



Comparative Analysis of Fuels for Cooking: Life Cycle Environmental Impacts and Economic and Social Considerations

Appendix B: Detailed Scope and Methodology

December 2016

Submitted to:

Global Alliance for Clean Cookstoves
1750 Pennsylvania Avenue, NW, Suite 300
Washington, DC 20006

Submitted by:

Eastern Research Group, Inc. (ERG)
4200 Somerset Drive, Suite 132
Prairie Village, KS 66208

Table of Contents

	Page
B.1 INTRODUCTION	B-1
B.1.1 Life Cycle Assessment (LCA) Overview.....	B-1
B.2 SCOPE OF THE STUDY.....	B-1
B.2.1 Functional Unit	B-1
B.2.2 Geographic Scope	B-2
B.2.3 Fuel Systems Studied.....	B-2
B.2.4 System Boundary	B-3
B.2.4.1 System Components Excluded	B-5
B.2.5 Data Sources	B-5
B.2.6 Data Requirements for Environmental Data.....	B-6
B.2.6.1 Geographic Coverage.....	B-6
B.2.6.2 Technology Coverage	B-6
B.2.6.3 Temporal Coverage.....	B-7
B.2.6.4 Cut-off Criteria for the Environmental Data.....	B-7
B.2.7 LCIA Methodology and Environmental Impact Indicators	B-7
B.2.7.1 Scope of Impact Assessment	B-8
B.2.8 Economic Methodology and Indicators	B-10
B.2.8.1 Fuel Use 11	
B.2.8.2 Imports, Exports, Production and Demand.....	B-12
B.2.8.3 Fuel Cost 13	
B.2.9 Social Methodology and Indicators	B-18
B.3 LIFE CYCLE INVENTORY ASSUMPTIONS AND DATA SOURCES FOR COOKING FUELS	B-19
B.4 ALLOCATION METHODOLOGY FOR THE ENVIRONMENTAL ANALYSIS.....	B-46
B.5 BIOGENIC CARBON ACCOUNTING	B-46
B.6 NON-RENEWABLE FORESTRY CALCULATIONS.....	B-46
B.7 BLACK CARBON AND SHORT-LIVED CLIMATE POLLUTANTS CALCULATIONS	B-49
B.8 LCA MODEL FRAMEWORK	B-50
B.9 DATA LIMITATIONS	B-50
B.10 DATA ACCURACY AND UNCERTAINTY.....	B-50

List of Tables

	Page
Table B-1. Conversion Factors to Household Energy Cooking Use per Year for Each Focus Country	B-1
Table B-2. Environmental Indicator Units and Description	B-8
Table B-3. Economic Indicator Units and Description.....	B-11
Table B-4. Percentage of the Population in Urban/Rural Areas by Country	B-14
Table B-5. Fuel Quantity per Cooking Basis.....	B-15
Table B-6. Estimated Household Size by Country	B-15
Table B-7. Exchange Rates and BEA GDP Deflator used to convert to 2013 USD	B-17
Table B-8. Social Indicators and Descriptions	B-18
Table B-9. Process Descriptions for Firewood.....	B-19
Table B-10. Process Descriptions for Charcoal Briquettes from Wood.....	B-21
Table B-11. Process Descriptions for Charcoal Briquettes from Bamboo	B-22
Table B-12. Process Descriptions for Non-Carbonized Briquettes from Sawdust.....	B-25
Table B-13. Process Descriptions for Non-Carbonized Briquettes from Crop Residues	B-28
Table B-14. Process Descriptions for Wood Pellets.....	B-30
Table B-15. Process Descriptions for Wood Chips	B-32
Table B-16. Process Descriptions for Ethanol from Sugarcane	B-35
Table B-17. Process Descriptions for Ethanol from Wood	B-36
Table B-18. Process Descriptions for Biogas from Cattle Dung	B-38
Table B-19. Process Descriptions for LPG.....	B-40
Table B-20. Process Descriptions for Coal (India and China Only).....	B-42
Table B-21. Process Descriptions for Electricity (India and China Only)	B-42
Table B-22. Process Descriptions for Unprocessed Crop Residue (India and China Only).....	B-43
Table B-23. Process Descriptions for Kerosene (India and China Only).....	B-43

Table B-24. Process Descriptions for Dung Cake (India Only)B-44

Table B-25. Process Descriptions for DME (China Only)B-44

Table B-26. Process Descriptions for Natural Gas (China Only).....B-45

Table B-27. Electrical Grid Mix by CountryB-45

Table B-28. Cooking Energy per Household and Number of Households using Wood for
Cooking by Country.....B-48

Table B-29. Percentage of Renewable and Non-renewable Wood by CountryB-48

Table B-30. Characterization Factors for BC eqB-50

List of Figures

	Page
Figure B-1. System Boundaries for Cookstove Fuel Production, Distribution and Use	B-4

B.1 INTRODUCTION

This appendix presents the detailed scope, methodology and assumptions for the *Comparative Analysis of Fuels for Cooking: An Assessment of Environmental, Economic and Social Impacts* study.

B.1.1 Life Cycle Assessment (LCA) Overview

Environmental indicators are assessed in this study through application of life cycle assessment (LCA). LCA is recognized as a scientific method for making comprehensive, quantified evaluations of the environmental benefits and tradeoffs for the entire life cycle of a product system, beginning with raw material extraction and continuing through disposition at the end of its useful life. This LCA investigates current and potential cooking fuels used in different countries throughout the world, starting from fuel collection and extraction, and continuing through fuel processing, distribution, use, and disposal/reuse if applicable. By capturing the system-wide impacts of cooking fuels, the environmental tradeoffs of the fuels can be compared based on a consistent and holistic framework.

B.2 SCOPE OF THE STUDY

This section discusses the overall scope of the study necessary to accomplish the study goals. The components include the functional unit, geographic scope, investigated fuel systems, study boundaries, data sources, allocation, Life Cycle Impact Assessment (LCIA) methodology and indicators, economic indicators, social indicators, use of results, and online guide.

B.2.1 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, an energy functional unit is a proper basis of comparison. Therefore, the LCA results and the cost results are based on energy delivered for cooking per household per year. This includes the energy required for use (i.e., combustion) in the cookstove and for transportation to households and retail locations, as well as the additional energy required for feedstock production and fuel processing. Table B-1 provides the household energy factors used to normalize the results for each country. These energy factors 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 B-1. Conversion Factors to 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, 2014

Table B-1. Conversion Factors to Household Energy Cooking Use per Year for Each Focus Country

Country	GJ/Household/year	Sources
Ghana	4.96	IEA, 2014, GVEP International, 2012c
Nigeria	16.1	IEA, 2014, Accenture, 2011
Guatemala	15.6	ESF, 2013

GJ= gigajoules.

B.2.2 Geographic Scope

Between 2012 and 2014, the Alliance mobilized resources for growing the global clean cookstove markets in eight countries. The Alliance selected these focus countries based on the size of the impacted population, the maturity of each country's clean cookstove market, the magnitude of need, and the strength of partner (including government) commitment. These eight countries represent the geographic scope of the present analysis:

 **China**

 **India**

 **Bangladesh**

 **Guatemala**

 **Ghana**

 **Kenya**

 **Nigeria**

 **Uganda**

B.2.3 Fuel Systems Studied

This study focuses on bio-based and fossil-based fuels either currently used or available for future use in the Alliance focus countries. This analysis considers the following 11 feedstock-fuel combinations for all countries:

- Unprocessed solid biomass
 - Firewood
- Processed solid biomass
 - Charcoal briquettes from wood
 - Charcoal briquettes from bamboo
 - Non-carbonized briquettes from sawdust
 - Non-carbonized briquettes from crop residues
 - Wood pellets
 - Wood chips
- Liquid/gas
 - Ethanol from sugarcane
 - Ethanol from wood
 - Biogas from cattle dung
 - Liquefied petroleum gas (LPG)

The India and China analyses include the fuels listed above and several others. Environmental sustainability data are available for these additional fuels through an initial companion study

conducted by the U.S. Environmental Protection Agency (EPA).¹ At this time, an analysis of corresponding economic and social/gender data has not occurred. Analyses of these additional fuels for the other six countries are outside the scope of this study. Below are the additional fuels included for India and China.

- | | |
|--|--|
| <ul style="list-style-type: none"> • India — Electricity — Kerosene — Hard coal — Crop residue (unprocessed) — Dung cake | <ul style="list-style-type: none"> • China — Electricity — Kerosene — Hard coal — Crop residue (unprocessed) — Natural gas — Dimethyl ether |
|--|--|

B.2.4 System Boundary

As illustrated in Figure B-1, the following four life cycle stages are covered in the environmental portion of the study:

1. **Feedstock Production:** Includes all stages from extraction or acquisition from nature of the fuel feedstock through production of the feedstock in a form ready to be processed into a cookstove fuel (e.g., harvesting of sugarcane and transport to the mill for processing);
2. **Processing:** Covers steps of converting the fuel feedstock into a fuel ready to be used in a cookstove;
3. **Distribution:** Includes transportation steps for transporting the fuel to the consumer; and
4. **Use:** Covers all steps associated with combustion of the fuel in the cookstove and disposal of any combustion wastes or residues.

For primary agricultural products, the system boundaries start at biomass cultivation. For agricultural residues, including dung, the system boundaries begin at residue collection. 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. 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. The use phase is modeled to reflect emissions from the combustion (i.e., burning) of the cooking fuels. Associated air pollution levels and constituents depend on the fuel's elemental composition (i.e., average fixed carbon, ash content, and volatile matter) and the cookstove technology or technology mix (i.e., thermal efficiency) for each stove and country combination. 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 these wastes on land around the house or using them as soil amendments to benefit household-level crop production.

¹ Publication of the EPA fuels analysis is anticipated in early 2016.

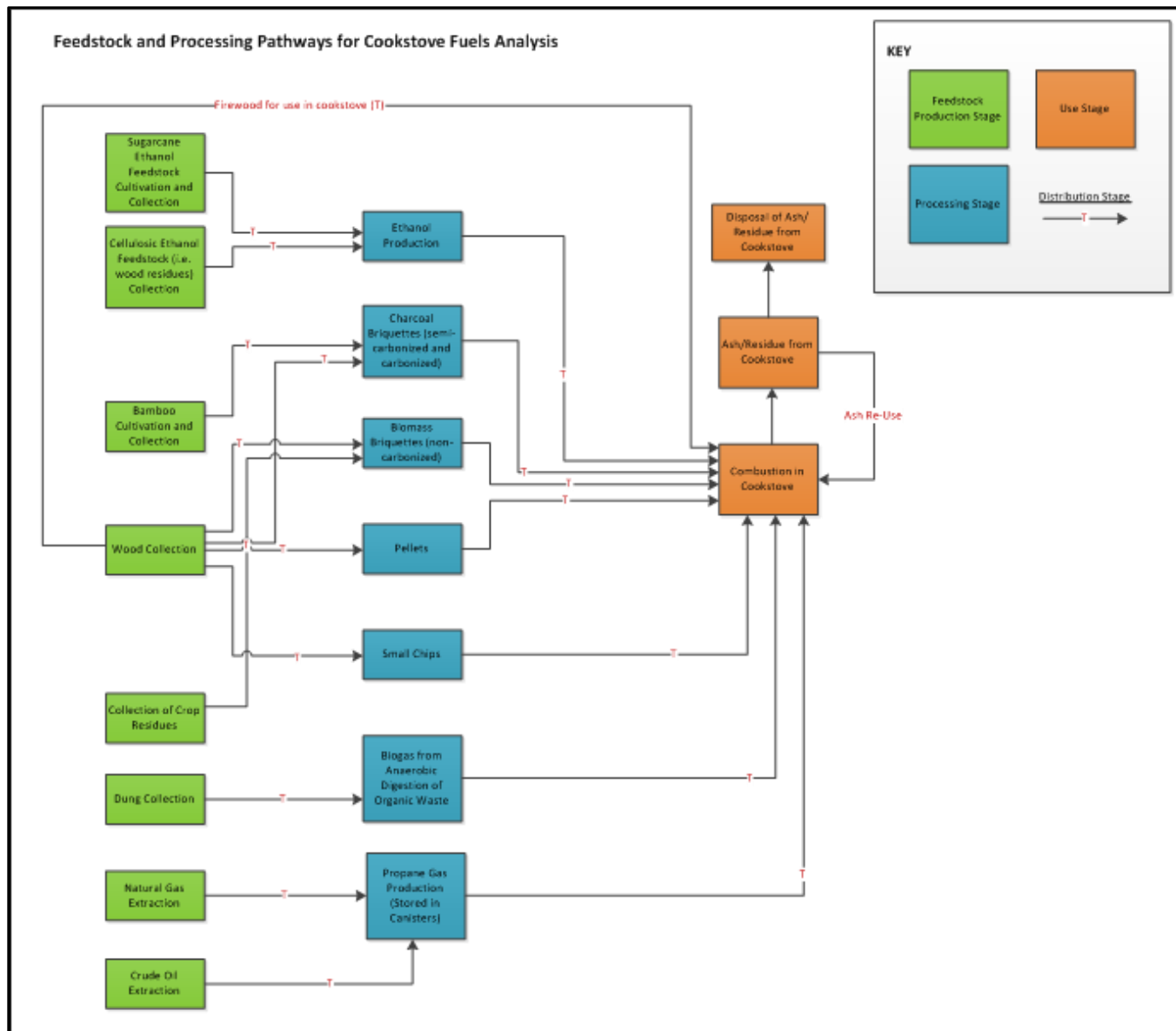


Figure B-1. System Boundaries for Cookstove Fuel Production, Distribution and Use

B.2.4.1 System Components Excluded

The following components of each system are not included in this study:

- **Cookstove Production and Distribution:** The focus of this study is the life cycle of fuels used within all cookstoves in the countries; therefore, all burdens associated with production and distribution of the cookstove itself are excluded from the analysis. Per a previous LCA examining production of fuel-efficient cookstoves,¹ the use phase dominates life cycle greenhouse gas (GHG) emissions regardless of the fuel type utilized.²
- **Human Energy Expended during the Collection of Fuels:** The environmental analysis does not include human biological energy or emissions. Shifts in fuels may decrease the human energy and emissions associated with the collection of fuel materials in some cases. Social indicators may take into account the differences in human energy expended for various cooking fuels.
- **Food and Food Wastes:** The focus of this study is the life cycle of fuels used to cook the food in the investigated countries; therefore, all environmental and economical burdens associated with production, preparation, storage, consumption, and disposal of the food being prepared using the fuels are excluded from the analysis. Social indicators may take into account the differences in taste of food prepared with various cooking fuels.
- **Capital Equipment, Facilities, and Infrastructure:** The energy and wastes associated with the manufacture of buildings, roads, pipelines, motor vehicles, industrial machinery, etc. are not included. The energy and emissions associated with production of capital equipment, facilities, and infrastructure generally become negligible when averaged over the total output of product or service provided over their useful lifetimes.

