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FINANCIAL AND ECONOMIC ANALYSIS OF CHARCOAL AND WOOD USE FOR COOKING AND DEMAND- AND SUPPLY-SIDE ALTERNATIVES FOR FOREST CONSERVATION IN FOUR URBAN AREAS OF THE DEMOCRATIC REPUBLIC OF THE CONGO

APRIL 5, 2023

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FINANCIAL AND ECONOMIC ANALYSIS OF CHARCOAL AND WOOD USE FOR COOKING AND DEMAND- AND SUPPLY-SIDE ALTERNATIVES FOR FOREST CONSERVATION IN FOUR URBAN AREAS OF THE DEMOCRATIC REPUBLIC OF THE CONGO

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ACRONYMS AND ABBREVIATIONS

CBA	Cost-benefit analysis
CDF	Congolese Franc
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DDI	USAID Bureau for Development, Democracy, and Innovation
DRC	Democratic Republic of the Congo
EEI	Center for Environment, Energy, and Infrastructure (USAID/DDI)
EMD	Center for Economics and Market Development (USAID/DDI)
FAO	Food and Agriculture Organization of the United Nations
g	Grams
GDP	Gross domestic product
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ha	Hectare(s)
IEA	International Energy Agency
IFDC	International Fertilizer Development Center (formerly, now a non-acronym name)
IPCC	Intergovernmental Panel on Climate Change
KCJ	Kenya ceramic-lined jiko
kg	Kilogram(s)
kWh	Kilowatt-hour(s)
m	Meter(s)
m^3	Cubic meter(s)
MJ	Megajoule(s)
LPG	Liquefied petroleum gas
MSI	Management Systems International
NCS	Natural Climate Solutions Division (USAID/ EEI)
$PM_{2.5}$	Fine particulate matter with a diameter of 2.5 micrometers (microns) or less
SNEL	*Société Nationale d'Électricité*
T	Metric tons
tCO_2e	Metric tons of carbon dioxide equivalent

TERA	Technologies, Renewable Energy, Academy Project (UNDP and UNCDF)
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VAT	Value-added tax
VSL	Value of a statistical life
WHO	World Health Organization
WWF	World Wide Fund for Nature

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EXECUTIVE SUMMARY

USAID commissioned Management Systems International (MSI) to conduct financial and economic analyses of household cooking fuel supply and demand alternatives in the Democratic Republic of the Congo (DRC). This study focused on four cities – Bukavu (South Kivu Province), Goma (North Kivu Province), Kinshasa (the capital and largest city), and Kisangani (Tshopo Province). It compared the present value of the financial and economic costs of producing charcoal in five types of kilns and cooking with eight combinations of household stoves and fuels. The charcoal production methods included a traditional earth mound kiln (the most common method), IFDC improved earth mound kiln, Casamance improved earth mound kiln, portable metal drum kiln, and brick kiln. The cooking alternatives included wood in a three-stone stove (open fire); charcoal in traditional metal stoves, charcoal in low- and medium- efficiency artisan-produced stoves (adaptations of the Kenya ceramic-lined jiko); charcoal in two high-efficiency, imported, mass manufactured stoves (Jikokoa Xtra and EcoZoom Jet); a liquefied petroleum gas (LPG) stove; and a single-burner coil electric hotplate. All monetary values are in 2020 U.S. dollars.

The *financial analyses* assessed the costs to households and charcoal producers and used a 10-year time horizon. The *economic analyses* adjusted the financial costs for market distortions (taxes, tariffs, and subsidies) and included, the global social costs of greenhouse gas (GHG) emissions, the lost value of forest environmental goods from unsustainable woodfuel harvesting, and local premature mortality risks from fine particulate exposures ($PM_{2.5}$):

- **The social cost of greenhouse gas emissions.** Carbon dioxide, methane, and nitrous oxide emissions were costed at the U.S. Government's 2021 preliminary global social cost estimate of $51 per metric ton of carbon dioxide equivalent (tCO_2e) in 2020 and the U.S. EPA's 2022 draft revised estimate of $190/$tCO_2e$.
- **The lost value of forest environmental goods per hectare (ha) of unsustainable woodfuel harvesting** at a conservative, domestic value of $224 and a higher global median of $486.
- **The costs of premature mortality risks from exposure to fine particulates ($PM_{2.5}$) from cooking with woodfuels indoors and outdoors**. $PM_{2.5}$ risks are higher where woodfuels are typically used in cooking indoors (Goma and Bukavu) and lower where this is usually done outdoors (Kinshasa and Kisangani). Two country-specific values of a statistical life (VSL) were used -- $18,601 in the base case and $40,716 in the sensitivity analysis.

The economic analyses used a 50-year time horizon to capture the long-term social costs of GHG emissions, lost value of forest environmental services, and premature mortality risks from fine particulate exposures. The financial and economic analyses were based on a 12 percent real discount rate, with sensitivity tests at 3 percent and 7 percent real discount rates.

Both the financial and economic analyses included sensitivity testing of a 50 percent increase in average annual consumption of all fuels and a concurrent 25 percent increase in wood and charcoal prices and a 50 percent increase in the LPG price. The base case economic analysis used the lower estimates of the social cost of GHGs, values for lost forest environmental services, and VSL. Sensitivity testing examined the effects of using the higher values of the social cost of GHGs, lost forest environmental services, and VSL.

Table S-1 presents the discounted financial costs of the five kilns per ton of charcoal produced in the four locations. It was based on a 12 percent real discount rate and the assumption that each kiln would be operated at an 80 percent capacity use rate. Except for the metal drum kiln, the cost-effectiveness rankings of the kilns corresponded to their relative carbonization efficiencies. Even though the more efficient kilns had higher capital costs, their greater efficiencies more than offset their higher capital costs. The large brick beehive kiln (also called a half-orange kiln) was the least-cost alternative. The metal drum kiln was the highest-cost alternative because of its low production capacity and relatively high labor costs. The cost-effectiveness rankings of the kilns were the same at the two lower discount rates.

TABLE S-1: Present Value of the Financial Costs of Charcoal Production by Kiln Type at a 12 Percent Discount Rate (U.S. Dollars Per Ton of Charcoal)

Kilns	Bukavu	Goma	Kinshasa	Kisangani
Brick beehive	$7.92	$9.14	$6.22	$2.66
Casamance earth mound	$9.19	$10.56	$7.08	$3.35
Improved earth mound	$11.43	$13.16	$7.85	$3.74
Traditional earth mound	$12.91	$15.45	$10.07	$4.30
Portable steel drum	$13.80	$15.79	$25.65	$10.80

Table S-2 summarizes the discounted economic costs of the kilns in the four locations at the 12 percent discount rate. The social costs of GHGs accounted for an average of 68 percent of the total discounted economic costs in the base case scenario. In Bukavu and Goma, the kilns with the lowest GHG emissions per ton of charcoal had the lowest economic costs. This was also the case in Kinshasa and Kisangani, except for the metal drum kiln. The higher labor costs in Kinshasa and Kisangani made the economic costs of the labor-intensive metal drum kiln higher than the traditional earth mound kiln. The two lower discount rates did not change the economic cost rankings of the kilns.

TABLE S-2: Present Value of the Economic Costs of Charcoal Production by Kiln Type at a 12 Percent Discount Rate (U.S. Dollars Per Ton of Charcoal)

Kilns	Bukavu	Goma	Kinshasa	Kisangani
Casamance earth mound	$25.71	$27.10	$24.50	$19.97
Brick beehive	$28.70	$29.95	$27.81	$23.54
Improved earth mound	$38.11	$39.86	$35.61	$30.54
Portable steel drum	$43.14	$45.15	$55.87	$40.24
Traditional earth mound	$45.91	$48.48	$44.36	$37.45

The analysis of fuels and stoves covered low and high unit prices for charcoal. Low-income households often buy small amounts of charcoal for daily use at a higher unit price than households who buy larger amounts at a time. Table S-3 presents the present value of financial costs for a household using one stove and fuel for all cooking over 10 years.

At the low unit price of charcoal purchased in bulk, the electric hotplate had the lowest financial costs in Bukavu, Goma, and Kinshasha. In Kisangani, the price of electricity was much higher, making the electric hotplate the second most expensive alternative for households. LPG had the highest financial costs in all four cities. The three-stone woodstove had higher financial costs than any of the charcoal stoves in Bukavu, Goma, and Kinshasa, but was the fourth least costly alternative in Kisangani, where fuelwood prices were lower. In Kisangani, the three-stone woodstove had higher financial costs than the high- or medium-efficiency charcoal stoves, but was less costly than the low-efficiency charcoal stoves. Differences in charcoal prices across the four cities affected some of the financial cost rankings. The traditional charcoal stove had higher financial costs than the low-efficiency improved charcoal stove in Goma, Kinshasa, and Kisangani. In Bukavu, the traditional and improved low-efficiency charcoal stoves had similar costs because the price of charcoal was lower.

At the high unit price of charcoal purchased in small, daily use volumes, the annual costs of charcoal increased and the fuel cost increase was larger with the less fuel-efficient charcoal stoves. The costs of cooking with electricity, LPG, or wood did not change with the charcoal price assumption, but that only changed some of the rankings of the stove and fuel combinations. The electric hotplate remained the lowest financial cost alternative in Bukavu, Goma, and Kinshasa, followed by the high- and medium-efficiency charcoal stoves. However, the high unit charcoal price made the low-efficiency charcoal stoves less financially cost-effective than the three-stone woodstove in Bukavu and Goma. In Kisangani, the three-stone woodstove had the lowest financial -cost alternative because of the high prices of electricity and charcoal relative to wood. The other stove and fuel combinations had the same rankings in the financial analysis at both unit prices of charcoal.

Table S-4 contains the discounted economic costs of the fuel and stove combinations. The economic costs were substantially higher than the financial costs, mainly due to the social cost of GHG emissions and the value of statistical lives lost from $PM_{2.5}$ exposure. The differences between the financial and economic costs were highest for the three-stone woodstove and the charcoal stoves, especially the less efficient charcoal stoves. However, the GHG emissions from LPG were underestimated due to lack of data on the emissions in petroleum extraction, processing, and transport. The premature mortality costs of cooking with LPG were also undercounted because of insufficient information on the health risks of nitrous oxide and methane exposure.

At the low unit price of charcoal purchased in bulk, the electric hotplate was by far the least-cost alternative in the economic analyses for Bukavu, Goma, and Kinshasha. However, in Kisangani, the electric hotplate had the third highest economic costs because of higher electricity prices. In Bukavu, the EcoZoom Jet charcoal stove had the second lowest economic costs, followed closely by the LPG stove, and the Jikokoa Xtra charcoal stove, but all had about the same discounted economic costs. The medium-efficiency charcoal stove had substantially higher economic costs than the high-efficiency charcoal stoves and LPG and the economic costs were even higher for the low-efficiency charcoal stoves. In Goma and Kinshasha, the LPG stove had lower economic costs than the high-efficiency charcoal stoves, but the medium- and low-efficiency charcoal stoves had higher economic costs than these stoves. In Kisangani, the two high-efficiency charcoal stoves had much lower economic costs than the LPG stove with the EcoZoom Jet offering a small cost advantage over the Jikokoa Xtra. The discounted economic costs of the EcoZoom Jet were less than half those of the LPG stove in Kisangani. The three-stone woodstove had the highest economic costs in Bukavu, Goma, and Kinshasha. However, the three-stone woodstove had lower economic costs than the LPG stove in Kisangani, where fuelwood prices were lower and LPG prices higher.

At the high unit price of charcoal purchased in small volumes, only some of the economic cost rankings changed. The electric hotplate remained the lowest economic cost alternative in Bukavu, Goma, and Kinshasha and the third lowest in Kisangani. In Kisangani, the LPG stove was still the highest economic cost alternative and the EcoZoom Jet charcoal stove remained the second lowest-cost alternative, followed by the Jikokoa Xtra charcoal stove. In Bukavu, Goma, and Kinshasha, the three-stone woodstove continued to be the most expensive alternative, but the LPG stove became less costly than the high-efficiency charcoal stoves. The medium- and low-efficiency charcoal stoves were more affected by the higher unit price of charcoal than the high-efficiency charcoal stoves.

