used throughout each step of a product’s life cycle from raw material extraction through manufacture, use, and eventual disposal. Energy is tracked based on the heating value of the fuel utilized from point of extraction (or from point of collection in the case of crop residues), with all energy values summed together and reported on a megajoules (MJ) basis.
Net Energy Demand	MJ/Household per year	Net energy demand is equivalent to the total energy demand indicator, but with the final energy delivered to the pot subtracted from the overall energy impacts.
Global Climate Change Potential (100a)[3]	kg CO_2 eq/Household per year	The GCCP impact category represents the heat trapping capacity of greenhouse gases (GHGs) over a 100-year time horizon and was developed to allow comparisons of the global warming impacts of emissions and reductions of different gases. All GHGs are characterized to kg carbon dioxide (CO_2) equivalents according to the Intergovernmental Panel on Climate Change’s 2013 5th Assessment Report global warming potentials. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. Important emissions characterized in this indicator include CO_2, CH_4, and N_2O. Chlorofluorocarbons (CFCs) are also characterized, although these pollutants are typically released at much smaller quantities in the cooking fuel supply chain relative to the other GHGs. A more detailed discussion of the treatment of biogenic carbon and non-renewable forestry is provided in Section 2.2.2.

[3] There is uncertainty associated with methods to quantify estimates of fuel wood renewability that can affect GCCP indicator results. Estimating fuel wood renewability continues to be an area of ongoing research. While this study relies on a conservative methodology based on Singh et al. (2014), an alternative methodology described by Bailis et al. (2015) is available. Differences between the methodologies are primarily related to: supply potentials, fuel wood demand estimates, and the specificity of the spatial relationships between fuel wood users and locations of fuel wood resources. An area of future work could be to run a sensitivity analysis to assess the magnitude of differences between the methodologies and effect on overall results.

Table 2-2. Indicators and Descriptions

Indicator	Unit	Description
Black Carbon and Short-Lived Climate Pollutants	kg BC eq/Household per year	Short-lived climate pollutants (SCLPs) have a strong impact on the climate, but remain in the atmosphere for a shorter period of time than longer-lived climate pollutants such as CO_2.[3] Reducing these emissions can have immediate beneficial impacts on climate change. BC is one main component of SLCPs formed by incomplete combustion of fossil and bio-based fuels, and is the carbon component of particulate matter (PM) 2.5 that most strongly absorbs light and thus has potential short-term (e.g., 20-year) radiative forcing effects (i.e., potential to contribute to climate warming). Organic carbon (OC) is also a carbon component of PM and possesses light-scattering properties typically resulting in climate cooling effects. PM from the cookstove sector is typically released with other criteria air pollutants, such as carbon monoxide (CO), nitrogen oxides (NO_x), and sulfur oxides (SO_x), which may result in additional warming impacts or exert a cooling effect on climate. **This indicator characterizes all PM and co-emitted pollutants to BC equivalents depending on the relative magnitude of short-term warming or cooling impacts**. A detailed description of this indicator is provided in Appendix B Section 7.
Particulate Matter Formation Potential*	kg PM10 eq/Household per year	PM is a complex mixture of small organic and inorganic particles and liquid droplets (e.g., dust or soil particles, metals, organic chemicals, and acids such as sulfates and nitrates).[4] Inhalation of PM, particularly from particles less than 10 micrometers in diameter, results in many negative human health impacts, such as effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. **Primary pollutants (including PM2.5) and secondary pollutants (e.g., SO_x and NO_x) leading to PM formation are characterized here to kg PM10 equivalents**.
Fossil Fuel Depletion*	kg oil eq/Household per year	Fossil fuel depletion captures the consumption of fossil fuels. Fossil fuels are fuels with high carbon content from natural processes (e.g., decomposition of buried dead organisms) that are created over a geological time frame (e.g., millions of years) and are not renewed over a human time frame. Coal, natural gas, and crude oil are the primary fossil fuels. Since fossil fuels are not replenished over the human time scale, use (i.e., depletion) of them is considered non-renewable. All fuels are normalized to kg oil equivalents based on the heating value of the fossil fuel.
Water Depletion	m^3/Household per year	Water depletion represents water consumption during a product's life cycle (i.e., the sum of consumption from different water sources). Water depletion impacts in this study are based on the volume of freshwater inputs to the life cycle of the assessed fuels. Water may be used in the product, evaporated, or returned to the same or different water body or to land. If the water is returned to the same water body, it is assumed to be a consumptive (i.e., depleting) use if the water is returned at a degraded quality.
Terrestrial Acidification Potential (i.e., Acid Rain)*	kg SO_2 eq/Household per year	Emissions such as SO_2, NOx, and ammonia (NH_3) react with water in the atmosphere and eventually are deposited to the earth as acid rain. This rain can fall a considerable distance from the original source of the air emissions and cause damage to the affected ecosystem. Soils in particular, which support plant life, can be negatively impacted by acid rain. Acids can also be deposited via dry deposition (i.e., when acid particles stick to surfaces without precipitation). Terrestrial acidification potential, assessed in this study, quantifies the acidifying effect of substances on their land environment. Acidification of water bodies is not included in this indicator.

Table 2-2. Indicators and Descriptions

Indicator	Unit	Description
Freshwater Eutrophication Potential (i.e., Excess Nutrients to Water Bodies) *	kg P eq/Household per year	Freshwater eutrophication assesses the potential impacts from excessive load of macro-nutrients to the environment and eventual deposition in freshwater. Introduction of excess nutrients to surface waters can cause the rapid growth of aquatic plants. This growth (generally referred to as an "algal bloom") reduces the amount of dissolved oxygen in the water, thus decreasing the oxygen available for aquatic species. Waterbodies can either be phosphorous (P) limited or nitrogen (N) limited (i.e., either introduction of P or N nutrients determines the extent of algal blooms). This study assumes that fresh surface water is P-limited, and therefore pollutants covered in this category are all P-based (e.g., phosphate, phosphoric acid, phosphorus).
Photochemical Oxidant Formation Potential (i.e., Smog) *	kg NMVOC eq/Household per year	While ozone in the stratosphere protects against harmful ultraviolet (UV) radiation, ground-level (i.e., tropospheric) ozone is harmful to humans in high concentrations. Ground-level ozone is also called photochemical oxidant formation or "smog". The photochemical oxidant formation potential results in this study determine the formation of reactive substances (i.e., ground-level ozone) that cause harm to human health and vegetation. Some key emissions leading to photochemical oxidant formation include CO, methane (CH_4), NO_x, non-methane volatile organic compounds (NMVOCs), and SO_x. These emissions react with volatile organic compounds (VOCs) in the presence of sunlight to produce ground-level ozone.
****Indicator results characterized according to the ReCiPe impact assessment method.***		
Economic Indicators		
Fuel Use	%	The fuel use indicator captures what percentage of the country population uses each fuel as their primary cooking fuel. Data on the percentage of the population in each country using various cooking fuels are primarily drawn from the Alliance's country profiles. Appendix B Section 2.8.1 covers the methodology for developing the fuel use percentages in further detail.
Fuel Cost	2013 USD/ Household per year	The fuel cost indicator assesses the average cost to the end-users of purchasing each cooking fuel. Results are shown based on the cost to household per year in 2013 U.S. dollars (USD). Data on the cost to the end user are drawn from a number of sources (see Appendix B Section 2.8.3). All cooking timeframes are converted to a cost per year basis three meals per day, 12 months per year, 52 weeks per year, and 365 days per year as the assumptions. All costs are converted to 2013 USD by dividing the original local currency estimate by the exchange rate for the appropriate data year and multiplying by the 2013 USD conversion factor for that data year.
Imports, Exports, Production, and Demand	Tonnes/year	The level of imports, exports, production, and demand of different fuels gives a sense of the relative importance of each fuel per country, as well as the degree to which a country is reliant on imports or able to meet its demand (assumed to equal current consumption) through domestic production. These data are not specific to cooking fuels, but instead capture all fuel uses. Overall supply can be estimated by summing production and imports and then deducting exports. Fuel supply can then be compared with demand to assess the fuel availability (or lack of) per country.

Table 2-2. Indicators and Descriptions

Social Indicators	
Indicator	**Description**
Government Policies/Programs	The Government Policies/Programs indicator highlights any government policies, programs, subsidies, or general positions related to fuel and energy sector initiatives. When official positions are unavailable, anecdotal evidence of government activities is presented.
Supply & Access Challenges	The Supply & Access Challenges indicator presents information on logistical, infrastructural, and geographic barriers that prevent reliable access to fuels for cooking. Specific concerns include the impact of deforestation on feedstock and fuel availability and reliability issues related to producers and manufacturing processes. From the demand side, historical fuel-acquisition and -use patterns offer insight into household-level willingness to adopt new fuels.
Distribution & Adoption Challenges	The Distribution & Adoption Challenges indicator highlights barriers such as limited awareness of the alternative fuels, challenges faced by producers, cost, and other attitudinal barriers to alternative fuel adoption.
Protection & Safety	The Protection & Safety indicator assesses the perceived impacts to quality of life and wellbeing that may result from the transition to nontraditional cooking fuels. This indicator focuses primarily on the benefits of not having to manually gather firewood. It also presents anecdotal evidence on fuel-use concerns, such as canister explosions.
Time & Drudgery	The Time & Drudgery indicator reports the time spent collecting and cooking with various fuels with a particular focus on impacts to women and children.
Income Earning Opportunities	The Income Earning Opportunities indicator assesses data on manufacturing and distribution opportunities from the perspective of small-to-medium sized enterprises. This indicator also includes industry projections from cookstove sector market managers and entrepreneurs.
Opportunities for Women Along the Value Chain	The Opportunities for Women Along the Value Chain indicator offers insights into current employment in the cookstoves and fuels sector, and technical, business, and negotiation opportunities for women. It draws on lessons learned from women-centered initiatives and programs, anecdotal evidence from market managers and entrepreneurs, and data on women's integration into the clean cookstove sector.

2.1.6 *Data Sources*

Appendix C lists over 200 sources cited in this analysis. Example categories of sources are presented in Box 2-2. For all three dimensions of the analysis, the literature review process began by searching the most up-to-date, relevant sources, including Alliance reports and website information, as well as additional sources provided by the Alliance and its partners.

Box 2-2 – Data Source Examples

- Alliance Data and Documents
- Energy Sector Management Assistance Program
- Food and Agricultural Organization
- World Health Organization
- United Nations Framework Convention on Climate Change
- Peer-Reviewed Publications

Data used to model the selected environmental indicators were taken from published articles, reports, and previous LCAs.

Data for economic and social indicators, when possible, were gathered from multilateral organizations, such as the World Bank, United Nations, and Organisation for Economic Co-operation and Development, are used. Where data were not available, literature searches of both peer-reviewed journal articles (using Google Scholar) and general Internet searches were performed. When selecting articles for social analysis, special attention was paid to country-specific studies emphasizing gender dynamics and urban-rural differences.

Phone interviews held during the analysis' research phase with Alliance Market Managers and several enterprises partnering with the Alliance allowed for a more on-the-ground look at country-specific conditions. Individual countries' national statistical bureaus were used to gather demographic data, such as household size. A more detailed discussion of the data sources is found in Appendix B.

2.2 ASSUMPTIONS AND USE

Stakeholders using the information from this analysis should be aware of the limitations of the underlying data. This analysis is based on research compiled in 2014 into early 2015 and may not capture information published more recently in this rapidly evolving sector. The analysis focused on baseline production methods (i.e., traditional kilns, of the selected fuels, rather than assessing scenarios with improved processing technologies). This analysis presents the current level of imports, exports, production, and consumption, as well as current prices. If any of these fuels were to be traded, produced or consumed at a significantly different level in the future, this would impact all of these variables, as well as the trade, production, and consumption of other fuels, but this analysis does not predict these interactions. Many of the non-traditional fuels analyzed are being produced and used on a scale too small to be captured in the country-level statistics used in the analysis. Data available on imports, exports, production, and demand of fuels were not sufficient to identify the share of fuels being used specifically for cooking; therefore, fuels were assessed in this category regardless of the sector (e.g., cooking) in which they are used. The cost of different fuels is one of the most important criteria for determining stove and fuel adopted, particularly by poorer households; however, there were numerous gaps in cost data, particularly for fuels at a small scale of production and use. Cost data are only presented for those cooking fuel and country combinations where information was available.

The remainder of this section discusses key methodological choices in the LCA model and public use of this analysis.

2.2.1 *Allocation Considerations*

Allocation is required for processes that produce more than one useful output (i.e., crop and wood residues, ethanol, and biogas). Allocation refers to partitioning the burdens of a process among more than one product. No single allocation method is suitable for every scenario. In this analysis, the baseline method used for modeling multi-output product processes with one primary product and one or more unavoidable co-products is the "cut-off" approach. Under this approach, all burdens are assigned to the primary product. For instance, burdens for crop residues begin at collection of the biomass residue from the field, and do not include impacts associated with primary cultivation of the crop. Impact for the cultivation stage are allocated to the primary food crop, and are outside the system boundaries of the study. A more detailed description of allocation considerations in this study can be found in Appendix B Section 4.

2.2.2 *Biogenic Carbon Accounting and Nonrenewable Forestry Calculations*

In biomass cooking fuels, CO_2 is removed from the atmosphere and incorporated into the material that is harvested from the forest or field. This carbon is stored in the material throughout the life of the product until that fuel is combusted or degrades, at which point the carbon is released back into the environment. Combustion and degradation releases are predominantly in the form of CO_2 and methane (CH_4). This study, in alignment with the Intergovernmental Panel on Climate Change (IPCC) methodology, assumes a net zero impact for biogenic (i.e., derived from biomass) carbon in the form of CO_2 emissions such as CO_2 emissions from the combustion of biomass cookstove fuels. Impacts associated with the emission of biogenic carbon in the form of CH_4 are included since CH_4 was not removed from the atmosphere and its global warming potential (GWP) is 28 times that of CO_2 when applying the IPCC 2013 LCIA method. The one exception to this is the CO_2 emissions associated with wood fuel derived from unsustainable forestry practices in the assessed countries. In the GHG analysis, the CO_2 emissions for the portion of the biomass fuel from unsustainable forestry practices are considered nonrenewable, and, therefore incorporated into the overall GCCP results. The calculations for the renewable and non-renewable supply of wood for cooking fuel use were based on a multi-step approach outlined by Singh and colleagues (2014). More detail on the calculations to determine the percentage of each assessed country's nonrenewable forestry percentages is provided in Appendix B Section 6.

2.2.3 *Public Use of This Analysis*

The results of this report are not intended to be used as the basis for comparative claims or purchasing decisions for a specific fuel. Rather, the findings are intended to provide directional guidance for the intended audiences, giving a snapshot of the indicators of several countries' range of fuels to identify options that have potential for minimizing impacts based on the best data available through February 2015. Uncertainties in life cycle data and impact assessment are present in all life cycle analyses. Small differences in fuel system results should not be interpreted as conclusive proof that the impacts of fuels are significantly different.

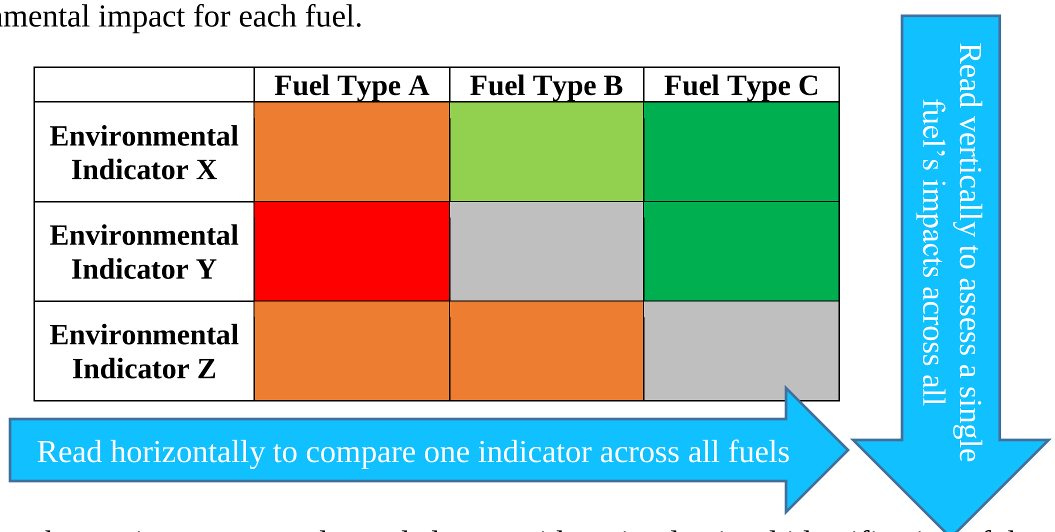
For the environmental indicators, ISO standards 14040 and 14044 for LCA require that a life cycle study used to make public claims about the environmental superiority of one system over another must include impact assessment and must undergo critical review. The intended use for this study does not require a panel peer review, based on the ISO 14044 criteria.

3. COUNTRY-SPECIFIC SUSTAINABILITY FACTORS FOR COOKING FUELS

3.1 OVERVIEW

The country summaries provide unique, country-specific insights on fuel choices from a life cycle environmental perspective combined with practical information on the economic and social advantages and challenges relevant for each fuel's use.

A table is provided for each country summarizing the ten environmental impacts modeled for each fuel. Each table row presents the modeled environmental indicator value; to compare an indicator across fuels, read horizontally across each column. For each fuel type, reading vertically down the column provides a summary of that fuel's impact for all indicators. Each indicator is individually modeled; therefore, there is no single aggregated metric of overall environmental impact for each fuel.



Within each row, impacts are color coded to provide a simple visual identification of those fuels that tend to have more (green) or less (red) favorable results for a given environmental indicator. The color coding thresholds are defined below and should not be interpreted as an indication of statistically significant differences in results. All values in the tables are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

(dark green)	Less than 5th percentile impact of all fuels
(light green)	Between 5th percentile and 25th percentile impact of all fuels
(gray)	Between 25th percentile and 75th percentile impact of all fuels
(orange)	Between 75th percentile and 95th percentile impact of all fuels
(red)	Greater than 95th percentile impact of all fuels

In each country summary, the environmental profile of each fuel is discussed, followed by a more in-depth discussion of several environmental indicators that were designated as of particular interest for the cooking sector, including total energy demand, global climate change potential (GCCP), black carbon (BC), and particulate matter (PM).

Asia

3.2 RESULTS FOR CHINA

3.2.1 *Country Overview*

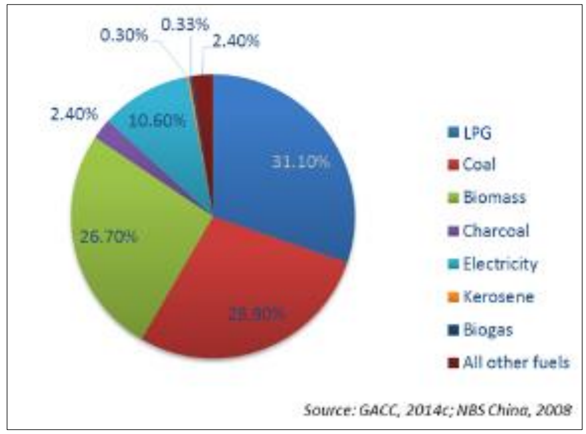


Figure 3-1. Cooking Fuel Use in China

In China, with the largest population in the world, just over half of the population lives in cities.[5] It is the only Alliance focus country where less than 50 percent of the population uses biomass (wood and crop residues) as a cooking fuel, mostly in rural areas for both cooking and heating, often using the same device. As is common for most developing countries, Chinese households own more than one stove that may use a variety of fuel types. The diversity of geographical regions and fuel options in results in distribution and availability barriers. As shown in Figure 3-1, more than half of the current mix of cooking fuels used in China are unprocessed solid fuels (e.g., firewood, crop residues, and coal), while liquid and gaseous fuels together make up one-third of the fuels used.

China has demonstrated its concern about health, environment, and clean energy by promoting initiatives such as the ethanol program of the early 2000's directed at transportation fuel[6,7] and its use of subsidies and low-interest loans to encourage biogas use for cooking in rural areas.[8,9] In March 2016, China's National People's Congress will pass the 13th Five Year Plan that will create a set of targets and guidelines spanning a range of social, economic, and a particular focus on environmental issues that would limit coal consumption and focus on green, low-carbon development and energy conservation.[10] China has also shown an overall trend of an approximately 2 percent increase in forest land per year in recent years.[11] This increase is the result of ambitious large-scale afforestation programs reported between 2000 and 2010.[12]

3.2.2 *Environmental Impact Assessment, by Impact Category*

Table 3-1 shows a summary of environmental impacts by fuel type for China. Figure 3-2 through Figure 3-5 provide additional details on several environmental indicators of high interest to the Alliance, namely total energy demand, GCCP, BC, and PM.

Table 3-1. Summary of Environmental Indicators for Cooking Fuels in China

Indicator*	Unprocessed Solid Biomass		Processed Solid Biomass						Liquid/Gas							Other			
	Firewood	Crop Residue	Charcoal Briquettes from Wood	Charcoal Briquettes from Bamboo	Non-Carbonized Briquettes from Sawdust	Non-Carbonized Briquettes from Crop Residues	Wood Pellets	Wood Chips	Ethanol from Sugarcane	Ethanol from Wood	Biogas from Dung	LPG	Kerosene	Natural Gas	DME*	Hard Coal	Electricity	*Median*	*All-fuel average***
TED (MJ/HH/YR)	32,391	39,159	52,177	56,042	52,194	15,638	12,434	14,339	32,318	12,548	9,014	13,794	14,577	10,150	31,681	44,249	30,023	*22,831*	*26,263*
NED (MJ/HH/YR)	27,437	34,205	47,223	51,088	47,240	10,685	7,480	9,385	27,364	7,594	4,061	8,840	9,623	5,196	26,727	39,295	25,069	*17,877*	*21,584*
GCCP (kg CO_2 eq/HH/YR)	1,390	271	2,824	1,496	264	198	949	754	439	40.4	52.1	930	1,027	1,056	1,711	3,885	2,458	*940*	*1,097*
BC/SLCP (kg BC eq/HH/YR)	1.48	3.43	21.2	4.32	0.63	0.71	0.053	1.09	-0.038	0.023	0.034	-0.087	-0.16	-0.011	0.27	0.23	-0.60	*0.14*	*1.81*
PMFP (kg PM10 eq/HH/YR)	7.36	16.9	96.6	13.6	29.2	3.25	1.10	4.65	0.83	1.01	0.38	0.98	1.15	0.28	3.73	3.37	6.61	*3.31*	*10.6*
FFD (kg oil eq/HH/YR)	0.012	0.076	0.97	1.09	12.4	16.9	41.2	4.07	78.5	2.62	0	319	335	241	550	782	474	*14.6*	*159*
WD (m^3/HH/YR)	0.093	0.58	5.88	5.70	74.9	103	275	4.24	343	23.3	5.16	283	358	28.6	136	378	2,598	*51.7*	*257*
TAP (kg SO_2 eq/HH/YR)	1.43	1.49	1.50	1.62	1.44	1.13	2.02	0.58	2.57	0.61	0.53	3.38	4.30	0.84	5.86	7.92	21.2	*1.49*	*3.24*
FEP (kg P eq/HH/YR)	0.30	1.88	1.38	0.81	0.40	0.082	0.043	0.10	0.17	0.023	0	0.040	0.051	0.0034	0.31	0.44	0.31	*0.14*	*0.35*
POFP (kg NMVOC eq/HH/YR)	8.96	12.5	51.9	120	5.61	5.49	1.37	9.77	1.61	0.53	0.56	1.98	2.10	1.12	9.97	5.94	9.26	*5.55*	*13.8*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country.
Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-1 highlights key observations and Figure 3-2 presents results for total energy demand for fuels in China by life cycle stage (See Appendix A, Section 3.2.2.1 for the detailed analysis). For this report, all total energy demand impacts for electricity are displayed in the use phase due to the variety of fuels used in the China's average electricity grid (79 percent coal, 14 percent hydro, 1.8 percent natural gas, 1.8 percent nuclear, 1.5 percent wind, 0.7 percent biomass, 0.2 percent oil, 0.2 percent waste, and 0.1 percent solar photovoltaic [PV]).[13]

Box 3-1– Total Energy Demand Observations for China

- It is more common to see higher efficiency stoves used in combination with wood chips and wood pellets compared to the unprocessed solid biomass fuels. This leads to the overall lower total energy demand for processed biomass fuels as compared to the traditional solid biomass fuels such as crop residues and firewood. Wood pellets in China, for instance, have a 90 percent lower total energy demand compared to unprocessed firewood.
- Overall, liquid and gas fuels, which have high energy content and are often used in combination with high efficiency stoves, show the lowest overall total energy demand impacts.
- Hard coal shows a high total energy demand resulting from low stove thermal efficiencies and the energy requirements of mining activities captured under the "Feedstock Production" phase.
- Electricity in China is derived primarily from coal (79%) and hydroelectric facilities (14.8%), which is the primary reason electricity impacts are similar to but slightly lower than coal.

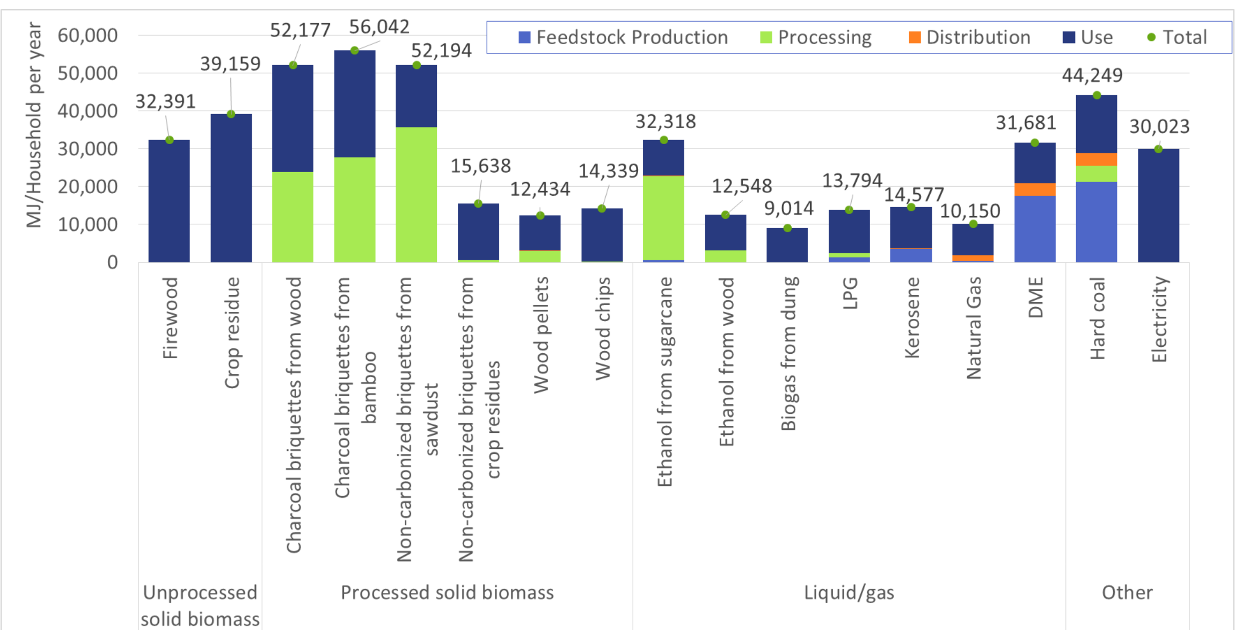


Figure 3-2. Total Energy Demand (MJ) for Cooking Fuel Types (China)
To produce, distribute and use cooking fuels by a single household per year

Box 3-2 highlights key observations and Figure 3-3 presents the GCCP impact results for fuels in China by life cycle stage (See Appendix A, Section 3.2.2.3 for the detailed analysis).

Box 3-2–Global Climate Change Potential Observations for China

- In China, the GCCP impact of firewood appears substantially better than other fuels in China. However, the better performance is in relation to the poor performance of some cooking fuels options in China rather than to the benefits of using unprocessed firewood.
- This study considers that 57 percent of wood-based biomass fuels are able to be sustainably sourced within China. The remaining 43 percent are produced using non-renewable practices and are not considered carbon-neutral. One hundred percent of wood for waste derived fuels (ethanol from wood and non-carbonized briquettes from sawdust) is considered carbon-neutral (see Section 2.2.2).
- With these renewability factors, GHG emissions from charcoal briquettes from wood are ten-fold higher than non-carbonized briquettes from sawdust in China.
- Charcoal briquettes from wood demonstrate relatively high GCCP impact scores. These impacts are split fairly evenly between the kilning process and combustion/use phase.
- The assumption that 100 percent of bamboo can be renewably harvested within China accounts for the higher GCCP performance of charcoal briquettes from bamboo compared to briquettes from other wood sources.
- Ethanol from wood is the fuel with the lowest GCCP impact score. This is because environmental burdens associated with the wood waste are allocated to the primary product (e.g., lumber), which falls outside of the system boundaries of this study.
- Hard coal has the greatest GCCP impacts in China, since it is derived from non-renewable carbon, and the thermal efficiency of coal stoves (27.2 percent to 37.1 percent) is relatively low compared to the other fossil fuel options (e.g., natural gas stove efficiency is 44.8 percent to 45.9 percent or LPG stove efficiencies between 42 percent and 45 percent). Coal is widely used and transported across long distances in China, resulting in a notable contribution of GHGs.
- Electricity in China is derived mainly from coal (79 percent) and hydroelectric facilities (14.8 percent), which is the primary reason electricity impacts are high.