B.2.5 Data Sources

Appendix C lists over 200 sources cited in this analysis. 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 and additional sources provided by the Alliance and its partners.

Data on economic and social indicators were gathered from a variety of sources. Where possible, data from multilateral organizations, such as the World Bank, United Nations, and Organisation for Economic Co-operation and Development, are used. In some cases, each individual country's national statistical bureaus or ministries collect and publish relevant data, although these types of datasets are limited both in number and granularity compared to those available for more developed nations.

Where data were not available from the aforementioned sources, literature searches of both peer-reviewed journal articles (using Google Scholar) and general Internet searches (using Google) were performed. Search terms typically included the name of the fuel or feedstock of interest, the

country name, and the indicator of interest (e.g., “biogas cost India” or “firewood time savings Kenya”). When selecting articles for social analysis, special attention was paid to 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. Organizations, such as International Center for Research on Women (ICRW), provided valuable insight to ongoing work being performed for the Alliance. Individual countries’ national statistical bureaus were used to gather demographic data, such as household size.

The selected environmental indicators are based on the production, processing, distribution, and use of various renewable and non-renewable fuels taken from published articles, reports, and LCAs (see Section B.3 for detailed information on sources for the environmental indicators). Many of the sources for the economic and social indicators are cited within those individual country sections of Appendix A. Complete citations for data sources used within the study are presented in Appendix C.

B.2.6 Data Requirements for Environmental Data

ISO standards 14040 and 14044 detail various aspects of data quality and data quality analysis of the environmental data. These ISO Standards state: “descriptions of data quality are important to understand the reliability of the study results and properly interpret the outcome of the study.” These ISO Standards list three critical data quality criteria: time-related coverage, geographical coverage, and technology coverage. The following subsections discuss these three critical data quality criteria and the typical specifications associated with high quality data.

B.2.6.1 Geographic Coverage

The geographic scope of this study includes the eight Alliance focus countries; however, some cooking fuels used in these countries include fuels imported from other regions of the world. High quality data and information for geography-dependent processes (e.g., energy production) are typically obtained from country specific articles and databases. Where country-specific data were not available, data were adapted from processes within industrialized countries as a proxy for the country specified substituting geographic-specific parameters (e.g., transportation and electricity specific for the focus country).

B.2.6.2 Technology Coverage

High quality data for technology-based processes were typically based on the most recent average country-specific technology mix (e.g., the current production methods China employs for mining and processing coal). It is more difficult to evaluate data quality for technologies to produce cooking fuels not yet in use or that have a current small market share. If more specific information was not available, data quality was evaluated for these technological processes based on current technological processes used in a similar country where fuel use is more common. Assumptions were made on issues such as percentages of mechanical briquetting versus hand-made briquettes. These assumptions are found for each fuel in Section B.3.

B.2.6.3 Temporal Coverage

Good quality temporal data are typically those that are less than six years from the reference year (2013 for this project), with the highest quality temporal data less than three years from the reference year. A difference of six years meets the top two data scores for temporal correlation as identified in theecoinvent pedigree matrix.³ In a few cases, data were taken from references prior to the 6 year temporal goal. Those data were reviewed and the decision was made that the data was still relevant for use in the case of the indicator, as opposed to being considered a data gap.

B.2.6.4 Cut-off Criteria for the Environmental Data

For this LCA, the cut off criterion used was one percent by mass. No material flow comprising less than one percent by weight of the system is included. This cut-off assumption is based on past LCA studies that demonstrate that materials that comprise less than one percent of system weight have a negligible effect on total LCA results. The exception to this criterion is if a material that is less than one percent by mass of the system inputs and is hazardous, toxic, and/or is expected to produce environmental burdens in excess of its weight fraction of the finished product, then the material should then be included in the LCA. Input materials were reviewed and evaluated as to whether emissions released would affect the results of the impact categories. It should be noted that if data were already compiled for components that comprise less than one percent of a system's weight, these components were included in the analysis.

B.2.7 LCIA Methodology and Environmental Impact Indicators

The full inventory of atmospheric and waterborne emissions generated in an LCA study is lengthy and diverse, making it difficult to interpret systems' differences in individual emissions in a concise and meaningful manner. Life Cycle Impact Assessment (LCIA) helps with interpretation of the emissions inventory. LCIA is defined in ISO 14044 Section 3.4 as the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product." In the LCIA phase, the inventory of emissions is first classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

Characterization factors have been defined to estimate the amount of impact potential of LCI results. There are two main methods to developing LCIA characterization factors. The 'midpoint' method links results to categories of commonly defined environmental concerns like eutrophication potential and global climate change potential. The 'endpoint' method further models the causality chain of environmental stressors to link LCI results to environmental damages (e.g., final impact to human and ecosystem health). ISO standard allows the use of either method in the LCIA characterization step. Overall, indicators close to the inventory result (midpoint) have a higher level of scientific consensus, as less of the environmental mechanism is modeled. Conversely, endpoint and damage oriented characterization models inevitably include much aggregation and some value-based weighting of parameters. To reduce uncertainty in communication of the results, this LCA focuses on indicators at the midpoint level.

B.2.7.1 Scope of Impact Assessment

This study addresses global, regional, and local impact categories of relevance to the cookstove sector, such as air emissions leading to human health issues, energy demand driving depletion of bio-based and fossil-fuel-resources, GHG and black carbon (BC) emissions causing both short-term and long-term climate effects. For most of the impact categories examined, the ReCiPe impact assessment method is utilized to represent global conditions (Goedkoop et al. 2008). For the category of Global Climate Change Potential (GCCP), contributing elementary flows are characterized using factors reported by the Intergovernmental Panel on Climate Change (IPCC) in 2013 with a 100 year time horizon (IPCC 2013). Considerations for biogenic carbon accounting are covered in Section B.5. BC and co-emitted species are characterized to BC – equivalents (eq) based on a novel method recently released by the Gold Standard Foundation (GSF) (GSF 2015). A detailed discussion of the BC methodology is presented in Section B.7. In addition, some inventory results are included in the results reported in the analysis:

- **Total Energy Demand**: This is a cumulative inventory of non-renewable energy extracted and renewable energy utilized. The energy demand includes processing energy, transportation energy, and feedstock energy.
- **Net Energy Demand**: This is the differences between the total energy required to produce and distribute the fuel and the amount of energy that is released from combusting the fuel.
- **Water Depletion**: This category is not an impact and is assessed only as inventory items. Information such as source and fate of these inventory items are included.

A summary of the LCI and LCIA categories and methods that are used in this study are presented in Table B-2. This study focuses on environmental impacts; therefore, human health impact categories are currently outside the project scope. Additionally, modeling human health impacts introduces a higher level of uncertainty to the study results. Human health impacts are dependent not only on emission quantities, but also on the fate and transport of the emitted substances and the concentrations and pathways by which organisms are exposed to these substances. These detailed types of exposure information are not tracked in an LCI, requiring an additional layer of assumptions about the environmental mechanism be made by the developer of the LCIA methodology.

Table B-2. Environmental Indicator Units and Description

Indicator	Unit	Description
<i>Total Energy Demand</i>	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.

Table B-2. Environmental Indicator Units and Description

Indicator	Unit	Description
<i>Net Energy Demand</i>	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.
<i>Global Climate Change Potential (100a)</i>	kg CO ₂ eq/Household per year	The global climate change potential (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 5 th 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 ₂ O. 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.
<i>Black Carbon and Short-Lived Climate Pollutants</i>	kg BC eq/Household per year	Short-lived climate pollutants (SLCPs) 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 . ⁴ Reducing these emissions can have immediate beneficial impacts on climate change. Black carbon (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 Section 7 of this Appendix.
<i>Particulate Matter Formation Potential*</i>	kg PM10 eq/Household per year ⁱⁱ	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). ⁵ 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.

ⁱⁱ While PM2.5 is the indicator of greatest importance to the cooking fuel sector, the units associated with this indicator must remain kg PM10 equivalents because the secondary pollutants leading to PM formation are characterized to PM10 in the applied ReCiPe impact assessment methodology. The methodology includes PM2.5, PM10, PMcoarse, PM>10, NH₃, NO_x, SO₂. The ReCiPe methodology was selected over the U.S. TRACI methodology (which does characterize particulate matter to PM2.5) because it has gone through much more rigorous review at a global level than TRACI.

Table B-2. Environmental Indicator Units and Description

Indicator	Unit	Description
<i>Fossil Fuel Depletion*</i>	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.
<i>Water Depletion</i>	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.
<i>Terrestrial Acidification Potential*</i>	kg SO ₂ eq/Household per year	Emissions such as SO ₂ , NO _x , 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.
<i>Freshwater Eutrophication Potential*</i>	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).
<i>Photochemical Oxidant Formation Potential*</i>	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.*

B.2.8 Economic Methodology and Indicators

Data was gathered on the economic impacts of using the feedstocks and fuels for cooking by focusing on three economic indicators. The fuel use indicator allows the reader to understand what cooking fuels are currently used within each country. Imports, exports, production and

demand (assumed to be equal to current consumption) provides quantities of which cooking fuels or their feedstocks are produced within or imported to the country and are available for use. The third indicator (Fuel Cost) is necessary to gauge the economic impacts of using various fuels on the end user. Table B-3 provides the list of Economic Indicators with descriptions of each indicator following the table.

Table B-3. Economic Indicator Units and Description

Indicator	Unit	Description
<i>Fuel Use</i>	%	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.
<i>Fuel Cost</i>	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.
<i>Imports, Exports, Production, and Demand</i>	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.

B.2.8.1 Fuel Use

Data on the percentage of the population in each country using various cooking fuels are primarily drawn from the Alliance’s country profiles. These data have the advantage of being standardized across countries and available for all countries of interest; however, the current fuels used do not necessarily correspond with the fuels in this study’s scope. For instance, the Alliance data present a comprehensive view of the cooking fuels used in each country, which means that some fuels (e.g., electricity, coal, and kerosene) are included in this fuel use indicator but are not otherwise studied in depth in this section. Additionally, some of the fuel use percentages available were broad, aggregated categories that include a number of focus fuels from this analysis (e.g., the Alliance data include a general category of “biomass,” whereas this study evaluates specific forms of biomass, such as firewood, wood chips, wood pellets, crop residue briquettes, etc.).

Where available, these data were supplemented with other estimates from the market assessments commissioned by the Alliance, information collected through conversations with the Alliance’s market managers, and other data identified through literature searches. These data were not used as the primary data source due to data gaps, as data on some fuels were not available for some countries. Additionally, many of these studies collected information on all fuel types that are used to any degree, rather than the primary fuel types used. The total of the

percentages of fuels used in some cases (either from one source or when combining sources) sums to greater than 100 percent. In spite of these limitations, data from these sources do fill in the granularity gaps in the Alliance data (e.g., by describing what types of biomass fuels are most commonly used), and are used to provide data for the fuel use patterns described in the Alliance data.

One limitation of the fuel use estimates is that they capture national-level patterns but often do not capture regional variations, such as differences in urban and rural fuel use. Where possible the Alliance data are supplemented with information on rural/urban differences in fuel use patterns.

Another limitation is that the national-level data do not reflect fuels that are being used on a pilot or very small-scale basis. Fuels that are used by less than 0.1 percent of the population are not captured in the figures below, but where information was available on pilot projects or small enterprises promoting fuels that are not widely used nationally, they are discussed qualitatively.

B.2.8.2 Imports, Exports, Production and Demand

Data on fuel imports, exports, production, and demand are drawn from four main multi-country datasets, and supplemented by any other available statistics. The four main datasets are:

1. **The United Nations Statistics Division's (UNSD) Energy Statistics database.**⁶ This database contains time series data for 220 countries on the net tonnages of fuels traded, produced, and consumed at national and household levels. The data are collected through each country's response to UNSD's Annual Questionnaire on Energy Statistics. This data source has the advantage of producing trade, production, and consumption statistics that can be compared with each other to get a sense of how self-sufficient each country is for the production of each fuel. However, of the fuels within the scope of this report, only propane and charcoal are included. Even for these fuels, data gaps exist for many of the countries covered.
2. **UNSD's Commodity Trade Statistics Database (Comtrade) database.**⁷ This database contains time series data on the quantity, net weight, and trade value of all kinds of merchandise for 254 countries, collected from each country's national bureau of statistics. Data are available for many of the feedstocks and fuels that are in the scope of this study, although there are data gaps for many of the countries covered. No data on the feedstocks/fuels of interest are available in this source for Bangladesh, Kenya, or Nigeria.
3. **The OECD/Food and Agriculture Organization of the United Nations (OECD/FAO) Agricultural Outlook 2014-2023 for Biofuel.**⁸ This source includes data on the volume in liters of the trade, production, and total consumption of ethanol. Like other OECD data, this dataset focuses primarily on OECD countries but includes some countries of interest. However data are missing, in part or entirely, for China, Guatemala, Kenya, and Uganda.
4. **FAO's FAOStat forestry data.**⁹ This database includes data on the net weight of production of various wood feedstocks and fuels, including firewood, wood charcoal,

wood pellets, and wood chips. These data are available for most countries of interest, although data on wood chips and pellets are only available for China.

Where other data points were found to fill in a data gap for a particular country/fuel combination, these are noted in the report. For example, the estimates of firewood consumption in Kenya and ethanol production in Guatemala come from articles and presentations on these topics.^{10,11}

In additions to the data gaps noted above, there are several other limitations to be considered. Most importantly, these data often do not differentiate between fuel used for cooking and fuel used for other purposes, such as industrial purposes or household heating and lighting. This is particularly an issue in the case of ethanol, which in most countries is likely being used for transportation or other industrial purposes rather than cooking. Second, the data sources may not include fuels or feedstocks that are collected and used by households or that are bought and sold in the informal economy. This is particularly an issue for firewood collected and used by individual households. Finally, while the Comtrade, OECD/FAO, and FAO data are all for the year 2013, the most recent year for which UNSD Energy Statistics data used for propane and charcoal were available during the data collection phase of this project was 2011. If major fluctuations occurred in the markets for propane or charcoal between 2011 and 2013, comparisons between those fuels data and that of other fuels in 2013 might have a high uncertainty.

B.2.8.3 Fuel Cost

Data on the cost of each fuel type are drawn from a number of sources, primarily market assessments commissioned by the Alliance, supplemented as needed by published articles, Alliance partners, and Alliance market managers.

It should be noted that it was not possible to find or estimate data on cost for many fuel/country combinations. In some cases, this was because the fuel is being used on a pilot or small-scale basis, and thus is not available outside a very limited region. Some data are based on a survey of a particular village or region and thus might not be nationally representative. Finally, the available cost data are point estimates for a given year and do not capture any changes in the market since the time they were collected. In the cost discussion for each country, it is noted whether costs for any of the fuels are subsidized.