TABLE S-3: Present Value of the Financial Costs of Stoves and Fuels by Charcoal Price at a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price
Single-burner, coil electric hotplate	$492	$492	$484	$484	$512	$512	$2,068	$2,068
High-efficiency, EcoZoom Jet charcoal stove	$986	$1,080	$1,277	$1,643	$1,217	$1,990	$632	$1,007
High-efficiency, Jikokoa Xtra charcoal stove	$1,010	$1,106	$1,306	$1,680	$1,245	$2,032	$655	$1,041
Medium-efficiency, improved charcoal stove	$1,167	$1,285	$1,490	$1,931	$1,495	$2,463	$735	$1,204
Low-efficiency, traditional charcoal stove	$1,557	$1,712	$2,042	$2,645	$1,939	$3,209	$971	$1,589
Low-efficiency, improved charcoal stove	$1,561	$1,718	$1,741	$2,258	$1,681	$2,774	$829	$1,359
Three-stone woodstove	$1,637	$1,637	$2,156	$2,156	$3,132	$3,132	$786	$786
LPG stove	$3,379	$3,379	$3,370	$3,370	$3,255	$3,255	$6,417	$6,417

TABLE S-4: Present Value of the Economic Costs of Stoves and Fuels by Charcoal Price at a 12 Percent Discount Rate (U.S. Dollars per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price
Single-burner, coil electric hotplate	$1,352	$1,352	$1,343	$1,343	$1,408	$1,408	$5,986	$5,986
High-efficiency EcoZoom Jet charcoal stove	$4,604	$4,743	$5,410	$5,948	$5,191	$6,328	$4,173	$4,724
High-efficiency Jikokoa Xtra charcoal stove	$4,661	$4,802	$5,479	$6,028	$5,258	$6,416	$4,248	$4,815
Medium-efficiency, improved charcoal stove	$5,232	$5,404	$6,092	$6,742	$6,055	$7,478	$4,751	$5,442
Low-efficiency, traditional charcoal stove	$5,601	$5,830	$6,846	$7,732	$6,618	$8,485	$4,968	$5,876
Low-efficiency, improved charcoal stove	$6,169	$6,400	$6,640	$7,400	$6,460	$8,066	$5,005	$5,785
Three-stone woodstove	$7,776	$7,776	$9,289	$9,289	$10,650	$10,650	$6,944	$6,944
LPG stove	$4,647	$4,647	$4,631	$4,631	$4,488	$4,488	$8,315	$8,315

Over the long term, the DRC Government and development assistance organizations can increase public and private investment in renewable electric power generation and grid and minigrid infrastructure. The electric hotplate was the least-cost alternative in the financial and economic analyses, except in Kisangani, where electricity was more expensive. Households often prefer to cook some foods with wood or charcoal and are unlikely to stop cooking with woodfuels even if they also use other fuels. Kinshasa had a relatively high grid access rate, yet many households regularly cooked with both electricity and charcoal.

The DRC has enormous untapped hydroelectric potential, but transmission and distribution costs for expanding access to the grid are high. Increasing access to grid electricity will require substantial investment and time, but would reduce the costs of cooking in three of the study areas and the environmental and health impacts of cooking in all four locations. The potential for building more local minigrids should also be considered.

In the near-term and medium-term, the DRC Government and development assistance organizations can increase the availability of high-quality, efficient, and cleaner charcoal stoves by facilitating imports of mass-manufactured stoves. Informal sector artisans produce nearly all of the traditional and improved household charcoal stoves in small batches and do not market them outside their local areas. These stoves have low fuel efficiency and durability due to poor raw materials, limited understanding of stove design principles, inconsistent production practices and weak quality control.

The Worldwide Fund for Nature (WWF) and other development assistance organizations have trained some informal sector artisans to make improved charcoal stoves, especially in Goma and Bukavu. However, the approach of training informal sector producers has been slow and has not increased stove quality enough. Widespread adoption of efficient improved stoves cannot be achieved by continuing the local artisan approach, especially without financing, better raw materials, and mechanized production.

A better solution would be to replace informal sector production of improved charcoal stoves with mass manufacturing. More efficient and durable charcoal stoves have been mass produced in several African countries and China. Mass manufacturing opens up the potential for economies of scale in production, product standardization, and better stove quality and durability.

In the near term, development assistance agencies or the Government could facilitate imports of mass manufactured, charcoal stoves. A first step would be to assess the experience of the existing mass manufacturers and efforts to sell these stoves in other countries. Households will also need reliable information to inform their purchase decisions. Marketing campaigns to build demand will need to be combined with efforts to ensure sufficient availability of the imported stoves. The affordability of imported, charcoal stoves could be improved by eliminating the value-added tax on imported charcoal stoves and electric hotplates and providing financing for sellers.

The DRC has a large potential market for imported household charcoal stoves. After a sufficient market has been demonstrated, development assistance organizations or the Government could consider facilitating domestic mass manufacturing of high-quality household charcoal stoves by the private sector.

Development assistance organizations can promote more efficient charcoal kilns and production practices to reduce wood consumption. A brick kiln can reduce unsustainable wood harvesting for charcoal. There can also be large differences in the carbonization efficiency of traditional kilns due to differences in the density and moisture content of the wood, weather during carbonization, kiln sizes, and worker practices in building and operating the kilns.

Traditional earth mound charcoal kilns are built by producers near the source of the wood for each production cycle. Traditional kilns are typically larger where wood is abundant and smaller where wood is scarce. Many charcoal producers, especially in Goma and Bukavu, use relatively small earth mound kilns. Some charcoal producers in North and South Kivu Provinces operate inside national parks. Farmers may produce charcoal for a short period after clearing trees for agriculture.

Informal sector charcoal producers cannot afford higher capital costs and rely on own unpaid labor that receives a share of the revenues. More efficient kilns that require purchased bricks or metal parts that have to be transported to production locations may not be practical since informal sector producers cannot afford the capital costs and lack access to financing.

The carbonization efficiency of a traditional kiln can be improved with some relatively low-cost materials and worker training. One example is the Casamance earth mound kiln with a chimney and flue vents for better air circulation. It can yield more charcoal per unit of wood and the charcoal may be better quality. However, the capital costs of the Casamance kiln are higher than the traditional kiln and some other improved earth mound kilns, and it is only likely to be adopted with support from development assistance organizations or the Government. The WWF's Ecomakala Project promoted the Casamance kiln in the DRC, but relatively few charcoal producers in the country have used it.

The higher capital costs of the Casamance kiln can be offset by the increase in charcoal production and the potential for higher quality charcoal that might be sold at a premium price. The purchased components for the Casamance kiln can be reused in subsequent production cycles. The production cycles are also faster. Per ton of charcoal produced, the financial costs of using the Casamance kiln are lower than the traditional kiln, but higher than the large brick kiln.

When the GHG emission reductions are taken into account, the present value of the economic costs per ton of charcoal were lower for the Casamance kiln than the other alternatives in all four study locations. Since the Casamance kiln is similar to the traditional kiln, it should be easier to get informal sector charcoal producers to adopt it instead of the much more expensive alternatives. Nevertheless, it will be challenging to scale up use of the Casamance kiln due to the large number of small-scale charcoal producers in the DRC.

The Casamance kiln can be promoted in tandem with the establishment of plantations for sustainable production of wood for charcoal making. The WWF's Ecomakala Project in North Kivu Province demonstrated the potential of a private plantation-based model for growing woodfuels sustainably. This and similar projects have enabled North and South Kivu Provinces to obtain 41 percent of their woodfuels from plantations. The Ecomakala Project also promoted low-cost, but more efficient, charcoal production methods such as the Casamance kiln. The lessons learned from these experiences could help development assistance organizations scale up this work and replicate it in other provinces, particularly around Kinshasa where wood was relatively scarce and charcoal in high demand.

1 BACKGROUND AND CONTEXT

USAID commissioned the E3 Analytics and Evaluation Project, implemented by Management Systems International (MSI), a Tetra Tech company, to conduct financial and economic cost-effectiveness analyses of supply- and demand-side alternatives for household cooking in four urban areas of the Democratic Republic of the Congo (DRC) -– Bukavu (South Kivu Province), Goma (North Kivu Province), Kinshasa (the capital and largest city), and Kisangani (Tshopo Province). This study built on similar analyses for Lilongwe, Malawi and Lusaka, Zambia (Matek *et al.* 2021a, 2021b).

This study compared the present value of the costs of producing charcoal in five types of kilns and cooking with eight combinations of household stoves and fuels. The charcoal production methods included a traditional earth mound kiln (the most common method), improved earth mound kiln, Casamance improved earth mound kiln, portable metal drum kiln, and brick kiln. The cooking alternatives included wood in a three-stone stove (open fire); charcoal in traditional metal stoves; charcoal in low- and medium-efficiency, low-quality, locally produced modifications of the Kenya ceramic-lined jiko (Hyman 1986 and 1987); charcoal in two high-efficiency, imported, mass manufactured stoves (EcoZoom Jet and Jikokoa Xtra); a liquefied petroleum gas (LPG) stove; and an imported, single-burner, coil electric hotplate. Annex A is the scope of work and Annex B contains the data collection instruments.

The Congo Basin contains the second largest expanse of tropical forest in the world, after the Amazon Basin. The DRC had about 60 percent of the 217 million hectares (ha) of forest in the Congo Basin (FAO 2020). These forests sequestered approximately 23.3 billion tons of carbon, 5.2 percent of the global carbon stored in vegetation (Saatchi *et al.* 2017 and Erb *et al.* 2017).

Deforestation refers to the permanent conversion of forests to other land uses. It is distinguished from *forest degradation*, a reduction of the tree cover on land that has not been converted to nonforest land uses. The World Resources Institute estimated that the DRC lost about 500,000 hectares (ha) of primary forest through deforestation in 2021, the second largest amount in the world. This loss was approximately 0.5 percent of the country's primary forests.

Use of *woodfuels* (firewood or charcoal) in household cooking is a major cause of deforestation and forest degradation in the country. Over 95 percent of DRC households relied on woodfuels for cooking and the demand was increasing. Population growth and economic development are increasing pressures on converting forests to agriculture and other land uses (IEA 2019). Deforestation and forest degradation from woodfuel use in the rapidly growing city of Goma poses a risk to Virunga National Park in eastern DRC. Virunga is a UNESCO World Heritage Site and important habitat for endangered mountain gorillas (Ndebo 2020; Marien 2009).

Griscom *et al.* (2009) estimated that unsustainable wood harvesting for firewood and charcoal accounted for 57 percent of forest greenhouse gas (GHG) emissions in Sub-Saharan Africa. The Food and Agriculture Organization of the United Nations (FAO) estimated that global production and use of woodfuels contributed 1.0-2.4 billion metric tons of carbon dioxide equivalent (tCO_2e) each year, 2-7 percent of anthropogenic greenhouse gas (GHG) emissions. Wood sourcing was responsible for 29-61 percent of the global carbon dioxide (CO_2) emissions from charcoal production while *carbonization* (the process of making charcoal) generated 28-61 percent of the total and charcoal *combustion* (burning) produced 9-18 percent. Charcoal transportation and distribution only contributed a small share of the total CO_2 emissions from charcoal (FAO 2017a).