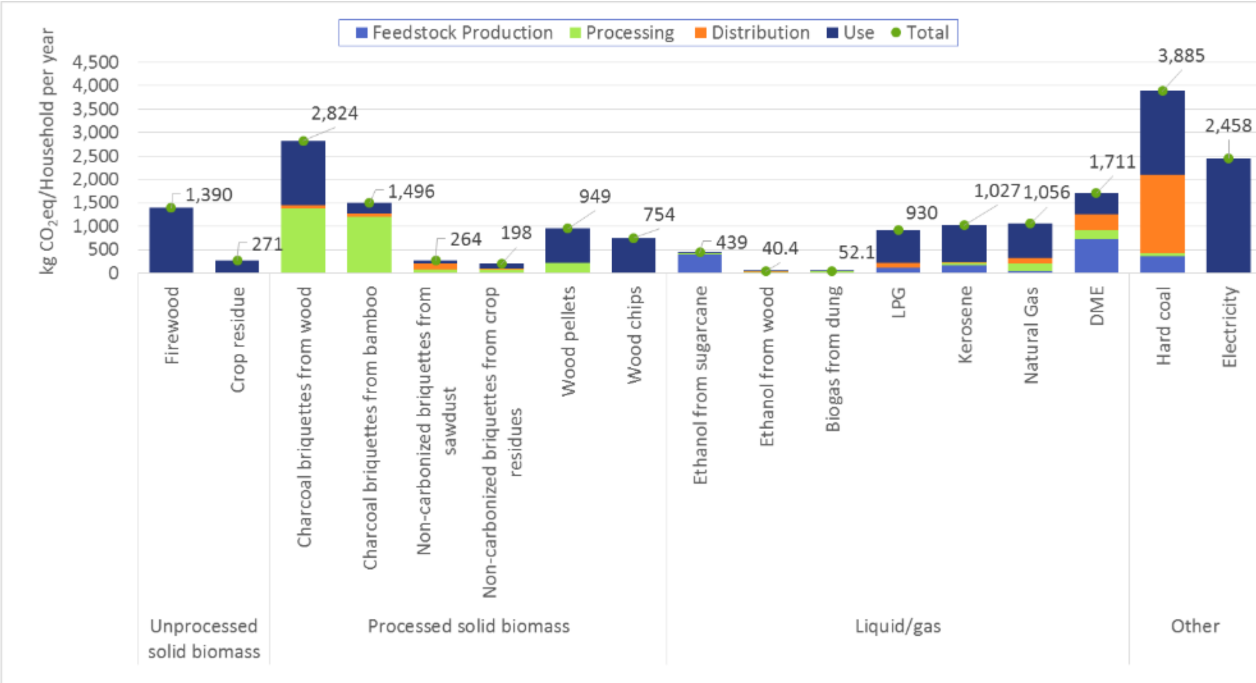


Figure 3-3. GCCP (100a) Potential Impacts (kg CO_2 eq) for Cooking Fuel Types (China)
To produce, distribute and use cooking fuels by a single household per year

Box 3-3 highlights key observations and Figure 3-4 presents the BC and short-lived climate pollutant impact results for fuels in China by life cycle stage (See Appendix A, Section 3.2.2.4 for the detailed analysis).

Box 3-3– Black Carbon and Short-Lived Climate Pollutant Observations for China

- Charcoal briquettes are not a commonly used fuel type in China, so the highest possible BC impacts for this fuel type are avoided. The relatively poor performance of the charcoal briquettes from wood in comparison to bamboo charcoal briquettes is due to the bamboo charcoal briquette industries use of more advanced technology for carbonization.
- Liquid and gas fuels result in the lowest overall BC impacts due to their minimal PM emissions when combusted. For instance, LPG in China results in an over 100 percent decrease in BC equivalent impacts when displacing firewood as the cooking fuel.
- Some life cycle stages exhibit negative impact scores on short-term climate change, which is the case when emissions of sulfur oxides (SOx) and organic carbon (both pollutants with net cooling effects on the climate) are greater than the emissions of BC and other co-emitted pollutants that lead to short-term warming impacts. This is the case for some life cycle stages of hard coal, as well as electricity (predominately coal), which comprise 29 and 31 percent of China's current fuel mix, respectively.

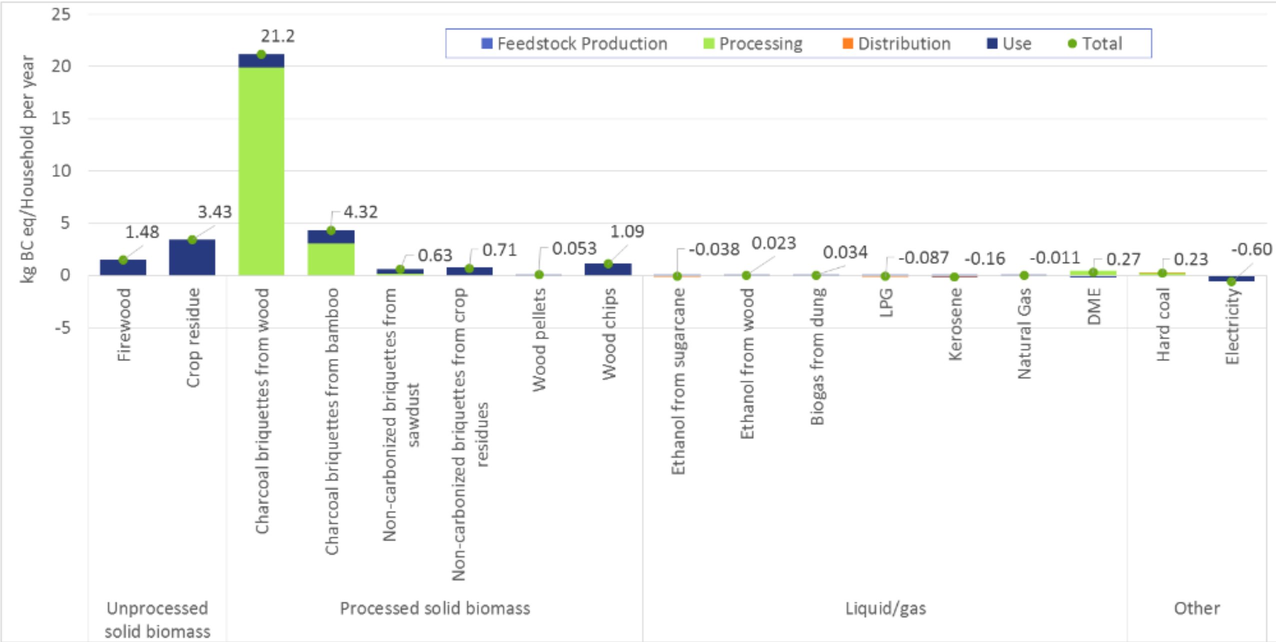


Figure 3-4. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (China)

To produce, distribute and use cooking fuels by a single household per year

Box 3-4 highlights key observations and Figure 3-5 shows the PM formation potential results for fuels in China by life cycle stage (See Appendix A, Section 3.2.2.5 for the detailed analysis).

Box 3-4– Particulate Matter Formation Potential Observations for China

- Firewood PM impacts in China are approximately 7.5 times greater than LPG. Firewood stove efficiencies in China range from 16.3 percent to 19.2 percent depending on the fuel/stove technology combination. The low efficiency stoves for firewood in China, coupled with overall higher criteria air pollutants from burning solid fuels leads to this notable PM impact from firewood as a cooking fuel.
- Charcoal briquettes from bamboo, a feedstock abundant in China, have notably lower PM impacts than wood charcoal briquettes (a fuel type not widely used in China) because a larger portion of bamboo charcoal briquettes are estimated to be produced in more advanced and efficient kilns, whereas all charcoal briquettes from wood in China are assumed to be produced in traditional earth mound kilns.

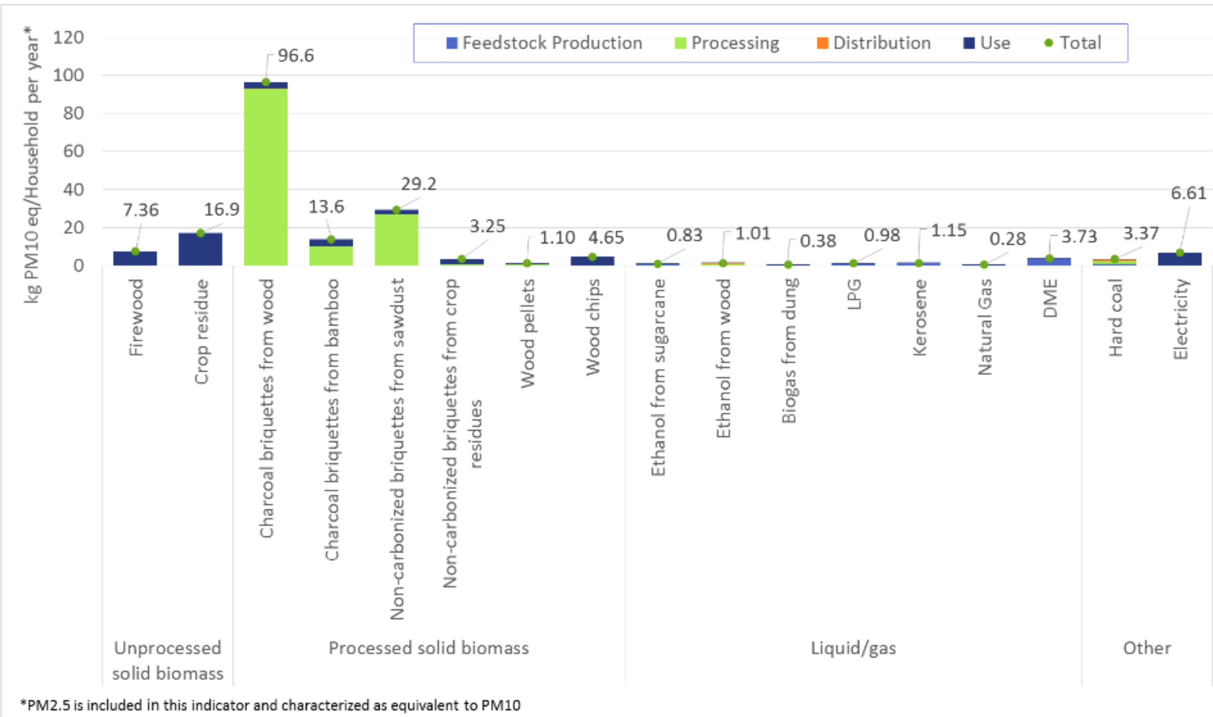


Figure 3-5. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (China)

To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators presented in

Table 3-1 can be found in Appendix A, Section A.2.2.

3.2.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-5 – Key Findings and Policy Considerations for China

- All environmental indicators for **firewood**, with the exception of water depletion and fossil fuel depletion, are in the mid to upper range compared to other fuels assessed for China.
- **Bamboo** is another unprocessed biomass feedstock that is often free for collecting. Currently, this feedstock is not commonly used in China in a processed charcoal briquette form. Producing briquettes from bamboo is a potential enterprise opportunity; however, purchased briquettes are unlikely to successfully compete in areas where bamboo can be collected for free and burned in unprocessed form.
- **Wood Pellets** generally have favorable environmental profiles compared to unprocessed biomass and coal, although slightly higher environmental impacts than liquid and gas fuels**.** Pellets are increasingly produced and sold in China by small enterprises mostly in urban areas. Improvements recommended in the China pellet supply chain, identified through the literature review, include better access to advanced technologies and capital. As of 2014, 58 percent of biomass pellet and briquette producers used government subsidies; however, 9 percent of pellet and briquette producers maintain they need more government support such as advanced technology, access to capital, and better promotion to make pellets profitable to overcome key market constraints.[14]
- **Ethanol** generally has low environmental impacts (with the exception of water consumption for sugarcane ethanol). Currently used within the transport sector; very little currently used as a cooking fuel. China's 12th Five Year Plan (2011-2015) set goals for increasing biomass and biofuel production—including the development of cellulosic ethanol—and as of 2014, China has seven plants licensed for ethanol production. Small enterprises producing ethanol gel are making it available to a small section of the country's population. The gelling process and additives result in some increases in environmental impacts. Growth in the ethanol sector will require increased production using sustainable feedstocks that do not compete with food supply directly (e.g., cassava and sweet sorghum).[15]
- As evidenced by an ethanol program in the early-to-mid 2000s[16] and an ongoing biogas subsidy,[17,18] liquid and gas fuels have historically had government support in China. Natural gas use (included in the "other fuels" category in Figure 3-1) has been growing rapidly in urban areas.[19] More than 20 years ago, there was a boom in **LPG** use in Chinese cities.[20] LPG, perceived as a safe fuel by the population, is quite common in urban areas, but distribution is somewhat unreliable in the rural areas,[21] and it is generally used only by wealthier households.
- **Biogas from Dung**: Whether produced from dung or crop residues, biogas is an attractive fuel option from both an environmental and economic perspective. As observed in other countries studying the impacts of biogas from dung, benefits are accrued as long as sufficient feedstock and maintenance support are available to the households.[22] The costs per household per year for biogas from both types of feedstocks, including the subsidized cost of the digester, are lower than costs for LPG.[23,24] Feasible mainly for rural consumers

Box 3-5 – Key Findings and Policy Considerations for China

with access to livestock wastes; shifts to large-scale industrial farming in China may reduce digester feedstock supply at household level. In addition to the national biogas program described in Box 3-6 below, some provincial governments provide subsidies or low-interest loans to help supply rural households with digesters.[25]

- Although China's forest area has shown a rate of increase of about 2 percent per year in recent years, the government is still concerned about deforestation. **Processed biomass fuels** in solid, liquid, and gas form are an opportunity to address deforestation through more efficient utilization of forestry resources. The Chinese government has encouraged production and use of biogas and ethanol as sustainable fuels, and the environmental results in this analysis confirm that these fuels have lower impacts than other fuels on a life cycle basis.
- **Coal** is a commonly used cooking fuel in rural China because it is affordable and widely available. The environmental indicators for coal are all in the mid to upper range.
- **Electricity**, used by almost 10 percent of households (mostly urban and peri-urban), also has mid- to high-range environmental indicators due to the high use of coal (79 percent) in China's electricity grid.
- While **electricity** is clean at the point of use in the home, environmental impacts associated with generating Chinese grid electricity (largely from coal) can be further reduced by shifting toward a less coal-dominated electricity grid.

Box 3-6– Featured Example for China

In 2006, the government of China began its national biogas program, using funding from the World Bank to provide biogas systems to 400,000 to 500,000 rural smallholder households. The program operates in five southeastern provinces—Anhui, Chongqing, Guangxi, Hunan, and Hubei—all of which are experiencing shrinking labor pools, increasing deforestation, and other environmental problems. Households participating in the program received a subsidy for their biogas system, paying ~ Yuan 1,300 for materials and Yuan 530 for hired labor (~ $285). In addition to these upfront costs, the system requires the dung from at least three pigs as digester feedstock, and users can expect to spend around Yuan 100 each time their system needs repair. Although only 60 percent of the biogas digesters installed in 2007 operated normally after installation, the social benefits of adopting biogas were profound for households able to afford repair costs and maintain sufficient feedstock supplies. Similarly, almost all households that switched to biogas (99 percent) saved time by not having to collect biomass to use as cooking fuel. On average, women saved 24 days per year in fuel collection time, men saved 10, and children saved four. Nearly all users (98 percent) reported that switching to biogas saved them time cooking, a savings felt especially by women, who saved an average of 1.2 hours per day cooking (compared to 0.5 hours saved by their male counterparts). China's household biogas service system provides income earning opportunities for many people, with a workforce of over 300,000 for construction, installation, and follow-up services, and six provincial training bases.[26] With strong government support, China's implementation of household biogas is "continuously ranked first in the world and has the widest scope and most extensive impacts."[27] Source: Christiansen, 2012.

3.3 RESULTS FOR INDIA

3.3.1 *Country Overview*

India is the second most populous country in the world, with almost 1.3 billion residents; the environmental, economic, and social implications of cooking fuel use therefore have large-scale effects.

Over two-thirds of the population of India still use solid fuels, such as firewood, crop residues, or dung, for cooking.[28] The other leading cooking fuel is LPG (25 percent). Kerosene, coal, and other fuels are used at much lower levels (see Figure 3-6). In February 2016, the government announced budget plans to set aside 2,000 crore to meet the initial cost of providing cooking gas connections to every rural household to protect the almost 142 million rural households from the "curse of smoke." [29] Cooking fuel affordability is a key issue, as approximately 33 percent of the Indian population lives below the poverty line, surviving on $1.25 per day.[30]

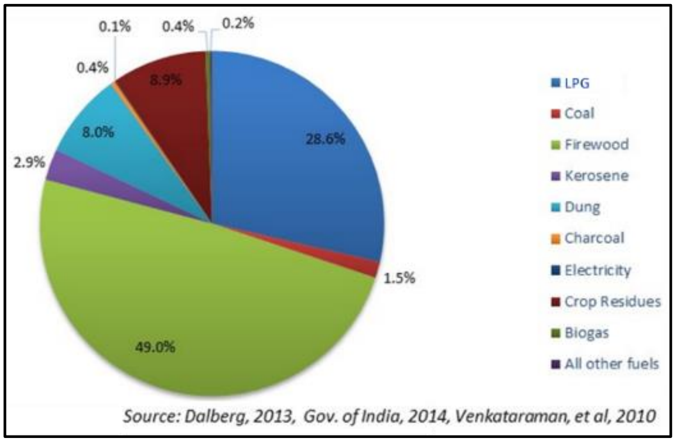


Figure 3-6. Cooking Fuel Use in India

In 2010, 31 percent of India's population lived in urban areas and 69 percent in rural areas.[31] The mix of cooking fuels used is quite different in each segment (Figure 3-7). Rural households have more access than urban households to biomass fuels that are free for the gathering, such as dung, firewood, and crop residues, while processed fuels such as LPG and kerosene are more readily available in urban areas. Access to fuel is also affected by seasonal weather, as rural households may be unable to gather biomass fuels on a regular basis during the monsoon season.

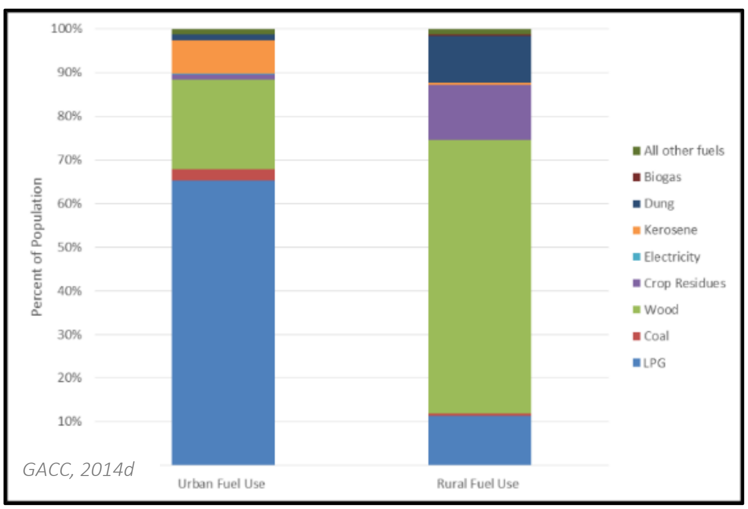


Figure 3-7. 2013 Cooking Fuel Mix Comparing Urban and Rural Fuel Use in India

Adequate supply of fuels to sustainably support demand is an important consideration. For example, although India has shown an overall trend of an approximately 2 percent increase in forest land per year in recent years,[32] the increases are not sufficient to meet all of the country's demand for firewood and other wood-derived cooking fuels.

Finally, cultural preferences are an important consideration. For example, there is a strong preference in India for the smell and taste of bread prepared using firewood, while fuel's influence on taste is generally not an issue for foods cooked in water (e.g., lentils, rice, and curries).[33] For homes where the cooking fire serves additional purposes (e.g., providing heat or light), changes to the cooking fuel or type of cookstove would likely require the household to use other fuels for these functions.

3.3.2 *Environmental Impact Assessment, by Impact Category*

Table 3-2, shows a summary of environmental impacts by fuel type for India. Figure 3-8 through Figure 3-11 provide additional details on several environmental indicators of high interest to the Alliance, namely total energy demand, GCCP, BC, and PM.

Table 3-2. Summary of Environmental Indicators for Cooking Fuels in India

Indicator*	Unprocessed Solid Biomass			Processed Solid Biomass						Liquid/Gas					Other			
	Firewood	Crop Residue	Dung Cake	Charcoal Briquettes from Wood	Charcoal Briquettes from Bamboo	Non-Carbonized Briquettes from Sawdust	Non-Carbonized Briquettes from Crop Residues	Wood Pellets	Wood Chips	Ethanol from Sugarcane	Ethanol from Wood	Biogas from Dung	LPG	Kerosene	Hard Coal	Electricity	*Median*	*All-fuel average***
TED (MJ/HH/YR)	30,981	9,670	51,628	40,989	47,704	37,110	13,098	8,362	12,976	26,127	8,507	7,306	7,852	10,373	55,317	21,853	*13,037*	*21,658*
NED (MJ/HH/YR)	26,966	5,655	47,613	36,974	43,689	33,095	9,083	4,347	8,961	22,112	4,492	3,291	3,837	6,358	51,302	17,838	*9,022*	*18,090*
GCCP (kg CO_2 eq/HH/YR)	2,166	530	765	2,298	1,132	277	215	683	644	384	43.3	42.2	1,206	728	3,865	1,665	*663*	*925*
BC/SLCP (kg BC eq/HH/YR)	4.19	9.72	20.1	17.2	9.58	1.78	3.37	0.080	1.79	-0.022	0.019	0.027	0.045	0.045	15.7	-0.076	*0.93*	*4.64*
PMFP (kg PM10 eq/HH/YR)	19.0	45.4	94.9	78.3	41.2	19.8	15.9	0.85	8.27	0.67	0.28	0.31	0.62	1.24	77.5	6.77	*7.52*	*22.8*
FFD (kg oil eq/HH/YR)	0.026	0.030	0.62	0.47	0.50	5.29	7.21	25.1	0.54	73.4	4.30	0	201	264	974	367	*2.46*	*107*
WD (m^3/HH/YR)	0.20	0.23	4.76	2.53	2.45	29.6	40.6	143	0.63	356	1.12	4.18	123	146	66.7	2,066	*4.47*	*166*
TAP (kg SO_2 eq/HH/YR)	1.60	2.47	3.01	1.34	1.34	1.49	1.17	1.17	0.72	2.00	0.37	0.43	1.29	1.60	7.51	16.1	*1.34*	*2.42*
FEP (kg P eq/HH/YR)	0.63	0.75	15.3	1.12	0.86	0.30	0.26	0.014	0.27	0.15	1.3E-05	0	0.011	0.013	0.0086	0.014	*0.081*	*1.10*
POFP (kg NMVOC eq/HH/YR)	24.2	35.1	74.9	42.3	71.9	12.4	12.3	0.95	10.5	1.37	0.90	0.46	2.92	4.65	31.6	8.08	*9.32*	*18.6*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country. Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-7 highlights key observations and Figure 3-8 displays the total energy demand results by life cycle stage for India. For this report, all total energy demand impacts for electricity are displayed in the use phase due to the variety of fuels used in the India's average electricity grid (71 percent coal, 11 percent hydro, 8 percent natural gas, 3 percent nuclear, 2.5 percent wind, 2 percent oil, 1.7 percent biofuels, 0.2 percent solar PV, and 0.09 percent waste).[34]

Box 3-7–Total Energy Demand Observations for India

- While processing the commercially made, non-carbonized sawdust briquettes, sawdust is heated to remove the moisture content of the briquettes, which results in the higher total energy demand compared to crop residue briquettes, wood chips, and wood pellets.
- Energy demand for the charcoal briquettes from wood and bamboo is relatively high, due to low charcoal briquette stove efficiencies in India and relatively high quantity of firewood input for carbonization at the charcoal kiln.
- For wood fuels and unprocessed crop residues, the wood pellets and wood chips have a lower total energy demand than traditional wood or crop residues. Although wood chips and wood pellets require more processing energy, they typically have a lower moisture content, greater energy content, and greater surface area than the traditional solid biomass, which allows the fuel to combust more efficiently. The stoves used to burn wood chips and wood pellets (30-53 percent efficiency) are usually more efficient than the stoves used to burn unprocessed solid biomass (8.5-13.5 percent); as a result, more of the energy content of the chips and pellets is converted into useful cooking energy.
- Ethanol from wood energy demand impacts in India are lower than those for sugarcane ethanol because the wood residues are directly converted to ethanol, whereas the sugarcane ethanol undergoes more agricultural and pre-processing steps (e.g., intermediate step of molasses production is required for sugarcane based ethanol specific to India) to manufacture the ethanol end product.
- Overall, liquid and gas fuels, as well as processed biomass fuels that don't involve a combustion processing step (e.g., wood pellets), lead to the lowest overall total energy demand impacts.
- Dung cake, in its raw form, also generates a notable total energy demand. The thermal efficiency of a dung burning stove is the lowest of all stove-fuel combinations for any country with a value of only 8.5 percent.
- Hard coal generates the greatest total energy demand, due mainly to the energy intensive phases of production and use. Its relative impacts in this category are greater than those seen in China due mostly to the lower coal stove thermal efficiencies observed in India (15.5 percent).

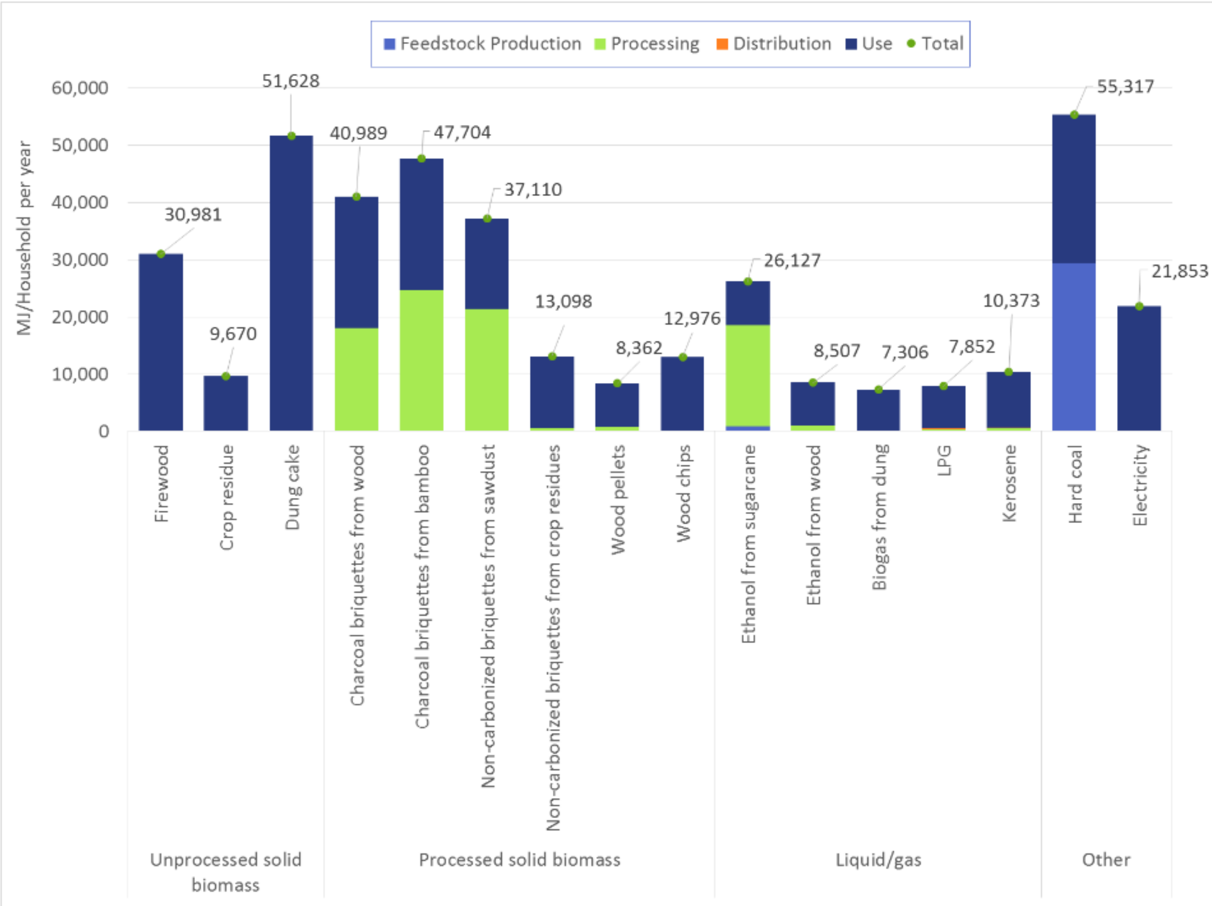


Figure 3-8. Total Energy Demand (MJ) for Cooking Fuel Types (India)
To produce, distribute and use cooking fuels by a single household per year

Box 3-8 highlights key observations and Figure 3-9 presents the GCCP impact results for fuels in India by life cycle stage.