The source data vary in the currency in which they are presented, the year in which they were collected, the frequency with which the cost would be incurred (i.e., per meal, per day, per week, per month, or per year), and the units used (i.e., whether the costs are for a particular weight of fuel). In order to convert these to a common basis that allows estimates to be compared across countries and across fuels, several calculations are necessary, as detailed below.

1. Generating urban/rural weighted averages

Where a data source presented two estimates, one for rural areas and one for urban areas, a nationally-representative weighted average based on the percentage of the population that lives in these areas is used. This calculation is as follows:

$$\text{weighted average} = (\text{percent}_{\text{rural}})(\text{price}_{\text{rural}}) + (\text{percent}_{\text{urban}})(\text{price}_{\text{urban}}).$$

The estimated percentages of the population living in rural and urban areas in each country are shown in Table B-4. These estimates are drawn primarily from the Alliance's market assessments, with the China estimate drawn from the World Bank's World Development Indicators database.

Table B-4. Percentage of the Population in Urban/Rural Areas by Country

Country	Rural	Urban	Source(s)
China	47%	53%	World Bank, 2014b
India	70%	30%	Dalberg, 2013
Bangladesh	72%	28%	Accenture, 2012a
Ghana	49%	51%	Accenture, 2012b
Guatemala	51%	49%	ESF, 2013
Kenya	78%	22%	GVEP International, 2012a
Nigeria	50%	50%	Accenture, 2011
Uganda	87%	13%	GVEP International, 2012b

2. Converting to kg

Data on physical units of fuel were converted to a common basis of kilograms. The biogas cost estimates in one source¹² were on a per-GJ basis, and this was converted to kilograms using the assumption that there are 100 kilograms of biogas per GJ of delivered energy (based on biogas produced from cattle dung and a stove thermal efficiency of 55 percent).

3. Converting weight/volume-based estimates to time-based estimates

Table B-5 shows the conversion factors used to convert data on kilograms of fuel to a meal- or time-basis. In many cases, costs were estimated on a per-kilogram of fuel basis. These estimates were converted to per-meal estimates using the average number of kilograms of the fuel typically used to make a meal.^{13,14} Similarly, estimates of the cost of firewood in Guatemala are typically given on a per-tarea basis (one tarea of firewood typically measures one meter high by 5 meters long by 35 cm wide). The volume of wood was converted to a per-month usage basis, which can then be converted to a per-household-per-year basis.¹⁵

Note that these estimates are not stove-specific, but rather are approximate estimates that reflect the stove mix currently used in the area discussed in each article.

Table B-5. Fuel Quantity per Cooking Basis

Kilogram Conversions		
Fuel	Kg per Meal	Source
LPG	0.45	Thurber et al., 2014
Firewood	0.45	Thurber et al., 2014
Crop Residue Pellets/Briquettes	0.45	Thurber et al., 2014
Charcoal	0.45	BMZ, 2014
Tarea Conversions		
Fuel	Tareas per Month	Source
Firewood	1.03	Wang et al., 2013

4. Converting to year-based estimates

Estimates for other cooking basis periods were converted to a cost per year using the assumptions that there are three meals per day, 12 months per year, 52 weeks per year, and 365 days per year.

5. Converting to cost per household

Most data sources presented costs expressed on a cost per household basis. Cost data that were expressed on a per person basis were converted to a cost per household using the estimated household sizes shown in Table B-6.

Table B-6. Estimated Household Size by Country

Country	Household Size	Source
China	3.10	TekCarta, 2015
India	4.91	Dalberg, 2013
Bangladesh	4.40	Accenture, 2012a
Ghana	4.00	Accenture, 2012b
Guatemala	4.90	ESF, 2013
Kenya	5.00	GVEP International, 2012a
Nigeria	5.50	Accenture, 2011
Uganda	4.70	GVEP International, 2012b

6. Annualizing biogas digester costs

When producing biogas, the feedstock (such as animal dung, crop residue, or food scraps) is considered a free waste product with no cost. In order to estimate a cost for biogas, the cost of the digester is annualized at an interest rate of 7 percent over 15 years (the average digester lifetime)¹⁶. This annualized cost represents the annual payment that would have to be made at this interest rate over the specified period in order to pay for the initial capital cost of the digester.

Annualization uses the formula:

$$\text{Annualized Cost} = \frac{rP}{1 - (1 + r)^{-N}}$$

where r is the interest rate;
 P is the initial payment; and
 N is the period.

In practice, this calculation is performed in Microsoft Excel using the formula PMT (rate, period, -initial cost). It should be noted that the biodigester costs in each country section refer only to the annualized cost of purchasing the digester. It is expected that there will also be some costs associated with biodigester maintenance and repair over the years (a few years of which are often included with the digester purchase),^{17, 18} but no data were available to quantify these costs.

7. Converting to 2013 US dollars (USD)

The cost estimates in the data sources are presented in a range of currencies and are from various years. In order to present costs in a consistent unit that allows for comparison across countries and fuels, 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.

The first step in this process is to convert any non-USD estimates to US dollars, using the currency exchange rate in the year the data were collected. These exchange rates are shown for each country and year in Table B-7.¹⁹

Next, the USD estimate for the year the data were collected is converted to 2013 USD using the US Bureau of Economic Analysis' (BEA) implicit price deflator for gross domestic product (GDP) index.²⁰ This is re-indexed to 2013 by dividing the value in 2013 by the value in a given year in order to produce as "2013 USD conversion factor," as shown in Table B-7.

8. Compiling estimates

Where a data source presented costs as a range, the median cost is used. In cases where a number of estimates were available for a country/fuel combination, the average of the estimates is employed.

Table B-7. Exchange Rates and BEA GDP Deflator used to convert to 2013 USD

Item		Year													
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Country	Currency	Currency per USD													
China	Yuan	8.279	8.277	8.277	8.277	8.277	8.194	7.973	7.608	6.949	6.831	6.770	6.461	6.312	6.196
India	Rupees	44.942	47.186	48.610	46.583	45.316	44.100	45.307	41.349	43.505	48.405	45.726	46.670	53.437	58.598
Bangladesh	Taka	52.142	55.807	57.888	58.150	59.513	64.327	68.933	68.875	68.598	69.039	69.649	74.152	81.863	78.103
Ghana	Cedis	0.545	0.716	0.792	0.867	0.899	0.906	0.916	0.935	1.058	1.409	1.431	1.512	1.796	1.954
Guatemala	Quetzal	7.763	7.859	7.822	7.941	7.946	7.634	7.603	7.673	7.560	8.162	8.058	7.785	7.834	7.857
Kenya	Kenyan Shillings	76.176	78.563	78.749	75.936	79.174	75.554	72.101	67.318	69.175	77.352	79.233	88.811	84.530	86.123
Nigeria	Naira	101.697	111.231	120.578	129.222	132.888	131.274	128.652	125.808	118.546	148.902	150.298	154.740	157.499	157.312
Uganda	Ugandan Shillings	1,644.475	1,755.659	1,797.551	1,963.720	1,810.305	1,780.666	1,831.453	1,723.492	1,720.444	2,030.488	2,177.558	2,522.746	2,504.563	2,586.890
Index		Index Value													
BEA GDP Deflator		81.890	83.755	85.040	86.735	89.118	91.985	94.812	97.340	99.218	100.000	101.226	103.315	105.174	106.739
2013 USD Conversion Factor		1.303	1.274	1.255	1.231	1.198	1.160	1.126	1.097	1.076	1.067	1.054	1.033	1.015	1.000

Sources: World Bank, 2014c, BEA, 2014.

B.2.9 Social Methodology and Indicators

Seven indicators describing the social and socioeconomic impacts of manufacturing, distributing, and consuming various feedstocks and cooking fuels were assessed by evaluating related literature. The term “indicator” is used to describe the key considerations or impact areas addressed and comprise a combination of quantitative data and qualitative insights. The first indicator provides government policies and programs related to the fuels used for cooking within the country, which could include programs encouraging certain fuels or subsidies for fuel use. Also included are policies related to the energy sector more broadly (e.g., sustainable energy targets) and those affecting feedstock availability (e.g., forestry initiatives). Two of the indicators (Income Earning Opportunities and Opportunities for Women Along the Value Chain) evaluate the capacity of each fuel/country combination to provide employment and enable the development of transferrable skills for sustained economic opportunity. Another set of indicators (Supply & Access Challenges and Distribution & Adoption Challenges) takes into account cultural factors and logistical considerations for both producers and consumers for the various fuels and feedstocks. The final grouping of indicators (Protection & Safety and Time & Drudgery) explore the end-user repercussions associated with procuring and cooking with each type of fuel. Within the discussions of these indicators, quantities for the indicator have been included wherever possible with recourse to a discussion assessment otherwise. These indicators distinguish between impacts on urban and rural populations wherever applicable, and have disaggregated findings by gender where relevant. Table B-8 provides the list of Social Indicators with descriptions of each.

Table B-8. Social Indicators and Descriptions

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.

Table B-8. Social Indicators and Descriptions

Indicator	Description
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.

In the literature search for these indicators, Alliance reports, partner outreach, and available case studies are the main sources. A “country-based” approach has been applied, in that only information based on or developed on the focus countries were included. For example, no country-neutral LPG time savings data were calculated to keep the social indicators focused on the focus countries.

B.3 LIFE CYCLE INVENTORY ASSUMPTIONS AND DATA SOURCES FOR COOKING FUELS

Many of the country- and fuel-specific assumptions (e.g., cookstove efficiencies and heating values) are provided in Appendix A tables at the beginning of the environmental sections of each country. Additional assumptions and data sources for the LCA of each of the fuels within each country in this analysis are provided in Table B-9 through Table B-26. The electrical grid mix modeled for each country is presented in Table B-27.

Table B-9. Process Descriptions for Firewood

Country	Description	Modeling Sources
China	Cooking fuel wood is harvested from mature trees or their big branches (e.g., eucalyptus, acacia, oak, pine, poplar, willows, etc.), obtained manually from local forest, sun-dried, and stored in a large storage room for at least 4 weeks prior to use. Brush wood, or thin branches of brushes which normally grow faster than trees, obtained locally are also modeled as sun-dried, and stored in a large storage room for at least 4 weeks prior to use. About 43% of firewood from China is assumed to be supplied by non-renewable forests. Fuel wood and brush wood are assumed to be collected manually and combusted in traditional and improved brick and metals stoves with efficiencies ranging from 16.3% to 19.2% depending on the fuel/stove technology combination. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in China is modeled as 15.3 MJ/kg.	FAO, 2010 Dalberg, 2014 Jingjing et al., 2001 Liu et al., 2011 Tsai et al., 2003 Zhang et al., 2000

Table B-9. Process Descriptions for Firewood

Country	Description	Modeling Sources
India	Typical tree species used for firewood in India are acacia, eucalyptus, bamboo, sheesham and mango. 41% of firewood from India is modeled as being supplied by non-renewable outside forests. Firewood is modeled as collected manually and combusted in a traditional mud stove. Collection losses are assumed to be 4%. The stove efficiency is modeled as 13.5%. The remaining ash is assumed to be land applied. The wood energy input of average fuel wood used in India is modeled as 15.84 MJ/kg.	FAO, 2010 Reddy & Venkataraman, 2002b Saud et al., 2012 Singh & Gundimeda, 2014 Singh et al., 2014 Smith et al., 2000 Venkataraman & Rao, 2001
Bangladesh	Firewood from Bangladesh is modeled as 100% supplied by non-renewable sources. Firewood is assumed to be collected manually and combusted in a traditional mud stove. The stove efficiency is modeled as 13.5%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in Bangladesh is modeled as 15.84 MJ/kg.	DOE ORNL, 2010 FAO, 2010 Ho et al., 2013 IEA, 2014 Singh et al., 2014
Guatemala	Firewood from Guatemala is modeled as 100% supplied by non-renewable sources. Firewood is assumed to be collected manually and combusted in a traditional mud stove. The stove efficiency is modeled as 15%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in Guatemala is modeled as 17.4 MJ/kg.	Boy et al., 2000 DOE ORNL, 2010 FAO, 2010 GACC, 2010
Ghana	Firewood from Ghana is modeled as 100 % supplied by non-renewable sources. Firewood is assumed to be collected manually and combusted in a traditional mud stove. The stove efficiency is modeled as 14%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in Ghana is modeled as 14 MJ/kg.	Afrane & Ntiamoah, 2011 DOE ORNL, 2010 FAO, 2010
Kenya	Firewood from Kenya is modeled as 100% supplied by non-renewable sources. Firewood is assumed to be collected manually and combusted in a traditional mud stove. The stove efficiency is modeled as 15%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in Kenya is modeled as 16 MJ/kg.	Afrane & Ntiamoah, 2011 DOE ORNL, 2010 FAO, 2010 GACC, 2010
Nigeria	Firewood from Nigeria is modeled as 100% supplied by non-renewable sources. Firewood is assumed to be collected manually and combusted in a traditional mud stove. The stove efficiency is modeled as 14%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in Nigeria is modeled as 14 MJ/kg.	Afrane & Ntiamoah, 2011 DOE ORNL, 2010 FAO, 2010
Uganda	Firewood from Uganda is modeled as 100% supplied by non-renewable sources. Firewood is assumed to be collected manually and combusted in a traditional mud stove. The stove efficiency is modeled as 15%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in Uganda is modeled as 16 MJ/kg.	Afrane & Ntiamoah, 2011 DOE ORNL, 2010 FAO, 2010 GACC, 2010