Combustion of woodfuels releases CO_2, methane (CH_4), and nitrous oxide (N_2O). Methane and nitrous oxide have stronger effects on atmospheric temperatures than CO_2 per ton (higher *radiative forcing*) but remain in the atmosphere for shorter time periods (lower *persistence*). *Global Warming Potential* (GWP) accounts for both of these factors and varies with the time period analyzed. This report uses 100-year GWP values. By definition, CO_2 has a global warming potential of 1.0. This analysis used 100-year GWP estimates from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) -- 32.0 for CH_4 and 282.0 for N_2O.[1]

Fine particles 2.5 microns in diameter or smaller ($PM_{2.5}$) are particularly harmful to human health because they penetrate deep into the lungs and enter the bloodstream. Exposure to $PM_{2.5}$ emissions from cooking with woodfuels can increase respiratory and other illnesses and premature mortality rates for the cooks and other household members, particularly children (WHO 2018). However, $PM_{2.5}$ exposures are substantially lower when cooking is done outdoors instead of indoors. Most cooking with woodfuels was done indoors in Bukavu and Goma and outdoors in Kinshasa and Kisangani (Gazull *et al.* 2020a, 2020b, 2020c; Imani and Moore-Delate 2021).

The environmental and health impacts of woodfuels use can be reduced by increasing the efficiency of charcoal kilns and cookstoves and shifting to cleaner cooking technologies. Electricity is a clean cooking fuel at the end-user level. However, only 19 percent of all households in the DRC had access to grid (mains) electricity in 2018. Grid access is mainly limited to urban areas. About 41 percent of urban households and only 1 percent of rural households in the DRC had access to the electric grid in 2021.[2] Population growth has increased the number of people in the country without access to grid electricity. The International Energy Agency (IEA) projected that this trend will accelerate worldwide and DRC will be one of the countries with the largest increase in the population without power grid access.[3]

Comprehensive data on grid access in the four cities were not available. However, survey data indicated that electricity was regularly used for cooking by 15.0 percent of the households in Bukavu, 13.2 percent in Goma, 66.4 percent in Kinshasa, and 0.5 percent in Kisangani (Gazull *et al.* 2020a, 2020b 2020c; Imani and Moore-Delate 2021).

The most common electric stoves in the DRC were single-burner, coil hotplates imported from Asia. These are the lowest-cost electric stoves and the alternative most comparable to a single-burner charcoal stove. Two- and four-burner coil hotplates are also available in the DRC, but are more expensive and not directly comparable to a charcoal stove. Electric coil hotplates are portable and allow users to control the cooking temperature. Induction hotplates cook much faster and more efficiently than coil units and their surfaces do not get hot. However, they are much more expensive and require more costly magnetic cooking pots (cast iron or stainless steel).

The DRC has considerable hydropower capacity and enormous additional potential.[4] There was 2,792 megawatts (MW) of installed hydropower capacity, 98 percent of the total power generation capacity. There was 2.2 MW of power generation capacity from natural gas and only 1 MW from solar power.[5] Two dams in Kongo Central province, Inga I and II, have an installed capacity of 1,775 MW (63.5 percent of national hydropower capacity). The Inga facilities have been undergoing maintenance to bring their

[1] The Sixth Assessment Report (IPCC 2021) updated GWP estimates to 27.2 for methane from agricultural sources, 29.8 for methane from fossil fuels, and 273 for nitrous oxide.
[2] https://www.trade.gov/country-commercial-guides/democratic-republic-congo-energy#:~:text=Despite%20millions%20of%20dollars%20of,one%20percent%20in%20rural%20areas.
[3] https://www.iea.org/commentaries/for-the-first-time-in-decades-the-number-of-people-without-access-to-electricity-is-set-to-increase-in-2022?utm_source=SendGrid&utm_medium=Email&utm_campaign=IEA+newsletters
[4] See https://trackingsdg7.esmap.org/country/democratic-republic-congo.
[5] https://www.usaid.gov/powerafrica/democratic-republic-congo

operations back to full capacity. Nevertheless, the country generated 97 percent of its electricity from hydropower in 2019 (IHA 2020). In 2021 the DRC generated over nine terawatt-hours of hydroelectricity (IHA 2022). The DRC has the largest undeveloped hydropower capacity in Africa and among the largest in the world – an additional100,000 MW is technically feasible (Tricard 2017). Only about 2.8 percent of the technically feasible capacity has been developed.[6]

Generation capacity is not the only constraint on access to electricity. The capital costs of expanding the electric transmission and distribution grid are high. Even in urban areas where grid expansion is more feasible, expansion will take a considerable time. The DRC is likely to remain dependent on woodfuels for household cooking in the short- to medium-term, especially in rural areas (World Bank 2020). As a result, the country will need to adopt less costly and environmentally damaging ways to produce and use woodfuels.

Liquefied petroleum gas (LPG) is an expensive fuel for low-income households due to the upfront costs of purchasing the imported cylinder, regulator, line, and cooking ring and the continuing costs of buying this imported fossil fuel. Some development assistance organizations and developing country governments have subsidized LPG fuel or stoves to reduce deforestation and forest degradation and $PM_{2.5}$ emissions. However, LPG subsidies are fiscally unsustainable and typically benefit higher income households more than lower income households.

LPG also generates indoor air pollution from methane and nitrogen dioxide (NO_2) that may persist at levels that pose a risk to health (Kephart *et al.* 2021). The extraction, processing, and transportation of LPG generates substantial GHG emissions. In 2021, a new policy required U.S. Government agencies to approve and report exemptions for funding carbon-intensive projects. LPG for household cooking exceeds the GHG emission threshold subject to this requirement.[7]

The Worldwide Fund for Nature (WWF) and other development assistance organizations have trained some informal sector artisans to make improved charcoal stoves, especially in Goma and Bukavu. Over 80 percent of households in Bukavu and Goma owned an improved charcoal stove (Gazull *et al.* 2020a, 2020b). However, many of these stoves are poorly designed and made and not as efficient and durable as the improved stoves mass manufactured in Kenya.

Relatively few households in Kinshasa and Kisangani owned improved charcoal stoves (Gazull *et al.* 2020c and Imani and Moore-Delate 2021). High-quality improved charcoal stoves are available in Kinshasha, but are not widely available in Kisangani. There were only four producers of improved charcoal stoves in Kisangani, with a total monthly production of 450 stoves. Most of these stoves were not very fuel efficient and some users reported problems such as fragility, heaviness, small size, and difficult handling (Moore-Delate 2021).

The United Nations Development Program (UNDP) and the United Nations Capital Development Fund (UNCDF) Technologies, Renewable Energy, Academy (TERA) Project in Kisangani trains informal sector

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[6] https://www.trade.gov/country-commercial-guides/democratic-republic-congo-energy#:~:text=Hydroelectric%20power%20accounts%20for%2096,located%20in%20Kongo%20Central%20province.

[7] On January 27, 2021, U.S. Executive Order 14008 required all Federal agencies to eliminate fossil fuel subsidies and establish a process to review exemptions from a prohibition on funding carbon-intensive projects. This executive order defined carbon-intensive projects as having lifetime emissions of over 250 gCO_2e per kWh of electricity or energy equivalent for other fuels. It exempted technical assistance and transmission and distribution investments for electric power. USG agencies can approve exemptions on national security and development grounds in International Development Association (IDA) and IDA-blend recipient countries, small island developing states, and conflict-affected countries. Agencies have to issue a public report on their approved exemptions annually.

artisans on improved charcoal stove designs and quality control. It aims to increase the fuel efficiency, durability, safety, and ease of use of improved charcoal stoves. [8]

Recent surveys in Bukavu, Goma, and Kinshasa (Gazull *et al.* 2020a, 2020b, 2020c) and Kisangani (Imani and Moore-Delate 2021) documented household cooking practices. Table 1 shows the cookstoves and fuels used by the respondents. Most households owned multiple types of stoves, but only used some infrequently. Between 90 and 96 percent of respondents in Bukavu and Goma and 69 to 73 percent in Kisangani and Kinshasha used charcoal to cook all meals every day. Approximately 11 percent of households in Bukavu and 27 percent in Kisangani cooked all meals with fuelwood.

Only 3-4 percent of the respondents in Bukavu and Goma and 0 percent in Kisangani regularly used electricity for cooking. Some of these households lacked access to the electric grid. Over 60 percent of the respondents in Kinshasha used electricity in cooking at least part of all daily meals and many also used charcoal to cook certain foods during the same meals.

Most respondents in Bukavu and Goma used low-efficiency improved charcoal stoves, but most in Kinshasa and Kisangani used low-efficiency traditional charcoal stoves. Approximately 74 percent of households in Bukavu and 87 percent in Goma mainly cooked indoors. Only 32 percent of households in Kinshasa and 25 percent in Kisangani cooked most meals indoors.

The *three-stone woodstove* is an open fire under a cooking pot balanced on three rocks. A three-stone stove has no capital or replacement cost. It has an average fuel efficiency of about 14 percent.[9]

Informal sector artisans throughout the country produce traditional and improved charcoal stoves. The designs and quality vary by location and producer. *Traditional charcoal stoves* are all-metal with perforated grills that support a cooking pot on or above the charcoal and no means to control the airflow or heat delivered to the pot. Informal sector artisans make the traditional charcoal stoves from scrap metal. The most common designs of traditional charcoal stoves varied considerably across the four study areas. *Improved charcoal stoves* have a higher fuel efficiency, longer effective life, and/or lower $PM_{2.5}$ exposures than traditional stoves.

Most of the improved charcoal stoves in the DRC are low-quality versions of the Kenya ceramic-lined jiko (KCJ). The KCJ was developed in Kenya in the early 1980s and subsequently promoted in many East, West, and Southern African countries. This stove has an hourglass-shaped, scrap metal cladding with handles for portability and an air inlet door that can opened or closed. A fired ceramic lining is cemented into the cladding (in Kenya, the cement is mixed with vermiculite to reduce the stove weight). The ceramic liner has holes in its base to allow ash to fall through for collection in the bottom section of the stove (Hyman 1986 and 1987). A good-quality KCJ has a fuel efficiency of about 34 percent and an expected life of up to two years.[10] The DRC adaptations of this stove are cylindrical and have lower fuel efficiencies than a high-quality KJC produced in other countries.

[8] https://forestsnews.cifor.org/73040/improved-cookstoves-an-untapped-market-in-drcs-kisangani?fnl=en
[9] http://catalog.cleancookstoves.org
[10] http://catalog.cleancookstoves.org

TABLE 1: Household Stoves and Fuels in the Four Cities

	Bukavu	Goma	Kinshasa	Kisangani
Percent of households with stoves for these fuels				
Wood	35.7%	27.5%	10.3%	40.1%
Charcoal	97.3%	99.0%	100.0%	87.8%
LPG	1.2%	11.6%	3.2%	0.4%
Electricity	16.5%	17.7%	71.9%	9.2%
Percent of households cooking all meals with these fuels				
Wood	10.8%	0.1%	0.0%	27.4%
Charcoal	89.9%	95.8%	73.2%	68.9%
LPG	0.3%	2.0%	1.0%	0.0%
Electricity	3.6%	3.5%	60.2%	0.0%
Most common stove for each fuel				
Wood	Three-stone woodstove	Improved woodstove	Three-stone woodstove	Three-stone woodstove
Charcoal	Low-efficiency, improved stove	Low-efficiency, improved stove	Low-efficiency, traditional, charcoal stove	Low-efficiency, traditional, charcoal stove
LPG	Single cooking ring over LPG cylinder	Single cooking ring over LPG cylinder	Single cooking ring over LPG cylinder	Single cooking ring over LPG cylinder
Electric	Single-burner, coil electric hotplate	Single-burner, coil electric hotplate	Double-burner, coil electric hotplate	Single-burner, coil electric hotplate
Percent of households with improved charcoal stoves	81.0%	83.6%	12.0%	48.0%
Percent of households usually cooking outdoors	25.8%	13.0%	68.0%	75.4%

Sources: Gazull *et al.* 2020a, 2020b, 2020c (Bukavu, Goma, and Kinshasa) and Imani and Moore-Delate 2021 (Kisangani)

The WWF's EcoMakala Project reported that households in Goma often had "...pirates of the WWF stoves (jiko and nguvu nyeusi)...with artisans not receiving training and not following a standardized protocol resulting in differences of weight, geometric dimensions, and quality."[11] Stove producers complained that, "The absence of a proof of quality, such as a quality seal, does not allow them to

11 https://www.co2logic.com/sites/default/files/documents/EcoMakala%20Virgunga%20Energy%20project%20PDD_v.1.0_17062017_GS%20PFA.pdf

confirm that their stoves meet certain quality requirements and efficiency." (Women's Refugee Commission 2014).