Box 3-8– Global Climate Change Potential Observations for India

- Fuels produced using dung, crop residues, bamboo and sugarcane all perform relatively well due to the modeling assumption that these feedstocks are carbon neutral (see Appendix B for detailed assumptions).
- Charcoal briquettes from bamboo demonstrate the lowest performance of fuels from these carbon neutral feedstocks due to large processing energy requirements. Based on the trend in forest area and the annual generation of biomass per hectare, a little less than 60 percent of the firewood required for cooking can be sustainably sourced in India; therefore, the combustion emissions for the non-renewable 40 percent of wood are not considered carbon-neutral (see Section 2.2.2). This adjustment is also applied to charcoal briquettes from wood, wood pellets, and wood chips.
- For charcoal briquettes, GCCP impacts for carbonization of the wood in the kiln are comparable in magnitude to the emissions from charcoal briquette combustion in a cookstove. Charcoal kiln impacts are largely driven by the methane emissions during the carbonization process.

Box 3-8– Global Climate Change Potential Observations for India

- Hard coal has the highest impacts; the thermal efficiency of coal stoves (15.5 percent) is relatively low compared to the other fossil fuel options (e.g., LPG stove efficiency is 57 percent). Coal is a more common cookstove fuel type in China compared to India. Coal in India is modeled as mined from a surface mine, and only used directly for cooking in sites nearby the mine. This varies from the situation in China in which coal is transported longer distances for use as a cooking fuel.
- Electricity in India is derived from a mix of coal (approximately 71 percent) and petroleum fuels, as well as some hydropower, which is the primary reason its impacts fall between coal usage and fuels derived from crude oil or natural gas. For consistency with other fuels, the emissions from fuel combustion for electricity generation are shown in the use stage, although these emissions occur at the power plant, not at the household level.

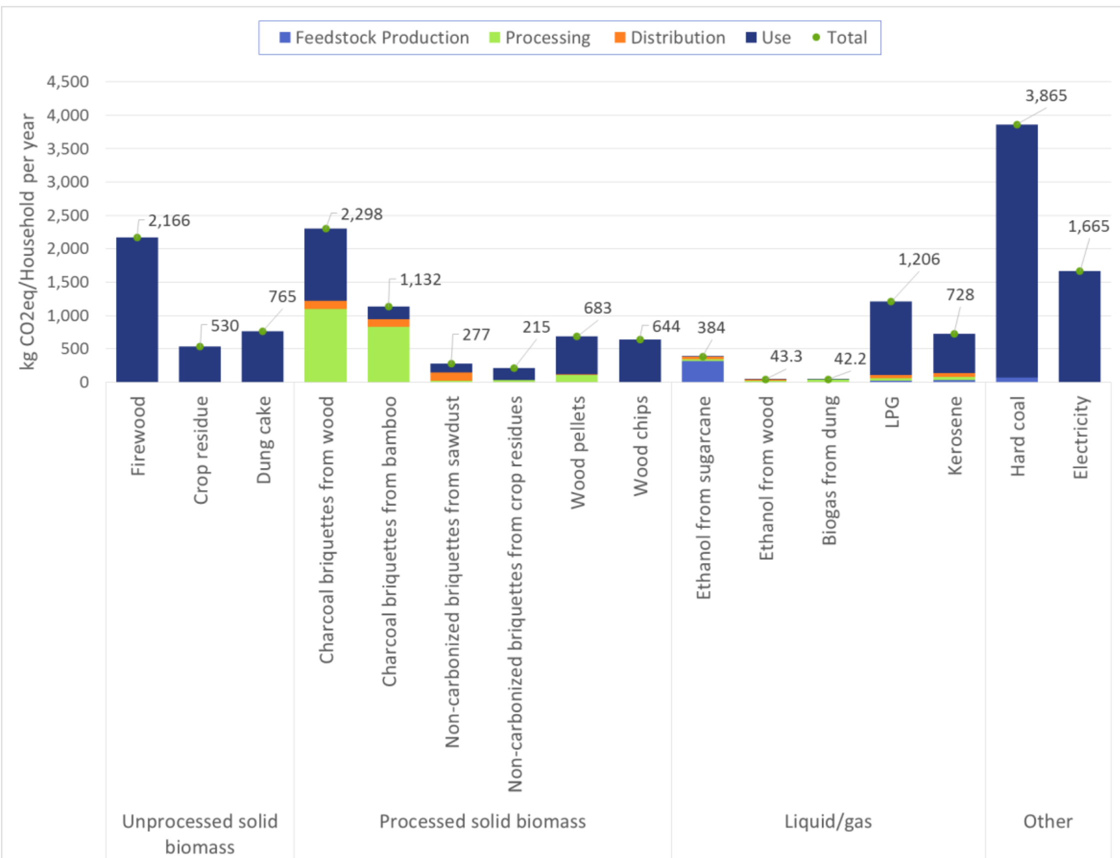


Figure 3-9. GCCP (100a) Potential Impacts (kg CO_2 eq) for Cooking Fuel Types (India)
To produce, distribute and use cooking fuels by a single household per year

Box 3-9 highlights key observations and Figure 3-10 displays the BC and short-lived climate pollutant results for fuels in India by life cycle stage.

Box 3-9– Black Carbon and Short Lived Climate Pollutant Observations for India

- The highest BC impacts are seen for traditional unprocessed biomass fuels, as well as charcoal briquettes and hard coal, which tend to have high PM emissions when combusted.
- The two charcoal briquettes also produce relatively high BC emissions, approximately 90 percent of which are associated with the carbonization process, whereas the BC impacts for the other fuels assessed occurs during the use phase.
- Liquid and gas fuel, wood pellets, and electricity use result in the lowest overall BC impacts.
- Dung cake has the highest BC emissions of all the fuels due in part to the fact that it has the lowest stove thermal efficiency of all the studied fuels.
- A substantial portion of coal in India used for electricity is assumed to have high sulfur content, resulting in emissions of sulfur dioxide, which in turn lead to net cooling impacts. There are more emission controls in India for particulate matter from coal power plants as compared to coal used directly in a cookstove, which is the reason such a large BC difference is seen for electricity and hard coal, even though much of the electricity grid in India is comprised of coal.

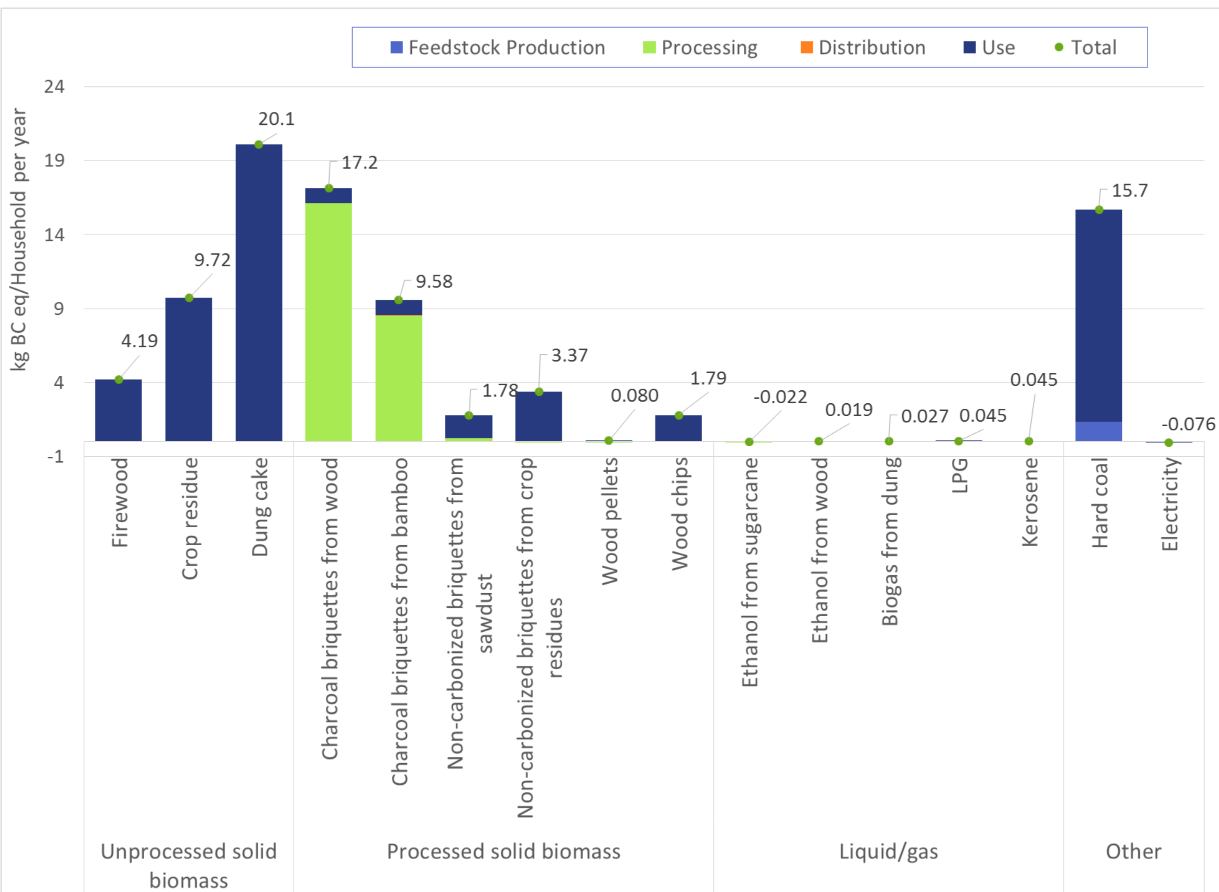


Figure 3-10. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (India)

To produce, distribute and use cooking fuels by a single household per year

Box 3-10 highlights key observations and Figure 3-11 shows the PM formation impact results for fuels in India by life cycle stage.

Box 3-10– Particulate Matter Formation Potential Observations for India

- The majority of charcoal briquettes impacts come during the carbonization stage (96 percent), which contrasts with the predominately use phase impacts of non-charcoal based fuels.
- PM impact values for charcoal briquettes from bamboo are lower than those produced by wood charcoal briquettes because a larger portion of charcoal briquettes from bamboo is estimated to be produced in more efficient brick kilns, whereas all charcoal briquettes from wood in India is assumed to be produced in traditional earth mound kilns.
- Processing PM impacts for non-carbonized briquettes from sawdust are associated with energy combustion necessary to reduce moisture content from 40 percent in the original greenwood[35] to 10 percent moisture in the final product.
- Wood chips have a slightly higher PM impact compared to wood pellets because the model assumes the densified pellets combust more efficiently than the chips during the use phase.
- Most of the PM impacts for electricity are derived from the coal mix in the average Indian electrical grid.

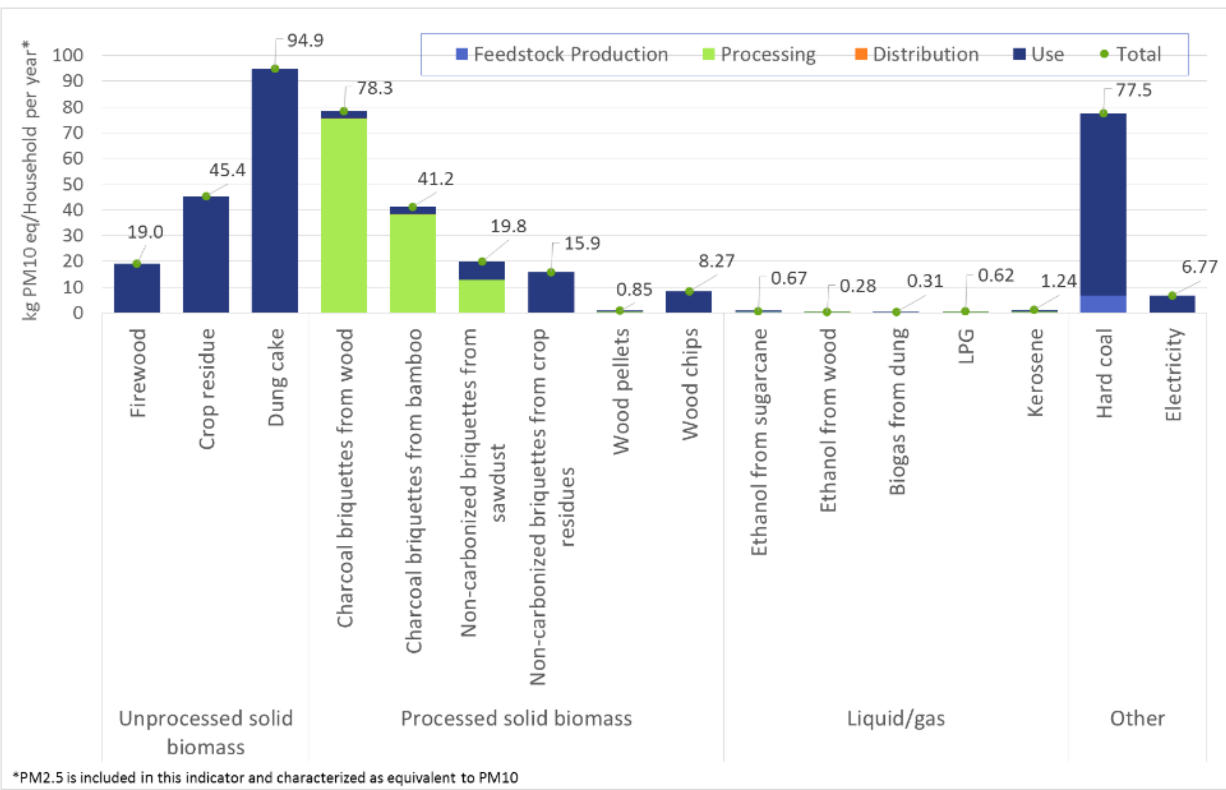


Figure 3-11. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (India)

To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators in Table 3-2 can be found in Appendix A, Section A.3.2.

3.3.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-11 – Key Observations and Policy Insights for India

- While **firewood** is currently the main cooking fuel used in India, all environmental indicators for this fuel, with the exception of fossil fuel and water depletion, are in the mid to high range compared to other fuels. Firewood supply is only partially sustainable based on current consumption and forest stock trends, so either afforestation must be increased or some of the population will need to shift to alternative cooking fuels. Firewood is heavily utilized because it is generally free for gathering in rural areas and does not have to be purchased, which is an important consideration for the poorer population in India.
- For **solid fuels derived from wood**, the fuel's heating value and the processing steps required to convert the wood into the end fuel product both influence the fuel's environmental profile.
    - Among the various wood-derived solid fuels, wood chips and pellets show the most favorable results.
    - Non-carbonized briquettes from sawdust have mostly mid-range results.
    - Charcoal briquettes have the least favorable results of the solid fuels derived from wood.
- **Non-carbonized briquettes** are more favorable relative to **charcoal briquettes**. Briquettes for cooking do not appear to be a popular fuel choice,[36] in India likely due to cost when compared to firewood and subsidized LPG. Some small enterprises are working toward increasing the use of non-carbonized briquettes, as they burn hotter and with less smoke than firewood.
- Promising from an environmental aspect, but very little use of liquid **ethanol** as a cooking fuel in India, and minimal information about ethanol for cooking use and cost is available. It should be noted that the results for wood-derived ethanol are more uncertain than sugarcane ethanol because there are no data available on commercial-scale facilities producing ethanol from wood wastes. India currently places high taxes on ethanol as a cooking fuel to discourage alcohol consumption.[37] One potential solution to this challenge could be to include additives to make ethanol non-consumable, and/or change current policy to provide an excise tax waiver. Ethanol (and other liquid fuels) can present some safety issues in the household, however, due to risk of spills of flammable liquid or accidental ingestion by children.
- **Biogas from Dung** typically results in lowest overall environmental impacts for indicators assessed. Mainly feasible for use in rural areas, such as dairy farms which are abundant in India, although food waste digesters could be a solution in urban areas. Affordable if the digester's upfront cost can be financed (see Appendix A, Section A.3.3). For many households, digester prices (up to 20,000 INR—more than 300

Box 3-11 – Key Observations and Policy Insights for India

USD)[38] make them prohibitively expensive for outright purchase; however, amortizing the cost over the unit's lifetime results in costs per HH per year that are lower than most fuels (other than freely collected biomass fuels and wood chips). Because of the high purchase price, loans, subsidies, or payment plans must be available for most households to make purchasing a digester financially viable. However, once the system is established, the household has a reliable fuel supply at no additional cost (aside from system maintenance) as long as it has sufficient livestock to provide dung as feedstock. Feeding and maintaining the digester takes substantially less time than collecting firewood (i.e., 10 hours per month for the digester[39] versus three to 10 hours per *week* for gathering firewood [40,41,42,43,44]). This would free up time for the women and children in the household to pursue other useful activities. The biogas (mostly methane) burns with a blue flame and provides the heat quickly, which saves cooking time compared to traditional fuels. Household digesters using dung as feedstock are primarily feasible in rural areas, while food wastes could potentially be used to feed larger scale digesters in urban areas. However, on a larger scale in the urban areas, installing piping to distribute the gas to households may be a significant challenge.

- While a nonrenewable fuel source, **LPG** is another fuel that shows lower to mid-range environmental impacts in all categories except fossil fuel depletion. While LPG stoves have high efficiencies and low emissions, resulting in overall lower energy demand and BC indicators, the GCCP indicator is higher than many biomass fuels due to the GHG combustion emissions for this fossil fuel. LPG, perceived as a safe fuel by the Indian population, is used by more than 25 percent of Indian households; most of this is within urban areas. Subsidies have worked well to increase LPG use in urban areas; however, the poorest households are still either unable or hesitant to adopt this fuel due to costs or distribution issues.
- **Dung cake, coal, and electricity** have high impacts in most of the environmental indicators. Dung generally has benefits and drawbacks similar to firewood (free for collecting in rural areas, but low cooking efficiency).
    - Coal and electricity are primarily used only in urban areas, where they comprise a very small percentage (less than 2 percent) of cooking fuel use. The environmental indicators for electricity are higher than most other fuels because 71 percent of the fuel used to produce electricity is coal.[45] Rural areas may lack access to electricity, plus the supply can be very unreliable. Another factor inhibiting electricity use is that some perceive it as dangerous due to the risk of shocks.
- **Electricity**, which is available to a majority of the population, is a clean fuel at point of use but has high overall GCCP results because the Indian electricity grid is highly dependent on coal. In order to make electricity a viable, clean cookstove option, India would need to put policy in place to overcome several issues, including:
    - Establishing the infrastructure required for the remaining rural areas.
    - Improving the network's reliability.
    - Focusing on a cleaner energy source for electricity generation.

3.4 RESULTS FOR BANGLADESH

3.4.1 *Country Overview*

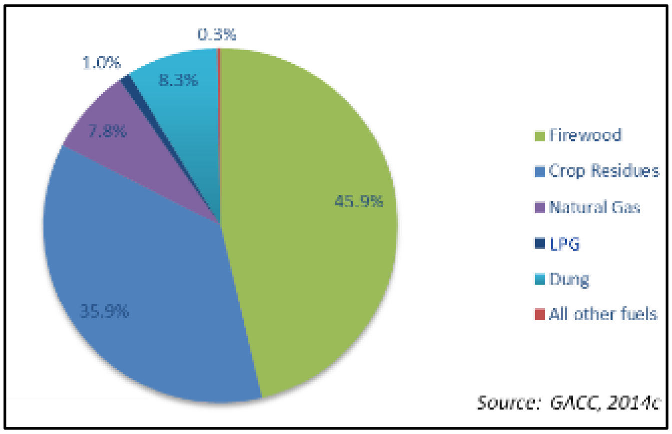


Figure 3-12. Cooking Fuel Use in Bangladesh

Bangladesh has the eighth largest population in the world.[46] Over 90 percent of the population is reliant on firewood, crop residues, or dung for their cooking fuel, as shown in Figure 3-12. Approximately 72 percent of the population lives in rural areas[47], and about 43 percent lives below the international poverty line, making Bangladesh among the poorest countries in the world.[48] As a result, fuel cost is an important concern. With the exception of kerosene[49], improved fuels are beyond the financial reach for many consumers. The Bangladesh Petroleum Corporation controls most of the dependable kerosene supply, including its relatively stable pricing system, which is generally uniform across the country in both rural and urban regions. Since access to local biomass is becoming more difficult due to deforestation, biomass fuels are becoming a marketed commodity.[50]

Bangladesh relies heavily on biomass, with firewood, crop residues, and dung used as a fuel source in 99 percent of homes in rural areas and in more than 60 percent of homes in urban areas.[51] Many of the lowest income people live in remote or ecologically fragile areas, which are vulnerable to natural disasters.[52] Each year, about 18 percent of the country's land area is flooded.[53] When rural households are unable to gather wood or crop residues during the rainy season, they may have to purchase fuels. Most households have two traditional-type stoves, one outside and one inside for use in the rainy season.[54] This is less common in cities, where gas and electric stoves can be found.[55] Many homes are small and do not have the space to store large amounts of fuels, which is one reason fuels must frequently be gathered or purchased in small amounts.

Adequate supply of fuel resources to sustainably support current or increasing levels of use is an important consideration. Bangladesh has shown an overall trend of an approximately 0.2 percent decrease in forest land per year over recent years,[56] although deforestation now appears to have been largely slowed or stopped through concentrated action by the government and its development partners.[57] Given the population's heavy reliance on wood fuels, as well as demand for wood for other uses, the sustainability of the wood supply remains a concern.

Finally, cultural issues related to food and cooking fires are an important consideration. Cooking habits are similar across Bangladesh, with rice as the mainstay for most meals and a need to cook large volumes of food in large pots. For cultural and historical reasons, families prefer fixed traditional stoves and use whatever type of biomass they can gather.[58] As observed in other countries, cooking fires may serve additional purposes in the home, such as providing heat or light. Changes to the cooking fuel or type of cookstove would likely require the household to use other fuels for these functions.[59]

3.4.2 *Environmental Impact Assessment, by Impact Category*

Table 3-3 shows a summary of environmental impacts by fuel type for Bangladesh. Figure 3-13 through Figure 3-16 provide additional details on several environmental indicators of high interest to the Alliance, namely total energy demand, GCCP, BC, and PM.

Table 3-3. Summary of Environmental Indicators for Cooking Fuels in Bangladesh

	Unprocessed Solid Biomass	Processed Solid Biomass						Liquid/Gas					
Indicator*	Firewood	Charcoal Briquettes from Wood	Charcoal Briquettes from Bamboo	Non-Carbonized Briquettes from Sawdust	Non-Carbonized Briquettes from Crop Residues	Wood Pellets	Wood Chips	Ethanol from Sugarcane	Ethanol from Wood	Biogas from Dung	LPG	*Median*	*All-fuel average***
TED (MJ/HH/YR)	16,742	23,441	23,441	16,965	6,733	5,150	7,338	14,663	4,787	4,111	4,702	*4,744*	*7,115*
NED (MJ/HH/YR)	14,483	21,182	21,182	14,706	4,474	2,890	5,078	12,404	2,528	1,852	2,443	*2,485*	*5,735*
GCCP (kg CO_2 eq/HH/YR)	1,875	2,279	470	204	103	860	820	195	18.5	23.8	671	*63.2*	*418*
BC/SLCP (kg BC eq/HH/YR)	1.70	1.28	1.28	1.20	1.90	0.045	0.74	-0.014	0.010	0.015	0.0028	*0.0066*	*0.45*
PMFP (kg PM10 eq/HH/YR)	6.84	2.69	2.69	4.92	8.86	0.31	2.99	0.34	0.15	0.17	0.26	*0.22*	*1.68*
FFD (kg oil eq/HH/YR)	0.015	0.036	0.057	0.018	0.0060	22.2	1.01	34.0	2.42	0	111	*0.010*	*9.50*
WD (m^3/HH/YR)	0.11	0.20	0.20	0.061	0.046	15.8	1.08	155	0.63	2.36	44.7	*0.087*	*12.3*
TAP (kg SO_2 eq/HH/YR)	3.55	0.59	0.59	2.04	0.48	0.29	1.57	1.05	0.19	0.24	0.66	*0.27*	*0.63*
FEP (kg P eq/HH/YR)	0.37	0.64	0.64	0.20	0.15	0.0073	0.16	0.079	7.4E-06	0	0.0056	*0.0028*	*0.12*
POFP (kg NMVOC eq/HH/YR)	8.96	61.4	61.4	39.3	6.86	0.50	26.1	0.64	0.46	0.51	1.48	*0.51*	*11.5*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country.

Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-12 highlights key observations and Figure 3-13 displays the total energy demand impact results for fuels in Bangladesh by life cycle stage.

Box 3-12– Total Energy Demand Observations for Bangladesh

- Total energy demand impact trends by fuel type for Bangladesh are similar to those seen for India.
- Of all the stoves used in Bangladesh, firewood stoves have the lowest thermal efficiency, which contributes to its low performance in the use phase.
- Liquid and gas fuels, which have both high heating values and stove thermal efficiencies, are associated with the lowest overall total energy demand impacts.
    - Sugarcane ethanol, assumed to be produced from molasses and imported from India, requires a significant amount of agricultural and manufacturing energy, which contributes to its higher overall total energy demand.

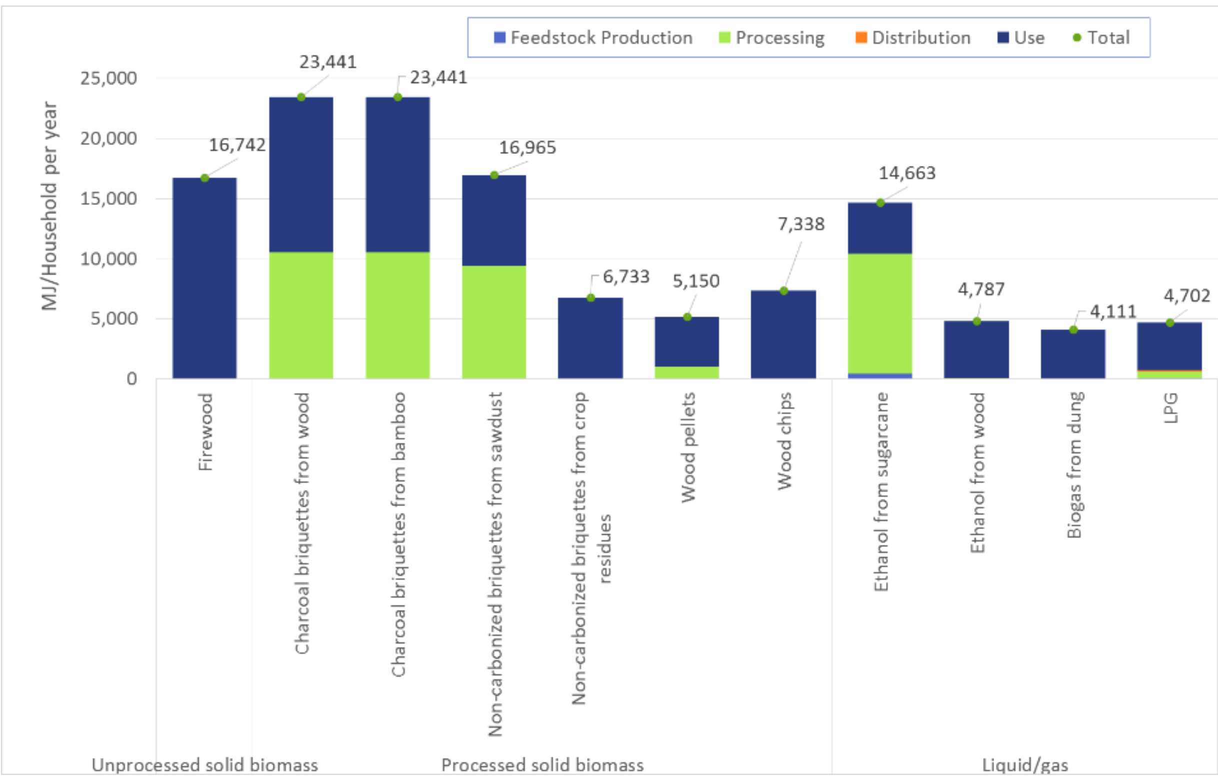


Figure 3-13. Total Energy Demand (MJ) for Cooking Fuel Types (Bangladesh)
To produce, distribute and use cooking fuels by a single household per year

Box 3-13 highlights key observations and Figure 3-14 presents the GCCP impact results for fuels in Bangladesh by life cycle stage.