Table B-10. Process Descriptions for Charcoal Briquettes from Wood

Country	Description	Modeling Sources
China	Charcoal is not heavily used as a cooking fuel in China, therefore, data is limited. The model is adapted from the India model with the following exceptions: 1) 42% of wood in China is assumed to be from nonrenewable forests 2) The average distance from the kiln to the retail is assumed to be 1,979 km by barge based on the average distance of main urban centers to forests, and 3) 90% of briquetting in China is assumed to be in motorized machines, while the rest is assumed to be manual.	Adam, 2009 Bhattacharya et al., 2000 Grover et al., 1996 Kadian et al., 2007 Pennise et al., 2001 Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 1999 Smith et al., 2000
India	Charcoal is produced from wood in a traditional earth mound kiln. The charcoal yield from the kiln is assumed to be 30% with the residue assumed to be disposed in a waste land. The wood the charcoal is derived from is assumed to be 41% supplied by non-renewable outside forests. The firewood is assumed to be collected and brought to the charcoal kiln manually. 50% of charcoal briquettes are produced manually, while 50% are produced in motorized machines. Charcoal is an informal sector in India. It is assumed charcoal is transported from the kiln to the retail 805 km by single unit truck based on the average distance between forests and urban centers in India. Physical losses of charcoal from the kiln to use in cookstove are assumed to be 5%. Charcoal is combusted in a metal stove with a stove efficiency of 17.5%. Remaining ash is land applied.	Adam, 2009 Bhattacharya et al., 2000 Grover et al., 1996 Kadian et al., 2007 Pennise et al., 2001 Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 1999 Smith et al., 2000
Bangladesh	The Bangladesh charcoal production model is adapted from a model of an earth mound kiln in Thailand. 3.35 kg of wood are required to produce 1 kg charcoal output. All wood in Bangladesh is calculated as from nonrenewable forestry practices. In Bangladesh, all briquetting is assumed to be done manually. Charcoal is transported 383 km via single unit truck based on the average distance between forested areas and main population centers in Bangladesh. The use phase is adapted from the India charcoal model.	Singh et al., 2014 Smith et al., 1999
Guatemala	Charcoal from wood in Guatemala is modeled as produced in a surface kiln. 3.484 kg of wood are required per 1 kg charcoal output. All wood in Guatemala is assumed to be sourced from nonrenewable resources. In Guatemala, all briquetting is assumed to be done manually. Charcoal is transported 330 km via single unit truck based on the average distance between forested areas and main population centers in Guatemala. The use phase is adapted from the Ghana charcoal model.	Afrane & Ntiamoah, 2011 Pennise et al., 2001
Ghana	Charcoal in Ghana is produced in an earth mound kiln, with 4.9 kg wood required per kg charcoal output. Only 3% of briquettes in African countries are assumed to be produced via motorized machines. The briquettes are transported 483 km by single unit truck based on the average distance between forested areas and large urban population centers in Ghana. The charcoal stove efficiency in Ghana is 18%, and the remaining ash is land applied.	Afrane & Ntiamoah, 2011 Grover et al., 1996 Pennise et al., 2001 Singh et al., 2014

Table B-10. Process Descriptions for Charcoal Briquettes from Wood

Country	Description	Modeling Sources
Kenya	Charcoal in Kenya is produced in an earth mound kiln. 3.215 kg of wood are required per kg charcoal produced. All wood in Kenya is assumed to be sourced from nonrenewable resources. Only 3% of briquettes in African countries are assumed to be produced via motorized machines. Charcoal is transported 323 km via single unit truck based on the average distance between forested areas and main population centers in Kenya. The use phase is adapted from the Ghana charcoal model.	Afrane & Ntiamoah, 2011 Grover et al., 1996 Pennise et al., 2001
Nigeria	The Nigeria charcoal model is adapted from the model produced for Ghana. The main difference is the distribution transport assumed. For Nigeria, charcoal is assumed to be transported 322 km by single unit truck (between kiln and retail) based on the average distance between main forested areas and urban population centers in Nigeria.	Afrane & Ntiamoah, 2011 Grover et al., 1996 Pennise et al., 2001 Singh et al., 2014
Uganda	The Uganda charcoal production model is adapted from the Kenya model. All wood in Uganda is assumed to be sourced from nonrenewable resources. The transportation assumption is adapted for Uganda conditions. Charcoal is transported 241 km via single unit truck based on the average distance between forested areas and main population centers in Uganda. The Uganda charcoal use phase model is adapted from the Ghana charcoal model.	Afrane & Ntiamoah, 2011 Grover et al., 1996 Pennise et al., 2001

Table B-11. Process Descriptions for Charcoal Briquettes from Bamboo

Country	Description	Modeling Sources
China	In China, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For China, 90% of the charcoal is modeled as produced in hot-tail kilns and 10% produced in earthen mounds. Briquettes are made using a combination of mechanical and manual processes. The briquetting methods in China are modeled as 90% motorized machines and 10% manual machines/manual. Mechanical processing includes charcoal pulverizing and briquette production. Manufacturer specifications for energy consumption were obtained assuming 10 tons per hour output by the pulverizer and briquetting machine. Briquettes are modeled as combusted in a stove with an efficiency of 17.5%. Transport and emissions for wood charcoal combustion in China are used as a proxy for bamboo charcoal briquettes.	Chen et al., 2015 Durai, 2015 Gongyi, 2013 GVEP International, 2012c Henan Machine, 2013 Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 NMBA, 2005 Pennise et al., 2001 Singh et al., 2014 Wu & Lin, 2012 Yu et al., 2011

Table B-11. Process Descriptions for Charcoal Briquettes from Bamboo

Country	Description	Modeling Sources
India	<p>In India, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Bamboo cultivation is modeled as not requiring irrigation. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For India, 50% of the charcoal is modeled as produced in hot-tail kilns and 50% produced in earthen mounds. Briquettes are made using a combination of mechanical and manual processes. The briquetting methods in India are modeled as 50% motorized machines and 50% manual machines/manual. Mechanical processing includes charcoal pulverizing and briquette production. Manufacturer specifications for energy consumption were obtained assuming 10 tons per hour output by the pulverizer and briquetting machine. Briquettes are modeled as combusted in a stove with an efficiency of 17.5%. Transport and emissions for wood charcoal combustion in India are used as a proxy for bamboo charcoal briquettes.</p>	<p>Chen et al., 2015 Durai, 2015 Gongyi, 2013 GVEP International, 2012c Henan Machine, 2013 Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 NMBA, 2005 Pennise et al., 2001 Singh et al., 2014 Wu & Lin, 2012 Yu et al., 2011</p>
Bangladesh	<p>In Bangladesh, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Bamboo cultivation is modeled as not requiring irrigation. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For Bangladesh, 100% of the charcoal is modeled as produced in earthen mounds. Briquettes are made by hand or with a hand operated press. Briquettes are modeled as combusted in a stove with an efficiency of 17.5%. Transport and emissions for wood charcoal combustion in Bangladesh are used as a proxy for bamboo charcoal briquettes.</p>	<p>Chen et al., 2015 Durai, 2015 GVEP International, 2012c Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 NMBA, 2005 Pennise et al., 2001 Singh et al., 2014 Wu & Lin, 2012 Yu et al. 2011</p>
Guatemala	<p>In Guatemala, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Bamboo cultivation is modeled as not requiring irrigation. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For Guatemala, 100% of the charcoal is modeled as produced in surface kilns. Briquettes are made by hand or with a hand operated press. Briquettes are modeled as combusted in a stove with an efficiency of 18%. Transport and emissions for wood charcoal combustion in Guatemala are used as a proxy for bamboo charcoal briquettes.</p>	<p>Afrane & Ntiamoah, 2011 Chen et al., 2015 Durai, 2015 GVEP International, 2012c Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 NMBA, 2005 Pennise et al., 2001 Wu & Lin, 2012 Yu et al., 2011</p>

Table B-11. Process Descriptions for Charcoal Briquettes from Bamboo

Country	Description	Modeling Sources
Ghana	<p>In Ghana, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Bamboo cultivation is modeled as not requiring irrigation. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For Ghana, 3% of the charcoal is modeled as produced in hot-tail kilns and 97% produced in earthen mounds. Briquettes are made using a combination of mechanical and manual processes. The briquetting methods in Ghana are modeled as 3% motorized machines and 97% manual machines/manual. Mechanical processing includes charcoal pulverizing and briquette production. Manufacturer specifications for energy consumption were obtained assuming 10 tons per hour output by the pulverizer and briquetting machine. Briquettes are modeled as combusted in a stove with an efficiency of 18%. Transport and emissions for wood charcoal combustion in Ghana are used as a proxy for bamboo charcoal briquettes.</p>	<p>Afrane & Ntiamoah, 2011 Chen et al., 2015 Durai, 2015 Gongyi, 2013 GVEP International, 2012c Henan Machine, 2013 Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 Pennise et al., 2001 NMBA, 2005 Wu & Lin, 2012 Yu et al., 2011</p>
Kenya	<p>In Kenya, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Bamboo cultivation is modeled as not requiring irrigation. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For Kenya, 3% of the charcoal is modeled as produced in hot-tail kilns and 97% produced in earthen mounds. Briquettes are made using a combination of mechanical and manual processes. The briquetting methods in Kenya are modeled as 3% motorized machines and 97% manual machines/manual. Mechanical processing includes charcoal pulverizing and briquette production. Manufacturer specifications for energy consumption were obtained assuming 10 tons per hour output by the pulverizer and briquetting machine. Briquettes are modeled as combusted in a stove with an efficiency of 18%. Transport and emissions for wood charcoal combustion in Kenya are used as a proxy for bamboo charcoal briquettes.</p>	<p>Afrane & Ntiamoah, 2011 Chen et al. 2015 Durai, 2015 Gongyi, 2013 GVEP International, 2012c Henan Machine, 2013 Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 NMBA, 2005 Pennise et al., 2001 Wu & Lin, 2012 Yu et al., 2011</p>
Nigeria	<p>In Nigeria, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Bamboo cultivation is modeled as not requiring irrigation. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For Nigeria, 3% of the charcoal is modeled as produced in hot-tail kilns and 97% produced in earthen mounds. Briquettes are made using a combination of mechanical and manual processes. The briquetting methods in Nigeria are modeled as 3% motorized machines and 97% manual machines/manual. Mechanical processing includes charcoal pulverizing and briquette production. Manufacturer specifications for energy consumption were obtained assuming 10 tons per hour output by the pulverizer and briquetting machine. Briquettes are modeled as combusted in a stove with an efficiency of 18%. Transport and emissions for wood charcoal combustion in Nigeria are used as a proxy for bamboo charcoal briquettes.</p>	<p>Afrane & Ntiamoah, 2011 Chen et al., 2015 Durai, 2015 Gongyi, 2013 GVEP International, 2012c Henan Machine, 2013 Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 NMBA, 2005 Pennise et al., 2001 Wu & Lin, 2012 Yu et al., 2011</p>

Table B-11. Process Descriptions for Charcoal Briquettes from Bamboo

Country	Description	Modeling Sources
Uganda	In Uganda, bamboo charcoal briquettes are modeled as supplied 100% by renewable sources. Bamboo cultivation is modeled as not requiring irrigation. Briquettes are made using bamboo culms that are cut by hand, gathered using manual labor, and air dried before carbonization. For Uganda, 3% of the charcoal is modeled as produced in hot-tail kilns and 97% produced in earthen mounds. Briquettes are made using a combination of mechanical and manual processes. The briquetting methods in Uganda are modeled as 3% motorized machines and 97% manual machines/manual. Mechanical processing includes charcoal pulverizing and briquette production. Manufacturer specifications for energy consumption were obtained assuming 10 tons per hour output by the pulverizer and briquetting machine. Briquettes are modeled as combusted in a stove with an efficiency of 18%. Transport and emissions for wood charcoal combustion in Kenya are used as a proxy for bamboo charcoal briquettes.	Afrane & Ntiamoah, 2011 Chen et al., 2015 Durai, 2015 Gongyi, 2013 GVEP International, 2012c Henan Machine, 2013 Hernandez-Mena et al., 2014 Kwaku, 2010 Liu et al., 2014 NMBA, 2005 Pennise et al., 2001 Wu & Lin, 2012 Yu et al., 2011

Table B-12. Process Descriptions for Non-Carbonized Briquettes from Sawdust

Country	Description	Modeling Sources
China	In China, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in China are modeled as 90% motorized machines and 10% manual machines/manual. Mechanical processing includes sieving, drying, preheating, densification, cooling, and packing. The stove efficiency is modeled as 29.9%. The remaining ash is assumed to be land applied. The average of heating values of fuel wood used in China is modeled as 18.6 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.	FAO, 2010 GACC, 2015a Grover et al., 1996 Raju et al., 2014 Charcoal Briquette Machine, 2015 Shanavas & Kumar, 2006 Urban Uganda, 2015 Zhang et al., 2000
India	In India, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in India are modeled as 50% motorized machines and 50% manual machines/manual. Mechanical processing includes sieving, drying, preheating, densification, cooling, and packing. The stove efficiency is modeled as 25.5%. The remaining ash is assumed to be land applied. The average heating value of fuel wood used in India is modeled as 18.8 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.	FAO, 2010 GACC, 2015a Grover et al., 1996 Kaur et al., 2012 Shanavas & Kumar, 2006 Singh & Gundimeda, 2014 Singh et al., 2014 Urban Uganda, 2015 Vyas et al., 2015

Table B-12. Process Descriptions for Non-Carbonized Briquettes from Sawdust

Country	Description	Modeling Sources
Bangladesh	<p>In Bangladesh, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Motorized machines are not used to process non-carbonized briquettes in Bangladesh, but instead are processed using manual machines or by hand. The stove efficiency is modeled as 29.9%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The average heating value of fuel wood used in Bangladesh is modeled as 18.6 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.</p>	<p>Afrane & Ntiamoah, 2012 Shahjahan, 2015 Davies et al., 2013 DOE ORNL, 2010 FAO, 2010 GACC, 2015a Grover et al. 1996 Ho et al., 2013 Raju et al., 2014 Charcoal Briquette Machine, 2015 Kaur et al., 2012 Shanavas & Kumar 2006 Urban Uganda 2015 Vyas et al., 2015</p>
Guatemala	<p>In Guatemala, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Motorized machines are not used to process non-carbonized briquettes in Guatemala, but instead are processed using manual machines or by hand. The stove efficiency is modeled as 20%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The average heating value of fuel wood used in Bangladesh is modeled as 18.6 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.</p>	<p>Afrane & Ntiamoah, 2012 Davies et al, 2013 DOE ORNL 2010 FAO, 2010 Grover et al., 1996 Raju et al., 2014 Charcoal Briquette Machine, 2015 Kaur et al., 2012 Murali et al., 2015 Shanavas & Kumar, 2006 Urban Uganda, 2015 Vyas et al., 2015</p>
Ghana	<p>In Ghana, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in Ghana are modeled as 3% motorized machines, 16% manual machines and 81% manual and are based on data collected for Uganda. Mechanical processing includes sieving, drying, preheating, densification, cooling, and packing. The stove efficiency is modeled as 20.33%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The average of heating values of fuel wood used in Uganda and Nigeria is used as a proxy for average fuel wood used in Ghana and is modeled as 18.8 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.</p>	<p>Afrane & Ntiamoah, 2012 Davies et al., 2013 DOE ORNL, 2010 GVEP International, 2012c GACC, 2015a Grover et al., 1996 Kaur et al., 2012 Shanavas & Kumar 2006 Urban Uganda, 2015 Vyas et al., 2015</p>