Imani *et al.* (2021a; 2021b) and Akalakou *et al.* (2021) visited markets in Bukavu, Goma, and Kinshasa and found that all of the improved charcoal stoves were locally made. The prices, materials, quality, and likely fuel efficiency and durability of these charcoal stoves varied and some did not appear to be substantially better than traditional stoves. Moore-Delate *et al.* (2019) noted that informal sector artisans lacked "...understanding of how charcoal burns or the amount of air needed for charcoal to heat the pot and food."

Moore-Delate *et al.* (2019) conducted controlled cooking tests for a small sample of artisan-produced improved and traditional charcoal stoves in Bukavu, Goma, and Kinshasa. The controlled cooking test results varied considerably by location due to differences in stove characteristics, fuel quality and conditions, and cooking practices. The improved charcoal stoves in the controlled cooking tests used between 1 percent more and 38 percent less fuel than the traditional stoves. No comparable cooking test data existed for Kisangani.

High-quality charcoal stoves with higher fuel efficiency and better durability were being mass manufactured in Kenya, other African countries, and Asia for both domestic and export markets. These stoves had well-engineered designs and were made with high-quality materials. However, they cost substantially more than the lower quality stoves produced by informal sector artisans. Examples included the Jikokoa and EcoZoom Jet.

Jikokoa means "the stove that saves" in Swahili. This metal stove was designed by Burn Design Lab in the United States. The Jikokoa holds the cooking pot on metal supports on top of the stove. The charcoal is placed inside the metal stove body below the grate. The Jikokoa has a dual-purpose tray for ash removal and air flow adjustments. The combustion chamber and cone deck are made of a high-temperature alloy that allows efficient and sustained high temperature burning. The metal handles have a shrink sleeve coating that stays cool. The stove is insulated with high-temperature ceramic wool.

The Jikokoa Xtra weighs 5.0 kg with dimensions of 305 x 302 x 275 centimeters. It can hold a 10-liter pot. It also has a high-power fuel efficiency of 43 percent. The suggested retail price in Nairobi was $50. This model was designed to be more durable than the Regular Jikokoa. The manufacturer provided a two-year warranty, but the expected life of the Jikokoa Xtra is three years.[12] At the time of this study, the Altech Group was already selling the Jikokoa Xtra in Goma and Kinshasa and planned to begin selling it in Kisangani.[13]

The Jikokoa Xtra is produced in Ruiru, Kenya by Burn Manufacturing, a social venture. Burn Manufacturing produces about 20,000 stoves per month and has sold over 450,000 Jikokoas of this model or a similar size.[14] Jikokoas have been sold in the Democratic Republic of Congo, Djibouti, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Myanmar, Nepal, Nigeria, Rwanda, Senegal, Somalia, South Africa, Uganda, United Republic of Tanzania, Zambia, and Zimbabwe.[15]

The EcoZoom Jet charcoal stove was designed by the Approvecho Research Center in the United States and is the first household charcoal stove that cooks with both radiated and conducted heat. It received

[12] http://catalog.cleancookstoves.org
[13] https://www.altech-rdc.com/products;
[14] https://www.burndesignlab.org/projects/the-jikokoa
[15] http://catalog.cleancookstoves.org

a gold award in the 2014 International Design Excellence Awards.[16] The body and reinforced door latch of the EcoZoom Jet are painted sheet metal. Forever Color technology allows the stove to retain its color longer. The stovetop and grate are cast iron for good heat conduction. There is a smaller, inner, refractory metal combustion chamber to direct heat to the bottom of the cooking pot and reduce heat losses around the sides of the pot. Inside the stove is an abrasion-resistant, lightweight clay and ceramic fiber insulating layer that withstands high temperatures. The adjustable door allows the user to control the heat. To prevent burns, the door latch and stainless-steel carrying handles have silicone grips. Nonslip rubber feet keep the stove from sliding while cooking.[17]

The Clean Cooking Alliance reported that the EcoZoom Jet had an average fuel efficiency of 45 percent.[18] Other tests have found a thermal efficiency of 42 percent at high power (boiling) and 56 percent at low power (simmering). The University of Nairobi reported that this stove consumed 145 grams (g) of charcoal [4.6 megajoules (MJ)] in a five-liter water boiling test, 76 percent less charcoal than the KCJ in the same test (19.1 MJ). Carbon monoxide emissions were 44 grams (g) for the EcoZoom Jet, 57 percent lower than the KCJ. The EcoZoom Jet took 27 minutes to boil the water, 42 percent longer than the KCJ. However, the EcoZoom Jet was reportedly 20 percent faster than the KCJ in food cooking tests.[19]

The EcoZoom Jet charcoal stove was initially manufactured in Nairobi, Kenya in two sizes -- 26- and 28-centimeter diameters. The larger model has a weight of 6.0 kg and dimensions are 260 x 260 x 190 millimeters. The Kenyan model was sold in Ethiopia, Nigeria, Somalia, Uganda, and Zambia.[20] The EcoZoom Jet is now being manufactured in China, with a monthly production capacity of 60,000 stoves (total for the charcoal and woodstove models). At the time of this study, the EcoZoom Jet was not being sold in the DRC. However, the manufacturer identified the DRC, Ghana, Haiti, Kenya, Nigeria, Senegal, and Zambia as its target markets.[21]

1.1 METHODS

This analysis estimated the present value of the financial and economic costs of various traditional and improved woodstoves and charcoal stoves as well as electric and LPG stoves. It also analyzed the costs of five different charcoal kiln types and sourcing wood from natural forests and sustainably managed commercial plantations.

The *financial analyses* focused on the costs of cooking for a household and the unit costs for a charcoal production enterprise over a 10-year period. Households incur costs in purchasing, maintaining, and replacing the stoves and buying fuel. The costs of charcoal production included sourcing wood for carbonization, building or buying a kiln, operating the kiln, and packaging the charcoal. The financial costs included any applicable taxes, tariffs, and subsidies.

The *economic analyses* adjusted the financial costs for market distortions (taxes, tariffs, and subsidies) and included, the global social costs of GHG emissions, the lost value of forest environmental goods from unsustainable woodfuel harvesting, and local premature mortality risks from fine particulate exposures ($PM_{2.5}$):

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16 https://ecozoom.com/blogs/ecozoom/14787593-zoom-jet-wins-gold-in-international-design-excellence-awards#:~:text=Zoom%20Jet%20Wins%20Gold%20in%20International%20Design%20Excellence%20Awards,-July%2007%2C%202014&text=The%20Zoom%20Jet%2C%20our%20charcoal,experts%20over%202%2C000%20other%20entries
17 http://catalog.cleancookstoves.org
18 http://catalog.cleancookstoves.org
19 https://cdn.shopify.com/s/files/1/0420/5925/files/Zoom_Jet_Technical_Sheet.pdf?13902902402425526452
20 https://ecozoom.com/pages/rocket-stove-technology
21 https://www.engineeringforchange.org/solutions/product/ecozoom-jet/

- **The social cost of greenhouse gas emissions.** Carbon dioxide, methane, and nitrous oxide emissions were costed at the U.S. Government's 2021 preliminary global social cost estimate of $51 per tCO_2e in 2020 and the U.S. EPA's 2022 draft revised estimate of $190/$tCO_2e$.
- **The lost value of forest environmental goods per hectare (ha) of unsustainable woodfuel harvesting** at a conservative, domestic value of $224 and a higher global median of $486.
- **The costs of premature mortality risks from exposure to fine particulates ($PM_{2.5}$) from cooking with woodfuels indoors and outdoors**. $PM_{2.5}$ risks are higher where woodfuels are typically used in cooking indoors (Goma and Bukavu) and lower where this is usually done outdoors (Kinshasa and Kisangani). Two country-specific *values of a statistical life* (VSL) were used -- $18,601 in the base case and $40,716 in the sensitivity analysis.

The *VSL* is a country-specific measure of the average willingness to pay for a marginal reduction in the risk of premature death or willingness to accept compensation for a marginal increase in the risk. The economic analyses of cooking alternatives did not address the monetary value of time saved in cooking, sociocultural preferences for cooking with certain fuels or stoves, or income and jobs generated from domestic production or sale of the fuels and stoves.

The economic analyses used a 50-year time horizon to capture the long-term social costs of GHG emissions, lost value of forest environmental services, and premature mortality risks from fine particulate exposures. The financial and economic analyses were based on a 12 percent real discount rate, with sensitivity tests at 3 percent and 7 percent real discount rates.

Following the USAID (2015) guidelines, present values were calculated at three real discount rates in both the financial and economic analyses —12 percent in the base case and 3 and 7 percent in sensitivity analyses. The two lower discount rates are used in U.S. Government analyses of domestic regulatory decisions).[22] All monetary values are in 2020 U.S. dollars. Local currency values were adjusted to a common basis year of 2020 with an inflation index and converted to U.S. dollars at an exchange rate of 1,985 Congolese Francs (CDF) per dollar on November 8, 2021.[23]

2 ASSUMPTIONS FOR THE COST-EFFECTIVENESS ANALYSES

The team analyzed stoves based on their average fuel savings compared to the traditional charcoal stove in prior controlled cooking tests (Moore-Delate *et al.* 2019). The charcoal stoves were categorized as 1) *low efficiency* (fuel savings of 20.0 percent or less), 2) *medium efficiency* (fuel savings of 20.1-29.9 percent), and 3) *high-efficiency* (fuel savings of 30.0 percent or more). Since controlled cooking tests had not been done in Kisangani, the team adapted the Kinshasha stove test data for Kisangani. The prior household surveys found that cooking practices in Kisangani were similar to those in Kinshasa in improved charcoal stoves use and location of cooking with woodfuels. The main difference was that many households in Kinshasha used both charcoal and electricity for cooking, which was uncommon in Kinsangani.

Table 2 describes the types of stoves included in this analysis. Figure 1 contains photos of typical stoves available at local markets in each of the four cities.

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[22] For a financial analysis, the USAID (2015) guidelines recommend a discount rate based on the cost of loan financing available to the target group (the nominal annual percentage rate adjusted to remove the projected inflation rate). The team did not use this approach because loan financing was not available in the DRC for purchasing charcoal kilns or household stoves.
[23] https://www1.oanda.com/currency/converter/

TABLE 2: Descriptions of the Types of Stoves Included in This Analysis

Type of Stove	Description	Average Life (Months)[a]
Three-stone woodstove	• Approximately 10% of households in Bukavu and 27% of households in Kisangani used this regularly • Few households used it in Goma or Kinshasa	N/A
Low-efficiency, traditional charcoal stove	• Few households in Bukavu and Goma used this all-metal stove • Many households in Kisangani and Kinshasa used it regularly, but many households in Kinshasha also cooked with electricity	6[a]
Low-efficiency, improved charcoal stove	• Poorly made version of the Kenya ceramic-lined jiko by informal sector artisans	16[a]
Medium-efficiency, improved charcoal stove	• Relatively well-made version of the Kenya ceramic-lined jiko by informal sector artisans	
High-efficiency, imported charcoal stove	• Jikokoa Xtra and EcoZoom Jet mass-manufactured stoves	36[b]
LPG stove	• Imported cooking ring, regulator, line, and cylindrical fuel tank	72 [b]
Single-burner, coil electric hotplate	• Imported	36[c]

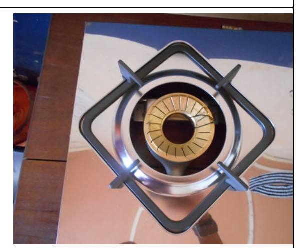
[a] Moore-Delate *et al.* 2019
[b] http://catalog.cleancookstoves.org
[c] Averages from the MSI team's rapid market appraisal in Kinshasa and Kisangani

2.1 ASSUMPTIONS FOR THE FINANCIAL ANALYSIS OF STOVES AND FUELS

Table 3 contains the average market prices for various stoves. Most of the data on stove prices came from surveys of vendors in Bukavu (Imani *et al.* 2020a), Goma (Imani *et al.* 2020b), and Kinshasa (Akalakou *et al.* 2021) and the team's rapid market appraisal in Kisangani. The cost of the various charcoal stoves produced by informal sector artisans varied across the four cities. Average prices were lowest in Kisangani. Prices of similar stoves were 5 percent higher in Bukavu than in Kisangani, 28 percent higher in Goma, and 214 percent higher prices in Kinshasha.