Box 3-13– Global Climate Change Potential Observations for Bangladesh

- Unprocessed firewood and charcoal briquettes from wood display the largest climate change impacts.
- The poor GCCP performance of all non-waste wood products in Bangladesh is due to the modeling assumption that 100 percent of wood in Bangladesh is harvested in an unsustainable manner and is therefore not carbon-neutral (see Section 2.2.2).
- This also explains why bamboo briquette has an impact score that is over 130 percent lower than that generated by wood briquettes in this impact category.
- Non-carbonized briquettes from sawdust also benefits from its use of a waste-product as fuel feedstock. With the cut-off modeling methodology used in this analysis, wood wastes are treated as a “free” product (all burdens are allocated to the primary wood product; e.g., lumber, which is outside the scope of this study), so emissions of biomass CO_2 for fuels derived from wood waste are treated as carbon-neutral.
- Wood pellets and chips are burdened with the same assumption, but their higher thermal efficiencies of combustion contributes to their reduced climate impact.
- Bamboo, sugarcane, and crop residues are all assumed to be derived from renewable biomass in the Bangladeshi context; therefore, the CO_2 emissions released from combustion of these fuels is considered carbon-neutral, as discussed in detail in Appendix B. Impacts for these renewable fuels during the use phase are driven by nitrous oxide and methane emissions during cookstove use.
- Impacts associated with fertilizer production and emissions from application also play a role in the overall impacts of sugarcane ethanol.
- Ethanol from wood also benefits from its use of a waste-product as fuel feedstock. Emissions of biomass CO_2 for fuels derived from wood waste are treated as carbon-neutral.
- Biogas and ethanol from wood are the two lower impact fuels. Both have high heating values and high stove thermal efficiencies.

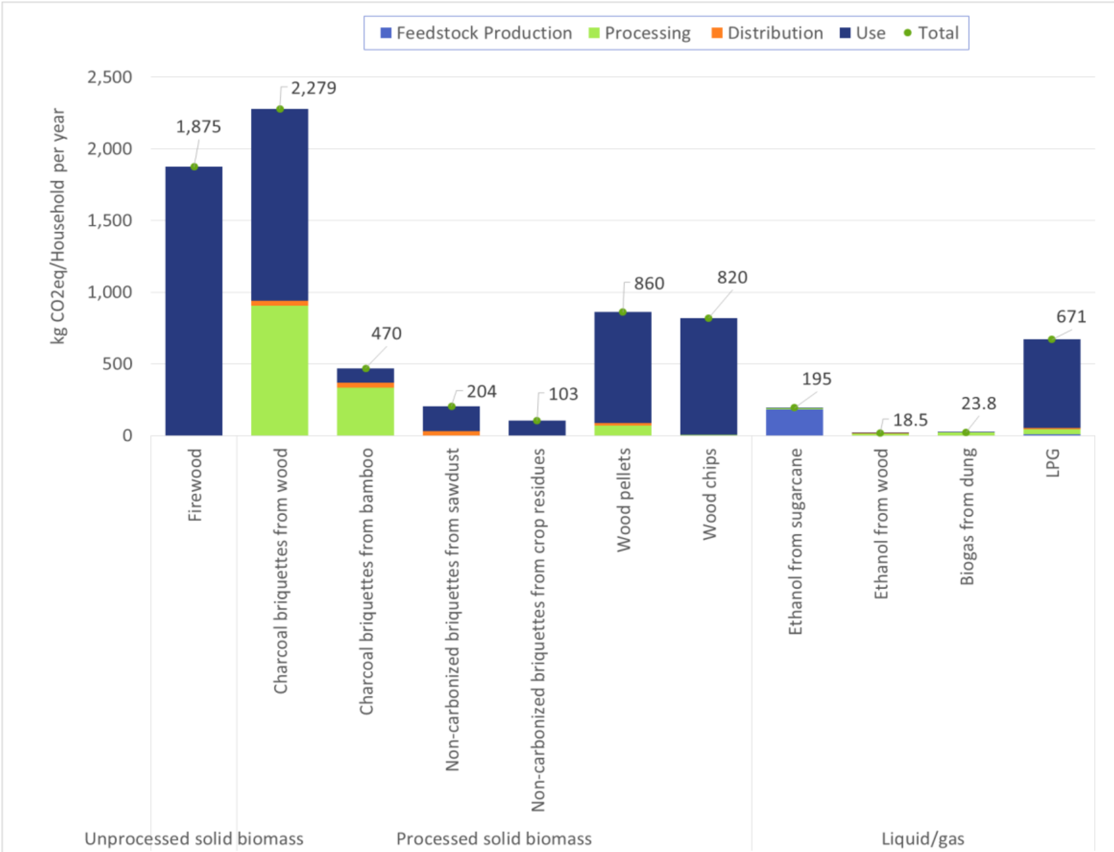


Figure 3-14. GCCP (100a) Potential Impacts (kg CO_2 eq) for Cooking Fuel Types (Bangladesh)

To produce, distribute and use cooking fuels by a single household per year

Box 3-14 highlights key observations and Figure 3-15 displays the BC and short-lived climate pollutant impact results for fuels in Bangladesh by life cycle stage.

Box 3-14– Black Carbon and Short Lived Climate Pollutants Observations for Bangladesh

- Similar to India, the highest BC impacts are seen for unprocessed firewood and non-carbonized briquettes from crop residues. Both fuels produce black carbon emissions almost exclusively during the use phase due largely to the high particulate matter emissions associated with combustion of these types of solid biomass fuels.
- Carbonized (i.e., charcoal) and non-carbonized briquettes from other feedstocks have slightly lower BC associated emissions. Charcoal briquettes split their impact in this category between the use and processing phase. Annual, household BC impact scores for both forms of charcoal briquettes have significantly better relative performance in Bangladesh than in other countries investigated, which is due in part to the lower charcoal kiln particulate matter emissions in Bangladesh reported in the literature (see Appendix Table B-1), and also the overall lower household cooking energy requirements for Bangladesh compared to other countries.
- As in other countries, use of liquid and gas fuels and wood pellets results in the lowest overall BC impacts. For all of these fuels, pollutant emissions with a net cooling effect in some life cycle stages serve to reduce the overall impacts.

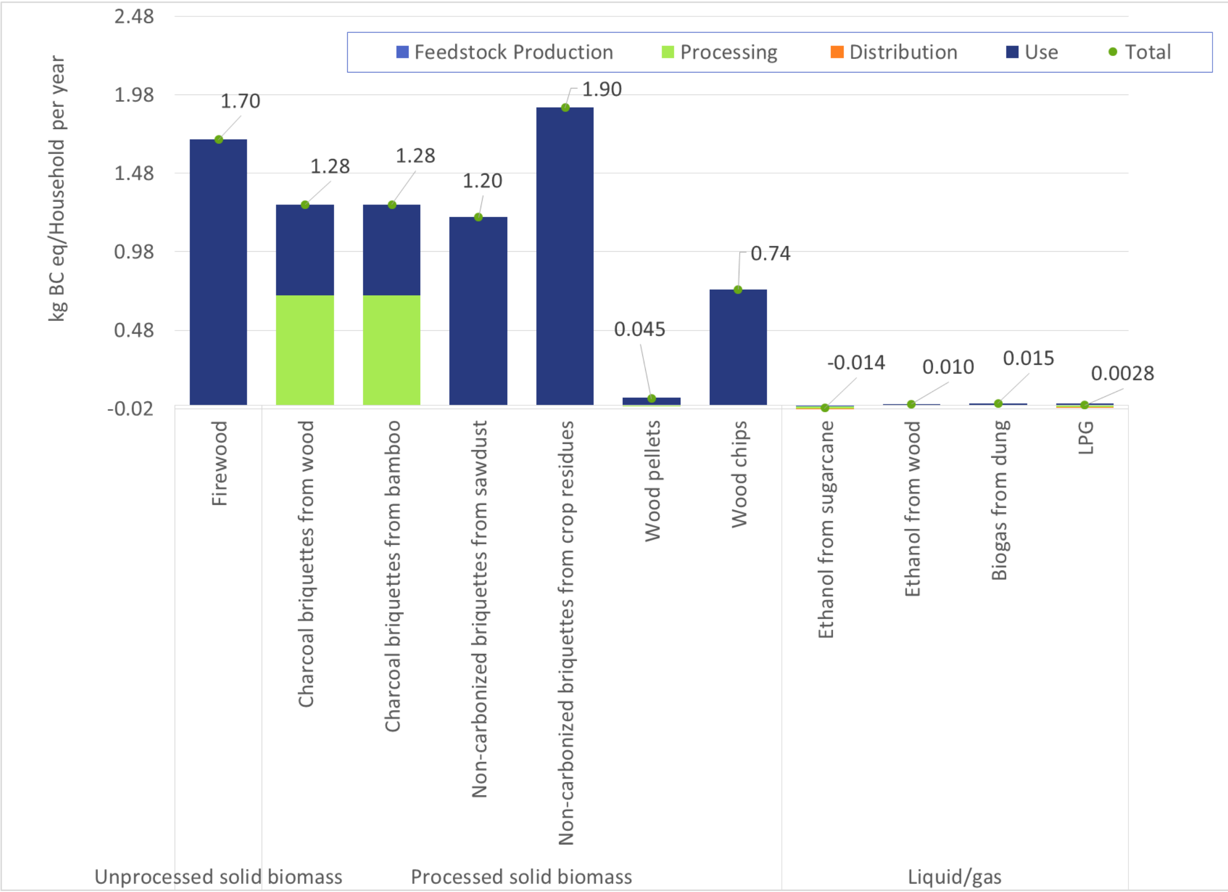


Figure 3-15. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (Bangladesh)

To produce, distribute and use cooking fuels by a single household per year

Box 3-15 highlights key observations and Figure 3-16 shows the PM formation impact results for fuels in Bangladesh by life cycle stage.

Box 3-15– Particulate Matter Formation Potential Observations for Bangladesh

- The highest PM impacts are seen for unprocessed firewood and non-carbonized briquettes from crop residues. Both of these fuels produce PM emissions almost exclusively during the use phase.
- LPG, ethanol, biogas and wood pellets all have small PM impacts, due to high heating values and stove thermal efficiencies.

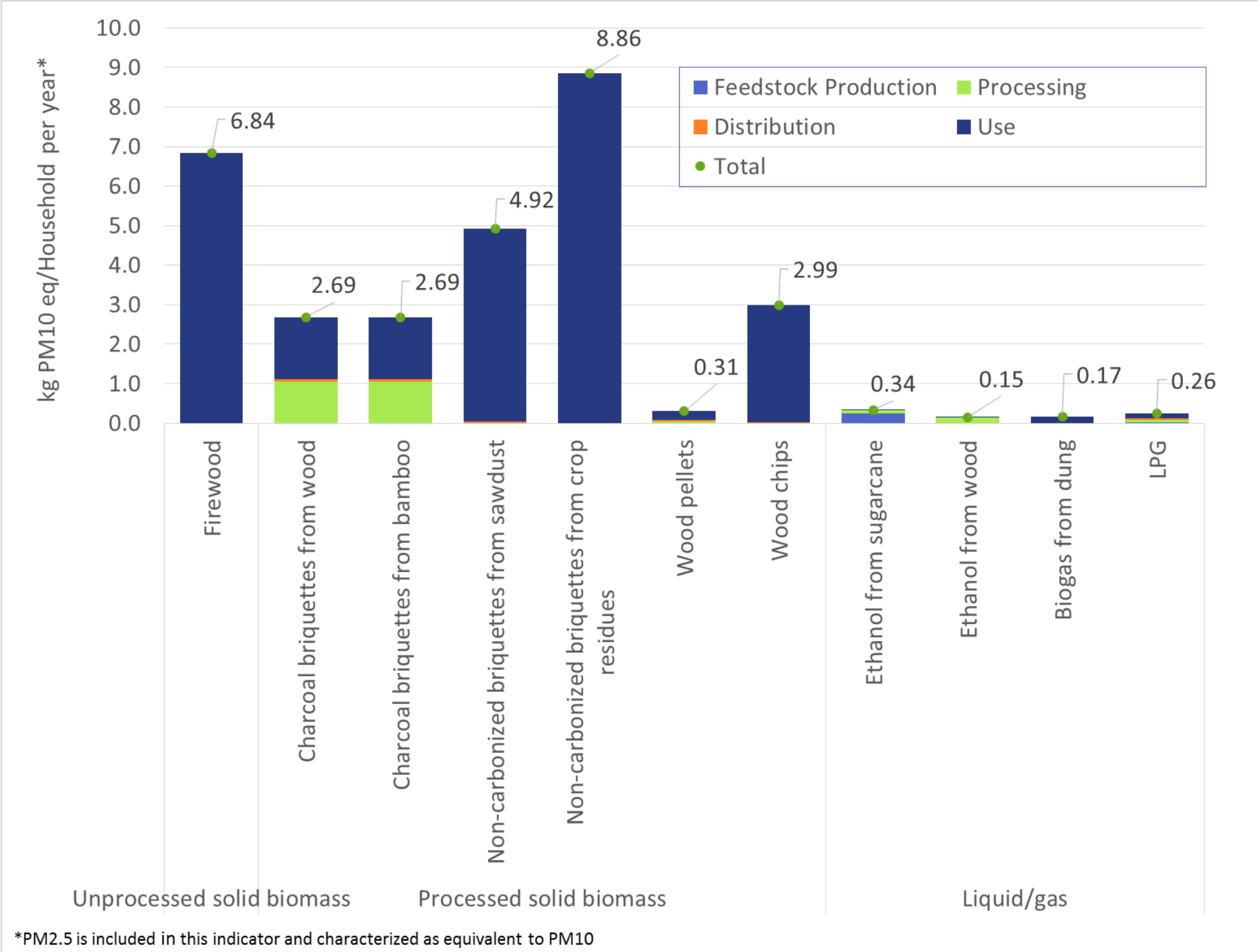


Figure 3-16. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (Bangladesh)

To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators in Table 3-3 can be found in Appendix A, Section A.4.2.

3.4.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-16 – Key Observations and Policy Insights for Bangladesh

- The results for the GCCP and BC indicators for **firewood** are high compared to liquid and gas fuels, as well as many of the processed biomass fuels. Firewood collection is time-consuming, averaging almost 60 hours per household annually.[60] With only about 11 percent of Bangladesh under forest cover[61] and longer distances to travel to make up for biomass shortages, fuel collection time and labor—especially that demanded of rural women—will increase.[62] Firewood is often free to collect; even when purchased, firewood costs less than half as much as LPG.

Box 3-16 – Key Observations and Policy Insights for Bangladesh

- **Processed Solid Biomass** such as non-carbonized briquettes show some advantages over charcoal briquettes for total energy demand and GCCP, but charcoal briquettes are cleaner burning (lower or comparable BC and lower PM). There is little difference in the costs of firewood and non-carbonized briquettes from crop residues, but briquettes are not commonly used in Bangladesh.[63] Wood pellets are affordable, cleaner burning, and sold on a smaller scale. Cookstoves that can use pellets and briquettes, as well as other fuels, are becoming more available;[64] however, awareness of the availability of improved stoves and fuels is low. In general, increased use of processed biomass fuels is hampered by lack of knowledge about these fuels and their health benefits, as well as lack of access to stoves for efficiently burning processed biomass.
- **Wood chips** and **pellets** show some advantages in environmental impacts over unprocessed biomass and tend to be more affordable than liquid and gas fuels.
- **Ethanol** from wood and from sugarcane performed well environmentally compared to solid biomass and fossil-based fuel. No information on economic indicators was available for Bangladesh, although there is significant production of ethanol. [65] Data are not available to determine what share of domestically-consumed ethanol is used at the household level, though evidence from market managers indicate it is used minimally as a cooking fuel despite past government initiatives to promote its adoption.[66] One possible explanation for its limited use as a cooking fuel is that there is currently a preference for using ethanol as fuel for transportation.
- **Biogas** from dung has lower total energy, GCCP, PM and BC indicators compared to most other assessed fuels and can be affordable with micro-financing through government programs. However, many rural households may not have sufficient livestock to support a digester. Biogas systems have been increasing in Bangladesh through the Sustainable and Renewable Energy Development Agency (SREDA), an independent agency that includes stakeholder representatives in the community, such as NGOs, academics, businesses, and financial institutions, micro-financing of small fuel-based enterprises and household or community. More than 30,000 biogas plants have been installed in the country since 2005 by Grameen Shakti.[67,68]
- **LPG**, while a nonrenewable fuel source, is fuel that shows lower to mid-range environmental impacts in all categories except fossil fuel depletion. LPG accounts for a very small share of cooking fuel use in Bangladesh due to cost and unreliability of the distribution network. High duties on imported fossil fuels increase price beyond the reach of much of the population. Natural gas is more widely used in urban areas and is less costly than firewood; however, shortages of natural gas are not uncommon, forcing consumers to use other fuels at times.

Latin America

3.5 RESULTS FOR GUATEMALA

3.5.1 *Country Overview*

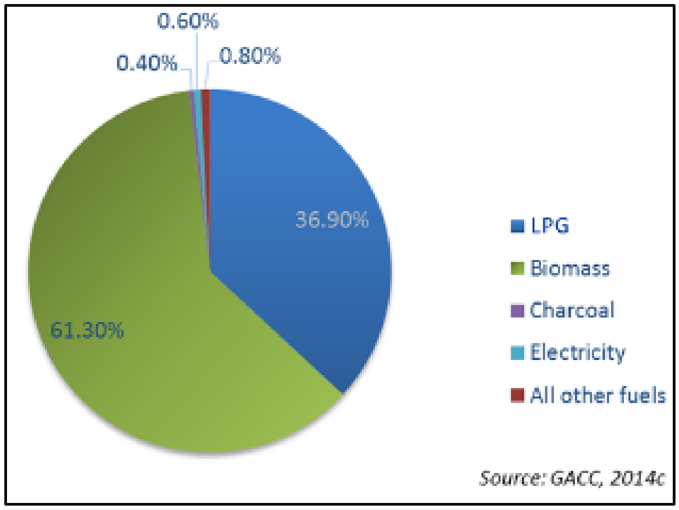


Figure 3-17. Cooking Fuel Use in Guatemala

Guatemala is Central America's most populous country,[69] with the population almost equally divided between urban and rural areas.[70] Overall, the dominant cooking fuels currently used in Guatemala are unprocessed solid fuels (e.g., firewood and crop residues) and LPG, as shown in Figure **3-17**. Adequate fuel supply is a key consideration. For example, Guatemala has shown an overall trend of an approximately 1.5 percent decrease in forest land per year over recent years,[71] and 48 percent of Guatemala's land area is under the threat of severe drought.[72] LPG is more commonly used in urban areas, with 75 percent of urban households and only 25 percent of rural households using LPG.[73] Electricity is available to approximately 82 percent of the population but is currently too expensive for the poor; Charcoal briquettes are produced and used by residents to a small degree, but they are used to a greater extent for commercial cooking.[74]

Fuel cost is another key issue. Fifty-four percent of the population is under the national poverty line of about $3.21 per capita per day,[75] and approximately 14 percent of the Guatemalan population lives below the international poverty line ($1.25 per capita per day).[76] Due to the poverty in Guatemala, many households can only afford to purchase fuel a day at a time.[77] Even those who can afford cleaner cooking fuels may still use biomass fuels to some extent. For example, a staple in the Guatemalan diet is beans, which require long cooking times and therefore may be too expensive to cook using a cleaner purchased fuel such as LPG.

3.5.2 *Environmental Impact Assessment, by Impact Category*

Table 3-4 shows a summary of environmental impacts by fuel type in Guatemala Figure 3-18 through Figure 3-21 provide additional details on several environmental indicators of high interest to the Alliance, namely total energy demand, GCCP, BC, and PM.

Table 3-4. Summary of Environmental Indicators for Cooking Fuels in Guatemala

Indicator*	Unprocessed Solid Biomass	Processed Solid Biomass						Liquid/Gas					
	Firewood	Charcoal Briquettes from Wood	Charcoal Briquettes from Bamboo	Non-Carbonized Briquettes from Sawdust	Non-Carbonized Briquettes from Crop Residues	Wood Pellets	Wood Chips	Ethanol from Sugarcane	Ethanol from Wood	Biogas from Dung	LPG	*Median*	*All-fuel average***
TED (MJ/HH/YR)	104,300	211,088	207,685	117,412	52,361	40,199	51,041	42,721	33,129	28,453	48,630	*36,664*	*52,057*
NED (MJ/HH/YR)	88,663	195,451	192,049	101,776	36,724	24,563	35,405	27,084	17,492	12,817	32,993	*21,028*	*42,501*
GCCP (kg CO_2 eq/HH/YR)	11,728	19,682	5,616	1,380	349	5,720	5,714	236	123	164	4,768	*200*	*3,082*
BC/SLCP (kg BC eq/HH/YR)	9.97	68.1	68.1	7.49	2.30	0.33	4.84	0.023	0.072	0.11	-0.40	*0.047*	*8.94*
PMFP (kg PM10 eq/HH/YR)	34.0	305	305	25.8	9.51	2.49	16.6	0.76	1.01	1.21	1.47	*1.11*	*39.0*
FFD (kg oil eq/HH/YR)	0.079	0.16	0.30	0.12	0.0094	59.8	12.7	41.6	16.7	0	1,667	*0.044*	*99.9*
WD (m^3/HH/YR)	0.60	0.74	0.74	0.42	0.069	1,961	13.4	255	4.35	16.3	139	*0.51*	*133*
TAP (kg SO_2 eq/HH/YR)	8.06	3.93	4.00	6.80	1.22	2.61	4.20	3.35	1.27	1.66	3.63	*1.47*	*2.26*
FEP (kg P eq/HH/YR)	1.95	2.36	2.36	1.36	0.22	0.064	0.94	0.13	5.1E-05	0	0.024	*0.012*	*0.52*
POFP (kg NMVOC eq/HH/YR)	362	287	287	273	16.3	3.43	176	13.5	3.16	1.78	9.27	*3.30*	*79.5*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country.
Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-17 highlights key observations and Figure 3-18 displays the total energy demand impact results for fuels in Guatemala by life cycle stage.

Box 3-17– Key Total Energy Demand Observations for Guatemala

- The average Guatemalan household requires 15.6 GJ of cooking energy annually, this is second only to Nigeria, and is nearly 10 GJ above the comparable value for the next highest country Uganda (see Table B-1). This yields very high total energy demand results for Guatemala.
- Wood pellets and wood chips have lower total energy demand than traditional firewood. Wood resources in Guatemala are assumed to be harvested in a manner that is non-renewable. Like other countries, the liquid and gas fuels are among the top performers in this impact category demonstrating impact scores. In Guatemala, it is assumed that the sugarcane is converted directly to ethanol (rather than to the intermediate product of molasses as seen in India), similar to the supply chain seen in Brazil.

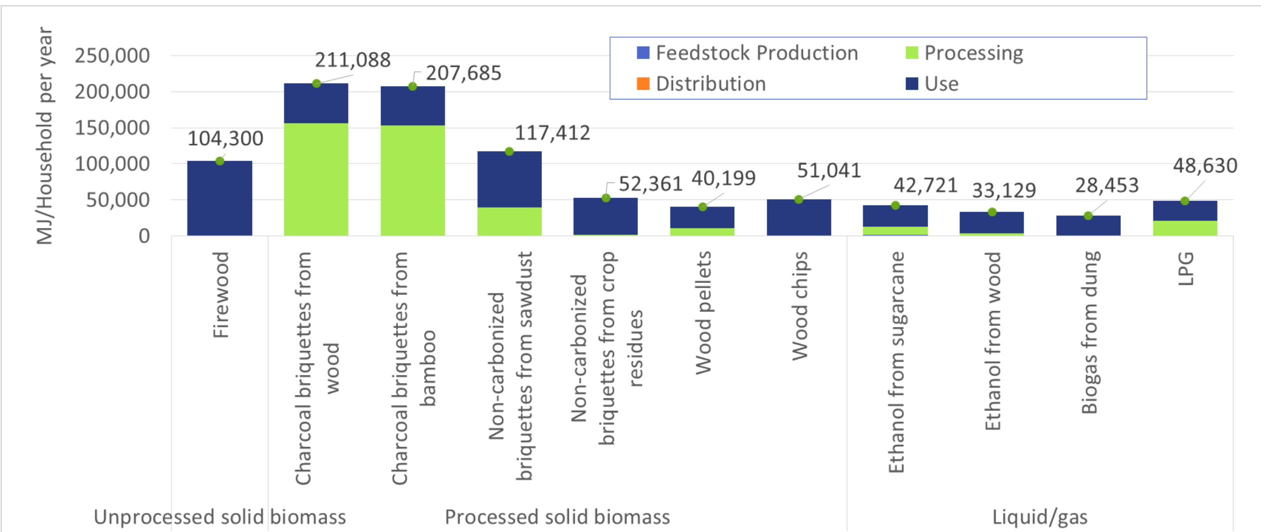


Figure 3-18. Total Energy Demand (MJ) for Cooking Fuel Types (Guatemala)
To produce, distribute and use cooking fuels by a single household per year

Box 3-18 highlights key observations and Figure 3-19 presents the GCCP impact results for fuels in Guatemala by life cycle stage.

Box 3-18– Global Climate Change Potential Observations for Guatemala

- Firewood also has high climate change impacts in part due to low cookstove thermal efficiencies and the use of non-renewable harvesting practices in Guatemala.
- Charcoal briquettes from wood have the largest GCCP impacts of all the studied fuels. As charcoal briquettes are not commonly used in Guatemala, these GCCP impacts are avoided. Combustion emissions for charcoal briquettes from bamboo are significantly lower than for charcoal briquettes from wood as bamboo is a renewable crop.
- Wood chips and wood pellets have an impact roughly half the level of firewood, wood feedstock is still considered to be harvested using non-renewable practices but stove

Box 3-18– Global Climate Change Potential Observations for Guatemala

efficiencies improve from 15 percent (for firewood) to approximately 30 and 50 percent, respectively (for wood chips and wood pellets).

- Both forms of ethanol and biogas are associated with the lowest three GCCP impact results among the Guatemalan fuels included in this study. Ethanol from wood is assumed to be carbon-neutral via the cut-off method assumptions (see Section 2.2.2) and what small emissions do occur are the result of nitrous oxide and methane emissions that result from combustion.
    - Biogas impacts are primarily due to methane leakage during biogas production in an anaerobic digester. While sugarcane is treated as a renewable resource, impacts associated with fertilizer production and emissions from application do play a role in the sugarcane ethanol overall GCCP impacts.

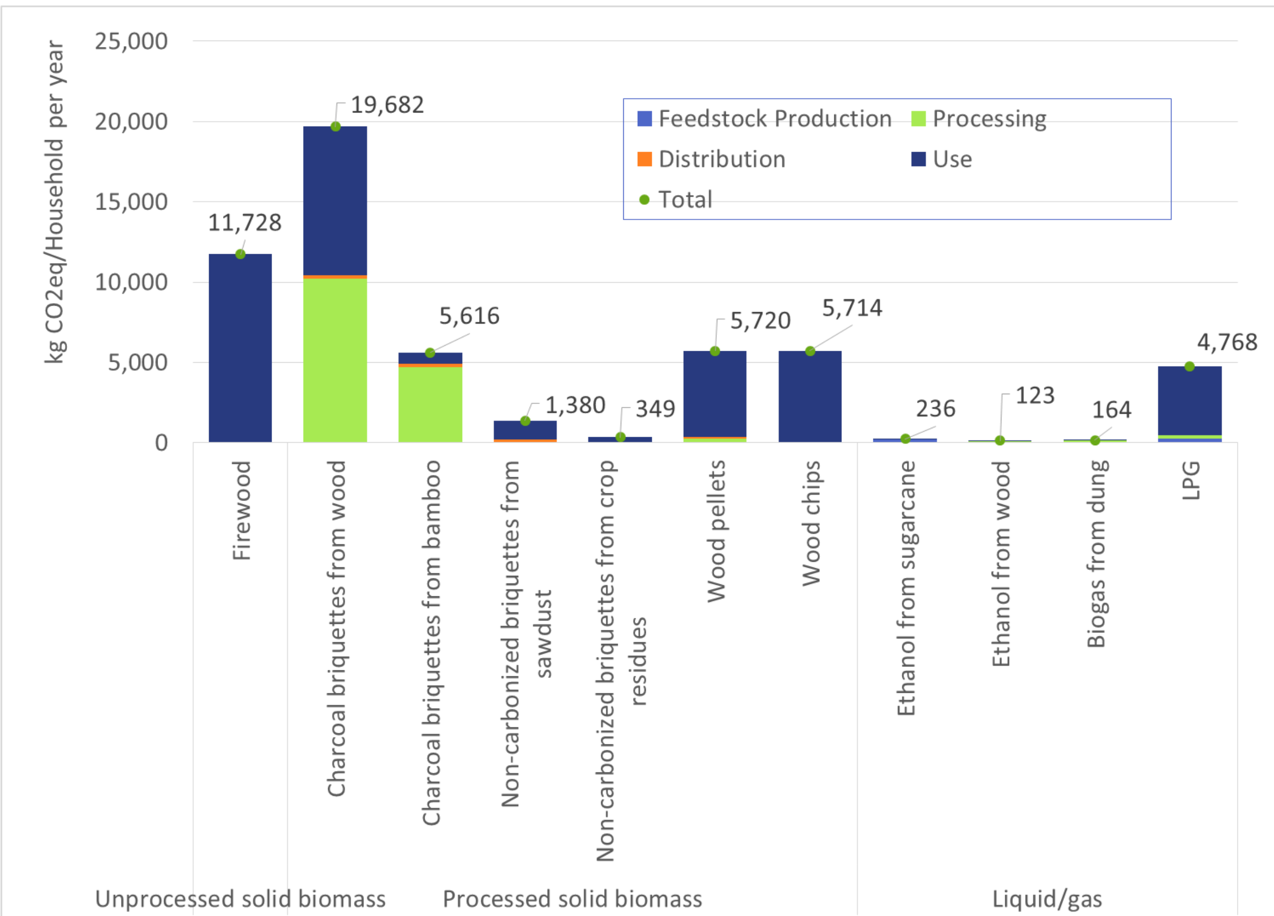


Figure 3-19. GCCP (100a) Potential Impacts (kg CO2 eq) for Cooking Fuel Types (Guatemala)

To produce, distribute and use cooking fuels by a single household per year

Box 3-19 highlights key observations and Figure 3-20 displays the BC and short lived climate pollutant impact results for fuels in Guatemala by life cycle stage.