Table B-12. Process Descriptions for Non-Carbonized Briquettes from Sawdust

Country	Description	Modeling Sources
Kenya	<p>In Kenya, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in Kenya are modeled as 3% motorized machines, 16% manual machines and 81% manual and are based on data collected for Uganda. Mechanical processing includes sieving, drying, preheating, densification, cooling, and packing. The stove efficiency is modeled as 20.33%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The average of heating values of fuel wood used in Uganda and Nigeria is used as a proxy for average fuel wood used in Kenya and is modeled as 18.8 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.</p>	<p>Afrane & Ntiamoah, 2012 Davies et al., 2013 DOE ORNL, 2010 GVEP International, 2012c GACC, 2015a Grover et al., 1996 Kaur et al., 2012 Shanavas & Kumar, 2006 Urban Uganda, 2015 Vyas et al., 2015</p>
Nigeria	<p>In Nigeria, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in Nigeria are modeled as 3% motorized machines, 16% manual machines and 81% manual and are based on data collected for Uganda. Mechanical processing includes sieving, drying, preheating, densification, cooling, and packing. The stove efficiency is modeled as 20.3%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The average heating value of fuel wood used in Nigeria is modeled as 17.6 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.</p>	<p>Afrane & Ntiamoah, 2012 Davies et al, 2013 DOE ORNL, 2010 GACC, 2015a Grover et al., 1996 Kaur et al., 2012 Shanavas & Kumar 2006 Urban Uganda 2015 Vyas et al., 2015</p>
Uganda	<p>In Uganda, non-carbonized briquettes from wood are modeled as supplied 100% by renewable sources. Briquettes are made using sawdust modeled as containing 40% moisture on a wet basis. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in Ghana are modeled as 3% motorized machines, 16% manual machines and 81% manual and are based on data collected for Uganda. Mechanical processing includes sieving, drying, preheating, densification, cooling, and packing. The stove efficiency is modeled as 20.3%. Ash production is based on an average ash content of 3.3%. The remaining ash is assumed to be land applied. The heating value of average fuel wood used in Kenya is modeled as 20.1 MJ/kg. Emissions for firewood combustion are used as a proxy for the combustion of non-carbonized briquettes.</p>	<p>Afrane & Ntiamoah, 2012 DOE ORNL, 2010 Ferguson, 2012 GACC, 2015a Grover et al., 1996 Kaur et al., 2012 Shanavas & Kumar, 2006 Urban Uganda, 2015 Vyas et al., 2015</p>

Table B-13. Process Descriptions for Non-Carbonized Briquettes from Crop Residues

Country	Description	Modeling Sources
China	<p>In China, briquettes from wheat, rice, and maize residue are modeled as supplied 100% by renewable sources. Briquettes are made using unprocessed crop residue modeled as containing 8.71% ash for wheat, 17.43% ash for rice, and 6.28% ash for maize. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in China are modeled as 90% motorized machines and 10% manual machines/manual. Crop briquettes are sold in local markets, and mechanically produced briquettes are modeled as being transported 5 km to retail. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop residue briquettes is modeled as 15.5 MJ/kg. Ash remaining after combustion is land applied.</p>	<p>Charcoal Briquette Machine, 2015 FAO, 2015 GACC, 2015a Grover et al., 2012 GVEP International, 2011 Kaur et al. 2012 Liu et al., 2011 Srivastava n.d. Vyas et al., 2015 Zhang et al., 2000</p>
India	<p>In India, briquettes from wheat and rice residue are modeled as supplied 100% by renewable sources. Briquettes are made using unprocessed crop residue modeled as containing 8.8% ash for wheat and 17.43% ash for rice. Briquettes are produced using a combination of mechanical and manual processes. The briquetting methods in India are modeled as 50% motorized machines and 50% manual machines/manual. Crop briquettes are sold in local markets, and mechanically produced briquettes are modeled as being transported 5 km to retail. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop residue briquettes is modeled as 16.84 MJ/kg. Ash remaining after combustion is land applied.</p>	<p>Charcoal Briquette Machine, 2015 FAO, 2015 GACC, 2015a Grover et al., 2012 GVEP International, 2011 Kaur et al., 2012 Liu et al., 2011 Singh et al., 2014 Srivastava, 2007. Tumuluru et al., 2010 Vyas et al., 2014</p>
Bangladesh	<p>In Bangladesh, briquettes from rice husks and rice straw are modeled as supplied by 100% renewable resources. Briquetting in Bangladesh is done with manual machines. Crop briquettes are sold in local markets, and no motorized transport is modeled. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop briquettes in Bangladesh is 14.5 MJ/kg. Ash remaining after combustion is land applied.</p>	<p>Asaduzzaman, 2010 GACC, 2015a GVEP International, 2011 Shahjahan, 2015 Singh et al., 2014 Vyas et al., 2015</p>
Guatemala	<p>In Guatemala, briquettes from maize straw are modeled as supplied by 100% renewable resources. Briquetting in Guatemala is done with manual machines. Crop briquettes are sold in local markets, and no motorized transport is modeled. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop briquettes in Guatemala is 16.1 MJ/kg. Ash remaining after combustion is land applied.</p>	<p>GACC, 2015a Grinnell, 2015 GVEP International, 2011 Nyer, 2012 Zhang et al., 2000</p>

Table B-13. Process Descriptions for Non-Carbonized Briquettes from Crop Residues

Country	Description	Modeling Sources
Ghana	In Ghana, briquettes from cocoa pods, maize stalks, millet stalks, rice straw, and sorghum stalk are modeled as supplied by 100% renewable resources. Briquettes are made using unprocessed crop residue modeled as containing 23.3% cocoa pods, 49.3% maize stalk, 4.3% millet stalks, 15.9% rice stalks, and 7.2% sorghum stalk based on overall production tonnes in Ghana. 3% of briquetting in African countries is modeled as motorized, with the rest being produced manually. Crop briquettes are sold in local markets, and mechanically produced briquettes are modeled as being transported 5 km to retail. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop briquettes in Ghana is 15.6 MJ/kg. Ash remaining after combustion is land applied.	Charcoal Briquette Machine, 2015 Duku et al., 2011 FAO, 2015 GACC, 2015a GVEP International, 2011 GVEP International, 2012c
Kenya	In Kenya, briquettes from coconut husks, coffee husks, and maize stalks are modeled as supplied by 100% renewable resources. Briquettes are made using unprocessed crop residue modeled as containing 3.5% coconut husks, 1.1% coffee husks, and 95.4% maize stalks based on overall production tonnes in Kenya. 3% of briquetting in African countries is modeled as motorized, with the rest being produced manually. Crop briquettes are sold in local markets, and mechanically produced briquettes are modeled as being transported 5 km to retail. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop briquettes in Kenya is 15.6 MJ/kg. Ash remaining after combustion is land applied.	Charcoal Briquette Machine, 2015 FAO, 2015 GACC, 2015a GVEP International, 2010 GVEP International, 2011 GVEP International, 2012c GVEP International, 2013 Phyllils2, 2015 Simonyan & Fasina, 2013
Nigeria	In Nigeria, briquettes from cocoa pods, ground nuts, maize stalks, millet stalks, rice straw, and sorghum stalk are modeled as supplied by 100% renewable resources. Briquettes are made using unprocessed crop residue modeled as containing 1.2% cocoa pods, 9.9% groundnuts, 34.5% maize stalk, 16.6% millet stalks, 15.6% rice stalks, and 22.2% sorghum stalk based on overall production tonnes in Ghana. 3% of briquetting in African countries is modeled as motorized, with the rest being produced manually. Crop briquettes are sold in local markets, and mechanically produced briquettes are modeled as being transported 5 km to retail. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop briquettes in Nigeria is 17.6 MJ/kg. Ash remaining after combustion is land applied.	Charcoal Briquette Machine, 2015 FAO, 2015 GACC, 2015a GVEP International, 2011 GVEP International, 2012c Simonyan & Fasina, 2013
Uganda	In Ghana, briquettes from cocoa pods, maize stalks, millet stalks, rice straw, and sorghum stalk are modeled as supplied by 100% renewable resources. Briquettes are made using unprocessed crop residue modeled as containing 23.3% cocoa pods, 49.3% maize stalk, 4.3% millet stalks, 15.9% rice stalks, and 7.2% sorghum stalk based on overall production tonnes in Ghana. 3% of briquetting in African countries is modeled as motorized, with the rest being produced manually. Crop briquettes are sold in local markets, and mechanically produced briquettes are modeled as being transported 5 km to retail. Briquettes are combusted in a stove with an efficiency of 31.0%. The average heating value of crop briquettes in Ghana is 15.6 MJ/kg. Ash remaining after combustion is land applied.	BMW, 2009 Charcoal briquette machine, 2015 Duku et al., 2011 GACC, 2015a GVEP International, 2010 GVEP International, 2011 GVEP International, 2012c GVEP International, 2013 Phyllils2, 2015 Simonyan & Fasina, 2013

Table B-14. Process Descriptions for Wood Pellets

Country	Description	Modeling Sources
China	It is assumed that wood species (based on the China national fuel/brush wood mix) typical for use in China are manually collected from local areas to be pelletized by small-scale manufacturers. Approximately 41% of the wood and brush inputs are assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the China geographic scope. Some incoming transport to pelletization (freight and truck) are accounted for to reflect transport for supplies to small-scale manufacturers and pellets from site to market. The model for biomass pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in China is modeled as 15.9 MJ/kg. Remaining ash is land applied.	Boman, 2005 Dalberg, 2014 Jetter et al., 2012 Jingjing et al., 2001 Jungbluth et al., 2007 Liu et al., 2011 Roy et al., 2013
India	It is assumed that wood in India is manually collected from local areas to be pelletized by small-scale manufacturers. Approximately 41% of the wood input is assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the India geographic scope. Some incoming transport to pelletization (freight and truck) are accounted for. The model for biomass pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in India is modeled as 17.94 MJ/kg. Remaining ash is land applied.	Boman, 2005 Dalberg, 2013 Jetter et al., 2012 Jungbluth et al., 2007 Roy et al., 2013 Singh et al., 2014
Bangladesh	It is assumed that wood species typical for use in Bangladesh are manually collected from local areas to be pelletized by small-scale manufacturers. All wood inputs are assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the Bangladesh geographic scope. Some incoming transport to pelletization (by truck) is accounted for to reflect transport for supplies to small-scale manufacturers and pellets from site to market. The model for wood pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in Bangladesh is modeled as 17.9 MJ/kg. Remaining ash is land applied.	Boman, 2005 Jetter et al., 2012 Jungbluth et al., 2007 Roy et al., 2013 Singh et al., 2014

Table B-14. Process Descriptions for Wood Pellets

Country	Description	Modeling Sources
Ghana	It is assumed that wood species typical for use in Ghana are manually collected from local areas to be pelletized by small-scale manufacturers. All wood inputs are assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the Ghana geographic scope. Some incoming transport to pelletization (by truck) is accounted for to reflect transport for supplies to small-scale manufacturers and pellets from site to market. The model for biomass pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in China is modeled as 17.9 MJ/kg. Remaining ash is land applied.	Boman, 2005 Jetter et al., 2012 Jungbluth et al., 2007 Roy et al., 2013 Singh et al., 2014
Nigeria	It is assumed that wood species typical for use in Nigeria are manually collected from local areas to be pelletized by small-scale manufacturers. All wood inputs are assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the Nigeria geographic scope. Some incoming transport to pelletization (by truck) is accounted for to reflect transport for supplies to small-scale manufacturers and pellets from site to market. The model for wood pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in Nigeria is modeled as 17.9 MJ/kg. Remaining ash is land applied.	Boman, 2005 Jetter et al., 2012 Jungbluth et al., 2007 Roy et al., 2013 Singh et al., 2014
Guatemala	It is assumed that wood species typical for use in Guatemala are manually collected from local areas to be pelletized by small-scale manufacturers. All wood inputs are assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the Guatemala geographic scope. Some incoming transport to pelletization (by truck) is accounted for to reflect transport for supplies to small-scale manufacturers and pellets from site to market. The model for wood pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in Guatemala is modeled as 17.9 MJ/kg. Remaining ash is land applied.	Boman, 2005 Jetter et al., 2012 Jungbluth et al., 2007 Roy et al., 2013 Singh et al., 2014
Kenya	It is assumed that wood species typical for use in Kenya are manually collected from local areas to be pelletized by small-scale manufacturers. All wood inputs are assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the Kenya geographic scope. Some incoming transport to pelletization (by truck) is accounted for to reflect transport for supplies to small-scale manufacturers and pellets from site to market. The model for wood pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in Kenya is modeled as 17.9 MJ/kg. Remaining ash is land applied.	Boman, 2005 Jetter et al., 2012 Jungbluth et al., 2007 Roy et al., 2013 Singh et al., 2014

Table B-14. Process Descriptions for Wood Pellets

Country	Description	Modeling Sources
Uganda	It is assumed that wood species typical for use in Uganda are manually collected from local areas to be pelletized by small-scale manufacturers. All wood inputs are assumed to be derived from non-renewable forestry practices. The processing energy and distribution transport are adapted from Austria and central Europe. Electricity is required for pelletization and is representative of the Uganda geographic scope. Some incoming transport to pelletization (by truck) is accounted for to reflect transport for supplies to small-scale manufacturers and pellets from site to market. The model for wood pellet combustion is based on laboratory testing results. The efficiency of the stove is assumed to be 53%. The heating value for wood pellets in Uganda is modeled as 17.9 MJ/kg. Remaining ash is land applied.	Boman, 2005 Jetter et al., 2012 Jungbluth et al., 2007 Roy et al., 2013 Singh et al., 2014

Table B-15. Process Descriptions for Wood Chips

Country	Description	Modeling Sources
China	In China, biomass is not used in urban areas as a cooking fuel. However, stoves using wood chips as cooking fuel are commercially available and used in rural areas. It is assumed rural consumers purchase wood chips from small enterprise start-ups, so the processing of wood chips is modeled as 100% mechanically chipped. Because electricity in China is accessible, an adapted ecoincent process for a stationary electric wood chipper is used as well as data for diesel-powered mobile wood chippers for processing the wood. Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in China is modeled as 15.3 MJ/kg. The efficiency of the stove is modeled as 31%.	GEA, 2012 GACC, 2015a Weidema et al., 2013 Zhang et al., 2000
India	In India, wood chips are modeled as processed by hand (manually) in rural areas or processed by small enterprises using mechanical chippers in urban areas. Based on the number of households relying on solid fuels in India, 87% of wood chips are modeled as manually chipped and 13% are mechanically chipped. The processing energy for diesel powered mobile wood chippers is modeled using an adapted European process. Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Wood collected in local areas is carried on foot to rural households and has no transportation impacts. Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in India is modeled as 15.84 MJ/kg. The efficiency of the stove is modeled as 31%.	GACC, 2015a Dalberg, 2013 Singh et al., 2014 Singh & Gundimeda, 2014 Weidema et al., 2013