Artisanal charcoal stoves ranged from low to medium efficiency, depending on the designs and quality of materials and production. Because efficiency data were not available for artisanal charcoal stoves in each location and it was difficult to assess the efficiency by appearance, the team assumed that the low- and medium-efficiency artisanal stoves sold for the same prices.

FIGURE 1: Photos of Typical Stoves Available in the Four Cities

	Traditional Charcoal Stoves	Improved Charcoal Stoves (Artisanal)	Electric Stoves	LPG Stoves
Bukavu				
	Photo source: Pascal Murhula			
Goma				
	Photo source : Imani *et al.* 2020a and Benjamin Munyamali			
Kinshasa				
	Photo source : Imani *et al.* 2021c			
Kisangani				
	Photo source: Junior Evariste			

High-efficiency, imported charcoal stoves: Jikokoa Xtra and EcoZoom Jet

	Photo source: Burn Manufacturing (https://www.burndesignlab.org/projects/jikokoa-g4)		Photo source: https://www.engineeringforchange.org/solutions/product/ecozoom-jet/

Some producers of ceramic-lined, metal charcoal stoves sold replacement ceramic liners that extended the life of the metal cladding so that the whole stove would not need to be replaced when the ceramic liner cracked or broke (Moore-Delate 2021). Some stove retailers sold metal inserts (*pads*) that fit on top of the base of the ceramic liner to extend the useful life of the liners. The metal pads cost $0.50 and also added about six months to the stove's life. Replacement liners cost about $1.00 with installation in Goma and extended the stove life about six months (Moore-Delate 2021). The financial analysis assumed that households purchased the pads with a stove and a replacement liner when needed.

Between 11 and 23 percent of the household survey respondents in Bukavu, Goma, and Kinshasa reported that the high upfront cost of the LPG cooking ring, regulator, hose, and filled tank was a barrier to adopting this fuel. Limited availability of LPG also constrained use of this fuel in some areas.

TABLE 3: Average Stove Prices in the Four Cities (2020 U.S. Dollars)

Stove	Bukavu[b]	Goma[c]	Kinshasa[d]	Kisangani[e]
Three-stone woodstove	$0.00	$0.00	$0.00	$0.00
Low-efficiency, traditional charcoal stove	$2.52	$3.02	$3.02	$2.04
Low-efficiency, improved artisanal charcoal stove	$3.53	$4.53	$11.08	$3.35
Medium-efficiency, artisanal charcoal stove	$3.53	$4.53	$11.08	$3.35
High-efficiency, Jikokoa Xtra charcoal stove[a]	$27.50	$27.50	$27.50	$27.50
High-efficiency, EcoZoom Jet charcoal stove[g]	$24.75	$24.75	$24.75	$24.75
LPG stove				
Starter kit (stove, regulator, hose, and full six-kg tank)[f]	$58.39	$58.39	$47.46	$50.73
Replacement unit	$60.45	$40.30	$34.26	$45.34
Single-burner coil electric hotplate	$22.67	$19.14	$23.17	$22.17

[a] Altech Group 2021
[b] Imani *et al.* 2020a, unless otherwise noted
[c] Imani *et al.* 2020b, unless otherwise noted
[d] Akalakou *et al.* 2021, unless otherwise noted
[e] MSI team's rapid market appraisal, unless otherwise noted
[f] Gazull *et al.* 2020a and 2020b and Imani and Moore-Delate 2021. Because the Kinshasa survey did not report a price for the full kit, the MSI team added the cost of a six-kilogram (kg) cylinder ($13.20) and the other components ($34.26). For Kisangani, the team used DAP Energy's advertised price for a six-kg kit in Goma (Imani 2021).
[g] The MSI team estimated the DRC price for the EcoZoom Jet by multiplying its price in Malawi ($36.00) by the ratio of the DRC price for the Jikokoa in the DRC ($27.50) to its price in Malawi ($40.00) reported in Matek et al. (2021a).

TABLE 4: Thermal Efficiency and Average Annual Household Cooking Fuel Consumption by Stove and Fuel and Location

Stove	Bukavu		Goma		Kinshasa		Kisangani	
	Average Thermal Efficiency	Average Annual Fuel Consumption	Average Thermal Efficiency	Average Annual Fuel Consumption	Average Thermal Efficiency	Average Annual Fuel Consumption	Average Thermal Efficiency	Average Annual Fuel Consumption
Three-stone woodstove[a]	14.0%	2,649 kg	14.0%	3,501 kg	14.0%	3,648 kg	14.0%	3,394 kg
Low-efficiency, traditional charcoal stove[b]	22.4%	950 kg	22.4%	1,255 kg	22.4%	1,308 kg	22.4%	1,217 kg
Low-efficiency, improved artisanal charcoal stove	22.2%	959 kg	26.1%	1,078 kg	26.1%	1,123 kg	26.1%	1,045 kg
Medium-efficiency, artisanal charcoal stove	29.7%	715 kg	30.5%	920 kg	29.4%	995 kg	29.4%	926 kg
High-efficiency, Jikokoa Xtra charcoal stove[c]	36.1%	589 kg	36.1%	778 kg	36.1%	811 kg	36.1%	754 kg
High-efficiency, EcoZoom Jet[d]	36.9%	576 kg	36.9%	762 kg	36.9%	794 kg	36.9%	739 kg
Single-burner LPG stove[a]	56.0%	247 kg	56.0%	327 kg	56.0%	341 kg	56.0%	317 kg
Single-burner, coil electric hotplate[e]	83.4%	2,266 kWh	83.4%	2,994 kWh	83.4%	3,120 kWh	83.4%	2,903 kWh

[a] Thermal efficiency from http://catalog.cleancookstoves.org

[b] Thermal efficiency from Ekouedjen *et al.* 2020

[c] Thermal efficiency reduced from 43.5 percent (http://catalog.cleancookstoves.org) to reflect typical household cooking practices

[d] Thermal efficiency reduced from 45.0 percent (http://catalog.cleancookstoves.org) to reflect typical household cooking practices

[e] Thermal efficiency from Sweeney *et al.* 2014

Survey data for households in Bukavu, Goma, and Kisangani provided a sufficient sample size for reliable estimates of charcoal use by households that only used this fuel for cooking. The team assumed that the average charcoal consumption per household was with the most commonly used charcoal stove in each of these cities. Table 4 contains the average thermal efficiency and annual fuel consumption of the various stoves in each of the four locations. Table 5 lists the heat content of each fuel. Data from these two tables were combined to estimate the amount of fuel required for cooking with the various stoves and fuels. Since most households in Kinshasa used charcoal and electricity, both fuels were included in the total energy consumption estimates for the capital city.

TABLE 5: Heating Value of the Fuels

Fuel	Heating Value	Sources
Wood	18.41 MJ/kg	http://catalog.cleancookstoves.org
Charcoal	31.98 MJ/kg	Jetter and Kariher 2009
LPG	46.6 MJ/kg	http://catalog.cleancookstoves.org
Electricity	3.6 MJ/kWh	https://home.uni-leipzig.de/energy/energy-fundamentals/03.htm

Wood and charcoal are sold in diverse, volume-based units that vary in weight by seller, location, season, and year. The survey field teams collected data on prices for various unit sizes and weighed them to estimate average prices per kilogram at a sample of markets in each of the four cities (Gazull *et al.* 2020a, 2020b, 2020c; Imani and Moore-Delate 2021). Wood and charcoal can be purchased in small volumes for daily consumption at a relatively high price per kilogram or in larger volumes at a lower price per kilogram.

Since few households with grid access in the study areas had individual electricity meters, the analysis team obtained data on electricity prices from household surveys. The national electric utility, *Societe Nationale d'Electricite* (SNEL), only meters neighborhoods. It charges each household with a legal connection an equal share of the total consumption in their neighborhood.[24] SNEL also charges different tariffs for different classes of users and subscription types, which also contributes to variation in electricity costs at the household level (USAID 2019). Table 6 summarizes the average prices of cooking fuels in the four cities.

[24] Typically, two to five residential customers have illegal grid connections for every legal connection in the DRC (USAID 2019).

TABLE 6: Prices Per Kilogram of Fuelwood, Charcoal, and LPG and Per Kilowatt-Hour of Electricity (2020 U.S. Dollars)

Fuels	Unit Price Level	Bukavu[a]	Goma[b]	Kinshasa[c]	Kisangani[d]
Fuelwood	Single price[e]	$0.109	$0.109	$0.152	$0.041
Charcoal	Low	$0.285	$0.283	$0.258	$0.138
	High	$0.314	$0.368	$0.430	$0.228
LPG	Single price[f]	$1.744	$1.744	$1.656	$3.526
Electricity	Low	$0.026	$0.026	$0.027	$0.123[g]
	High	$0.149	$0.149	$0.088	

[a] Gazull *et al.* 2020a

[b] Gazull *et al.* 2020b

[c] Gazull *et al.* 2020c

[d] Imani and Moore-Delate 2021

[e] Fuelwood prices vary by type and other characteristics. However, the sources for fuelwood prices (Gazull *et al.* 2020a, 2020b, and 2020c; Imani and Moore-Delate 2021) reported only one price.

[f] Converted from $/kWh using a conversion factor of 13.7 kWh/kg (Gazull *et al.* 2020a, 2020b, 2020c). This price only reflects the fuel price and assumes that the household already has a tank that can be refilled.

[g] The MSI team estimated the electricity price by dividing average household consumption (10.95 kWh per month) by average monthly expenditures on electricity. The analysis assumed that 30 percent of the average electricity consumption was used for cooking.

2.2 ASSUMPTIONS FOR THE FINANCIAL ANALYSIS OF CHARCOAL KILNS

The team interviewed small, nonrepresentative samples of charcoal producers around each of the four cities. Table 7 compares the characteristics and costs of charcoal production in the four areas. The interviewed charcoal producers in Bukavu usually obtained wood from tree plantations. In the other three cities, charcoal producers generally collected wood from natural forests or land cleared for agriculture. Interviewed charcoal producers in Kinshasa and Kisangani generally used larger kilns than those in Bukavu and Goma.

Carbonization efficiency is the weight of charcoal produced divided by the weight of wood used, multiplied by 100. Kilns with a higher carbonization efficiency waste less wood, potentially reducing deforestation or forest degradation and the associated GHG emissions. The interviewed charcoal producers estimated the typical wood input and charcoal output for their earth mound kilns and the team calculated average carbonization efficiencies. The sample sizes were relatively small in each location. Imputed efficiencies ranged from 10 and 23 percent across the locations. While carbonization efficiencies are best measured, rather than imputed from recall data, these values were within the range reported in other studies of traditional earth mound kilns. The analyses used measured efficiencies from the literature for each kiln type.