Box 3-19– Black Carbon and Short-Lived Climate Pollutants Observations for Guatemala

- Firewood, non-carbonized briquettes and wood chips all produce low to moderate impact scores, which are dominated by emissions resulting from use phase combustion.
- Charcoal briquettes from wood and bamboo are modeled as having the same transport requirements and combustion emissions in Guatemala due to a lack of specific information for bamboo briquettes. This leads to identical impact scores in the BC impact category. Emissions from the use of more traditional surface kilns to carbonize the charcoal briquettes is what leads to the high BC emissions in from those fuels.
- Wood pellets and all of the liquid and gas fuels generate low impact scores in this category. Both high combustion efficiency, yielding low PM emissions, and net cooling impacts of some life cycle stages due to emissions of sulfur dioxide contribute to their low relative scores.

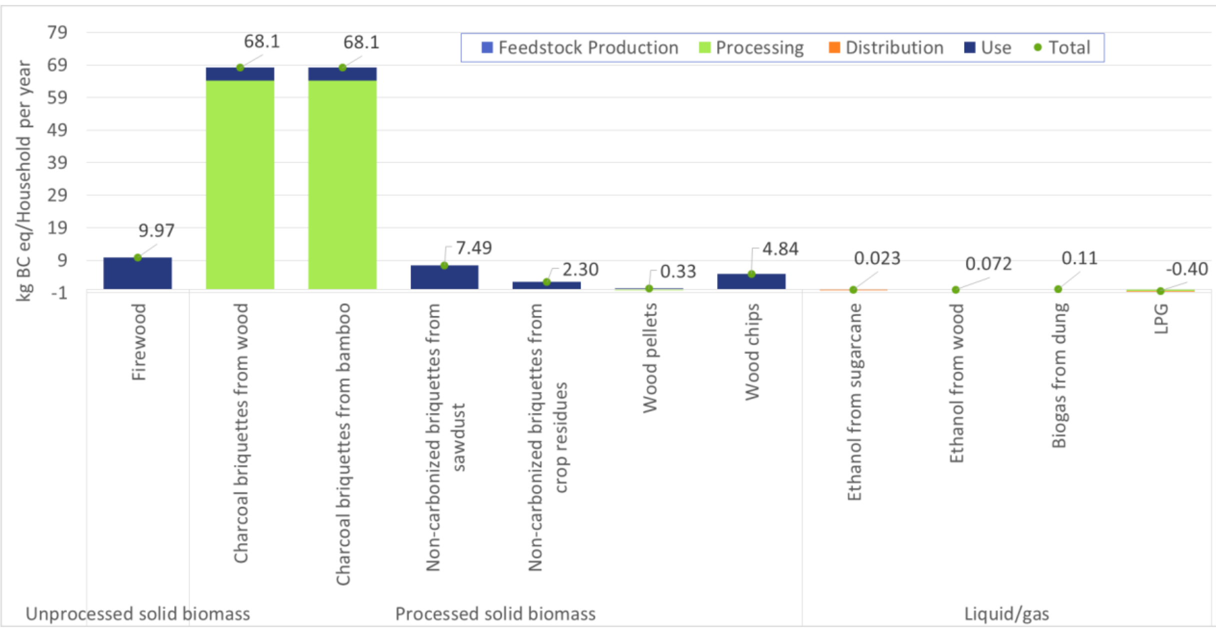


Figure 3-20. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (Guatemala)
To produce, distribute and use cooking fuels by a single household per year

Box 3-20 highlights key observations and Figure 3-21 shows the PM formation impact results for fuels in Guatemala by life cycle stage.

Box 3-20– Particulate Matter Formation Potential Observations for Guatemala

- The relative performance of fuel-stove combinations in this impact category is very similar to the pattern observed in BC impacts discussed in Box 3-19.

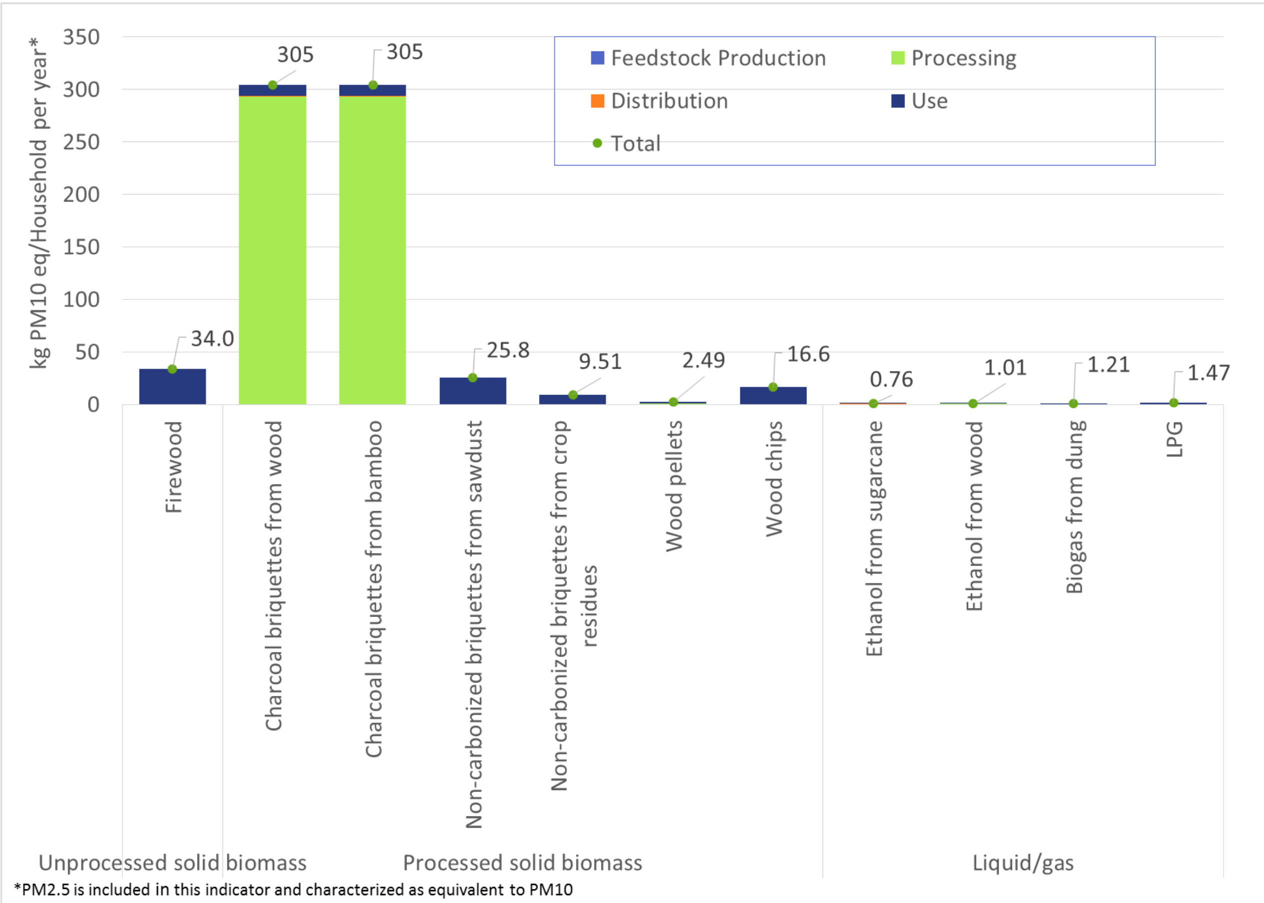


Figure 3-21. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (Guatemala)

To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators in Table 3-4 can be found in Appendix A, Section A.5.2.

3.5.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-21 – Key Observations and Policy Insights for Guatemala

- **Firewood** is the most widely used[78] and available cooking fuel in Guatemala;[79] however, environmental indicators related to air emissions are in the mid to high range compared to other fuels. Guatemala's firewood supplies are becoming increasingly vulnerable due to deforestation and increasingly less accessible due to heightened efforts to protect government-owned forests.[80] Firewood theft from protected lands, however, is not uncommon. Some communities have designated firewood collectors who gather wood in larger quantities and sell it at depots.[81] Unlike other focus countries, wood gathering in Guatemala is dominated by men (75 percent of collection), which may lessen some of the risks experienced by women and girls gathering firewood, such as physical strains and harassment.[82,83]
- **Non-carbonized briquettes from crop residues**: Environmental indicators for GCCP, PM and BC are promising, but economic potential is unknown. Some of the briquette-type fuels that were imported in the past were more costly than firewood and were therefore unsuccessful in the marketplace.
- Many of the other fuels evaluated for Guatemala are either only available regionally through small enterprises or not used within the country at this time. Bamboo is used as a fuel within Guatemala, but it is generally burned unprocessed, rather than converted to more energy-efficient charcoal briquettes. The same is true of crop residues, such as palm fronds, pine cones, and copra. Although non-carbonized briquettes, wood pellets, and wood chips have low to mid-range environmental indicators, these fuels are not commonly seen in this country.[84]
- **Ethanol**: Majority of domestic supply is exported to Europe, Central America, and Mexico.[85] The quantity of ethanol not exported is typically used as transportation fuel or for other industrial or food purposes. Little information is available about use as a cooking fuel in Guatemala; safety issues such as flammable liquid spills can be a concern. Rural adoption would require a reliable distribution network that could provide ethanol in container sizes that rural users are able to afford and transport conveniently.
- **Biogas from Dung** compares favorably with other fuels from an environmental standpoint, and biogas systems are currently being marketed by small enterprises within Guatemala. Mainly feasible only for those households in rural areas that have enough livestock to efficiently run the digester. This obstacle could potentially be overcome by households combining their feedstocks, although the issues of adequate supply of biogas produced and piping to multiple homes could be a challenge. The fuel is affordable over the system's lifetime, and safety issues are advantageous compared to the use of current biomass solid fuels. Successful promotion at the commercial level has relied on both the subsidization of upfront costs and raising awareness about the aggregate time and energy savings.[86] There are pilot projects (see the featured example in Box 3-22) focused on small production enterprises using food scraps and dung to produce biogas. Knowledge gained from enterprise-level pilot programs will serve to

Box 3-21 – Key Observations and Policy Insights for Guatemala

educate households about the potential cost savings they could realize by using biogas instead of conventional fuels.

- **LPG** is currently one of the more widely used fuels which is imported and distributed without substantial government barriers;[87]generally has lower environmental impacts compared to traditional biomass cooking fuels and is more affordable than purchased firewood. LPG is much more commonly used in urban areas than in rural areas for a number of reasons. A substantial affordability issue for rural users are the high refill costs associated with using large cylinders that are required to be entirely refilled; partial refills are prohibited.[88] Rural users are more vulnerable to transportation issues such as delays in LPG delivery from central depots to more remote retail locations.[89] In addition, rural users often use public transportation or bicycles when traveling to purchase LPG, making transport of bulky cylinders difficult. Distribution costs are passed on to rural consumers in the form of higher LPG prices. The recent availability of smaller LPG cylinders in Guatemala has the potential to alleviate consumer cylinder transport difficulties, as well as to reduce refill costs.[90]

Box 3-22–Featured Example for Guatemala

Accelerating deforestation and increasingly limited access to energy supplies has prompted enterprises such as Alterna to explore cooking fuel solutions other than traditional sources. Their approach, in partnership with WISIONS, seeks to use biogas technology to transform freely available resources, such as manure and foodscraps, into high-value products, such as biogas and organic fertilizer. Their project is aimed at micro and small entrepreneurs who can save energy and money by incorporating biogas technology into their production systems (roasting peanuts, drying coffee beans, etc.). Although the initiative is intended for companies in the food processing chain, several lessons learned are immediately applicable to the promotion of biogas systems at the household level. First and foremost is the importance of subsidizing upfront costs, providing assistance with the installation of new systems, and providing ongoing technical support once the biogas system is in place. Such logistical support is critical for helping new users overcome the uncertainties of switching to a new, relatively complex fuel source, and financial aid can help new users get their biogas systems up and running in environments with limited micro-financing or borrowing options. Another component of Alterna’s success is to promote awareness among new and potential users of the correlation between daily effort and biogas production. Although the daily operation and maintenance of a biogas system may exceed the level of effort users are used to expending on fuel purchasing or collection, Alterna found that helping users understand that their efforts would result in substantial aggregate savings (usually around $440 in energy per year) helped increase adoption and retain users of their system. Source: Alterna, 2015.

3.6 RESULTS FOR NIGERIA

3.6.1 *Country Overview*

Nigeria is Africa's most populous country. Sixty-two percent of the country's population is below the international poverty line of $1.25 per capita per day.[91] In 2010, Nigeria's population was evenly split, with 50 percent living in rural areas and 50 percent living in urban areas.[92] As shown in Figure 3-22, over 70 percent of the population uses biomass fuel (primarily firewood) for cooking.[93,94,95,96] The North Central region has the highest dependency on firewood.[97] Households may depend on only one fuel or use a mix depending on availability and cost.[98]

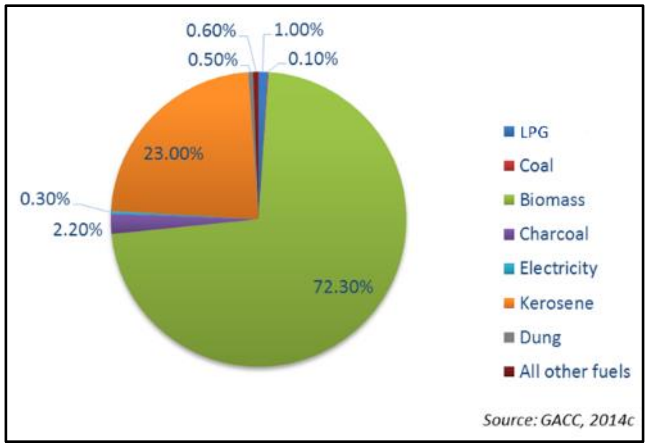


Figure 3-22. Cooking Fuel Use in Nigeria

Kerosene is used in almost a quarter of total households[99], primarily in the south.[100] Charcoal is used to a small degree by farmers in rural areas. Electricity, coal, dung, and LPG are each used by 1 percent or less of households. Only 40 percent of Nigerian households have access to electricity.[101] Nigeria has large coal reserves, so this is likely a cheap fuel alternative where it can be easily mined; however coal is a dirty fuel to burn with a high environmental footprint. Dung is used by a small section of the rural population that keeps livestock. LPG is limited to the rich due to high upfront costs and is mainly used in the south close to the import location.

As in other countries, fuel use patterns vary with income level and urban or rural setting. LPG is most commonly used by high-income urban residents; wood by low-income rural residents; and a mix of wood, charcoal, and kerosene by middle-income residents in both urban and rural areas.[102] A survey of Nigerians found kerosene to be the most desirable fuel, primarily due to its ease of use.[103]

Adequate supply is especially important given the high dependence on biomass fuels. There has been an over 3 percent decrease in forest land per year over recent years.[104] Deforestation is more acute in the north.[105] Logging, subsistence agriculture, and firewood collection are leading causes of forest clearing in Nigeria.[106] Annually, Nigeria is losing about 1,355 square miles of cropland and rangeland due to desertification, where dry lands become increasingly arid.[107] As a result, some consumers will likely be forced to start using other fuels as biomass becomes scarcer.

Households across Nigeria eat similar foods and have the same cooking habits; however, urban households are moving away from traditional cooking for speed and convenience.[108] Rural households use firewood stoves outdoors to avoid smoke and reduce fire hazards. [109] Typical foods include yams and cassava, which require significant boiling and preparation time. Urban households usually cook in enclosed passageways and reduce cooking time by replacing yams and cassava with rice that requires less cooking time. [110]

3.6.2 *Environmental Impact Assessment, by Impact Category*

Table 3-5 presents a summary of the environmental impacts evaluated for each fuel in Nigeria. Figure 3-23 through Figure 3-26 provide additional details on several environmental indicators of high interest to the Alliance, namely total energy demand, GCCP, BC, and PM.

Table 3-5. Summary of Environmental Indicators for Cooking Fuels in Nigeria

	Unprocessed Solid Biomass	Processed Solid Biomass						Liquid/Gas					
Indicator*	**Firewood**	**Charcoal Briquettes from Wood**	**Charcoal Briquettes from Bamboo**	**Non-Carbonized Briquettes from Sawdust**	**Non-Carbonized Briquettes from Crop Residues**	**Wood Pellets**	**Wood Chips**	**Ethanol from Sugarcane**	**Ethanol from Wood**	**Biogas from Dung**	**LPG**	***Median***	***All-fuel average****
TED (MJ/HH/YR)	114,855	322,267	314,079	122,583	58,145	43,160	52,343	43,912	34,080	28,483	111,077	*38,620*	*69,166*
NED (MJ/HH/YR)	98,770	306,181	297,991	106,498	42,059	27,075	36,257	27,827	17,995	12,397	94,992	*22,535*	*59,336*
GCCP (kg CO_2 eq/HH/YR)	12,929	24,512	4,976	1,428	737	6,010	5,851	241	126	48.0	6,214	*183*	*3,504*
BC/SLCP (kg BC eq/HH/YR)	11.0	27.2	26.6	7.70	13.5	0.34	4.97	0.025	0.074	0.16	0.27	*0.12*	*5.10*
PMFP (kg PM10 eq/HH/YR)	37.4	102	99.0	29.6	63.1	2.02	17.0	0.76	1.04	0.84	1.92	*0.94*	*19.7*
FFD (kg oil eq/HH/YR)	0.11	0.25	0.19	2.01	2.41	128	4.60	42.0	17.2	0	2,605	*0.15*	*156*
WD (m^3/HH/YR)	0.82	1.23	1.21	12.1	15.0	789	5.08	262	4.48	51.5	151	*1.22*	*71.9*
TAP (kg SO_2 eq/HH/YR)	8.81	3.27	3.25	7.01	3.45	1.50	4.11	3.39	1.30	0.25	4.13	*1.40*	*2.25*
FEP (kg P eq/HH/YR)	2.65	1.26	1.23	1.48	1.05	0.049	1.20	0.13	5.3E-05	0	0.019	*0.0096*	*0.50*
POFP (kg NMVOC eq/HH/YR)	399	455	452	280	48.9	3.13	180	13.8	3.25	1.31	34.9	*3.19*	*104*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country.
Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-23 highlights key observations and Figure 3-23 displays the total energy demand impact results for fuels in Nigeria by life cycle stage.

Box 3-23– Total Energy Demand Observations for Nigeria

- Of the countries included in this study, Nigeria has the highest annual household cooking energy requirement, 16.1 GJ on average (see Table B-1).
- The impact of charcoal briquettes in Nigeria and Ghana are greater than in other study countries due to the low stove efficiencies and large quantity of fuelwood required to carbonize charcoal in traditional earth mound kilns. It is estimated that 4.9 kg of wood are required to produce 1 kg of wood-based charcoal in Nigeria (see Table B-10).
- Wood pellets and wood chips have a lower total energy demand than traditional firewood, due to improved stove thermal efficiencies. Wood chips total energy demand is approximately 75 percent lower than that for unprocessed firewood.

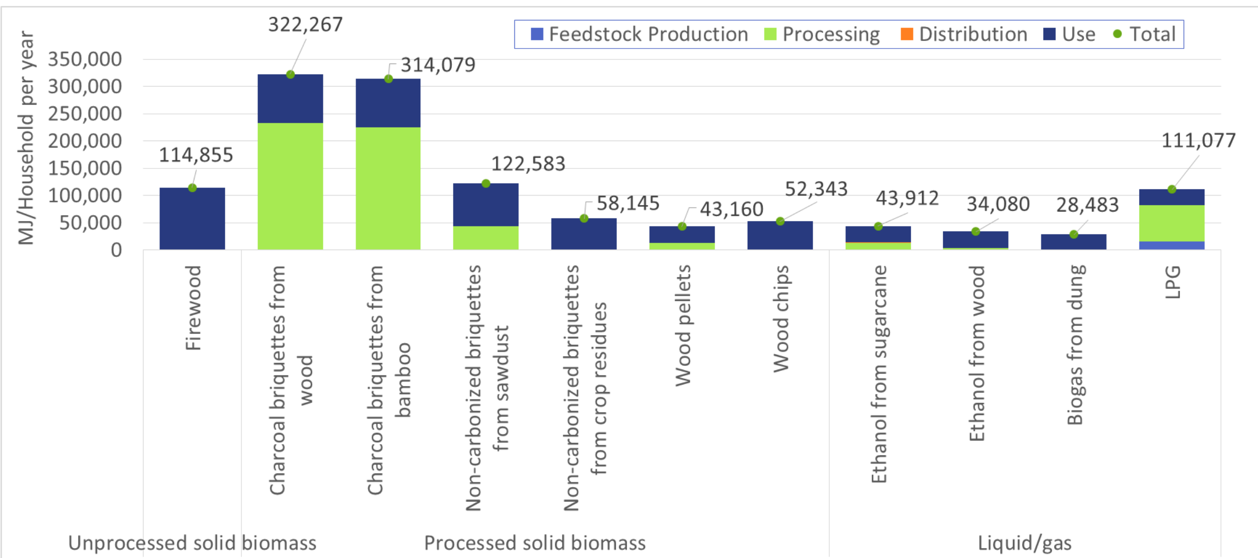


Figure 3-23. Total Energy Demand (MJ) for Cooking Fuel Types (Nigeria)
To produce, distribute and use cooking fuels by a single household per year

Box 3-24 highlights key observations and Figure 3-24 presents the GCCP impact results for fuels in Nigeria by life cycle stage.

Box 3-24– Key Global Climate Change Potential Observations for Nigeria

- Charcoal briquettes from wood have the largest GCCP impact score, nearly twice that of firewood, which is the next most impactful alternative. Sixty-one percent of the impact is from kiln emissions. Wood-based fuels are not carbon neutral because the wood supply in Nigeria is considered non-renewable based on a decreasing forest area. Charcoal briquettes from bamboo have an impact score that is over 125 percent lower because bamboo resources in Nigeria are assumed to be carbon-neutral (see Section 2.2.2).
- Wood pellets and wood chips are also assumed to be derived from unsustainably harvested feedstocks, but because of increased stove thermal efficiency, their GCCP impact is roughly half of unprocessed firewood's.
- Biogas is the best performing fuel in this impact category, with a GCCP impact score less than 40 percent of ethanol from wood, the next best performing fuel. Biogas GCCP impacts in Nigeria are primarily from methane leakage during production in an anaerobic digester (1 percent of biogas escapes as fugitive emissions).
- LPG produces a similar impact score to wood pellets and wood chips. Close to one-third of LPG impacts is from inefficient crude oil extraction (i.e., feedstock production). The relative share of feedstock production impacts is higher for Nigerian LPG than it is for other countries such as India, China, and Bangladesh. Nigerian LPG is assumed to be produced within Nigeria.

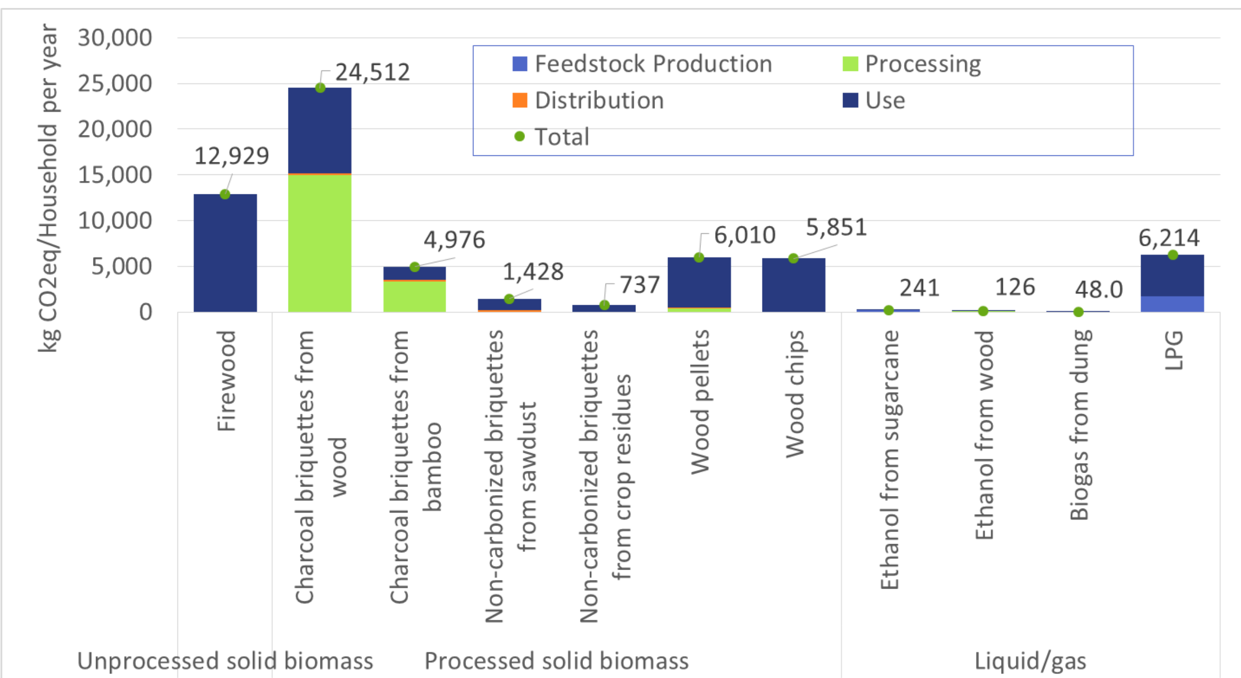


Figure 3-24. GCCP (100a) Potential Impacts (kg CO_2 eq) for Cooking Fuel Types (Nigeria)
To produce, distribute and use cooking fuels by a single household per year

Box 3-25 highlights key observations and Figure 3-25 displays the BC and short-lived climate pollutant impact results for fuels in Nigeria by life cycle stage.

Box 3-25– Black Carbon and Short-Lived Climate Pollutants Observations for Nigeria

- Charcoal briquettes have the highest BC impact. They have high PM emissions when processed in a kiln and, to a lesser extent, when combusted. Kiln emissions contribute over 80 percent of total BC and SLCP impacts for charcoal briquettes from wood and bamboo.

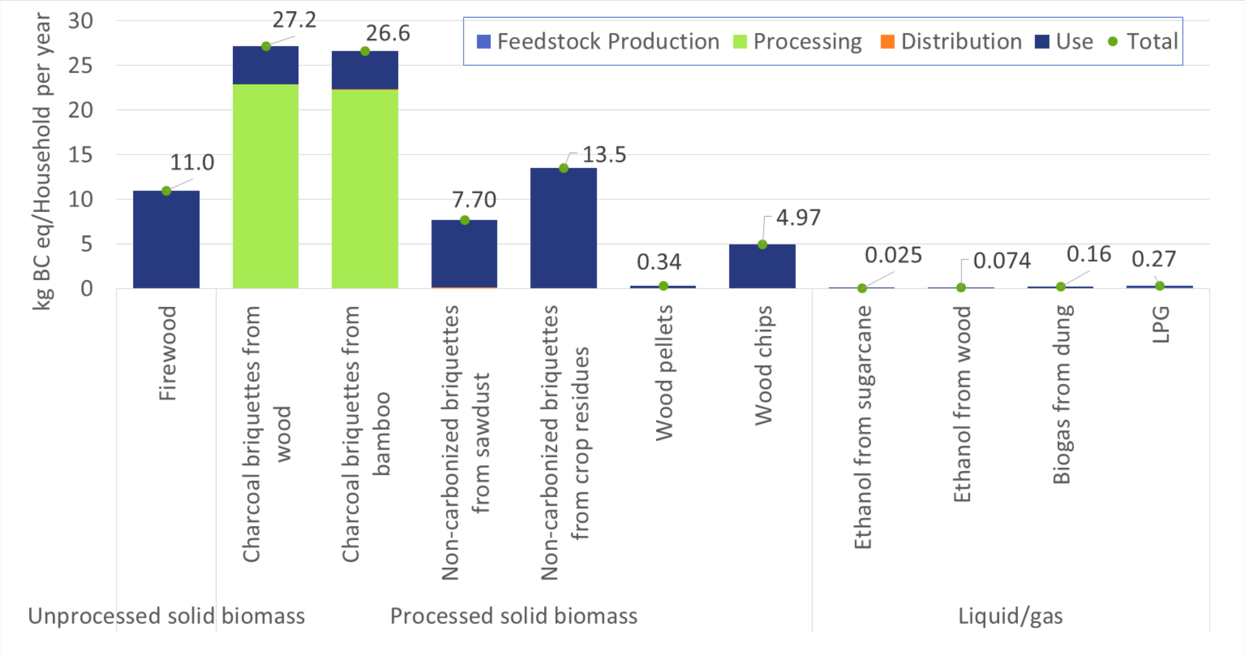


Figure 3-25. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (Nigeria)

To produce, distribute and use cooking fuels by a single household per year

Box 3-26 highlights key observations and Figure 3-26 shows the PM formation impact results for fuels in Nigeria by life cycle stage.