Table B-15. Process Descriptions for Wood Chips

Country	Description	Modeling Sources
Bangladesh	<p>In Bangladesh, wood chips are modeled as processed by hand (manually) in rural areas or processed by small enterprises using mechanical chippers in urban areas. Based on the population relying on biomass resources as primary fuel for cooking, 56% of wood chips are modeled as manually chipped and 44% are mechanically chipped. The processing energy for diesel-powered mobile wood chippers is modeled using an adapted European process.</p> <p>Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Wood collected in local areas is carried on foot to rural households and has no transportation impacts. Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in Bangladesh is modeled as 15.84 MJ/kg. The efficiency of the stove is modeled as 31%.</p>	<p>DOE ORNL, 2010 GACC, 2015a Accenture, 2012a Ho et al., 2013 Singh et al., 2014 Weidema et al., 2013</p>
Guatemala	<p>According to the Market Manager for Guatemala, wood chips are not being used in cookstoves as fuel. In this analysis, it is assumed small business entrepreneurs who purchase a chipper are the only source for wood chips in Guatemala, so wood chips are modeled as processed 100% by a mechanical wood chipper. The processing energy for diesel-powered mobile wood chippers is modeled using an adapted European process. Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in Guatemala is modeled as 17.4 MJ/kg. The efficiency of the stove is modeled as 31%.</p>	<p>Boy et al., 2000 DOE ORNL, 2010 GACC, 2015a Grinnell, 2015 Weidema et al., 2013</p>
Ghana	<p>In Ghana, wood chips are modeled as processed by hand (manually) in rural areas or processed by small enterprises using mechanical chippers in urban areas. Based on the population relying on biomass resources as primary fuel for cooking, 72% of wood chips are modeled as manually chipped and 28% are mechanically chipped. The processing energy for diesel-powered mobile wood chippers is modeled using an adapted European process. Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Wood collected in local areas is carried on foot to rural households and has no transportation impacts.</p> <p>Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in Ghana is modeled as 14 MJ/kg. The efficiency of the stove is modeled as 31%.</p>	<p>Afrane & Ntiamoah, 2012 Boy et al., 2000 DOE ORNL, 2010 GACC, 2015a Weidema et al., 2013 WEO, 2006</p>

Table B-15. Process Descriptions for Wood Chips

Country	Description	Modeling Sources
Kenya	<p>In Kenya, wood chips are modeled as processed by hand (manually) in rural areas or processed by small enterprises using mechanical chippers in urban areas. Based on the population relying on biomass resources as primary fuel for cooking, 72% of wood chips are modeled as manually chipped and 28% are mechanically chipped. The processing energy for diesel-powered mobile wood chippers is modeled using an adapted European process. Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Wood collected in local areas is carried on foot to rural households and has no transportation impacts. Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in Kenya is modeled as 16 MJ/kg. The efficiency of the stove is modeled as 31%.</p>	<p>DOE ORNL, 2010 GACC, 2015a GACC, 2010 Weidema et al., 2013 WEO, 2006</p>
Nigeria	<p>In Nigeria, wood chips are modeled as processed by hand (manually) in rural areas or processed by small enterprises using mechanical chippers in urban areas. Based on the population relying on biomass resources as primary fuel for cooking, 72% of wood chips are modeled as manually chipped and 28% are mechanically chipped. The processing energy for diesel-powered mobile wood chippers is modeled using an adapted European process. Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Wood collected in local areas is carried on foot to rural households and has no transportation impacts. Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in Nigeria is modeled as 14 MJ/kg. The efficiency of the stove is modeled as 31%.</p>	<p>Afrane & Ntiamoah, 2012 DOE ORNL, 2010 GACC, 2015a Weidema et al., 2013 WEO, 2006</p>
Uganda	<p>In Uganda, wood chips are modeled as processed by hand (manually) in rural areas or processed by small enterprises using mechanical chippers in urban areas. Based on the population relying on biomass resources as primary fuel for cooking, 72% of wood chips are modeled as manually chipped and 28% are mechanically chipped. The processing energy for diesel-powered mobile wood chippers is modeled using an adapted European process. Transportation of mechanically chipped wood is modeled as 10 km from a local lumber yard to chipper and 5 km from chipper to markets/street vendors by diesel truck. Wood collected in local areas is carried on foot to rural households and has no transportation impacts. Firewood combustion and heating values are used as a proxy for wood chip combustion and heating values. The heating value of wood chips used in Uganda is modeled as 16 MJ/kg. The efficiency of the stove is modeled as 31%.</p>	<p>Afrane & Ntiamoah, 2012 DOE ORNL, 2010 GACC, 2015a GACC, 2010 Weidema et al., 2013 WEO, 2006</p>

Table B-16. Process Descriptions for Ethanol from Sugarcane

Country	Description	Modeling Sources
China	Ethanol in China is assumed to be produced in India and transported to China (see India model assumptions). Transport to China is modeled as 8,227 km (by ship) based on the distances between major ports in the two countries.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Tsiropoulos et al., 2014
India	In India, sugarcane cultivation practices are almost exclusively manual, with the exception of ploughing, which is mechanized in some states. Pre and post-harvest burning is not practiced in most of India. Sugarcane is transported 12 km to the sugarcane mill. The output products of the conventional sugar mill are sugar, molasses, bagasse, and electricity from surplus bagasse. Conventional mills represent 75% of the sugar production in India. Bagasse provides all necessary energy requirements at the mill and surplus electricity is produced which is considered a useful co-product to replace grid electricity in India. Sugarcane ethanol is then produced from the molasses. This study considers a weighted average of ethanol distilleries as standalone distilleries and as adjacent to sugar refineries. Molasses is transported on average 75 km to the ethanol plant. Sugarcane ethanol production energy is also provided by bagasse. The model is based on a hydrous ethanol yield (for 95% ethanol by volume) of 84.7 liters/tonne canne and an ethanol density of 0.789 kg/l. It is assumed the ethanol is transported 100% 750 km by heavy duty vehicle to the distributor and 100% 100 km by light duty vehicle from the distributor to retail. Sugarcane ethanol combustion emissions are based on laboratory testing, rather than field results. 35.9 kg of ethanol are required to deliver 1 GJ of heat energy for cooking, with a cookstove thermal efficiency of 53%.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Macedo et al., 2008 Prakash et al., 2005 Singh et al., 2014 Singh & Gundimeda, 2014 Tsiropoulos et al. 2014
Bangladesh	Ethanol in Bangladesh is assumed to be produced in India and transported to Bangladesh (see India model assumptions). Transport to Bangladesh is modeled as 673 km (by ship) based on the distances between major ports in the two countries.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Tsiropoulos et al., 2014
Guatemala	For Guatemala, sugarcane ethanol is assumed to be produced in Brazil, the largest global producer of ethanol from sugarcane. Sugarcane production is modeled as 80% manual and 20% mechanical harvest. Ethanol is produced directly from the cane (i.e., cannot converted first to molasses). Ethanol is produced via fermentation route using energy from the bagasse. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Ethanol is transport by ship from Brazil to Guatemala 6,556 km. Sugarcane ethanol combustion emissions are based on laboratory testing, rather than field results. 35.9 kg of ethanol are required to deliver 1 GJ of heat energy for cooking, with a cookstove thermal efficiency of 53%.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Ecoinvent Centre, 2010 Macedo et al., 2008

Table B-16. Process Descriptions for Ethanol from Sugarcane

Country	Description	Modeling Sources
Ghana	For Ghana, sugarcane ethanol is assumed to be produced in Brazil, the largest global producer of ethanol from sugarcane. Sugarcane production is modeled as 80% manual and 20% mechanical harvest. Ethanol is produced directly from the cane (i.e., cannot converted first to molasses). Ethanol is produced via fermentation route using energy from the bagasse. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Ethanol is transport by ship from Brazil to Ghana 5,177 km. Sugarcane ethanol combustion emissions are based on laboratory testing, rather than field results. 35.9 kg of ethanol are required to deliver 1 GJ of heat energy for cooking, with a cookstove thermal efficiency of 53%.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Ecoinvent Centre, 2010 Macedo et al., 2008
Kenya	Ethanol in Kenya is assumed to be produced in India and transported to Kenya (see India model assumptions). Transport to Kenya is modeled as 4,409 km (by ship) based on the distances between major ports in the two countries.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Tsiropoulos et al., 2014
Nigeria	For Nigeria, sugarcane ethanol is assumed to be produced in Brazil, the largest global producer of ethanol from sugarcane. Sugarcane production is modeled as 80% manual and 20% mechanical harvest. Ethanol is produced directly from the cane (i.e., cannot converted first to molasses). Ethanol is produced via fermentation route using energy from the bagasse. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Ethanol is transport by ship from Brazil to Nigeria 6,070 km. Sugarcane ethanol combustion emissions are based on laboratory testing, rather than field results. 35.9 kg of ethanol are required to deliver 1 GJ of heat energy for cooking, with a cookstove thermal efficiency of 53%.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Ecoinvent Centre, 2010 Macedo et al., 2008
Uganda	Ethanol in Uganda is assumed to be produced in India and transported to Uganda (see India model assumptions). Transport to Uganda is modeled as 673 km (by ship) and 1,144 km (by truck) based on the distances between major ports in the two countries.	Aprovecho Research Center, 2006 Aprovecho Research Center, 2009 Tsiropoulos et al., 2014

Table B-17. Process Descriptions for Ethanol from Wood

Country	Description	Modeling Sources
China	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Chinese conditions. Ethanol is assumed to be transported 1979 km by barge based on the average distance between forests and large population centers in China stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012

Table B-17. Process Descriptions for Ethanol from Wood

Country	Description	Modeling Sources
India	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Indian conditions. Ethanol is assumed to be transported 800 km by single unit truck based on the average distance between forests and large population centers in India. The stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012
Bangladesh	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Bangladesh conditions. Ethanol is assumed to be transported 383 km by truck based on the average distance between forests and large population centers in Bangladesh. The stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012
Guatemala	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Guatemala conditions. Ethanol is assumed to be transported 330 km by truck based on the average distance between forests and large population centers in Guatemala. The stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012
Ghana	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Ghana conditions. Ethanol is assumed to be transported 483 km by single unit truck based on the average distance between forests and large population centers in Ghana. The stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012
Kenya	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Kenya conditions. Ethanol is assumed to be transported 322 km by truck based on the average distance between forests and large population centers in Kenya. The stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012

Table B-17. Process Descriptions for Ethanol from Wood

Country	Description	Modeling Sources
Nigeria	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Nigeria conditions. Ethanol is assumed to be transported 322 km by single unit truck based on the average distance between forests and large population centers in Nigeria. The stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012
Uganda	Ethanol is produced from wood residues based on a process model for ethanol fermentation. Ethanol is assumed to be produced domestically. Combustion emissions are modeled as equivalent to sugarcane ethanol. Electricity is co-produced with ethanol, but no credit for exported electricity is applied in the model. Transport and electricity inputs are adapted for Uganda conditions. Ethanol is assumed to be transported 241 km by single unit truck based on the average distance between forests and large population centers in Uganda. The stove efficiency of ethanol is modeled as 53%.	ANL, 2014 Aprovecho Research Center, 2009 Aprovecho Research Center, 2006 IEA, 2012

Table B-18. Process Descriptions for Biogas from Cattle Dung

Country	Description	Modeling Sources
China	Biogas production data developed for the India context is used as a surrogate for the biogas module in China. Similar impacts are seen for biogas from cattle dung from across most geographic regions.	Afrane & Ntiamoah, 2011 Bagepalli, 2007 Borjesson & Berglund, 2006 Kadian et al., 2007 Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 2000 Vivekanandan & Kamraj, 2011
India	This study considers a 2 m ³ household type fixed dome anaerobic digester (AD) operating in continuous feeding mode for 350 days/year and 10 years operational life. The AD is loaded with 19.3 kg/day of fresh dung mixed with small quantities of water. This produces 1.31 m ³ /day of biogas. Leakage is the source of fuel production emissions. Approximately 1% of biogas generated is assumed to leak from the system. Digested slurry is a useful co-product and stored for applications in land farming. The AD is located at the same house as the fuel is used (distributed through piping), so no transport is modeled. The stove efficiency of the biogas stove is assumed to be 55%.	Afrane & Ntiamoah, 2011 Bagepalli, 2007 Borjesson & Berglund, 2006 Kadian et al., 2007 Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 2000 Vivekanandan & Kamraj, 2011
Bangladesh	Biogas production data developed for the India context is used as a surrogate for the biogas module in Bangladesh. Similar impacts are seen for biogas from cattle dung from across most geographic regions.	Afrane & Ntiamoah, 2011 Bagepalli, 2007 Borjesson & Berglund, 2006 Kadian et al., 2007 Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 2000 Vivekanandan & Kamraj, 2011

Table B-18. Process Descriptions for Biogas from Cattle Dung

Country	Description	Modeling Sources
Guatemala	Biogas production data developed for the India context is used as a surrogate for the biogas module in Guatemala. Similar impacts are seen for biogas from cattle dung from across most geographic regions.	Afrane & Ntiamoah, 2011 Bagepalli, 2007 Borjesson & Berglund, 2006 Kadian et al., 2007 Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 2000 Vivekanandan & Kamraj, 2011
Ghana	Data from feedstock amounts and biogas yields were derived from various technologies used at the household level in Ghana and through questionnaires and field measurements. Emissions from biogas production and combustion were from literature. The stove efficiency of the biogas stove is modeled as 55%.	Afrane & Ntiamoah, 2011 Auer et al., 2006 Borjesson & Berglund, 2006 Marchaim, 1992 Pennise et al., 2001 Smith et al., 2000
Kenya	The Ghana biogas model is used as a surrogate for Kenya. Similar impacts are seen for biogas from cattle dung from across most geographic regions.	Afrane & Ntiamoah, 2011 Auer et al., 2006 Borjesson and Berglund, 2006 Marchaim, 1992 Pennise et al., 2001 Smith et al., 2000
Nigeria	The Ghana biogas model is used as a surrogate for Nigeria. Similar impacts are seen for biogas from cattle dung from across most geographic regions.	Afrane & Ntiamoah, 2011 Auer et al., 2006 Borjesson and Berglund, 2006 Marchaim, 1992 Pennise et al., 2001 Smith et al., 2000
Uganda	The Ghana biogas model is used as a surrogate for Uganda. Similar impacts are seen for biogas from cattle dung from across most geographic regions.	Afrane & Ntiamoah, 2011 Auer et al., 2006 Borjesson & Berglund, 2006 Marchaim, 1992 Pennise et al., 2001 Smith et al., 2000