TABLE 7: Characteristics and Costs of Charcoal Production, by Location (2020 U.S. Dollars)

	Bukavu	Goma	Kinshasa	Kisangani
Sample size	8	8	12	24
Share of producers earning all or most of their income from charcoal	62%	88%	92%	71%
Median number of traditional earth mound kiln cycles in 2020	28	22	10	5
Sources of wood for charcoal production				
Land cleared for farming	0.0%	25.0%	0.0%	16.7%
Collected from natural forests	25.0%	50.0%	58.3%	66.7%
Purchased from tree plantation	62.5%	25.0%	8.3%	0.0%
Purchased from other private party	0.0%	0.0%	8.3%	16.7%
Obtained from own plantation	12.5%	0.0%	25.0%	0.0%
Median kiln size				
Cubic meters (m^3) of wood input	5.50	4.12	18.00	20.50
Kg of wood input	2,898	2,250	9,000	11,898
Median weight of charcoal produced per cycle (kg)	300	330	2,100	1,125
Estimated median carbonization efficiency	12.4%	15.0%	22.9%	9.6%
Median cost of a ton of wood	$11.52	$12.90	$4.97	$2.23
Median total production cost per kg of charcoal	**$0.14**	**$0.13**	**$0.07**	**$0.05**
Median cost of wood	$0.11	$0.08	$0.02	$0.02
Median charcoal production costs	$0.04	$0.05	$0.05	$0.02
Median marketing costs	$0.00	$0.00	$0.04	$0.00
Median producer price per kilogram of charcoal	**$0.19**	**$0.20**	**$0.17**	**$0.10**

Charcoal producers in Bukavu and Goma reported significantly higher unit production costs than those in Kinshasa and Kisangani because wood purchased from plantations costs more than wood collected from natural forests or land cleared for farming. The wood costs included the cash price per unit of wood or the right to collect wood and the labor costs for collection and transport. If the interviewed charcoal producers did not pay a cash wage rate, the interviewers asked how much it would have cost to hire labor for this task. Table 8 compares the cost of wood for charcoal production in the four study areas.

TABLE 8: Median Wood Prices by Source and Location (2020 U.S. Dollars Per Metric Ton)

Wood Source	Median Cost ($/ton)			
	Bukavu	Goma	Kinshasa	Kisangani
Plantations	$18.64	$14.86	$9.57	N.A.
Other sources	$7.05	$10.33	$4.53	$2.01

Figure 2 shows the types of kilns included in this analysis. Most charcoal producers in the DRC used traditional earth mound kilns (Imani 2021; Schure *et al.* 2012; GIZ 2014). The workers stacked the wood, covered it with a layer of leaves or grass, sealed it with soil, and set the wood on fire so that combustion takes place in a low oxygen environment. Earth mound kilns are single-use structures that have to be rebuilt each production cycle.

Most of the rest of the costs of an earth mound kiln besides wood are for labor, usually unpaid workers who receive a share of the charcoal produced or the sales revenue. Labor is required to prepare the wood, construct the kiln, tend the carbonization and cooling processes, take down the earth mound, and unload and bag the charcoal. There are some one-time, capital costs for basic tools with a long useful life -- machetes, rakes, and hoes. The carbonization time varies with the size of the traditional earth mound kiln, moisture content and other characteristics of the wood, and the weather. It can take up to two weeks or more (Ellegård *et al.* 2002; van Beukering *et al.* 2007; and Nturanabo, Byamugisha, and Preti 2011).

Carbonization efficiencies of traditional earth mound kilns in the literature range from 7.5 to 31.1 percent. This analysis used the midpoint of these estimates – 19.1 percent. The team observed two simple, improved earth mound kilns in the study areas. The improved earth mounds included vents to improve airflows and increase carbonization efficiency. However, there was insufficient information to assess whether these kilns were actually more efficient than traditional earth mound kilns.

FIGURE 2: Photos of the Analyzed Kilns

Traditional Earth Mound Kiln

Photo source: Benjamin Munyamali

Simple, Improved Earth Mound Kiln

Photo source: Gerard Imani

Improved Earth Mound Kiln

Photo source: Gerard Imani

Casamance Kiln

Photo source: Thierry Lusenge (2020)

Steel Drum Kiln

Photo source: Odur (2021)

Brick Beehive (Half-Orange) Kiln

Photo source: Odur (2021)

Other researchers have described various improved earth mound kilns that involve more careful wood stacking methods and air vents and one or more metal chimneys to improve ventilation and carbonization efficiency. More careful preparation and stacking of the wood increases the labor required for improved earth mound kilns, but data were not available on the labor costs (Oduor, Githiomi, and Chikamai 2006 and Kalenda *et al.* 2013). Carbonization typically takes about five days in an improved earth mound kiln with metal chimneys (Nahayo, Ekisel, and Mukarugwisa 2013). These kilns have reported carbonization efficiencies between 13.3 and 30.0 percent -- a midpoint value of 21.6 percent. The analysis estimated that the metal chimney for these kilns cost $200.

The *Casamance kiln* is a better designed, improved earth mound kiln with a larger, more elaborate chimney. The Casamance kiln was named for the region in Senegal where it was promoted under a USAID-funded project. This kiln has vents at the base and a better-designed and positioned chimney with baffles to control air flow. The chimney can be made from four used 200-liter steel drums. The Casamance kiln requires more user skill for careful arrangement of the stacked wood to improve airflows and charcoal producers will need training on how to do this well. (Karch, Boutette, and Christophersen 1987; Mundhenk, Gomis, and Sy 2010; Vos and Vis 2010). Casamance kilns have higher capital costs than traditional earth mound kilns and the simple improved earth mound kilns used in the DRC.

Karch, Boutette, and Christophersen (1987) reported that construction of a Casamance kiln with a capacity of 100 cubic meters (m^3) of wood took nine person-days if the wood had already been obtained, dried, and cut. Kimaryo and Ngereza (1989) reported that construction and operation of a much smaller, eight m^3 Casamance kiln in Tanzania required six person days. Although a Casamance kiln requires more time and skill to construct and operate, it can reduce the time required for carbonization and produce higher quality charcoal than a traditional earth mound kiln (Kimaryo and Ngereza 1989; Nturanabo, Byamugisha, and Preti 2011). Carbonization takes about five days in a Casamance kiln and requires continuing vigilance for the entire period, including at night (Karch, Boutette, and Christophersen 1987; FAO 1987). Field tests have found carbonization efficiencies of Casamance kilns between 16.8 percent and 39.3 percent -- a midpoint of 28.0 percent.

The IFDC and WWF promoted the Casamance kiln in North Kivu Province in the DRC.[25] A master charcoaler trained by the WWF worked with other organizations to introduce this kiln in Bukavu, Kisangani, Luki, and Mampu.[26] Informal sector artisans in the DRC can construct the chimney for about $450 (Lusenge 2020).

The MSI team analyzed five types of charcoal kilns: 1) the traditional earth mound kiln; 2) a simple, improved earth mound kiln; 3) the Casamance kiln; 4) a portable, single metal drum kiln; and 5) a large, stationary brick kiln. The literature review and interviews for this study did not find evidence that charcoal producers in the DRC were using portable drum kilns or brick kilns, but these kilns have been adopted in other African countries. The Casamance kiln also did not appear to be widely used in the DRC.

Metal drum kilns consist of one or more 200-liter oil drums modified by informal sector artisans (Smith and Pennise 1999; Oduor, Githiomi, and Chikamai 2006). A single-drum kiln can be easily moved around close to the wood sources. A single-drum kiln has higher capital costs than a traditional earth mound kiln, but lower capital costs than the Casamance kiln, which uses four metal drums. A metal drum kiln can last two to three years (FAO 1987). Each production cycle in a single-drum kiln only

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[25] A 2011 video documentary on an IFDC-promoted Casamance kiln in the DRC is available at https://vimeo.com/25721658.
[26] Lusenge 2020.

takes two to three days (FAO 2014). However, the production capacity of a single-drum kiln is very low; it can only produce 12-18 kg of charcoal per cycle. The reported carbonization efficiency of a single-drum kiln ranged from 20 percent to 38 percent, a midrange of 29 percent (Smith and Pennise 1999; FAO 2017a). The team estimated that a single-drum kiln would cost about $115 in the DRC.

The *stationary brick kiln* design is a standard beehive kiln (also known as a half-orange kiln). It can be constructed by local artisans with soft-fired bricks and mud mortar (FAO 1987). The labor and materials cost vary with the size and location. This kiln can have a useful life of five to eight years. Each carbonization cycle takes three to seven days (Kalende *et al.* 2013; FAO 2014). This analysis assumed a relatively small unit with an input capacity of 17 m^3 of wood. Stationary brick kilns are best located near tree plantations with a sustainable supply of wood and may be impractical for small-scale producers without a regular supply of wood near the fixed kiln location (GIZ 2015).

Locally produced bricks are available in Bukavu, Kisangani, and Kinshasa, but the volcanic soils around Goma are not suitable for brickmaking. Bricks are costly to produce and heavy to transport. The transport costs vary with road conditions and distance from the producer. The team analyzed a beehive kiln with a 4-meter diameter and 17 m^3 wood capacity. Brickmakers in Bukavu reported that the 5,000 bricks needed would sell for $160-190 and transport would cost $80-120 for 35-45 kilometers. It would take six to nine person-days of skilled labor to construct a brick kiln of this size (Kimaryo and Ngereza 1989; Karch, Boutette, and Christophersen 1987), a midpoint of 7.5 person-days. A skilled mason in the study area can earn $15.11 per person-day. A 17 m^3 kiln would cost $346 to $416 if located close to a brick production area. The team assumed a total cost of $500 to allow for higher transportation and labor costs.

Table 9 summarizes secondary data on the carbonization efficiencies of the analyzed kilns. In addition to the kiln design, the weather during the process and characteristics of the wood (density and chemical composition of the tree species, size, and moisture content) affects the carbonization efficiency (van Beukering *et al.* 2007; GIZ 2014; GIZ 2015). Producer skills in constructing and operating the kilns are also affect the carbonization efficiency. Nturanabo, Byamugisha, and Preti (2011) found that more experienced producers obtained higher carbonization efficiencies with traditional earth mound kilns than less experienced charcoal makers. Schure *et al.* (2019) observed that yields improved during the testing process as producers learned how to manage the carbonization process better or took more care in kiln construction and operation. Vos and Vis (2010) and Morgan-Brown and Samweli (2016) concluded that the skills of the charcoal makers can be a more important factor in carbonization efficiency than the kiln design.

TABLE 9: Carbonization Efficiency and Carbonization Times for Charcoal Kilns

Kiln Type	Range of Carbonization Efficiency	Sources for Carbonization Efficiency	Carbonization Efficiency Assumed in the Analysis	Carbonization Time Assumed in the Analysis (Days Per Cycle)[a]	Sources for Carbonization Time
Traditional earth mound	7.5-31.1%	• Smith *et al.* 1999 • Pennise *et al.* 2001 • Mundhenk, Gomis, and Sy 2010 • Nturanabo 2011 • Nahayo, Ekisel, and Mukarugwisa 2013 • Morgan-Brown and Samweli 2016 • FAO 2017	19.5%	12.5	• FAO 1987 • Nahayo, Ekisel, and Mukarugwisa 2013
Improved earth mound	13.3-30.0%	• Nahayo, Ekisel, and Mukarugwisa 2013 • Morgan-Brown and Samweli 2016 • FAO 2017	20.7%	5.0	• Oduor, Githiomi, and Chikamai 2006 • Nahayo, Ekisel, and Mukarugwisa 2013
Casamance earth mound	16.8-39.3%	• Kammen and Lew 2005 • Mundhenk, Gomis, and Sy 2010 • Nturanabo 2011 • Nahayo, Ekisel, and Mukarugwisa 2013 • FAO 2017	28.0%	5.0	• FAO 1987 • Karch, Boutette, and Christophersen 1987 • Oduor, Githiomi, and Chikamai 2006 • Nahayo, Ekisel, and Mukarugwisa 2013
Portable steel drum	20.0-38.0%	• Nturanabo 2011 • Sparrevik *et al.* 2015 • FAO 2017	29.0%	1.0	• Oduor, Githiomi, and Chikamai 2006 • Burnette 2013 • Kalende *et al.* 2013 • FAO 2017
Brick beehive	27.0-35.0%	• Smith *et al.* 1999 • Pennise *et al.* 2001 • FAO 2017	31.0%	4.0	• FAO 1987 • Kalende *et al.* 2013

Table 10 compares the wood input capacity and production cycle time in various work tasks for the five charcoal kilns in the four locations. The capacity of the traditional and improved earth mound kilns varied by location and reflected the median sizes reported in the MSI team's interviews with 52 charcoal producers. The team assumed that the Casamance kiln had a capacity of 24 m^3 of wood, similar to the ones IFDC and WWF promoted in North Kivu Province. The capacity of the portable steel kiln was for a single 200-liter oil drum unit. The capacity of the brick beehive kiln was based on a 17 m^3 model in Kenya. The MSI team estimated the weight of input wood used in the traditional earth mound kiln by dividing the median reported weight of charcoal produced by the assumed carbonization efficiency. The team assumed that the weight of the input wood for other types of kilns was proportional to their internal volumes relative to the traditional earth mound kiln.