Box 3-26– Particulate Matter Formation Potential Observations for Nigeria

- The relative performance of Nigerian fuel-stove combinations for PM is very similar to the pattern observed in BC impacts.
- Charcoal briquette fuels have the greatest PM formation impacts. The kiln dominates the overall life cycle impacts. Charcoal briquettes from bamboo have slightly lower PM impacts than charcoal briquettes from wood because a portion is produced in more advanced kilns, whereas all charcoal briquettes from wood is assumed to be produced in traditional earth mound kilns.
- Non-carbonized briquettes from sawdust the next highest PM impact, approximately 30 percent of charcoal briquettes from wood.

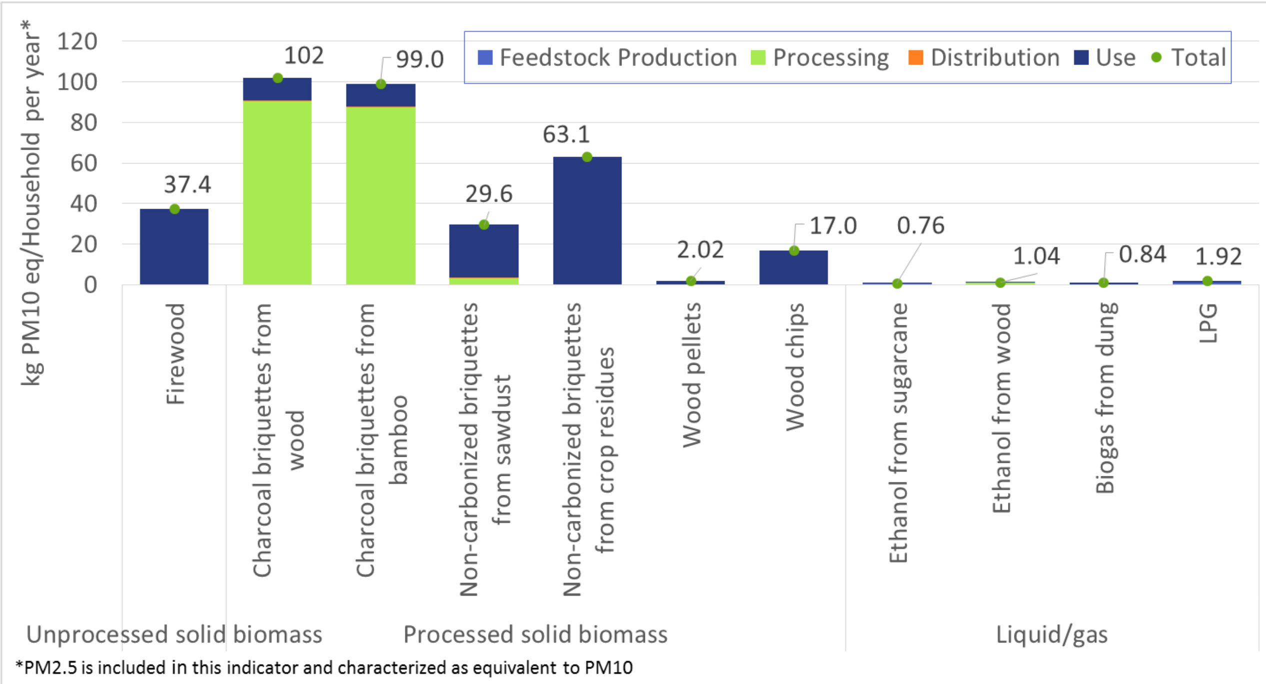


Figure 3-26. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (Nigeria)
To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators in Table 3-5 can be found in Appendix A, Section A.6.2.

3.6.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-27 – Key Observations and Policy Insights for Nigeria

- **Firewood** is currently the main cooking fuel used in Nigeria;[111] however, it broadly has a greater environmental impact than other options. Although expensive to purchase,[112] it is currently heavily used because it is generally free to gather in rural areas with access to forest land. Although documentation of Nigeria-specific drawbacks were not found in the literature, as observed in other countries, there are substantial challenges associated with fuel collection. These include the physical strain, the potential for injury walking long distances with heavy loads, and the possibility of encounters with wildlife such as venomous snakes.[113,114] Deforestation in Nigeria has substantial implications for those relying on firewood (and wood-derived fuels), including longer collection distances, higher prices for purchased wood, and potential shortages.
    - Declining forest area will reduce supply of firewood and wood-derived fuels. Approximately 8.2 million rural Nigerian households (28 percent of total households) rely on collected firewood and are most vulnerable to unsustainable forestry practices. Clear plans—such as an update to the 2003 National Energy Policy[115]—and promotion of alternative cooking fuels, are needed to address deforestation and ensure that citizens have affordable and clean fuel options.
- **Ethanol:** Little data is available on costs; some risks of burns and spills during use. Gel ethanol addresses spillage, but environmental impact will likely increase due to extra processing and additives; time savings decreases due to lower burning temperature of gel. Efforts to coordinate the manufacture and distribution of ethanol liquid and ethanol gel are in still underdevelopment (see Box 3-28 for featured example).
- **Biogas from Dung:** Mainly feasible for use in rural areas where dung is readily available; affordable if there is micro-financing for digesters. Time savings and safety preferable to current biomass solid fuels. Advanced pilot projects are underway.[116]
- **LPG:** Although there is substantial domestic production, LPG is unsubsidized and only affordable by the wealthiest. The cylinders are currently only available in large sizes, and no information was found on efforts to reduce cylinder size to make this a more affordable option. Even with smaller cylinders, LPG may not be affordable for poorer rural populations without financial assistance (e.g., subsidies). There are also barriers within the distribution and supply chain. LPG is used for cooking primarily in southern Nigeria, close to where it is produced. Transporting LPG to northern regions increases the cost to the customer and creates feasibility issues for end-users who might need to transport cylinders long distances from retail locations to their households. Affordability issues will likely persist for the poorest of the Nigerian population regardless of their location, but the availability of smaller cylinders could help, especially in southern regions where transportation costs are less pronounced.
- **Kerosene** is widely used in Nigeria. Kerosene is preferred by consumers due to ease of use and a lower subsidized price. However, the industry might undergo privatization because of supply and price fluctuations.[117] While kerosene environmental impacts were not evaluated in Nigeria, kerosene is likely to have greater impacts than LPG

Box 3-27 – Key Observations and Policy Insights for Nigeria

based on comparable trends of these two fuels in China and India. Price fluctuations, supply shortages, smuggling, hoarding, and adulteration are not uncommon.

- Consumer awareness is a major challenge for all processed fuels. A government-sponsored education program could promote cleaner fuels and alleviate the general public's fears pertaining to LPG and other pressurized fuels. Another barrier is distribution and supply logistics to northern Nigeria. Improved infrastructure could reduce transportation costs and increase the likelihood that fuels produced on a larger scale in the south could be distributed and sold in the northern part of the country at a competitive price. Encouragingly, many state governments have committed to funding road repairs.[118]
- There are a number of small enterprises producing and selling nontraditional fuels in Nigeria, but policies designed to help small alternative fuel entrepreneurs achieve success do not appear to exist. These enterprises could scale up operations with governmental financial assistance.[119]
- With the exception of charcoal briquettes from bamboo and wood pellets, for which no production evidence was found within Nigeria, small enterprises are locally producing the majority of fuels analyzed here, even if only in small quantities. **Charcoal briquettes** have greater environmental impacts but, a more reliable supply chain compared to other solid processed biomass fuels. Non-carbonized briquettes from crop residues and sawdust, as well as wood chips, are available regionally from small enterprises.

Box 3-28– Featured Example for Nigeria

Project Gaia is a nonprofit organization founded in 1995 and incorporated in 2007. Among its worldwide activities is a project in Nigeria to produce ethanol from cassava residue and cashew apple. Project Gaia intends to install 21 ethanol microdistilleries that will contract with small farms to receive their waste products. By mixing their product with an extremely bitter chemical (bitrex) and blue dye, Project Gaia ensures that its ethanol is only used as a cooking fuel. Project Gaia states that one liter of ethanol saves 16 pounds of wood per day, and smart packaging helps end-users transition from traditional fuel to ethanol with fewer safety concerns (e.g., leak-proof and unpressurized canisters). This group has a history of hiring women to work in their distilleries (in Ethiopia, 50 percent of their distillery workforce are women), sales, and training positions. Moreover, Project Gaia educates and trains women to cook safely and efficiently with ethanol. Source: Project Gaia, 2015.

3.7 RESULTS FOR GHANA

3.7.1 *Country Overview*

Ghana is Western Africa's second most populous country, with the population evenly divided between urban and rural areas. [120] Almost 30 percent of the people live below the international poverty line of $1.25 per capita per day.[121,122] About half of Ghana's population relies on biomass (primarily firewood), while just over a third uses charcoal and about 10 percent use LPG, as shown in Figure 3-27. The fuel mix differs for rural and urban households. Firewood is most commonly used in rural areas (80 percent), while LPG (20 percent) and charcoal (53 percent) are mainly used in urban areas.[123,124] All other fuels combined account for a little over 3 percent of cooking fuel use, including fuels such as charcoal from bamboo, non-carbonized briquettes from crop residues, wood pellets, and biogas.

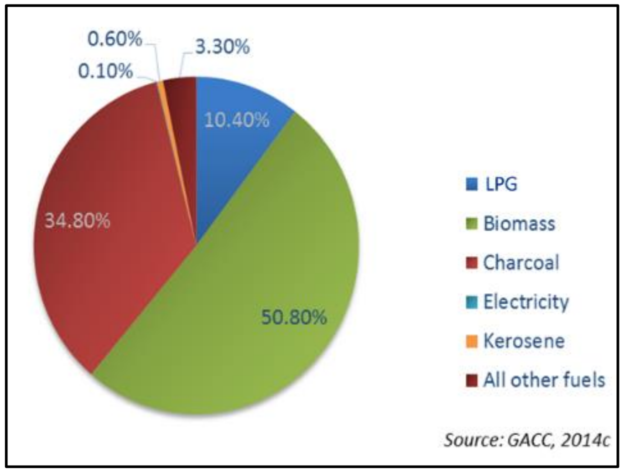


Figure 3-27. Cooking Fuel Use in Ghana

Adequate supply of fuel to sustainably support current or increasing levels of use is an important concern, particularly for biomass fuels. Ghana has shown an overall trend of an approximately 2 percent decrease in forest land per year over recent years.[125] Seventy-two percent of the country is vulnerable to desertification,[126] and recurrent drought in the north severely affects agricultural activities.

Finally, cultural issues around food and cooking fires are an important consideration. The flavor imparted to certain foods by specific cooking fuels can be very important to consumers, leading to resistance to changing fuel types. Households across Ghana generally eat similar foods and have the same cooking habits; the primary difference is fuel choice. In northern Ghana and rural areas, basic wood stoves, such as three-stone stoves and mud stoves, are most common.[127] Many households have multiple stoves, cooking outdoors with firewood and indoors with cleaner fuels; different fuels may be used for different types of meals.[128]

3.7.2 *Environmental Impact Assessment, by Impact Category*

Table 3-6 shows that cooking fuel environmental impact trends in Ghana. Figure 3-28 through Figure 3-31 provide additional details on several environmental indicators of high interest to the Alliance, namely total energy demand, GCCP, BC, and PM.

Table 3-6. Summary of Environmental Indicators for Cooking Fuels in Ghana

	Unprocessed Solid Biomass	Processed Solid Biomass						Liquid/Gas					
Indicator*	**Firewood**	**Charcoal Briquettes from Wood**	**Charcoal Briquettes from Bamboo**	**Non-Carbonized Briquettes from Sawdust**	**Non-Carbonized Briquettes from Crop Residues**	**Wood Pellets**	**Wood Chips**	**Ethanol from Sugarcane**	**Ethanol from Wood**	**Biogas from Dung**	**LPG**	***Median***	***All-fuel average****
TED (MJ/HH/YR)	35,444	99,451	96,924	37,657	15,898	12,749	16,153	13,532	10,517	8,790	34,245	*11,633*	*21,187*
NED (MJ/HH/YR)	30,480	94,487	91,960	32,693	10,934	7,785	11,189	8,568	5,553	3,826	29,281	*6,669*	*18,153*
GCCP (kg CO_2 eq/HH/YR)	3,990	7,595	1,536	470	226	1,826	1,805	72.9	43.7	14.8	1,915	*58.3*	*1,083*
BC/SLCP (kg BC eq/HH/YR)	3.39	8.40	8.22	2.37	4.17	0.10	1.53	0.0084	0.023	0.051	0.083	*0.037*	*1.57*
PMFP (kg PM10 eq/HH/YR)	11.5	31.6	30.6	9.08	19.5	0.68	5.25	0.23	0.33	0.26	0.59	*0.29*	*6.09*
FFD (kg oil eq/HH/YR)	0.033	0.067	0.038	0.33	0.40	21.6	1.42	12.5	5.31	0	803	*0.036*	*46.9*
WD (m^3/HH/YR)	0.25	1.14	1.14	13.2	18.1	953	1.57	80.6	1.38	15.9	73.8	*1.14*	*64.5*
TAP (kg SO_2 eq/HH/YR)	2.72	1.14	1.13	2.29	1.07	0.66	1.27	1.01	0.42	0.076	1.26	*0.54*	*0.72*
FEP (kg P eq/HH/YR)	0.82	0.39	0.38	0.42	0.32	0.016	0.37	0.040	1.6E-05	0	0.0059	*0.0030*	*0.15*
POFP (kg NMVOC eq/HH/YR)	123	141	140	86.5	15.1	0.53	55.7	4.24	1.04	0.40	10.8	*0.78*	*32.1*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country.

Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-29 highlights key observations and Figure 3-28 displays the total energy demand impact results for fuels in Ghana by life cycle stage.

Box 3-29– Total Energy Demand Observations for Ghana

- Charcoal briquettes from both wood and bamboo require the most total energy demand to provide a household's annual cooking fuel. Earthen mound kilns are used to process the majority of both types of charcoal briquettes in Ghana contributing the most to the total energy demand. Ghana, along with Nigeria, has the highest inefficiencies of the studied countries during kiln carbonization.
- Wood pellets and wood chips have a lower total energy demand than traditional firewood. This is in large part due to the better stove thermal efficiencies that are associated with pellet and chip stoves.

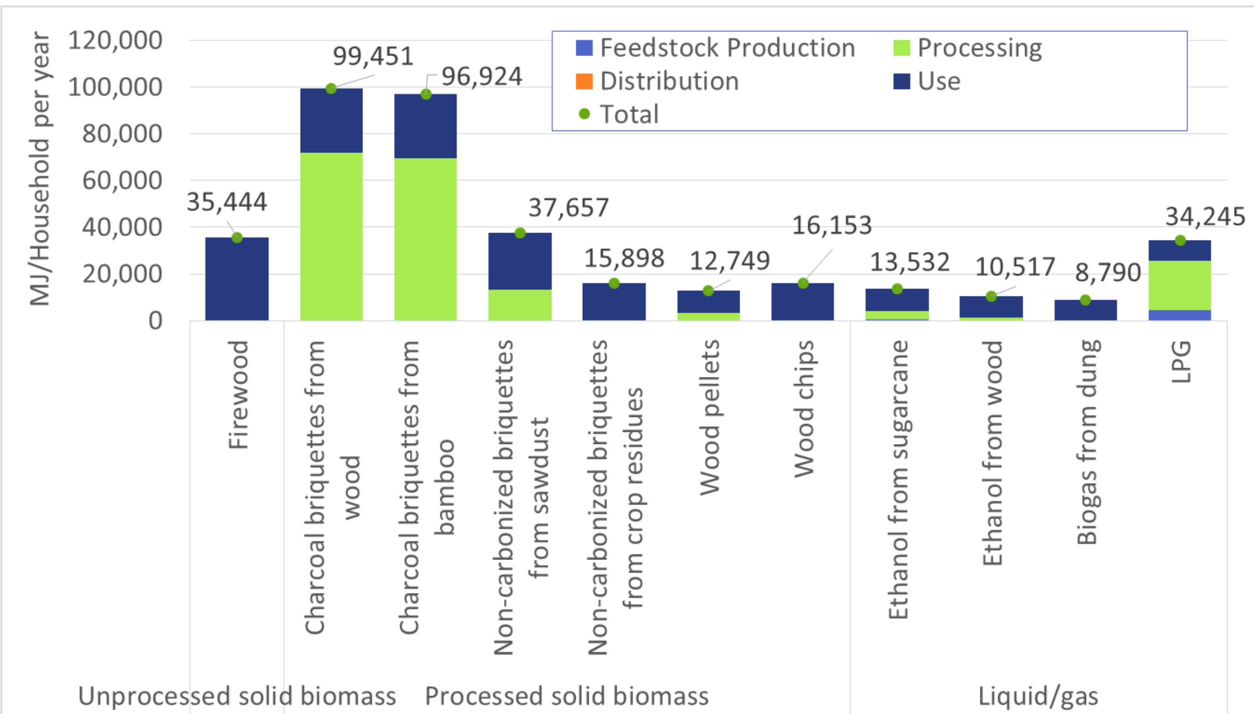


Figure 3-28. Total Energy Demand (MJ) for Cooking Fuel Types (Ghana)
To produce, distribute and use cooking fuels by a single household per year

Box 3-30 highlights key observations and Figure 3-29 presents the GCCP impact results for fuels in Ghana by life cycle stage.

Box 3-30– Global Climate Change Potential Observations for Ghana

- Most of the impact for charcoal briquettes comes from emissions resulting from kiln operation. The wood supply in Ghana is considered non-renewable based on a decreasing forest area, which prevents wood based fuels from claiming carbon neutrality. Charcoal briquettes from bamboo have a significantly lower impact score due to the fact that bamboo resources in Ghana are assumed to be carbon-neutral.
- Wood pellets and wood chips are also harvested unsustainably, but their increased stove thermal efficiency decreases their GCCP impact when compared to unprocessed firewood. The thermal efficiency for unprocessed firewood in Ghana is 14 percent in comparison to respective efficiencies of 31 and 53 percent for wood chip and wood pellet stoves.
- Close to a third of LPG impacts stem from emissions resulting from crude oil production. Like Nigeria, Ghanaian LPG fuel exhibits higher relative impacts than it does in other countries such as India, China, and Bangladesh. This is a result of less advanced and efficient petroleum production processes in most African countries.

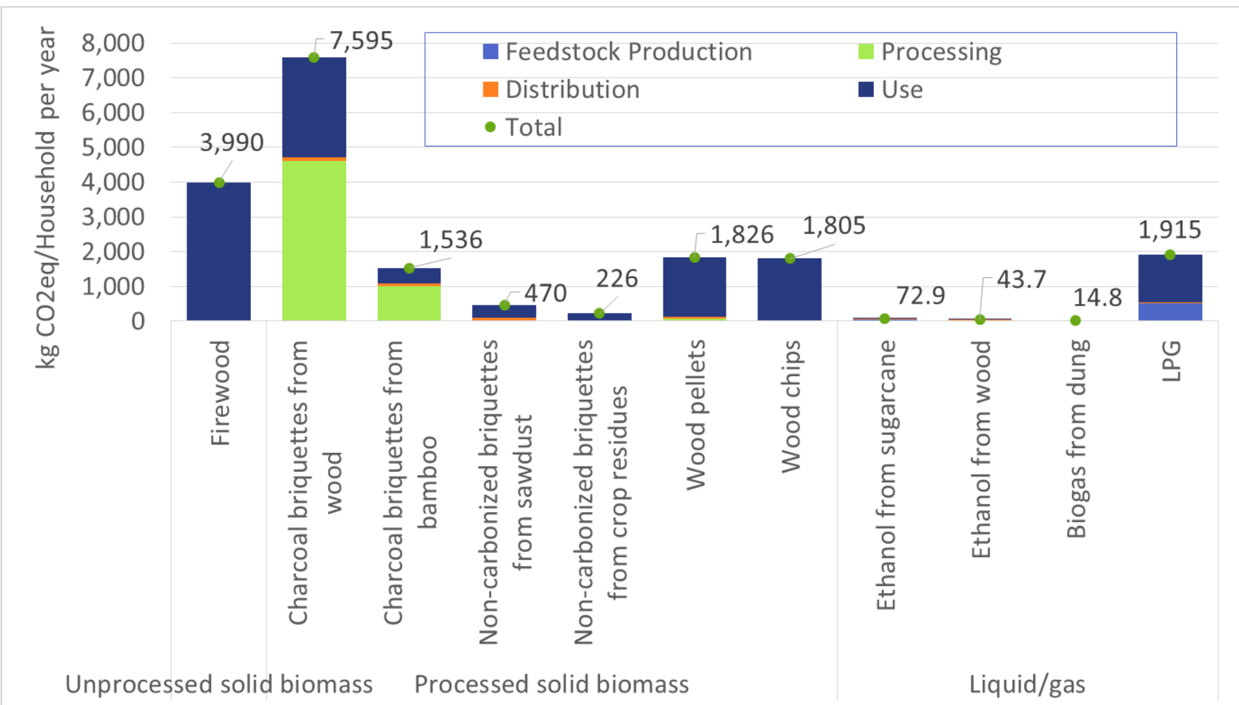


Figure 3-29. GCCP (100a) Potential Impacts (kg CO_2 eq) for Cooking Fuel Types (Ghana)
To produce, distribute and use cooking fuels by a single household per year

Box 3-31 highlights key observations and Figure 3-30 displays the BC and short-lived climate pollutant impact results for fuels in Ghana by life cycle stage.

Box 3-31– Black Carbon and Short-Lived Climate Pollutants Observations for Ghana

- The highest BC impacts are seen for charcoal briquettes, which tend to have high PM emissions when processed in a kiln and also when combusted. For both types of charcoal briquettes, the kiln contributes over 80 percent of total impacts.

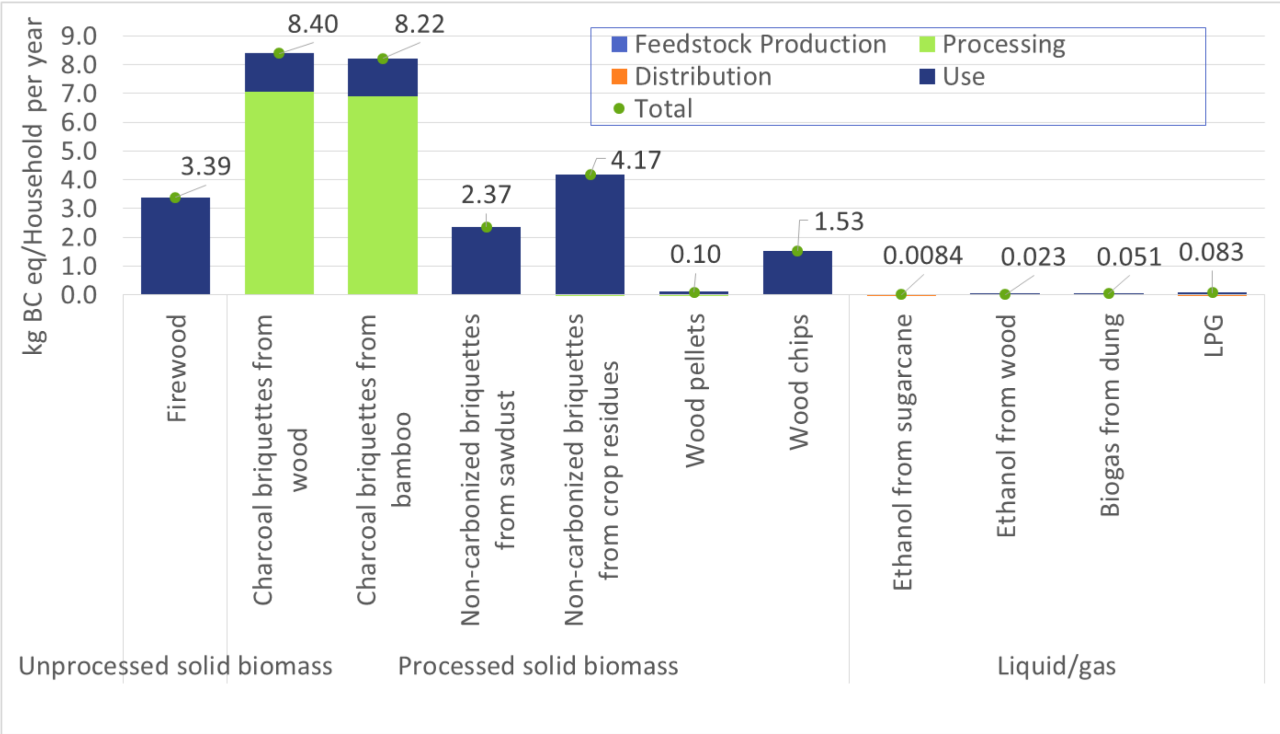


Figure 3-30. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (Ghana)

To produce, distribute and use cooking fuels by a single household per year

Box 3-32 highlights key observations and Figure 3-31 shows the PM formation impact results for fuels in Ghana by life cycle stage

Box 3-32– Particulate Matter Formation Potential Observations for Ghana

- Charcoal briquettes in Ghana lead to the greatest PM formation impacts, followed by briquettes from crop residues/sawdust and firewood. For charcoal briquettes, the wood carbonization in the kiln dominates the overall life cycle impacts contributing over 88 percent of total impacts for these fuels.

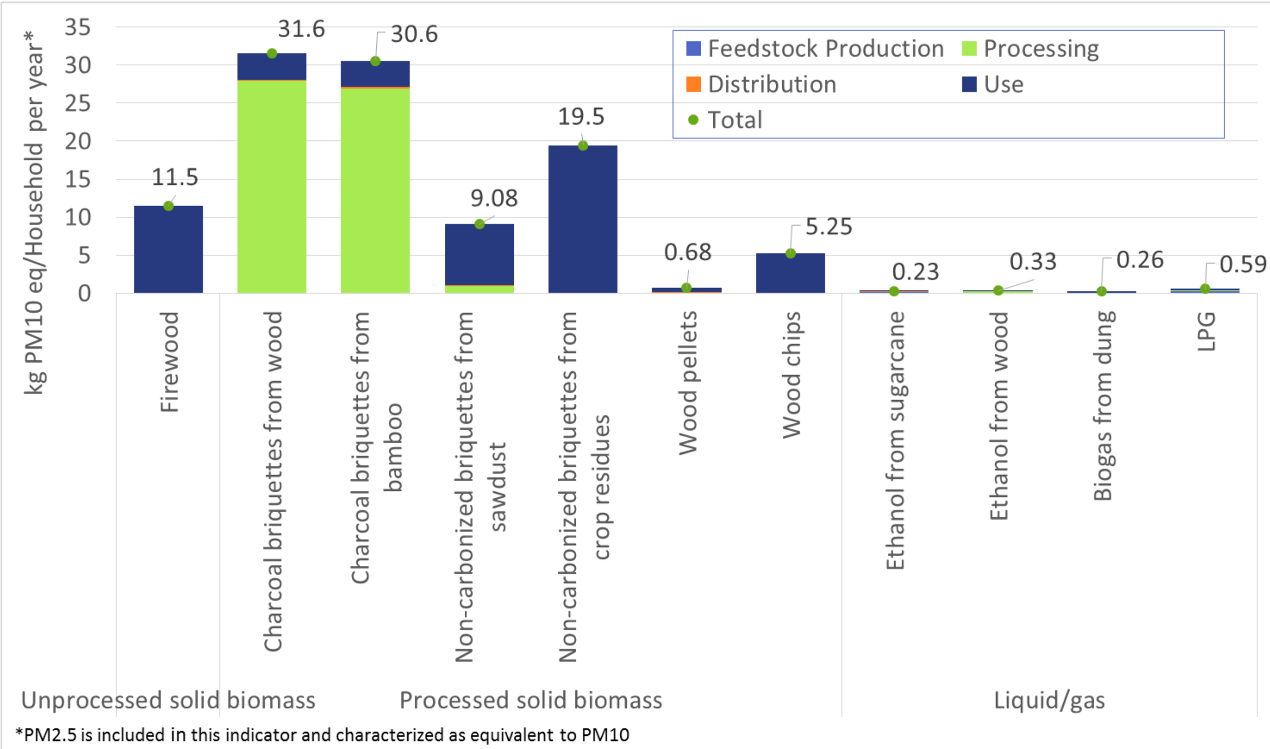


Figure 3-31. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (Ghana)

To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators in Table 3-6 can be found in Appendix A, Section A.7.2.