Table B-19. Process Descriptions for LPG

Country	Description	Modeling Sources
China	<p>LPG production for China is based on two Swiss refineries for the year 2000. Electricity grid mix and rail transport are adapted to the China geographic scope. The bottling stage is simulated based on the model created for India. The bottling stage is simulated based on the per-day production scenario of IOCL Barkhola bottling plant located in Assam, India. This is one of the recent state-of-the art bottling plants in Southeast Asia and is considered representative of bottling plants in China. LPG is bottled in steel canisters. Incoming transport to the bottling plant is 60% rail (1000 km) and 40% heavy duty vehicle (500 km). The bottled LPG is then transported 100% 750 km by heavy duty vehicle to the distributor and 100% 100 km by light duty vehicle from the distributor to retail. LPG is combusted in traditional and infrared stoves which have average efficiencies assumed to be 45% and 42%, respectively.</p>	<p>Emmenegger et al., 2007 Dalberg, 2014 Singh & Gundimeda, 2014 Sing et al., 2014 Tsai et al., 2003 Zhang et al., 2000</p>
India	<p>LPG in India is produced from both natural gas (NG) 21% and crude oil (CO) 79%. Each route is described separately. LPG from NG: Natural gas extraction is based on drilling, metering, testing and servicing of oil wells and production data of Oil and Natural Gas Corporation (ONGC is the largest oil company in India). 84% comes from offshore sources and 16% comes from onshore sources. LPG production is based on the scenario of LPG production line of ONGC Uran Gas fractioning plant located near Mumbai, India. Natural gas is transported to the gas fractioning plant by pipeline (500 km from onshore, 250 km from offshore). Outputs from LPG production are allocated on a direct mass basis. The bottling stage is simulated based on the per-day production scenario of IOCL Barkhola bottling plant located in Assam, India. This is one of the recent state-of-the art bottling plants commissioned by IOCL and is considered representative of bottling plants in India. LPG is bottled in steel cylinders. Incoming transport to the bottling plant is 60% rail (1000 km) and 40% heavy duty vehicle (500 km). The bottled LPG is then transported 100% 750 km by heavy duty vehicle to the distributor and 100% 100 km by light duty vehicle from the distributor to retail. The LPG stove efficiency is assumed to be 57%.</p> <p>LPG from CO: This model only considers the domestic production of petroleum refining products. The error from excluding overseas production chain is not expected to impact findings significantly because only the extraction stage is impacted (not the refining stage) and Indian companies engage in extraction of crude oil that follow operational standards focused on globally accepted practices equivalent to overseas oil companies. Crude oil is from onshore and offshore sources. Mass allocation is used to partition petroleum refining burdens to different products. Onshore crude oil is 30% of inputs, and is transported 1000 km by rail to the refinery; offshore crude oil makes up 70% of the inputs and is transported 500 km to the port and then 60% is transported 1000 km by rail and the remaining 40% is transported 500 km by heavy duty vehicle. The bottling stage is simulated based on the per-day production scenario of IOCL Barkhola bottling plant located in Assam, India. This is one of the recent state-of-the art bottling plants commissioned by</p>	<p>Chen et al., 2007 IOCL, 2011 Kadian et al., 2007 Reddy & Venkataraman, 2002a Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 2000</p>

Table B-19. Process Descriptions for LPG

Country	Description	Modeling Sources
	IOCL and is considered representative of bottling plants in India. LPG is bottled in steel cylinders. Incoming transport to the bottling plant is 60% rail (1000 km) and 40% heavy duty vehicle (500 km). The bottled LPG is then transported 100% 750 km by heavy duty vehicle to the distributor and 100% 100 km by light duty vehicle from the distributor to retail. The LPG stove efficiency is assumed to be 57%.	
Bangladesh	Crude oil is assumed to be produced in Saudi Arabia and transported to Bangladesh. Crude oil is transported by ship 5,834 km between Saudi Arabia and Bangladesh. LPG is refined in Bangladesh and then transported to retailers in steel cylinders. The LPG use phase for LPG is adapted from the India model. The LPG stove efficiency is assumed to be 57%.	Ecoinvent, 2010 Singh et al., 2014
Guatemala	LPG in Guatemala is assumed to be produced in the Gulf Coast of the US. The LPG is assumed to be from crude oil and refined in Houston. The transport from Houston to Guatemala is modeled as 2,650 km by ship. The LPG stove efficiency is assumed to be 57%.	Ecoinvent, 2010 Singh et al., 2014
Ghana	LPG in Ghana is modeled as produced 100% from crude oil. The crude oil is produced in Nigeria. LPG is either refined in Nigeria and imported to Ghana, or crude oil is imported to Ghana and the LPG is refined at Ghana's only refinery (Tema Oil Refinery). The transport from Nigeria to Ghana is modeled as 433 km by ship. LPG is transported in steel cylinders throughout the country. The LPG stove efficiency is assumed to be 57%.	Afrane & Ntiamoah, 2011
Kenya	LPG in Kenya is assumed to be 100% derived from crude oil. The crude oil is assumed to be produced in Algeria and transported to Kenya by ship (8,445 km). LPG is bottled in steel cylinders and transported and then transported 482 km by truck within Kenya. The LPG stove efficiency is assumed to be 57%.	Afrane & Ntiamoah, 2011 Ecoinvent, 2010
Nigeria	The Nigeria LPG model is adapted from the Ghana model, with transport assumptions adapted for Nigeria. All crude oil is produced domestically in Nigeria. The LPG stove efficiency is assumed to be 57%.	Afrane & Ntiamoah, 2011
Uganda	The Uganda LPG model is adapted from the Kenya model, with modified transportation assumptions. From the Mombasa port, the LPG is assumed to be transported 1,144 km to Kampala. From the An additional The LPG stove efficiency is assumed to be 57%.	Afrane & Ntiamoah, 2011 Ecoinvent, 2010

Table B-20. Process Descriptions for Coal (India and China Only)

Country	Description	Modeling Sources
China	Coal is assumed to be produced in an open cast surface mine (reflective of surface mines in national provinces especially the Shanxi region). Transport of coal from mines to storage sites as well as average losses during transport are reflected. The process also estimates emissions due to leaching of coal heaps to groundwater at storage sites. Coal may be used unprocessed, washed and dried, formed into briquettes, or formed into honeycomb briquettes. Coal is combusted in metal and brick stoves (both traditional and improved) which have efficiencies assumed to range from 14% - 37% depending on the fuel/stove technology combination. The coal ash remaining after combustion as well as the overburden is assumed to be disposed in landfills.	Dalberg, 2014 Dones et al., 2007 Röder et al., 2004 Tsai et al., 2003 Zhang et al., 2000
India	Coal is assumed to be produced in an open cast surface mine (surface mines represent over 80% of total coal production in India, but almost 100% of coal grades used for cooking). Coal is combusted in a metal stove and the stove efficiency is assumed to be 15.5%. The coal ash remaining after combustion as well as the overburden is assumed to be disposed in landfills. The consumption of coal for cooking is primarily nearby coal mines, with an average transport distance of 100 km (rail) and transport losses of 1%.	Chen et al., 2006 Ghose, 2004 Ghose 2007 Reddy & Venkataraman 2002a Röder et al., 2004 Singh & Gundimeda, 2014 Singh et al., 2014 Zhi et al., 2008

Table B-21. Process Descriptions for Electricity (India and China Only)

Country	Description	Modeling Sources
China	The electricity mix is based on the average electricity mix in IEA for China (2011). This includes an electricity loss of 22% to account for distribution of the electricity to the consumer. The China average electricity grid is composed of 79% coal, 14% hydro, 1.8% natural gas, 1.8% nuclear, 1.5% wind, 0.7% biomass, 0.2% oil, 0.2% waste, and 0.1% solar PV per IEA statistics 2012. The assumed electric stove thermal efficiency is 67%.	Aprovecho Research Center, 2006 IEA, 2012
India	The electricity mix is based on the average electricity mix in IEA for India (2012). This includes an electricity loss of 37% to account for distribution of the electricity to the consumer. The grid is composed of 71% coal, 11% hydro, 8% natural gas, 3% nuclear, 2.5% wind, 2% oil, 1.7% biofuels, 0.2% solar PV, and 0.09% waste per IEA statistics 2012. The assumed electric stove thermal efficiency is 67%.	Aprovecho Research Center, 2006 IEA, 2012

Table B-22. Process Descriptions for Unprocessed Crop Residue (India and China Only)

Country	Description	Modeling Sources
China	Crop residues in China such as maize, wheat, and rice are also burned by households. They are characterized by low bulk density and low energy yield per weight basis. Crop residues are assumed to be manually collected and combusted in traditional and improved brick and metals stoves with efficiencies ranging from 10% to 17% depending on the fuel/stove technology combination. The remaining ash is assumed to be land applied.	Zhang et al. 2000 Tsai et al. 2003 Jingjing et al. 2001 Lui et al. 2011 Dalberg, 2014
India	Unprocessed crop residues such as rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed, mustard, and groundnut are burned by households in India. They are characterized by low bulk density and low energy yield per weight basis. Crop residues are assumed to be manually collected and combusted in traditional mud stove. Collection losses are assumed to be 6%. The stove efficiency is assumed to be 11%. The remaining ash after combustion is modeled as land applied.	Reddy & Venkataraman, 2002b Saud et al., 2012 Singh et al., 2014 Singh & Gundimeda, 2015 Smith et al., 2000 Venkataraman & Rao, 2001

Table B-23. Process Descriptions for Kerosene (India and China Only)

Country	Description	Modeling Sources
China	For China, production of petroleum products are adapted to the China geographic scope. The data set includes all flows of materials and energy for throughput of one kilogram of crude oil in the refinery. The multi- output process 'crude oil, in refinery' delivers the co-products gasoline, bitumen, diesel, light fuel oil, heavy fuel oil, kerosene, naphtha, propane/ butane, refinery gas, secondary sulfur, and electricity. The impacts of processing are allocated to the different products on a mass basis. Electricity grid mix and rail transport are adapted to the China geographic scope. The bottling stage is simulated based on the per-day production scenario of IOCL Barkhola bottling plant located in Assam, India. Kerosene is bottled in steel cylinders. Incoming transport to the bottling plant is 60 percent rail (1000 km) and 40 percent heavy duty vehicle (500 km). All bottled kerosene is modeled as being transported 750 km by heavy duty diesel vehicle to the distributor where it travels a further 100 km by light duty diesel vehicle from the distributor to retail. Kerosene is combusted in wick and pressure stoves (efficiency ranging from 44.8% to 45.9%).	Dalberg, 2014 Ecoinvent, 2010 Emmenegger et al., 2007 IOCL, 2011 Singh et al., 2014 Tsai et al. 2003 Zhang et al., 2000

Table B-23. Process Descriptions for Kerosene (India and China Only)

Country	Description	Modeling Sources
India	The India kerosene model only considers the domestic production of petroleum refining products. The error from excluding overseas production chain is not expected to impact findings significantly because only the extraction stage is impacted (not the refining stage) and Indian companies engage in extraction of crude oil that follow operational standards focused on globally accepted practices equivalent to overseas oil companies. Crude oil is from onshore and offshore sources. Mass allocation is used to partition petroleum refining burdens to different products. Onshore crude oil is 30% of inputs, and is transported 1000 km by rail to refinery; offshore crude oil makes up 70% of the inputs and is transported 500 km to the port and then 60% is transported 1000 km by rail and the remaining 40% is transported 500 km by heavy duty vehicle. Kerosene is transported 30% from the refinery to the distributor 1000 km by rail and 70% 1000 km by heavy duty vehicle. Kerosene is transported in a light duty vehicle 100 km from the distributor to retail. The bottling stage is simulated based on the per-day production scenario of IOCL Barkhola bottling plant located in Assam, India. This is one of the recent state-of-the-art bottling plants commissioned by IOCL and is considered representative of bottling plants in India. LPG is bottled in steel cylinders. The kerosene pressure stove efficiency is 47%.	IOCL, 2011 Kadian et al. 2007 Reddy & Venkataraman, 2002a Singh et al., 2014 Singh & Gundimeda, 2015 Smith et al., 2000

Table B-24. Process Descriptions for Dung Cake (India Only)

Country	Description	Modeling Sources
India	The dung of stall fed cattle and buffaloes are converted into dung cake mainly by women by mixing the manually collected dung with the residual feed (e.g., straw, wood chips). Dung cake is combusted in a traditional mud stove and the stove efficiency is assumed to be 8.5%. The physical losses for dung cake are also assumed to be 8.5%. The remaining ash after combustion is assumed to be land applied.	Reddy & Venkataraman, 2002b Saud et al., 2012 Singh et al., 2014 Singh & Gundimeda, 2014 Smith et al., 2000 Venkataraman & Rao, 2001

Table B-25. Process Descriptions for DME (China Only)

Country	Description	Modeling Sources
China	DME is modeled to be produced from coal gas delivered to rural China via pipeline network. The process technology, coal gas produced from coke oven gas, is adapted for the China geographic scope. Transport of the coal gas from plant to rural consumer is via high pressure network. The process technology is standard multiple-burner gas range; the combustion profile for this fuel/cookstove technology combination reflects use of only one burner. DME is available in bottles and in gaseous form under normal atmospheric conditions. The model for DME combustion is based on laboratory testing results for coal gas combustion in a traditional gas stove. The efficiency of the stove is assumed to be 46%.	Zhang et al., 2000 Tsai et al., 2003 Dalberg, 2014 Dones et al., 2007

Table B-26. Process Descriptions for Natural Gas (China Only)

Country	Description	Modeling Sources
China	Natural gas extraction is based on Russian production data and long-distance pipeline transport of natural gas to China. Energy requirements for operation of the gas pipeline network are adapted from an Italian company data set for delivery of natural gas to consumers via pipelines. The total leakage rate is based on European data. The electricity grid mix and rail transport are adapted to the China geographic scope. The fuel is burned in high efficiency stoves (53.7%-60.9%.)	Dalberg, 2014 Ecoinvent, 2010 Emmenegger, 2007 Tsai et al., 2003 Zhang et al., 2000

Table B-27. Electrical Grid Mix by Country

	India	China	Bangladesh	Nigeria	Ghana	Kenya	Uganda	Guatemala
Coal	71.1%	79.0%	1.8%	0.0%	0.0%	0.0%	0.0%	13.2%
Oil	2.0%	0.2%	11.5%	0.0%	20.8%	24.8%	16.0%	20.0%
Gas	8.3%	1.8%	85.1%	80.3%	12.0%	0.0%	0.0%	0.0%
Biofuels	1.7%	0.7%	0.0%	0.0%	0.0%	3.8%	0.0%	16.9%
Waste	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Nuclear	2.9%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydro	11.2%	14.8%	1.6%	19.7%	67.1%	51.9%	84.0%	47.4%
Geothermal	0.2%	0.0%	0.0%	0.0%	0.0%	19.3%	0.0%	2.6%
Solar PV	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Wind	2.5%	1.5%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%

Source: IEA, 2011-2012; Energypedia, 2015.

B.4 ALLOCATION METHODOLOGY FOR THE ENVIRONMENTAL ANALYSIS

For processes that produce more than one useful output, allocation is required. No single allocation method is suitable for every scenario. The method used for handling product allocation will vary from one system to another but the choice of allocation is not arbitrary. ISO 14044, Section 4.3.4.2 states that “the inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics.” 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. The cut-off method is outlined in detail in the 1993 EPA Life-Cycle Assessment: Inventory Guidelines and Principles document²¹.