Table 11 lists the charcoal yield per cycle, wood and labor costs, number of production cycles per year, capital cost, and expected life of the kilns in the four study locations. The MSI team estimated the production costs of the traditional earth mound kilns from data provided by the charcoal producers interviewed in each location. For the other kilns, the team assumed that the costs of the input wood and labor for loading and unloading were proportional to the input capacity. The interviewed charcoal producers earned most of their income from charcoal, but many were also involved in agriculture. The analysis assumed that labor costs for tending the kiln were proportional to the carbonization time. The total wood and labor costs per cycle varied across the four locations due to differences in kiln capacity; source, type, and sizes of wood; and local wage rates. The team assumed no labor cost for the time required to dry the wood before carbonization since the charcoal producers can make charcoal elsewhere or farm or do other work in the meantime.

Kimyaro and Negereza (1989) reported the average production time for each stage of the production cycle in a traditional earth mound kiln and the Casamance kiln. The MSI team adjusted these totals for other types of kilns based on their relative capacities. The team calculated the maximum number of production cycles per year from the cycle time and assumed that charcoal producers used the kilns 80 percent of the year.

TABLE 10: Wood Input Capacity and Production Cycle Time by Location and Kiln Type

Location and Kiln	Input Capacity (m^3)	Production Cycle Time (Days)				
		Wood Sourcing[a]	Construction[b]	Carbonization	Cooling and Unloading[f]	Total
Bukavu						
Traditional earth mound	5.5	1.8	1.5	12.5[c]	4.0	15.8
Improved earth mound	5.5	1.8	1.5	5.0[c]	4.0	8.3
Casamance earth mound	24.0	8.0	6.5	5.0[c]	4.0	19.5
Portable steel drum	0.2	1.0	1.0	1.0[d]	1.0	3.0
Brick beehive	17.0	5.7	2.9	4.0[e]	4.0	12.6
Goma						
Traditional earth mound	4.1	1.4	1.1	12.5[c]	4.0	15.0
Improved earth mound	4.1	1.4	1.1	5.0[c]	4.0	7.5
Casamance earth mound	24.0	8.0	6.7	5.0[c]	4.0	19.7
Portable steel drum	0.2	1.0	1.0	1.0[d]	1.0	3.0
Brick beehive	17.0	5.7	2.3	4.0[e]	4.0	11.9
Kinshasa						
Traditional earth mound	18.0	6.0	4.8	12.5[c]	4.0	23.3
Improved earth mound	18.0	6.0	4.8	5.0[c]	4.0	15.8
Casamance earth mound	24.0	8.0	6.7	5.0[c]	4.0	19.7
Portable steel drum	0.2	1.0	1.0	1.0[d]	1.0	3.0
Brick beehive	17.0	5.7	2.3	4.0[e]	4.0	11.9

TABLE 10: Wood Input Capacity and Production Cycle Time by Location and Kiln Type (Continued)

Kisangani						
Traditional earth mound	20.5	6.8	5.5	12.5[c]	4.0	24.8
Improved earth mound	20.5	6.8	5.5	5.0[c]	4.0	17.3
Casamance earth mound	24.0	8.0	6.7	5.0[c]	4.0	19.7
Portable steel drum	0.2	1.0	1.0	1.0[d]	1.0	3.0
Brick beehive	17.0	5.7	2.3	4.0[e]	4.0	11.9

[a] Two people can cut and stack 4 m^3 of wood per day with chainsaws (Nahayo, Ekise, and Mukarugwiza 2013), but most charcoal producers in the DRC do not use chain saws. The MSI team assumed a three-person team could cut and stack 3 m^3 of wood per day using only hand tools. Excludes time for drying wood before cutting (one month or more), but charcoal producers can operate another kiln or do other work during the wood drying time.

[b] Kiln construction time was based on an average of 0.27 days/m^3 of wood (Kimaryo and Negereza 1989) with a three-person team.

[c] Nahayo, Ekise, and Mukarugwiza (2013)

[d] FAO (2014)

[e] FAO (1987)

[f] Cooling times were from Karch, Boutette, and Christophersen (1987) for earth mound kilns; FAO (1987) for brick kilns, and FAO (2014) for portable steel drum kilns. This included time for unloading and packing charcoal from the earth mound and brick kilns on the assumption that enough labor will be tapped to complete the task in one day to minimize risks of theft and rain.

TABLE 11: Charcoal Production, Wood and Labor Costs, Cycles Per Year, Capital Cost, and Expected Life by Location and Kiln

Location and Kiln	Charcoal Yield Per Cycle (kg)	Wood and Labor Costs Per Cycle				Cycles Per Year[c]	Capital Cost ($)	Expected Life (Months)
		Wood ($)[a]	Loading ($)	Tending ($)	Unloading and Packaging ($)			
Bukavu								
Traditional earth mound	300	$39.04	$3.02	$1.51	$0.63	18	$0.00	One cycle
Improved earth mound	356	$39.04	$3.02	$0.58	$0.63	35	$200.00	30[c]
Casamance earth mound	2,103	$170.37	$13.19	$0.58	$2.75	15	$450.00	30[c]
Portable steel drum	18	$1.42	$0.11	$0.12	$0.02	97	$115.00	30[d]
Brick beehive	1,649	$120.68	$9.34	$0.58	$1.95	23	$500.00	96[e]
Goma								
Traditional earth mound	330	$17.63	$5.04	$2.52	$2.52	20	$0.00	One cycle
Improved earth mound	392	$17.63	$5.04	$0.97	$2.52	39	$200.00	30
Casamance earth mound earth mound	2,103	$69.95	$19.98	$0.97	$9.99	15	$450.00	30
Portable steel drum	18	$0.58	$0.17	$0.19	$0.08	97	$115.00	30
Brick beehive	1,649	$49.55	$14.16	$0.97	$7.08	24	$500.00	96
Kinshasha								
Traditional earth mound	2,100	$56.68	$25.19	$22.04	$22.67	13	$0.00	One cycle
Improved earth mound	2,494	$56.68	$25.19	$8.48	$22.67	18	$200.00	30
Casamance earth mound	2,103	$35.33	$15.70	$8.48	$14.13	15	$450.00	30
Portable steel drum	18	$0.29	$0.13	$1.70	$0.12	97	$115.00	30
Brick beehive	1,649	$25.03	$11.12	$8.48	$10.01	24	$500.00	96[f]
Kisangani								
Traditional earth mound	1,125	$24.18	$7.56	$5.54	$4.41	12	$0.00	One cycle
Improved earth mound	1,336	$24.18	$7.56	$2.13	$4.41	17	$200.00	30
Casamance earth mound	2,103	$28.14	$8.79	$2.13	$5.13	15	$450.00	30
Portable steel drum	18	$0.23	$0.07	$0.43	$0.04	97	$115.00	30
Brick beehive	1,649	419.93	$6.23	$2.13	$3.63	24	$500.00	96

[a] Median of costs reported by interviewed charcoal producers. Extrapolated to other types of kilns based on relative capacities.
[b] 365 days per year divided by cycle time multiplied by 80 percent capacity use rate and rounded off
[c] Chimney life for the improved earth mound and Casamance kilns assumed equal to the life of a steel drum kiln.
[d] FAO 1987
[e] FAO 2014

2.3 ASSUMPTIONS FOR THE ECONOMIC ANALYSIS OF STOVES AND FUELS AND KILNS

The DRC levied a 16 percent value-added tax (VAT) on imported household cooking stoves and fuels. This tax applies to the Jikokoa Xtra and EcoZoom Jet charcoal stoves, LPG and electric stoves, and LPG fuel. LPG fuel sales were also subject to a 1 percent urban tax. The VAT did not apply to electricity or woodfuels produced within the country. Residential tariffs only covered about half of the costs of electricity generation and transmission and distribution (World Bank 2020), an effective subsidy of 100 percent., Table 12 summarizes the tariffs, VAT, and subsidies on the various stoves and fuels.

TABLE 12: Total Tariffs and Value-Added Tax Rates for Stoves and Fuels

Stove and Fuels	Imported?	Tariffs, Taxes, and Subsidies
Three-stone woodstove	No	None
Traditional charcoal stove	No	None
Low-efficiency, improved charcoal stove	No	None
Medium-efficiency, improved charcoal stove	No	None
High-efficiency, Jikokoa Xtra charcoal stove	Yes	16% VAT
High-efficiency, EcoZoom Jet charcoal stove	Yes	16% VAT
LPG stove	Yes	16% VAT
LPG fuel	Yes	16% VAT plus 1% urban tax
Single-burner, coil electric hotplate	Yes	16% VAT
Electricity energy cost	No	100% effective subsidy because tariffs do not cover full generation, transmission, and distribution costs[a]

[a] World Bank 2020

Source: Adapted from Imani 2021

Table 13 contains GHG emission factors for the nine stove and fuel combinations. Table 14 lists the GHG emission factors for the five charcoal kilns.

TABLE 13: GHG Emission Factors for the Stoves and Fuels Analyzed

Stove	Fuel	Emission Factors (g/kg of Fuel, g/kWh for electricity)		
		CO_2	CH_4	Total CO_2e
Three-stone woodstove[a]	Wood	1,638	1.81	1,696
Traditional charcoal stove[b]	Charcoal	2,740	6.10	2,935
Low-efficiency, improved charcoal stove[c]	Charcoal	2,740	6.10	2,935
Medium-efficiency, improved charcoal stove[a]	Charcoal	2,740	6.10	2,935
High-efficiency, Jikokoa Xtra charcoal stove[a]	Charcoal	2,740	6.10	2,935
High-efficiency, EcoZoom Jet charcoal stove[a]	Charcoal	2,740	6.10	2,935
LPG stove[d]	LPG	3,535	0.07	3,537
Single-burner, coil electric hotplate[c]	Electricity	Included in total	Included in total	0.373

[a] Johnson *et al.* 2019 for CO_2; Jetter *et al.* 2012 for CH_4

[b] Johnson *et al.* 2019 for a Benin Cloporte stove, which is similar to the traditional charcoal stove in the DRC

[c] Johnson *et al.* 2019 for CO_2 from a similar stove in Vietnam, CH_4 from a medium-efficiency stove

[d] Shen *et al.* 2017

[e] The four study locations received electricity from the national grid, which has low GHG emissions since it is mainly from large hydropower (https://unfccc.int/sites/default/files/resource/Harmonized_Grid_Emission_factor_data_set.xlsx). However, hydropower is not GHG emission free because of CO_2 and CH_4 emissions in land inundation and reservoir operations (Manion *et al.* 2019) and it is not clear whether this has been taken into account in the country's grid emission factor.

TABLE 14: GHG Emission Factors for Kilns, Per Kilogram of Charcoal Produced[a]

Kiln Type	CO_2 (g)	CH_4 (gCO_2e)	N_2O (gCO_2e)	Total (gCO_2e)
Traditional earth mound	2,085	1,699	44	3,828
Improved earth mound	1,574	1,486	31	3,092
Casamance earth mound	979	924	32	1,903
Portable steel drum	1,538	1,872	7	3,417
Brick beehive	1,256	1,146	8	2,411

[a] FAO (2017) summarized studies of emissions and carbonization efficiencies for common kiln types. The MSI team adjusted the FAO emissions estimates to match the carbonization efficiencies used in this study. The emissions are inversely proportional to the carbonization efficiencies.