3.7.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-33 – Key Observations and Policy Insights for Ghana

- A high percentage of Ghanaians use a combination of **firewood and wood-based fuels, such as charcoal briquettes**, to meet their cooking fuel needs.[129,130] Despite the historical availability of these fuels,[131] they are increasingly vulnerable to shortages due to Ghana's deforestation rate and logistical challenges associated with transporting firewood from biomass-dense zones to other areas.[132] Moreover, all environmental indicators for firewood, with the exception of fossil fuel depletion and water depletion, are in the mid to high range compared to other fuels. The majority of the Ghana population who rely on firewood gather it themselves; traveling to remote locations to gather wood is physically straining and increases the likelihood of encountering natural hazards such as venomous snakes.[133]
- Of the three most widely used fuels in Ghana—**firewood, wood-based charcoal briquettes, and LPG**—wood and charcoal briquettes tend to show higher impacts than other fuels for many environmental indicators. LPG, commonly used in Ghana, yields more positive environmental results. Other fuels that tend to have lower impacts from

Box 3-33 – Key Observations and Policy Insights for Ghana

an environmental standpoint, but are not currently commonly utilized, are biogas and ethanol. However, these do not appear to have much potential for widespread adoption within Ghana.

- **LPG** shows more mid-level results for most environmental indicators, but barriers include high cost (more expensive than charcoal, even with subsidies), perception as being unsafe, supply shortages, unreliable distribution, and poor cylinder management. These perceptions may be difficult to overcome as most of the population has limited awareness of this fuel and needs more education regarding LPG use. Another major challenge to increasing LPG use includes the high upfront cost necessary to keep an uninterrupted supply of LPG on hand (e.g., purchasing more than one cylinder to have a spare on hand in case of shortages or distribution problems).[134]
- **Ethanol**: Little information was available regarding potential for use for cooking or cost. Ghana's ethanol production is largely used for alcoholic beverages. Any ethanol enterprise looking to shift feedstock processing capacity away from alcohol would most likely be inhibited by the legal protections historically afforded to the alcohol industry.[135]
- **Wood and charcoal briquettes** users are vulnerable to problems related to deforestation, including longer distances traveled to obtain wood, shortages, and possible price increases. Most at-risk are the approximately 3 million households in Ghana, representing 48 percent of total households, who rely on firewood as their primary fuel.[136] Government attempts to regulate the production of charcoal briquettes from wood by licensing legitimate enterprises have had an uncertain impact.[137]
- The United Nations Development Programme (UNDP) has invested in a program to develop new **briquette** technologies and institute effective licensing systems, which could create jobs in the charcoal briquette industry.[138] Although the UNDP effort would focus on charcoal briquettes from wood, there are an estimated seven to 10 existing companies that make briquettes from other sources,[139] which could also benefit from increased sectoral funding.
- Government of Ghana has recently emphasized the importance of sustainable development in the energy sector through the Strategic National Energy Plan (2006-2020), which outlines goals to increase renewable energy sources to 10 percent nationally by 2020 and increase rural electrification by renewables to 30 percent by 2020.[140]
- The Renewable Energy Act of 2011 and a national bioenergy policy "support the development, utilization, and efficient management of renewable energy sources."[141] Although much of the work to date has focused on the electricity grid, these policies could potentially be used to advance new cooking fuels.
- Ghana no longer has "least developed country" status with the UN, making it ineligible for Clean Development Mechanism credits. These have historically been used for funding emission reduction projects.[142]
- Small enterprise fuel producers struggle to access traditional sources of financial assistance. Due to high interest rates within the country (over 30 percent on average[143]), small enterprises have difficulties both applying for and making payments

Box 3-33 – Key Observations and Policy Insights for Ghana

on loans. The government is aware that this is a problem, but no information was found pertaining to government efforts to provide lower cost financing or grants. It is possible that the Renewable Energy Fund might be used to help start-up biofuel enterprises.

- According to the Alliance's market manager in Ghana, small enterprises are producing at least small amounts of all cooking fuels analyzed in this study, with the exception of ethanol and wood chips.[144] Biogas produced from dung shows low environmental results relative to other fuels, and there is some evidence that crop residue biogas digesters repurposed from a defunct initiative to promote biogas use at schools are still in use, but it is unclear how the biogas produced is being used.[145] There is some use of household biogas digesters, but it is difficult to get financing for these systems due to high interest rates in the country. Non-carbonized briquettes from crop residues, as well as wood residues and wood pellets, are available regionally from small enterprises.

3.8 RESULTS FOR KENYA

3.8.1 *Country Overview*

Kenya is the seventh largest country by population in Africa, with 78 percent of the population living in rural areas and 22 percent in urban areas in 2015.[146]

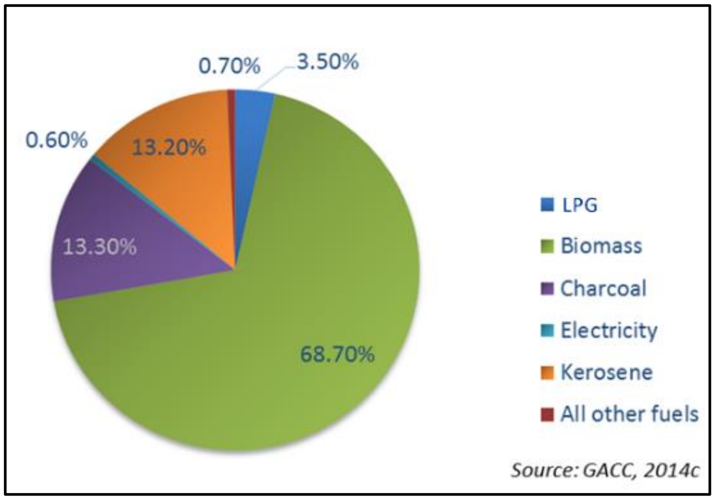


Figure 3-32. Cooking Fuel Use in Kenya

As shown in Figure 3-32, over two-thirds of the population rely on some form of unprocessed biomass as their cooking fuel. Firewood use is particularly dominant in rural and peri-urban areas and among those with low incomes.[147,148,149] Charcoal and electricity are more commonly used in urban areas than in rural areas.[150] About 3.5 percent of the population uses LPG, which is generally only affordable to the wealthy in urban areas.[151]

Adequate supply of fuel resources is an important consideration, as there may not be adequate feedstocks to sustainably support current or increasing levels of wood fuel use. Kenya has shown an overall trend of an approximately 0.5 percent decrease in forest land per year over recent years,[152] and forest cover has been reduced to between 2 and 6 percent of total land area. Although not the only cause, firewood harvested for fuel is a significant driver of deforestation.[153] Market assessments suggest that deforestation due to logging will increasingly threaten Kenya's economy, water supply, and ecosystems.[154] In addition to decreasing forest land, some regions are experiencing desertification where dry lands become increasingly arid. The arid and semi-arid lands are home to about 35 percent of the country's population and constitute about 80 percent of Kenya's total land.[155] Drought is a common occurrence in these areas, reducing vegetative cover and affecting the quality of the rangelands.[156] Eighty percent of Kenya is reported to be prone to desertification in recent years.[157] These issues threaten the use of other biomass fuels.

Fuel cost is another key issue. Many households in rural areas can collect firewood for free, although availability is decreasing. Firewood is purchased by 40 percent of rural users and 71 percent of peri-urban users.[158] The fuel price is higher in urban areas and subject to seasonal fluctuations.[159]

Households across Kenya generally eat similar foods and have the same cooking habits. Tea and porridge are two popular hot beverages and food, which require intense heat for boiling water. Rural households use three-stone fires and traditional cook stoves. Most kitchens are in separate huts and are usually poorly ventilated.[160] Cooking fires may serve multiple secondary purposes, such as providing heat or light for the home, heating water for bathing, preserving food (by drying above or near the fire), and socializing. Changes to the cooking fuel or type of cookstove would likely require the household to use other fuels for these functions.

3.8.2 *Environmental Impact Assessment, by Impact Category*

Table 3-7 shows a summary of environmental impacts by fuel type for Kenya. Figure 3-33 through Figure 3-36 provide additional details on several environmental indicators of high interest to the Alliance, namely total energy demand, GCCP, BC, and PM.

Table 3-7. Summary of Environmental Indicators for Cooking Fuels in Kenya

	Unprocessed Solid Biomass	Processed Solid Biomass						Liquid/Gas					
Indicator*	Firewood	Charcoal Briquettes from Wood	Charcoal Briquettes from Bamboo	Non-Carbonized Briquettes from Sawdust	Non-Carbonized Briquettes from Crop Residues	Wood Pellets	Wood Chips	Ethanol from Sugarcane	Ethanol from Wood	Biogas from Dung	LPG	*Median*	*All-fuel average***
TED (MJ/HH/YR)	30,433	59,871	58,906	34,609	14,610	11,472	14,785	29,687	9,667	8,079	29,995	*10,569*	*16,784*
NED (MJ/HH/YR)	25,870	55,309	54,344	30,046	10,048	6,909	10,222	25,124	5,104	3,516	25,432	*6,007*	*13,996*
GCCP (kg CO_2 eq/HH/YR)	3,422	5,400	1,686	505	208	1,649	1,663	399	35.7	13.6	1,529	*122*	*917*
BC/SLCP (kg BC eq/HH/YR)	2.91	7.66	7.51	2.19	3.83	0.093	0.50	-0.032	0.021	0.047	0.031	*0.026*	*1.38*
PMFP (kg PM10 eq/HH/YR)	9.93	28.9	28.1	8.47	17.9	0.61	4.82	0.73	0.29	0.24	0.89	*0.45*	*5.60*
FFD (kg oil eq/HH/YR)	0.025	0.046	0.045	0.26	0.27	14.8	1.15	70.4	4.88	0	708	*0.035*	*44.4*
WD (m^3/HH/YR)	0.19	0.77	0.76	8.65	11.9	627	1.26	315	1.27	14.6	276	*0.77*	*69.9*
TAP (kg SO_2 eq/HH/YR)	2.35	0.72	0.72	2.41	0.98	0.54	1.16	2.24	0.37	0.070	2.26	*0.46*	*0.77*
FEP (kg P eq/HH/YR)	0.62	0.31	0.31	0.39	0.30	0.015	0.30	0.16	1.5E-05	0	0.036	*0.0074*	*0.14*
POFP (kg NMVOC eq/HH/YR)	106	129	129	80.1	13.9	0.88	51.1	1.38	0.92	0.37	7.42	*0.90*	*28.9*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country.

Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-34 highlights key observations and Figure 3-33 displays the total energy demand impact results for fuels in Kenya by life cycle stage.

Box 3-34– Total Energy Demand Observations for Kenya

- Both ethanol from sugarcane and LPG exhibit poor relative performance in this impact category when compared to other African countries with the exception of Uganda. Over two-thirds of the total impact for both fuels results from the distribution phase within fuel processing as the model assumes these fuels need to be imported.

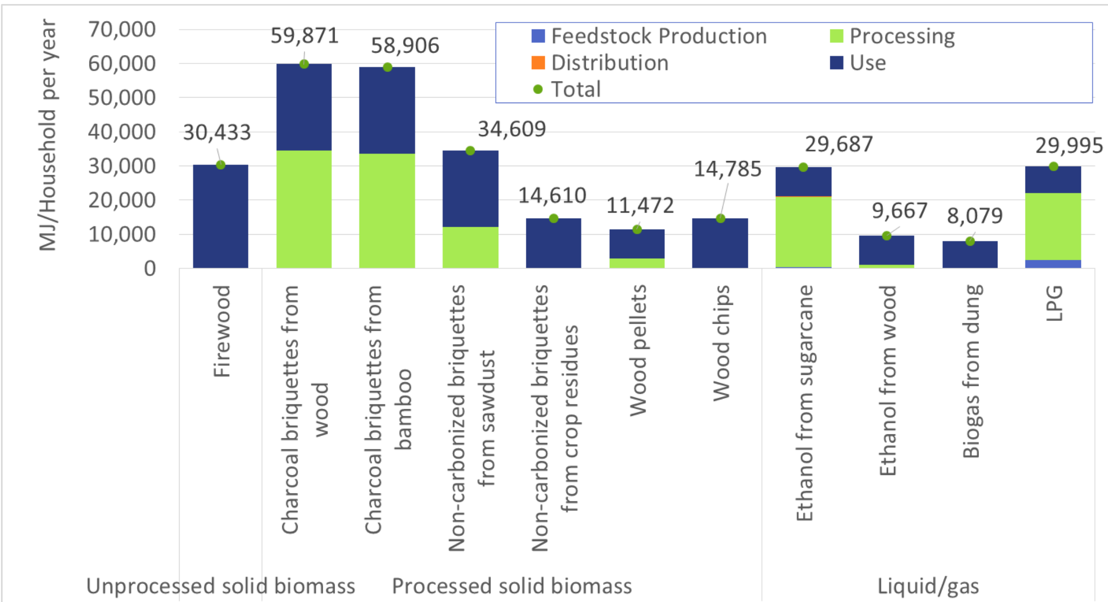


Figure 3-33. Total Energy Demand (MJ) for Cooking Fuel Types (Kenya)
To produce, distribute and use cooking fuels by a single household per year

Box 3-35 highlights key observations and Figure 3-34 presents the GCCP impact results for fuels in Kenya by life cycle stage.

Box 3-35– Global Climate Change Potential Observations for Kenya

- Charcoal briquettes from wood demonstrate a high impact namely due to emissions resulting from kiln operation. The wood supply in Kenya is considered non-renewable based on a decreasing forest area, which prevents wood based fuels from claiming carbon neutrality. Seventy-three percent of total charcoal briquette from bamboo GCCP impacts occur during kilning.
- Wood pellets and wood chips are also considered to be harvested unsustainably in Kenya, but their increased stove thermal efficiency decreases their GCCP impact by over 50 percent, when compared to unprocessed firewood.
- Wood ethanol and non-carbonized sawdust briquettes benefit from the cut-off modeling methodology used in this analysis, wherein wood wastes are treated as a “free” product (all burdens are allocated to the primary wood product; e.g., lumber, which is outside the scope of this study), so emissions of biomass CO_2 for fuels derived from wood waste are treated as carbon-neutral.

Box 3-35– Global Climate Change Potential Observations for Kenya

- LPG produces a similar impact score to that realized for both wood pellets and wood chips. Sixteen percent of total LPG GCCP impacts stem from emissions resulting from feedstock production, processing and distribution.

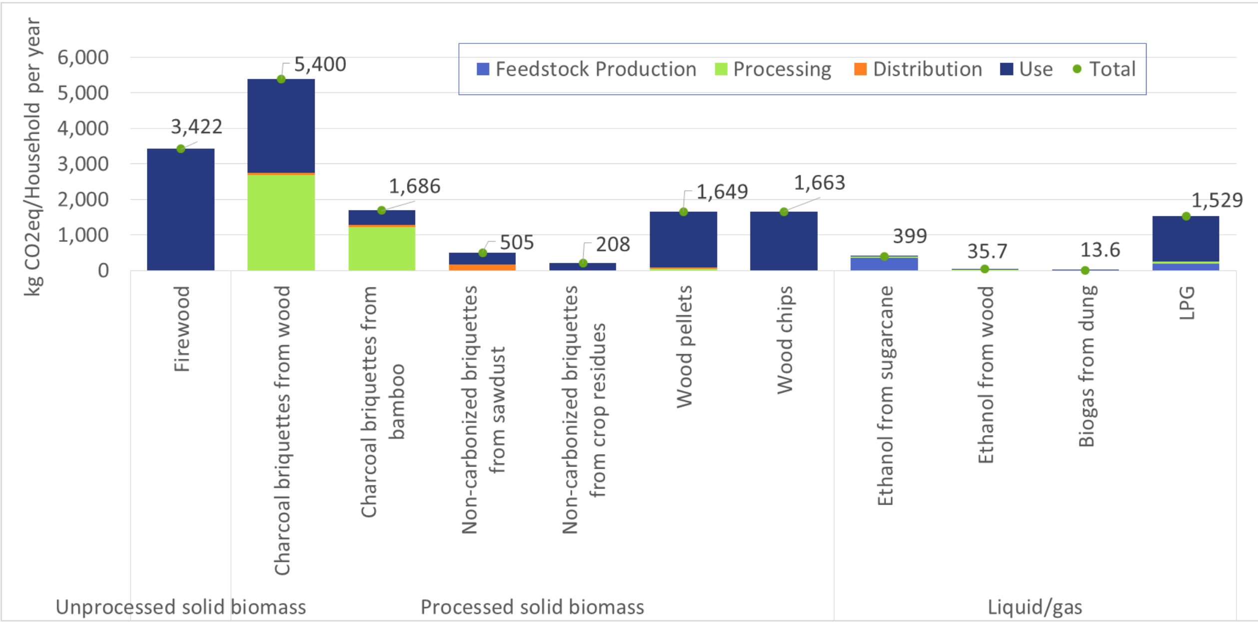


Figure 3-34. GCCP (100a) Potential Impacts (kg CO_2 eq) for Cooking Fuel Types (Kenya)
To produce, distribute and use cooking fuels by a single household per year

Box 3-36 highlights key observations and Figure 3-35 displays the BC and short-lived climate pollutant impact results for fuels in Kenya by life cycle stage.

Box 3-36– Black Carbon and Short-Lived Climate Change Pollutant Observations for Kenya

- The highest BC impacts are seen for charcoal briquettes, which tends to have high PM emissions when processed in a kiln and also when combusted. Both types of charcoal briquettes demonstrate impact scores over twice that of non-carbonized briquettes from crop residues, which have the next highest impact score. For both charcoal briquettes from wood and from bamboo, the kiln contributes over 80 percent of total impacts.

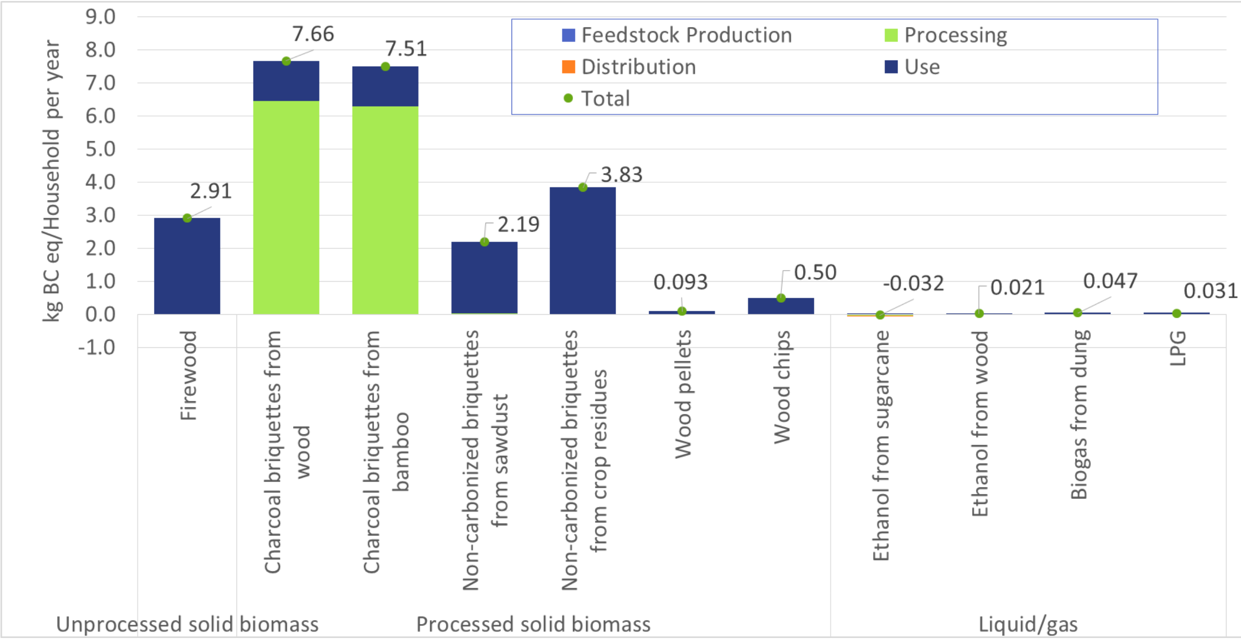


Figure 3-35. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (Kenya)

To produce, distribute and use cooking fuels by a single household per year

Box 3-37 highlights key observations and Figure 3-36 shows the PM formation impact results for fuels in Kenya by life cycle stage.

Box 3-37– Particulate Matter Formation Potential Observations for Kenya

- For charcoal briquettes, carbonization in the kiln dominates the overall life cycle impacts contributing over 88 percent of total impacts for these fuels.
- Charcoal briquettes from bamboo have slightly lower PM impacts than wood charcoal. This is because a small portion of bamboo charcoal briquettes are estimated to be produced in more advanced kilns, whereas all charcoal briquettes from wood in Kenya are assumed to be produced in traditional earth mound kilns.
- Advanced liquid fuels, as well as biogas and wood pellets, have comparably small PM impacts.

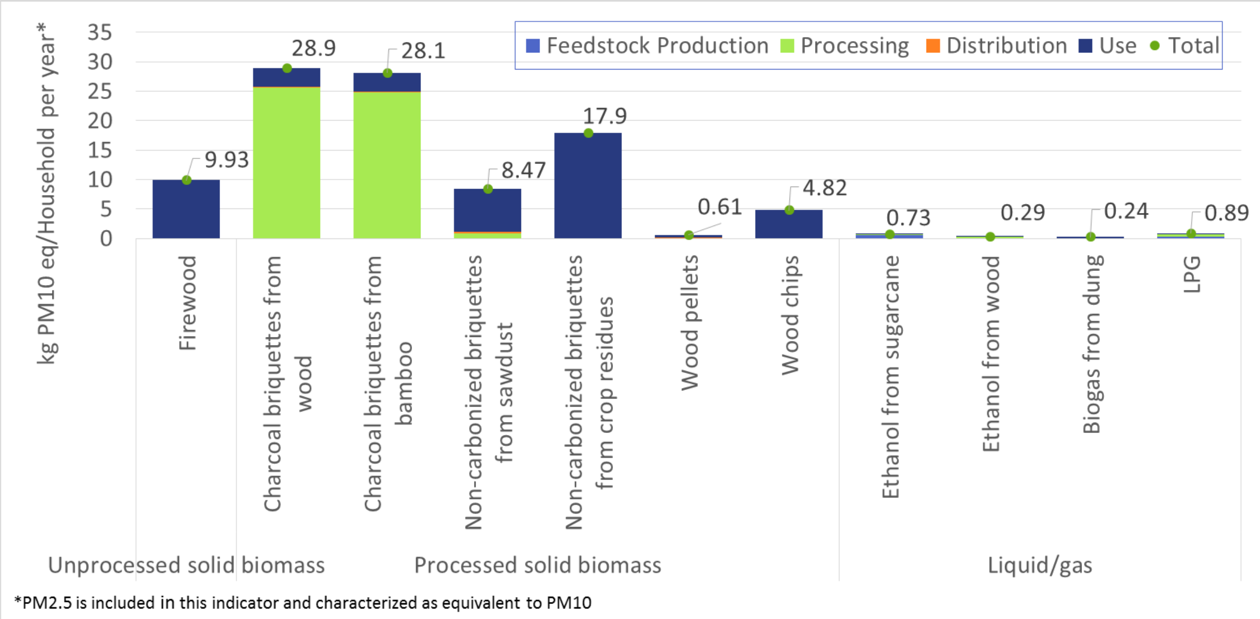


Figure 3-36. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (Kenya)

To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators in Table 3-7 can be found in Appendix A, Section A.8.2.

3.8.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-38 – Key Observations and Policy Insights for Kenya

- Although **firewood** is the most widely used and readily available cooking fuel in Kenya,[161,162] the environmental indicators for this fuel are mixed, with low fossil fuel and water depletion impacts relative to other cooking fuels in Kenya, but higher impacts in categories associated with air emissions (e.g., particulate matter formation, global climate change potential, terrestrial acidification potential, BC and short-lived climate pollutants, and photochemical oxidant formation potential).
- **Charcoal briquettes** derived from wood tend to have higher environmental impacts relative to other fuels, which should be an area of concern given the relatively high usage of charcoal in Kenya. Although they are relatively expensive, they are available in small packages with one or two days' worth of fuel, which helps makes them affordable and convenient to transport.[163] Studies indicate that bribes account for 20 to 30 percent of the final price paid by consumers for wood-derived charcoal, and unregulated trade results in landowners receiving very little compensation for the feedstock wood produced on their land.[164] Without incentives or creditors to enable communities to construct improved kilns for charcoal briquette production, converting firewood to charcoal often remains cost-prohibitive.[165] More research is needed to

Box 3-38 – Key Observations and Policy Insights for Kenya

understand the potential benefits of using improved kiln technologies as opposed to the traditional earth mound kilns assessed for Kenya in this study.

- Evidence suggests that there are opportunities for women in the retailing of charcoal even outside of community-based organizations.[166] In many cases, the income women generate through selling charcoal is used for livelihood needs, such as food, health, school fees, and rent.[167] Some business models for women-owned enterprises even involve a "special focus on utilizing the trading and networking skills of women in low income areas to sell briquettes."[168]

- Poor design and implementation of charcoal briquette policies have inhibited the development of this sector in Kenya.[169] For example, national policies are unclear on which ministries regulate briquettes[170] and current laws require that the certification cost of any retailed product will be borne by the producer,[171] thus constraining growth. On the other hand, Kenya's 2010 constitution mentions briquettes in the context of the government's commitment to sustainable energy and exploring future energy options,[172] perhaps indicating the near term promotion of more effective policies.

- **Ethanol** is promising from an environmental standpoint, but little information was available regarding potential cooking use or cost in Kenya. Income earning opportunities are limited by the fact that ethanol is both heavily taxed and must be transported to Tanzania for processing.[173] If produced in gel form, spill risks would be alleviated, but environmental indicators will likely increase due to the extra processing and additives; time savings would decrease due to lower burning temperature of gel. Recent developments include establishment of a Bioenergy and LPG Working Committee within the Ministry of Energy and Petroleum that is developing an Action Plan for the sector; and proposals for tax and other incentives for household and transport sectors.[174] The Treasury has recently made changes in tax regulations that effectively separate denatured bioethanol from the tax regime of ethanol in general. A key policy is the Ministries of Revenue, Trade, and Energy's institution of a tax structure for sugarcane-based ethanol as fuel for domestic use. Although the new legislation is aimed primarily at improving the competitiveness of Kenya's sugar industry, the new tax structure was supported by FAO's Policy Innovation Systems for Clean Energy Security (PISCES).[175]

- **Biogas from Dung r**epresents a very small portion of the current cooking fuel market in Kenya. The results in Table 3-7 clearly indicate that it has the best aggregate environmental performance among the studied fuels, with none of its impact scores falling in the lower quintile. Mainly feasible for use in rural areas, but many households may not have sufficient livestock to support a digester. Affordable if upfront cost of the digester can be financed. Government is promoting its use for cooking under the National Biogas Program.[176]

- **LPG** has mid-range environmental results and is cleaner burning (less particulates and BC) compared to wood and processed biomass fuels; however, LPG is expensive compared to firewood, which is gathered freely in rural and peri-urban communities by 60 percent and 29 percent of consumers, respectively.[177,178] The usual cylinder size is

Box 3-38 – Key Observations and Policy Insights for Kenya

13 kg, making LPG expensive and difficult to transport. Smaller LPG cylinders, together with government assistance to purchase cookstoves, would make it a more affordable fuel for a larger share of the population; however, LPG distribution to rural areas must be improved. Even if smaller cylinders are made available, there are distribution and supply chain barriers to overcome. Some of the high cost for LPG is due to the prevalence of middlemen in the supply chain, who add markups that increase the price to the end-user.[179] Another concern is the poor quality of the country's cylinder supply and the associated lack of information regarding who owns, refills, and maintains the cylinders.[180] Overall, these issues would be difficult to overcome for the poorest of the Kenyan population; however, with smaller cylinders, it may be possible to increase LPG use among urban lower and middle classes.

- According to the Alliance's market manager in Kenya, small enterprises are producing at least small amounts of all fuels analyzed in this study, with the exception of ethanol from wood residues and wood chips. Pilot startups are at early stages for the use of charcoal briquettes from bamboo, wood pellets, and ethanol (in gel form, see the featured example in Box 3-39).[181] Non-carbonized briquettes from crop residues and wood residues and liquid ethanol are available regionally from small enterprises; however, non-carbonized briquettes from wood residues are more likely to be used in commercial settings than in households.

Box 3-39– Featured Example for Kenya

Founded in 2009 and employing approximately 60 people, SimGas is the largest producer of modular biogas systems for rural households in Africa. The systems are marketed towards rural farmers who can generate fuel and bio-fertilizer (slurry) by feeding animal dung and water into the system. The resulting biogas is used to power cooking appliances and, although time savings vary greatly from household to household depending on which cook fuels were used originally, many adopters report time savings from both fewer fuel collection trips and faster cooking times. Moreover, the SimGas system is priced to have a breakeven point of two years, indicating the potential for substantial cost savings with long-term adoption. SimGas's success is driven by a number of factors complementing its livelihood impacts to end-users. The system is mass-produced yet customizable (through its modular design), easy to transport, quick to install, includes onsite training sessions (often utilizing its substantial—20 to 30 percent—female workforce to connect with female end-users), and is made more affordable through micro-financing options. Users can choose lease-to-own financing or arrangements where they pay for 50 percent of the biogas system upfront and finance the rest. Another key component of SimGas's success is the company's expanding distribution and service network of six hubs in Tanzania and Kenya. Each hub has a 20km coverage area, which helps ensure end-users receive maintenance support over the lifetime of their biogas digester. In addition to increasing its coverage in Tanzania and Kenya, SimGas plans to expand to Rwanda and India in the near future. Sources: SimGas, 2015a and 2015b and Versol, 2015.