Processes in the cookstove fuel life cycle requiring allocation include crop and wood residues and other products generating co-products. For instance, production of sugarcane ethanol may result in a net production of electricity from the combusted bagasse. For residues, burdens begin at collection of the biomass from the field or forest and do not include impacts associated with primary cultivation of the crop. For co-produced electricity from ethanol production, credits associated with exporting electricity are considered outside the system boundaries. The digested slurry from the biogas production in the AD may also be used as a fertilizer for supporting household crop production. The benefits realized from increased nutrients available from the land applied digested slurry is not captured in the impact assessment in this work. Multiple allocation methods exist and may have a significant influence on results.

B.5 BIOGENIC CARBON ACCOUNTING

In biomass fuel systems, carbon dioxide (CO₂) is removed from the atmosphere and incorporated into the material that is harvested from the forest or field. This (biogenic) 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 CO₂ and methane (CH₄). This study, in alignment with the IPCC methodology, assumes a net zero impact for biogenic carbon in the form of CO₂ emissions such as CO₂ emissions from the combustion of biomass cookstove fuels. That is, if the removed carbon from the atmosphere is returned to the atmosphere in the same form, the net impact GWP is zero. Impacts associated with the emission of biogenic carbon in the form of CH₄ are included since CH₄ was not removed from the atmosphere and its GWP is 28 times that of CO₂ when applying the IPCC 2013 100a LCIA method. The one exception to this is the CO₂ emissions associated with wood fuel derived from unsustainable forestry practices in the assessed countries. The method to account for such non-renewable biomass emissions are discussed in the next section.

B.6 NON-RENEWABLE FORESTRY CALCULATIONS

In the GHG analysis, the carbon dioxide emissions for the portion of the biomass fuel from unsustainable forestry practices are considered non-renewable, 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). First, the biomass stock (in cubic meters (cu m)) for each country (from FAO 2010 Table 10) was multiplied by the regional factor for tonnes of above-ground biomass (AGB) per cu m (from FAO 2010 Table 2.18) to calculate the tonnes of AGB. The amount of below-ground biomass (BGB) was calculated by multiplying the tonnes of AGB by the regional factor for BGB/AGB (from FAO 2010 Table 2.18). The amount of dead wood was then calculated using the regional factor for dead-to-live biomass ratio (from FAO 2010 Table 2.18) applied to the total AGB and BGB. Next, the average annual increase or decrease in forest land for each country was calculated based on the carbon stocks in living forest biomass reported for each country in 2000 and 2010 (from FAO 2010 Table 11). The annual firewood supply potential for each country was then calculated as the total weight of AGB and dead wood multiplied by country-specific factors for the percent accessibility to forests²² and the country-specific average annual change in forest land.

The annual demand for firewood cooking fuel (tonnes) for each country was calculated based on the country-specific cooking energy demand per household multiplied by the number of households using wood for cooking fuel, divided by the cooking energy per kg of firewood (calculated as the lower heating value of firewood multiplied by stove efficiency). Table B-28 provides the cooking energy per household per day and the number of households using wood for cooking fuel for each country. Finally, the renewable percentage of cooking firewood was calculated as the annual firewood supply potential divided by the total annual demand for cooking firewood. The percentage of annual firewood demand that cannot be met by the annual firewood supply potential was considered non-renewable. If a country showed a decreasing trend in forest land, the annual firewood supply potential was negative, and all cooking firewood use was considered non-renewable. Table B-29 displays the percent of renewable versus non-renewable wood per country as used in calculations for this analysis.

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.^{23, 24} 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 B-28. Cooking Energy per Household and Number of Households using Wood for Cooking by Country

Country			Source(s)
China	Cooking Energy (MJ/HH/day)	13.6	Zhou et al., 2007 ASTAE, 2013
	Households	141,000,000	
India	Cooking Energy (MJ/HH/day)	11.0	Habib et al., 2004 Singh et al., 2014
	Households	121,000,000	
Bangladesh	Cooking Energy (MJ/HH/day)	6.19	USAID, 2013 Accenture, 2012a
	Households	15,000,000	
Ghana	Cooking Energy (MJ/HH/day)	13.60	IEA 2014, GVEP International 2012c GVEP International 2012c
	Households	2,900,000	
Guatemala	Cooking Energy (MJ/HH/day)	42.84	ESF, 2013 ESF, 2013
	Households	2,100,000	
Kenya	Cooking Energy (MJ/HH/day)	12.5	IEA 2014, Africa Energy Outlook, GVEP International 2012a GVEP International 2012d
	Households	5,700,000	
Nigeria	Cooking Energy (MJ/HH/day)	44.07	IEA 2014, Accenture, 2011 GVEP International 2012d
	Households	6,100,000	
Uganda	Cooking Energy (MJ/HH/day)	16.31	BMW, 2009, Uganda, 2014 Accenture, 2011
	Households	22,800,000	

Table B-29. Percentage of Renewable and Non-renewable Wood by Country

Country	Renewable	Non-Renewable	Source(s)
China	57%	43%	World Bank, 2010; FAO, 2010; World Bank, 2013; Zhang et al., 2000; Jingjing, 2001; Zhou et al., 2007
India	35%	65%	World Bank, 2010; FAO, 2010; World Bank, 2013; Singh et al., 2014; Habib et al., 2004
Bangladesh	0%	100%	World Bank, 2010; FAO, 2010; USAID, 2013; Accenture, 2012a
Ghana	0%	100%	World Bank, 2010; FAO, 2010; GVEP International, 2012c; IEA, 2014
Guatemala	0%	100%	World Bank, 2010; FAO, 2010; ESF, 2013; Boy et al., 2000
Kenya	0%	100%	World Bank, 2010; FAO, 2010; IEA, 2014; GVEP International 2012a, GVEP International 2012d
Nigeria	0%	100%	World Bank, 2010; FAO, 2010; IEA, 2014; Accenture, 2011
Uganda	0%	100%	World Bank, 2010; FAO, 2010; BMW, 2009; Uganda, 2014; GVEP International 2012d

B.7 BLACK CARBON AND SHORT-LIVED CLIMATE POLLUTANTS CALCULATIONS

This section summarizes key physical parameters considered in the approach to include the differences in potential amounts of BC, organic carbon (OC), and co-emitted species produced from use of the investigated cookstove/fuel technologies. BC/OC and co-emitted species are formed by combustion of fossil and bio-based fuels (e.g., diesel, coal, crop residues).

Per the Gold Standard method²⁵, fuel production, transport, and consumption life cycle phases are included in the inventory and impact assessment. An inventory of BC and OC is based on the quantity of particulate matter (less than or equal to 2.5 microns of aerodynamic diameter--PM2.5) releases for each inventory step in the cookstove fuel/technology life cycle. In many cases, LCI data sources do not specify the type of particulate matter (PM) emissions (i.e., outputs are reported as 'particulate matter' or 'particulate matter, unspecified'). For upstream process inventories where PM emission speciation is not provided, no BC and/or OC emission factors are applied. However, co-emitted species emission factors for these processes are included. In the foreground cookstove fuel combustion, BC and OC emission factors based on quantity of PM releases (i.e., per fraction reported as PM2.5) are applied. Where no size distinctions between PM emissions have been made in LCI data sources, all PM emissions from fuel combustion are assumed to be of the fine particle variety, i.e., of less than or equal to 2.5 microns in size.

Carbon in PM2.5 emissions takes the following forms: 1) Organic carbon (OC); 2) Elemental carbon (EC), which usually includes soot; and 3) Carbonate ion (CO₃⁻). Methods which measure light absorption in PM2.5 assume that the light absorbing component is BC and partitioning of EC and OC is somewhat arbitrary. Though some components of OC may be light-absorbing (e.g., brown carbon or BrC), most researchers presume that OC possess light-scattering properties (i.e., producing climate cooling effects). Because there is high uncertainty and lack of consensus on the ratio BrC class of OC compounds for each fraction of OC, analyzing impacts of BrC in OC is excluded in this analysis and instead focus is placed on the EC or soot portion and the OC portions of the PM2.5 emissions. In other words, BC emissions may be estimated by assuming that only the EC portion of the PM2.5 emissions contributes to BC release and subsequent positive radiative forcing, while OC emissions are assumed to contribute to negative radiative forcing. This approach requires estimating the PM2.5 emission amount and source-specific EC-to-PM2.5 and then the BC-to-OC ratio for each of the fuel/stove technologies being investigated in the study.

Potential climate forcing impacts resulting from BC/OC and co-emitted species include direct, albedo, and other indirect effects. Overall, most estimates indicate BC effecting a net warming effect on climate but co-emitted species can have some offsetting effects, as discussed below. Species co-emitted with BC/OC such as carbon monoxide (CO), non-methane volatile organic carbon (NMVOCs), nitrogen oxides (NO_x), and sulfur dioxide (SO₂) are pre-cursors to the formation of sulfate and/or organic aerosols in the atmosphere. These aerosols affect reflectivity and other cloud properties and have a cooling affect.

BC and other short lived climate pollutants (SLCPs) such as the aforementioned co-emitted species are distinguished from other climate-forcing emissions (i.e., GHGs) in that their atmospheric lifetime is not as long-lived, so potential impacts are estimated on a shorter time-scale and can be very geographic and seasonally dependent (unlike long-lived, well-mixed

GHGs). However, short-lived forcing effects of BC are substantial compared to effects of long-lived GHGs from the same sources, even when the forcing is integrated over 100 years. The GCCP of BC/OC and co-emitted species included in this approach are assigned per global warming potential (GWP) 20-year BC eq. factors from IPCC 2013 as summarized in Table B-30.

Table B-30. Characterization Factors for BC eq

	Included in GSF 2015	GWP(20) per IPCC 2013	BC eq
Warming Effects	BC	2421	1
	NOx	16.7	0.00690
	CO	5.9	0.002
	NM VOC	14	0.006
Cooling Effects	OC	-244	-0.1
	SO4 (-2)	-141	-0.058

Source: GSF, 2015.

B.8 LCA MODEL FRAMEWORK

All LCI unit processes developed for this analysis were input into the open-source OpenLCA software (Version 1.4.2)²⁶. The OpenLCA model was reviewed to ensure that all inputs and outputs, quantities, units, and metadata were correctly imported. Associated metadata for each unit process was recorded in the unit process templates and imported into OpenLCA along with the model values.

Once all necessary data was imported into the OpenLCA software and reviewed, system models were created for each fuel and country combination. The models were reviewed to ensure that each elementary flow (i.e., environmental emissions, consumption of natural resources, and energy demand) was characterized under each impact category for which a characterization factor was available. The draft final system models were also reviewed prior to calculating results to make certain all connections to upstream processes and weight factors were valid. LCIA results were then calculated by generating a contribution analysis for the selected fuel product system based on the defined functional unit of 1 GJ of delivered heat for cooking. Results were then converted to cooking impacts per household per year by applying the factors in Table B-30.

B.9 DATA LIMITATIONS

Although the foreground fuel production, processing, distribution, and use processes in the environmental analysis were populated with data from reliable sources, most analyses still have limitations. Further, it is necessary to make a number of assumptions when performing LCA modeling, which could influence the final results of a study. Key limitations and assumptions of this analysis are described within the LCI Assumptions and Data Sources section, as well as within the Economic Methodology and Indicators section.

B.10 DATA ACCURACY AND UNCERTAINTY

An important issue to consider when using LCI study results is the reliability of the data. In a complex study with literally thousands of numeric entries, the accuracy of the data and how it

affects conclusions is truly a complex subject, and one that does not lend itself to standard error analysis techniques. Techniques such as Monte Carlo analysis can be used to study uncertainty, but the greatest challenge is the lack of uncertainty data or probability distributions for key parameters, which are often only available as single point estimates. However, the reliability of the study can be assessed in other ways.

A key question is whether the LCI profiles are accurate and study conclusions are correct. The accuracy of an environmental profile depends on the accuracy of the numbers that are combined to arrive at that conclusion. Because of the many processes required to produce each cup or packaging material, many numbers in the LCI are added together for a total numeric result. Each number by itself may contribute little to the total, so the accuracy of each number by itself has a small effect on the overall accuracy of the total. There is no widely accepted analytical method for assessing the accuracy of each number to any degree of confidence. For many chemical processes, the data sets are based on actual plant data reported by plant personnel. The data reported may represent operations for the previous year or may be representative of engineering and/or accounting methods. All data received are evaluated to determine whether or not they are representative of the typical industry practices for that operation or process being evaluated.

There are several other important points with regard to data accuracy. Each number generally contributes a small part to the total value, so a large error in one data point does not necessarily create a problem. For process steps that make a larger than average contribution to the total, special care is taken with the data quality.

There is another dimension to the reliability of the data. Certain numbers do not stand alone, but rather affect several numbers in the system. An example is the amount of material required for a process. This number affects every step in the production sequence prior to the process. Errors such as this that propagate throughout the system are more significant in steps that are closest to the end of the production sequence. For example, changing the efficiency of a stove affects the amount of the fuel input and therefore the required amount of fuel which must be produced and processed.

In addition to the uncertainty of the LCI emissions data, there is uncertainty associated with the application of LCIA methodologies to aggregated LCI emissions. For example, two systems may release the same total amount of the same substance, but one quantity may represent a single high-concentration release to a stressed environment while the other quantity may represent the aggregate of many small dilute releases to environments that are well below threshold limits for the released substance. The actual impacts would likely be very different for these two scenarios, but the life cycle inventory does not track the temporal and spatial resolution or concentrations of releases in sufficient detail for the LCIA methodology to model the aggregated emission quantities differently. Therefore, it is not possible to state with complete certainty that differences in potential impacts for two systems are significant differences. Although there is uncertainty associated with LCIA methodologies, all LCIA methodologies are applied to different fuel system models uniformly. Therefore, comparative results can be determined with a greater confidence than absolute results for one system.

Complete citations for data sources used within the study are presented in Appendix C.

¹ Wilson, 2013

² NREL, 2015

³ Weidema & Wesnaes, 1996

⁴ California Environmental Protection Agency Air Resource Board, 2015

⁵ US EPA, 2016

⁶ UNSD, 2011

⁷ UNSD, 2013

⁸ OECD/FAO, 2014

⁹ FAO, 2014

¹⁰ Ngusale et al., 2014

¹¹ Pottier, 2013

¹² Mainali, et al., 2012

¹³ Thurber et al., 2014

¹⁴ BMZ, 2014

¹⁵ Wang, et al., 2013

¹⁶ Mainali, et al., 2012

¹⁷ Grameen, 2015a

¹⁸ Versol, 2015

¹⁹ World Bank, 2014c

²⁰ BEA, 2014

²¹ US EPA, 1993

²² Drigo, 2014

²³ Singh et al., 2014

²⁴ Bailis et al., 2015

²⁵ GSF, 2015

²⁶ GreenDelta, 2015