3.9 RESULTS FOR UGANDA

3.9.1 *Country Overview*

Uganda is Eastern Africa's fourth largest country, with a 2015 population of 40.1 million.[182] As in most of the Alliance's focus countries, a large portion of the population uses unprocessed biomass to cook. Eighty-seven percent of the population lives in rural areas and 13 percent in urban areas.[183] As of 2012, 38 percent of the population in the country was below the international poverty line of $1.25 per capita per day.[184] One-third of households are headed by women.

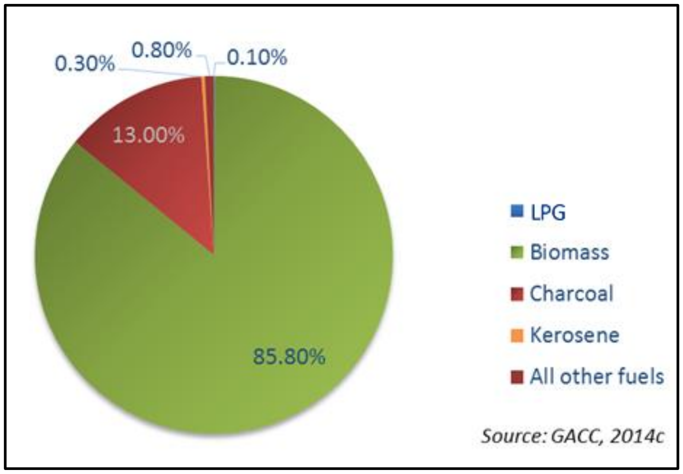


Figure 3-37. Cooking Fuel Use in Uganda

Unprocessed biomass makes up over 85 percent of the cooking fuels used in Uganda, as shown in Figure 3-37. Charcoal is the only other significant fuel, used by 13 percent of the population, mainly in urban and peri-urban areas. LPG and kerosene are used in small portions, less than 0.5 percent each. Government subsidies are available for kerosene, but not for LPG. The remaining 0.8 percent is a mix of fuels produced from small enterprises and possibly some electricity. Only 11 percent of the total population has access to electricity, which had subsidies removed a few years ago.

Adequate supply of resources to sustainably support current or increasing levels of firewood use is an important consideration. Uganda has had more than 2 percent decrease in forest land per year over recent years,[185] and only 15 to 26 percent of Uganda's land area is covered by forest.[186] Nearly 22 percent of the rural population live in areas with woody biomass shortfalls.[187]

Rural households mostly cook on three-stone fires, often in enclosed spaces.[188] Households across Uganda generally eat similar foods and have the same cooking habits (boiling and simmering).[189] Cookstoves are also used to boil water for tea and porridge.

3.9.2 *Environmental Impact Assessment, by Impact Category*

Table 3-8 shows a summary of environmental impacts by fuel type for Uganda. Figure 3-38 through Figure 3-41 provide additional details on several environmental indicators of high interest to the Alliance: total energy demand, GCCP, BC, and PM.

Table 3-8. Summary of Environmental Indicators for Cooking Fuels in Uganda

Indicator*	Unprocessed Solid Biomass	Processed Solid Biomass						Liquid/Gas					
	Firewood	Charcoal Briquettes from Wood	Charcoal Briquettes from Bamboo	Non-Carbonized Briquettes from Sawdust	Non-Carbonized Briquettes from Crop Residues	Wood Pellets	Wood Chips	Ethanol from Sugarcane	Ethanol from Wood	Biogas from Dung	LPG	*Median*	*All-fuel average***
TED (MJ/HH/YR)	39,705	78,111	76,858	45,211	21,616	14,775	19,289	38,731	12,611	10,540	39,125	*13,693*	*22,032*
NED (MJ/HH/YR)	33,752	72,159	70,905	39,259	15,664	8,823	13,337	32,779	6,659	4,588	33,173	*7,741*	*18,394*
GCCP (kg CO_2 eq/HH/YR)	4,464	7,027	2,200	508	271	2,121	2,170	540	43.7	17.8	2,007	*157*	*1,187*
BC/SLCP (kg BC eq/HH/YR)	3.80	10.0	9.79	2.84	5.00	0.12	0.65	-0.040	0.027	0.061	0.042	*0.034*	*1.79*
PMFP (kg PM10 eq/HH/YR)	12.9	37.6	37.0	10.7	23.3	0.73	6.29	0.98	0.38	0.31	1.18	*0.56*	*7.31*
FFD (kg oil eq/HH/YR)	0.033	0.047	0.11	0.18	0.24	12.8	1.50	91.9	6.36	0	923	*0.040*	*57.6*
WD (m^3/HH/YR)	0.25	1.52	1.37	16.4	24.7	1,304	1.65	411	1.66	19.0	379	*1.44*	*120*
TAP (kg SO_2 eq/HH/YR)	3.07	0.87	1.76	2.51	1.28	0.54	1.51	3.00	0.47	0.091	2.99	*0.51*	*1.01*
FEP (kg P eq/HH/YR)	0.81	0.41	0.40	0.48	0.39	0.018	0.39	0.21	1.9E-05	0	0.047	*0.0092*	*0.17*
POFP (kg NMVOC eq/HH/YR)	138	168	169	103	18.1	0.98	66.7	1.94	1.18	0.48	9.77	*1.08*	*37.7*

*TED = Total Energy Demand; NED = Net Energy Demand; GCCP = Global Climate Change Potential; BC/SLCP = Black Carbon and Short-Lived Climate Pollutants; PMFP = Particulate Matter Formation Potential; FFD= Fossil Fuel Depletion; WD = Water Depletion; TAP = Terrestrial Acidification Potential; FEP = Freshwater Eutrophication Potential; POFP = Photochemical Oxidant Formation Potential; CO_2= Carbon Dioxide; DME= Dimethyl Ether; MJ= Megajoules; NMVOC= Non-Methane Volatile Organic Compound; SO_2= Sulfur Dioxide; HH = Household; YR = Year.

**All-fuel average values calculate a straight average of the cooking fuels investigated for the country and do not consider the current weighted use of each fuel for cooking within the country.
Note: Descriptions of each environmental indicator are found in Table 2-2. Dark green represents the lowest 5th percentile fuel by impact, light green represents fuels between the 5th and 25th percentile by impact, grey represents fuels between the 25th and 75th percentile by impact, orange represents fuels between the 75th and 95th percentile by impact, and red represents fuels greater than the 95th percentile by impact. All values in the table are displayed to three significant digits. When determining percentiles (and accompanying color-coding), more significant digits were used. As a result, values that appear the same in the table may be color-coded differently.

Box 3-40 highlights key observations and Figure 3-38 displays the total energy demand impact results for fuels in Uganda by life cycle stage.

Box 3-40– Total Energy Demand Observations for Uganda

- The processing phase of the charcoal briquette life cycle contributes 57 percent of the total impact for both forms of charcoal briquette (i.e., from wood or bamboo).
- Both ethanol from sugarcane and LPG exhibit poor relative performance in this impact category when compared to other African countries with the exception of Kenya. This is driven by the distribution phase within fuel processing as the model assumes these fuels need to be imported.

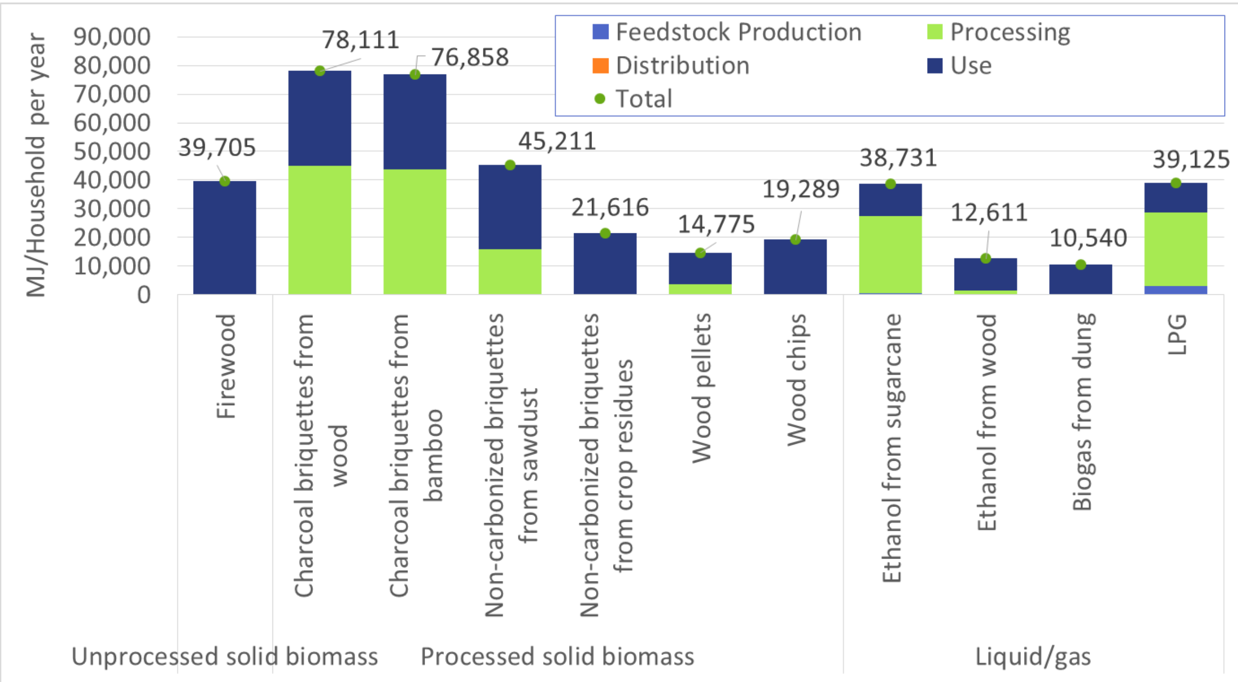


Figure 3-38. Total Energy Demand (MJ) for Cooking Fuel Types (Uganda)
To produce, distribute and use cooking fuels by a single household per year

Box 3-41 highlights key observations and Figure 3-39 presents the GCCP impact results for fuels in Uganda by life cycle stage.

Box 3-41– Global Climate Change Potential Observations for Uganda

- Wood-based fuels are not carbon neutral because the wood supply in Uganda is considered non-renewable based on a decreasing forest area. Charcoal briquettes from bamboo have a significantly lower impact because bamboo resources in Uganda are assumed to be carbon-neutral. The impacts of wood briquettes are over 3 times those of bamboo briquettes. Seventy-four percent of total bamboo charcoal briquette GCCP impacts occur during kilning.

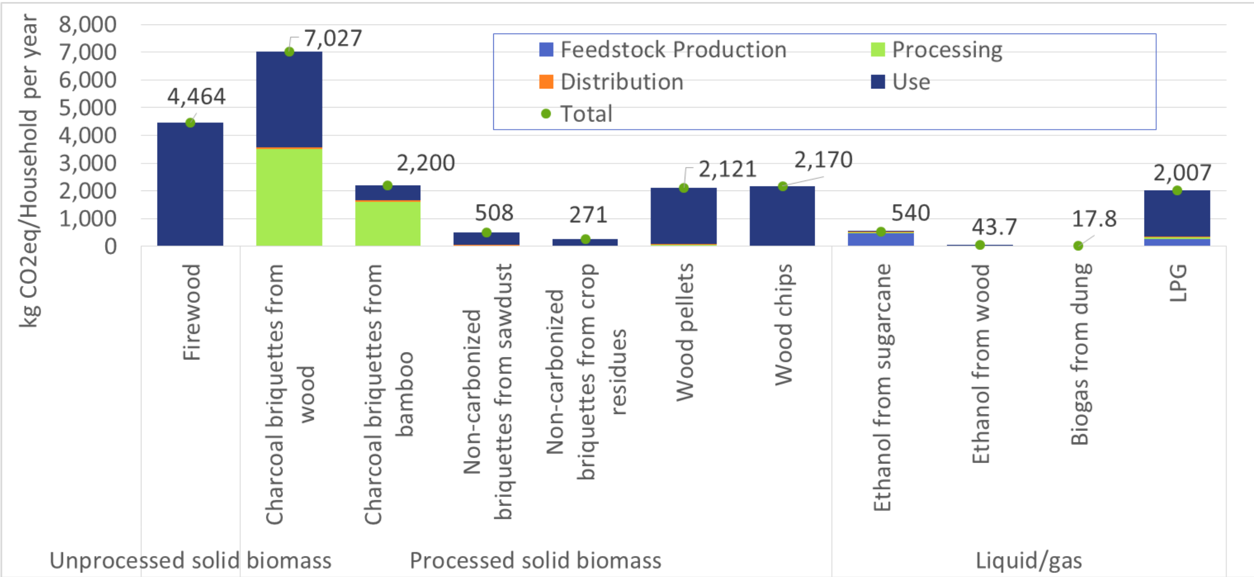


Figure 3-39. GCCP (100a) Potential Impacts (kg CO_2 eq) for Cooking Fuel Types (Uganda)
To produce, distribute and use cooking fuels by a single household per year

Box 3-42 highlights key observations and Figure 3-40 displays the BC and short lived climate pollutant impact results for fuels in Uganda by life cycle stage.

Box 3-42– Key Black Carbon and Short-Lived Climate Pollutants Observations for Uganda

- The highest BC impacts are seen for charcoal briquettes, which tend to have high PM emissions when processed in a kiln and also when combusted. Both charcoal briquettes demonstrate nearly twice the impact scores of non-carbonized briquettes from crop residues, which are the next most impactful fuel alternative. For both types of charcoal briquettes, the kiln contributes over 80 percent of total impacts.

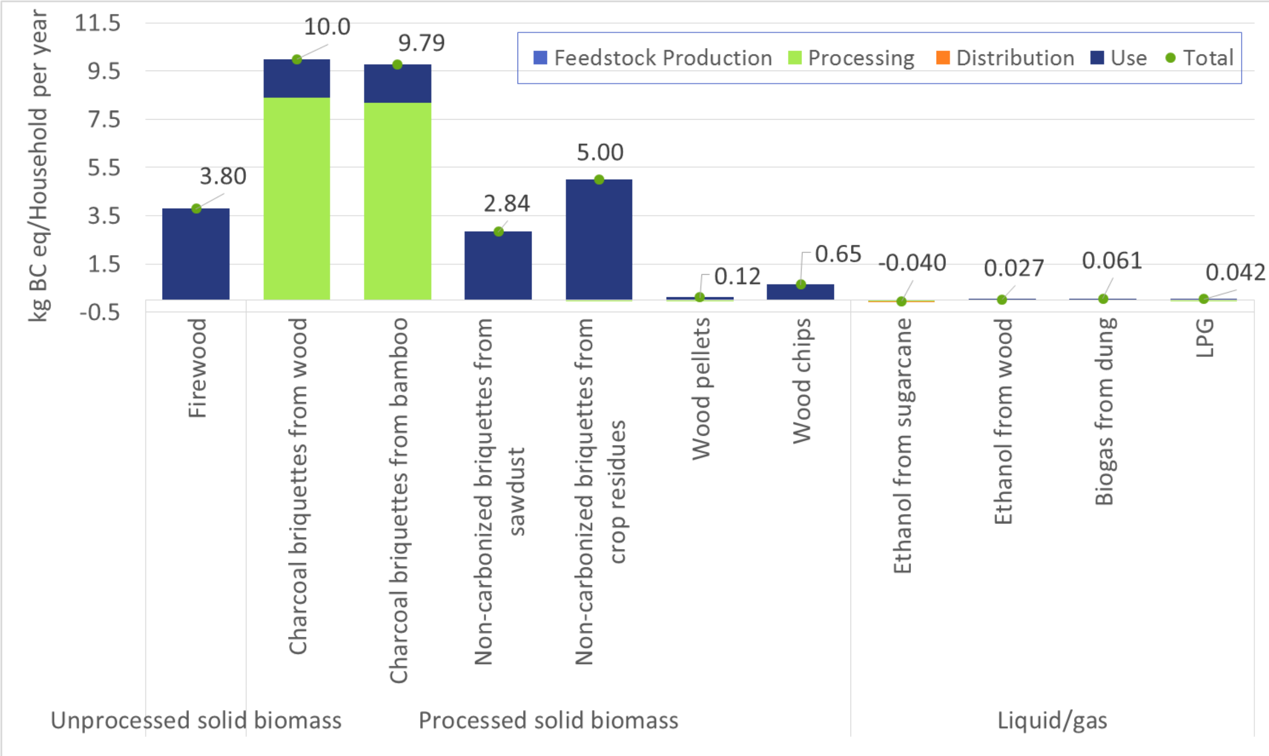


Figure 3-40. BC and Short-Lived Climate Pollutant Impacts (kg BC eq) for Cooking Fuel Types (Uganda)
To produce, distribute and use cooking fuels by a single household per year

Box 3-43 highlights key observations and Figure 3-41 shows the PM formation impact results for fuels in Uganda by life cycle stage.

Box 3-43– Key Particulate Matter Formation Potential Observations for Uganda

- Charcoal briquettes lead to the greatest PM formation impacts, followed by briquettes from crop residues and firewood. The impacts for both types of charcoal briquettes are nearly twice those of their nearest competitor, non-carbonized briquettes from crop residues.

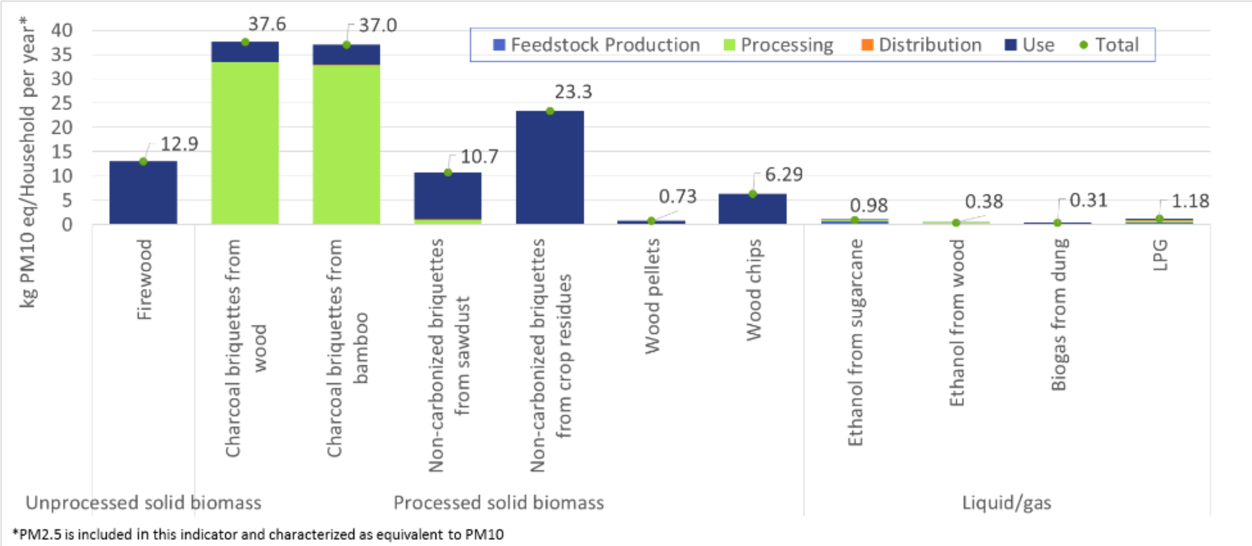


Figure 3-41. Particulate Matter Formation Potential Impacts (kg PM10 eq) for Cooking Fuel Types (Uganda)

To produce, distribute and use cooking fuels by a single household per year

Similar explanations of the other environmental indicators in Table 3-8 can be found in Appendix A, Section A.9.2.

3.9.3 *Key Observations and Policy Insights*

Key observations and related policy insights are highlighted below. Refer to Appendix A for the detailed analysis.

Box 3-44 – Key Observations and Policy Insights for Uganda

- **Firewood** is low cost;[190] the firewood market is informal and fragmented. Many people—especially in rural areas—collect it freely by hand. Time spent collecting firewood in Uganda takes an average of three hours per day for those living in urban areas and six hours per day for those living in rural areas.[191] This time requirement will only increase with deforestation.
- **Charcoal briquettes** have the greatest impact across the full fuel life cycle and are less affordable than firewood. Uganda's declining forest area is expected to result in supply-related issues for both fuels, especially among the 64 percent of rural and 41 percent of peri-urban consumers who gather firewood.[192] Due in part to the decreasing supply, the government has begun actively supporting producers of charcoal briquettes from wood with financial incentives, as cooking with charcoal briquettes is more efficient at the point of use compared to cooking with unprocessed firewood.[193,194] Despite its higher energy content, the life cycle environmental impacts of charcoal briquettes are greater than wood because it requires a substantial amount of energy to produce (see Figure 3-38 through Figure 3-41). The price of charcoal made from wood is quite high compared to other fuels use. Alternative feedstocks to wood, such as bamboo and crop residues, demonstrate slightly better environmental performance, further decrease pressure of forest resources, and provide a locally based business opportunity (see Box 3-45).

Box 3-44 – Key Observations and Policy Insights for Uganda

- Small charcoal briquette enterprises struggle to access traditional sources of financial assistance,[195] and affordability issues may follow from high production costs being passed on to consumers. Moreover, a variety of taxes (value-added, employment, etc.) disadvantage licensed producers of charcoal relative to their counterparts in the informal sector.[196]

- **Wood chips, wood pellets and non-carbonized briquettes** have mostly mid-range impacts; however, these fuels are not widely used in the Ugandan cooking fuel market (e.g., non-carbonized briquette production is 5,000-7,000 tonnes annually, representing less than one percent of the national cooking fuel market[197]). Due to their limited uptake, little information is available to evaluate cost and implementation. One encouraging sign is the adoption of non-carbonized briquettes at the commercial level. Although not used for cooking, briquettes made of rice husks, coffee pulp, maize stalks, and sawdust have begun to displace firewood and, to a lesser extent, charcoal as the primary fuel source at some schools, hospitals, and food-processing companies.[198] Pilot startups are at infant stages for the use of wood pellets, and non-carbonized briquettes from crop residues are available from small enterprises.[199] Some of these small enterprises are owned by women. Cost information was unavailable for wood pellets (a fuel with mostly lower environmental impact compared to wood and charcoal); however, if costs are comparable to non-carbonized briquettes from crop residues, pellets may make some inroads to the cooking fuel market.
- Fuels with lowest environmental impacts are **biogas** and **ethanol**; however, neither of these fuels is currently used to any significant extent in Uganda. Insufficient information was available to assess cost and implementation issues of ethanol.
- **Biogas from Dung** can be used in rural areas where dung is readily available, but biogas systems are very uncommon due to the initial cost of the digester and unavailability of loans to purchase them. Moreover, a study found that 34 percent of surveyed biogas-using households were inconvenienced due to challenges with mixing dung, an increased need for water, and performance issues with the biogas systems themselves.[200]Affordability concerns and design issues might improve now that cooking with biogas is promoted through a National Biogas Program.[201]
- **LPG** is a cleaner burning fuel that has comparatively lower life cycle impacts than the currently used wood and charcoal. It is used mainly by wealthier citizens in urban areas. Some consumers in perceive LPG as dangerous and are concerned about leakage or explosions. Although the supply of LPG in cities is fairly reliable, there is little or no infrastructure for rural distribution. As in Kenya, smaller LPG cylinders would make this fuel more affordable for a greater share of the population; however, poorer households may need assistance from the government or NGO programs to acquire an LPG cookstove, and the barriers within the distribution and supply chain would still need to be overcome.

Box 3-45– Featured Example for Uganda

As mentioned in Box 3-44, non-wood charcoal briquettes represent an opportunity market for small- and medium-sized enterprises. Sanga Moses founded Eco-fuel Africa in Uganda in 2010. He was inspired to start the company after seeing his sister carry firewood instead of attend school. She made the 10km trip frequently, only attending school two days per week. Determined to develop a cooking fuel solution to combat his family's reliance on firewood (like many others in Uganda), Moses collaborated with university students to design a kiln for carbonizing agricultural waste and a machine for compressing the resulting char into briquettes. The Eco-fuel system has been a success, creating opportunities for many beneficiaries along the value chain. On the production side, approximately 500 farmers use Moses's kiln to carbonize agricultural waste. Through microfinance solutions (lease-to-own payments for kilns), Eco-fuel Africa has helped many of these farmers realize a 30 to 50 percent increase in their incomes from selling char. The carbonization process takes only two to three hours per day, and can often be completed while the user attends to other household obligations. On the distribution side, by helping with startup expenses and providing training sessions, Eco-fuel Africa supports a network of female retailers. Many of the women who sell Eco-fuel briquettes have increased their incomes substantially, some up to 100 percent. Increased income results in greater food security, better educational opportunities, and a stronger likelihood of economic independence. Although Eco-fuel Africa operates on a relatively small scale in Uganda, government support, a backlog of entrepreneurs eager to join the initiative, and the substantial benefits already realized by participants indicate a strong opportunity for growth. Source: Black, 2015.

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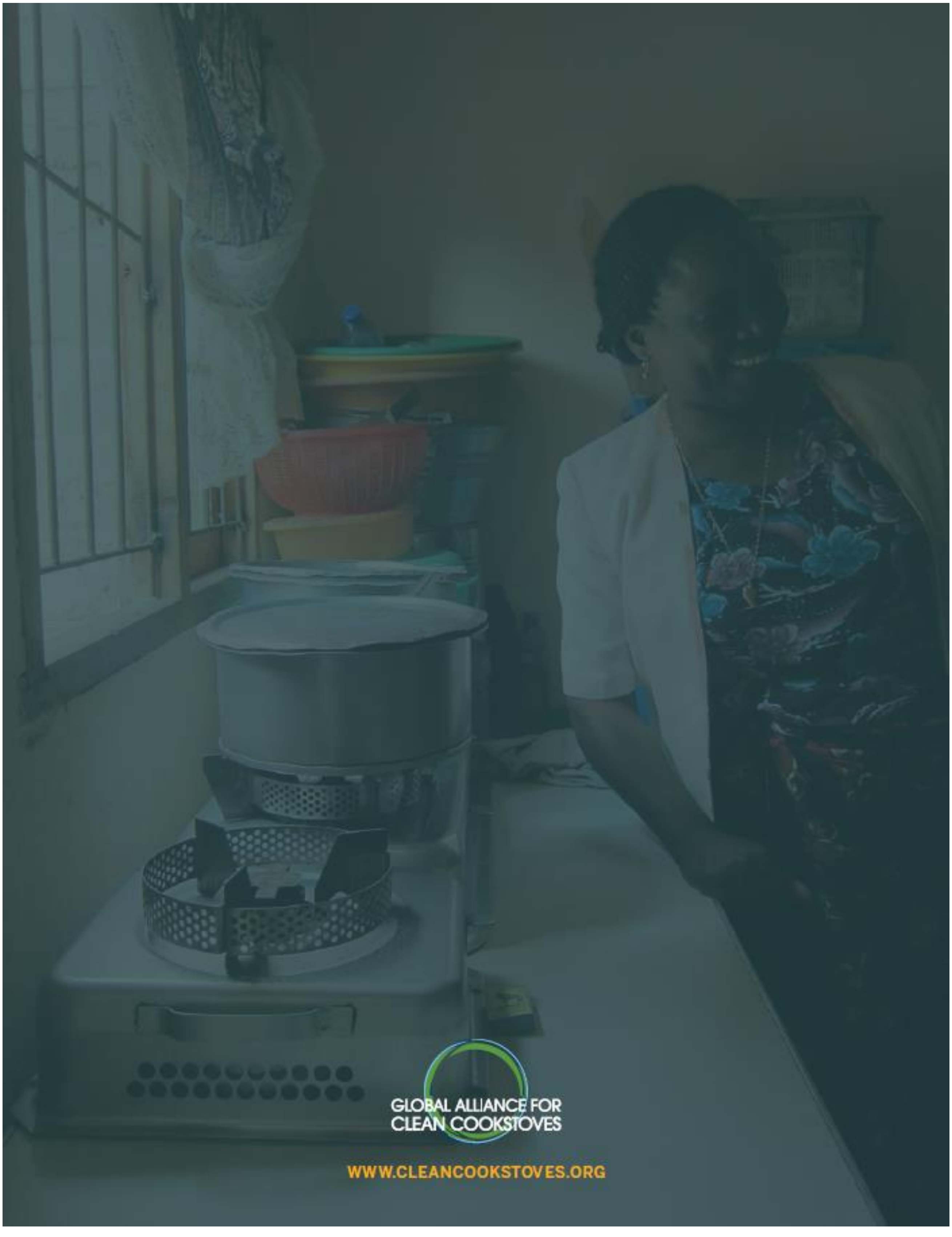
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