2.3.1 DEFORESTATION AND FOREST DEGRADATION FROM UNSUSTAINABLE WOOD HARVESTING

Unsustainable wood harvesting refers to harvesting amounts or methods that permanently degrade a forest's integrity or the ecological services it provides.[27] It can be difficult to operationalize this definition in a cost-benefit analysis (CBA). For example, small-scale land clearing may be unsustainable at the land plot level but sustainable at the landscape level (Chidumayo and Gumbo 2013). Selective harvesting of trees can be managed to avoid exceeding maximum sustained yields and preserve forest diversity. However, unmanaged selective harvesting of wood for charcoal production is severely degrading Virunga National Park near Goma and Kahuzi Biega National Park near Bukavu (Weisse and Lyons 2018; Dranginis 2016; Mapesa *et al.* 2013; Erickson-Davis 2021).

Although data were not available on the impacts of charcoal production on deforestation and forest degradation in the DRC, the impacts may be large. Tyukanina *et al.* (2018) attributed 93 percent of the forest canopy loss in the DRC between 2000 and 2014 to land clearing for small-scale agriculture or charcoal production. However, since farming and charcoal production may occur sequentially or simultaneously on a plot of land, they could not distinguish between these factors with available, high-resolution satellite imagery.

Table 15 summarizes secondary data on the sources of woodfuels in the four study locations, but the available information for Kinshasha and Kisangani is over a decade old. Approximately 59 percent of the woodfuels in Bukavu and Goma, 81 percent in Kinshasha, and 100 percent in Kisangani were obtained from natural forests or land cleared for agriculture. Commercial plantations provided 41 percent of the woodfuels in Bukavu and Goma, 16 percent in Kinshasha, and 0 percent in Kisangani. Most of these plantations are relatively small. These studies are roughly consistent with the team's findings of the interviews with charcoal producers.

TABLE 15: Woodfuel Sources by Location

Location	Land Cleared for Agriculture	Natural Forests	Plantations
Bukavu[a]	2%	57%	41%
Goma[b]	2%	57%	41%
Kinshasa[c]	52%	29%	16%
Kisangani[c]	62%	38%	0%

[a] Dubiez *et al.* 2021b

[b] Dubiez *et al.* 2021a

[c] Schure, Ingram, and Akalakou-Mayimba 2011

The team assumed that wood from natural forests or land cleared for agriculture is typically unsustainable while wood from commercial plantations is sustainably managed. The team estimated the volume of wood obtained from each source in the four areas. Schure, Ingram, and Akalakou-Mayimba (2011) identified the proportions from each of the provinces that provided most of the charcoal for Kinshasa and Kisangani. Imani *et al.* (2021a) reported that all of the charcoal sold in Bukavu was produced in South Kivu Province and 72 percent of the charcoal sold in Goma was produced in North Kivu Province while 28 percent was produced in South Kivu Province.

[27] Rainforest Alliance. https://www.rainforest-alliance.org/insights/what-is-sustainable-forestry/

The area of unsustainably harvested land needed for a household's annual charcoal consumption depends on the amount of charcoal used, kiln efficiency, percent of wood unsustainably harvested, and the average volume of wood harvested per hectare. Saatchi *et al.* (2017) estimated the average volume of wood per hectare in each province. The study team multiplied these volumes by the percent of charcoal from each province and estimated the area of unsustainably harvested forest cleared to meet the charcoal consumption of an average household:

$$\begin{aligned} &\mathit{Hectares\ unsustainbly\ harvested} \\ &= \left[\frac{\mathit{Annual\ quantity\ of\ charcoal\ consumed\ by\ household}}{\mathit{Kiln\ efficiency}} \right. \\ &\left. \times \mathit{Percentage\ of\ wood\ unsustainbly\ harvested}\right] \\ &\div \mathit{Average\ volume\ of\ wood\ per\ hectare} \end{aligned}$$

Table 16 lists the average weighted wood density per hectare in the areas that provide most of the charcoal for each of the four cities.

TABLE 16: Average Above Ground Biomass in the Areas That Provide Wood for Charcoal Production in the Four Cities

Location	Average Above Ground Biomass (Metric Tons Per Hectare)
Bukavu	228
Goma	228
Kinshasa	106
Kisangani	324

Source: Saatchi *et al.* 2017

2.3.2 COSTS OF DEFORESTATION AND FOREST DEGRADATION

The economic analysis estimated the monetary value of environmental services and forest-derived income lost due to unsustainable woodfuel harvesting. It considered both direct and indirect use values of forest ecosystems. *Direct use values* support the livelihoods, subsistence, or wellbeing of those who use the forests. Examples of direct use values include the value of woodfuels or bushmeat extracted from forests. *Indirect use* values are associated with ecosystem functions that sustain natural systems that indirectly support human wellbeing, such as soil erosion control, climate regulation, and watershed protection.

Estimates of the value of environmental services can differ by an order of magnitude or more, depending on the types of values considered, valuation methods, and available data on how forests affect human well-being. The team obtained direct and indirect use values from a synthesis of studies on DRC forests (UN-REDD Program 2015). That report estimated an annual national value of watershed protection services, woodfuels, bushmeat, and soil erosion control of $34 billion. The team converted this amount to 2020 U.S. dollars and divided by the forest area to estimate a value of $224 per hectare of forest. This estimate is reasonably consistent with values from Debroux *et al.* (2007), Nlom (2011), and Endamana *et al.* (2013). However, it is well below the global median of $486/ha (Ninan and Inoue 2013). The global median also included additional types of values that were not in the DRC estimate due to insufficient data, such as water quality, climate regulation, recreation, crop pollination, and foods and medicines. UN-REDD Program (2015) projected that the value of the DRC's forests would be similar to the global median if more complete data were available.

The MSI team assumed a conservative value of $224/ha of forest in the base case economic analysis and the global median of $486/ha in the sensitivity analysis. The total value of forest environmental services lost was the average value per hectare multiplied by the unsustainably harvested area.

2.3.3 COMMERCIAL TREE PLANTATIONS FOR FUELWOOD AND CHARCOAL

The analysis also considered wood production from sustainably managed plantations. Public or privately owned plantations can be managed to maximize the sustained yield of wood. Plantations of fast-growing tree species can yield substantially more wood per hectare than natural forests. Fuelwood can be obtained from prunings and trimmings and fallen wood in the earlier years before the trees are felled. Some tree species can be coppiced without felling and will sprout back. After the trees are felled or coppiced for fuelwood or other uses, plantations can be replanted to maintain future supplies. Replanting may not happen and is not necessarily on the same plot, but plantations are at least potentially sustainable.

When operated on a sufficiently large scale, plantations can reduce overharvesting of natural forests and the resulting reduction in carbon sequestration and loss of environmental services. However, the present value of financial costs is generally higher for wood from plantations than unsustainably harvested wood. If the economic costs of foregone environmental services are considered, some or all of the higher costs of plantation wood may be offset by the environmental benefits. Nevertheless, expansion of plantation forestry is unlikely to affect pressures to convert natural forests to agriculture or other land uses as a result of population growth and poverty. Plantation forestry may even exacerbate deforestation if it includes construction or upgrading of rural roads (Smith, Cooley, and Hyman 2018).

There are few large tree plantations for charcoal production in the DRC (Schure, *et al.* 2011 and Atyi and Bayol 2009). Donors, nongovernmental organizations, and private investors have supported several plantation projects for woodfuels, but their sustainability is uncertain (Proces, Bisiaux, and Marien 2011). Examples of these projects include

- The Mampu Village Project located on the Bateke Burnerau plateau east of Kinshasa (Bisisux *et al.* 2009). This plantation produced 8,000 to 12,000 tons of charcoal annually under a village agroforestry model.
- A private company, Novacel, established a 4,200-ha reforestation and carbon offset project at Ibi on the Bateke Burnerau (Ministry of the Environment, Nature Conservation, and Tourism 2009).[28]
- The WWF has supported large woodfuel plantations, including the Luki Biosphere Project and the Ecomakala Project.
- The Luki Biosphere Project in Kongo Central province established 1,000 hectares (ha) of small woodlots.

The Ecomakala Project helped 9,500 small-scale landowners in North Kivu Province establish sustainable woodfuel plantations for sustainable charcoal production on 12,037 hectares of cleared land on the

[28] Embracing Climate-Friendly Farming in the Congo Basin, https://medium.com/scouting-for-green/embracing-climate-friendly-farming-in-the-congo-basin-6b866f4ef16e

outskirts of Virunga National Park. The WWF subsidized initial planting costs, supported private nurseries for tree seedlings, and provided technical assistance on tree plantation management.[29] Most of the trees were *Acacia sp.*, *Cedrela*, *Eucalyptus saligna*, or *Grevillea robusta* (WWF 2013; Kaghoma 2015; Lusenge 2020).

2.4 THE FINANCIAL COST OF PRODUCING WOOD ON PLANTATIONS

The Ecomakala Project commissioned a financial analysis of project-supported plantations (Kaghoma 2015). The analysis estimated the cash costs and revenues of growing the wood through a survey of 388 plantation owners in five communities near Goma — Beni, Butembo, Kirumba, Kiwanja, and Sake. The analysis excluded imputed land rent. It is unclear whether it included the value of unpaid labor by the landowner and other members of the household.

The scenarios in this analysis corresponded to the terms of the contracts the landowners signed with the WWF. Khagoma considered three planting densities – spacings of 2.0 x 2.0, 2.5 x 2.5, and 3.0 x 3.0 meters. The time horizon reflected the 20-year contract between the project and the landowners. The analysis only considered harvesting alternatives that adhered to the contract requirements emphasizing wood for charcoal production and polewood, rather than timber.

Most of the plantations were young at the time of the study. Khagoma projected the annual production volumes, costs, and revenues based on actual experience and estimated future annual wood yields. The projected revenues included average net earnings of $240/ha from interplanted agricultural crops for the first three years before the tree canopy closed (mainly beans, casava, or soybeans, depending on the location) interplanted with trees. Khagoma excluded the costs of cutting or felling trees because the plantation owners received a stumpage price for selling standing wood. The buyers bore the wood harvesting and extraction costs. The analysis did not estimate charcoal production costs. The projected annual net revenues varied with the management practices and decreased over the 20-year timeframe as plantation yields leveled off. Khagoma estimated average annual net revenues of $1,082 from agricultural crops, polewood, and charcoal.

Kaghoma reported the costs and revenues in 2015 dollars. The MSI team adjusted the costs and revenues to 2020 U.S. dollars by 1) converting the values to DRC currency (CDF) at the average exchange rate in 2015, 2) converting the 2015 CDF values to 2020 CDF using national inflation rates, and 3) converting the 2020 CDF values back to U.S. dollars at an exchange rate of CDF 1,985 CDF per U.S. dollar. In 2020 U.S. dollars, the average cost to the landowners was $1,178/ha for plantation establishment and $250/ha/year for annual operations. The costs in the five communities varied depending on location-specific input prices and the tree spacing.

The MSI team calculated a present value of $5.48/ton as the cost of producing wood for charcoal. This was well below the $11.52/ton median price that the interviewed charcoal producers in North Kivu province reported paying for wood. The production costs of the wood are below the sales prices to allow for returns to unpaid labor, imputed land rent, selling costs, transportation, and profits. The MSI team also interviewed a small, nonrandom sample of other plantation operators in Bukavu, Goma, and Kinshasa to obtain data on management practices, costs, and revenues of tree plantations for woodfuels.[30]

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[29] https://www.ecomakala.org/.

[30] The team did not find any woodfuel plantations near Kisangani.

2.4.1 COSTS OF PREMATURE DEATH RISKS FROM EXPOSURE TO FINE PARTICULATES

The combined effects of ambient (outdoor) and indoor air pollution may cause between 4.9 and 7.0 million premature deaths per year worldwide, largely from stroke, heart disease, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections (WHO 2020; Institute for Health Metrics and Evaluation 2017). Indoor air pollution, largely from incomplete combustion products from cooking, may cause 1.5 million to 2.8 million of these deaths. The WHO attributed 164 deaths per 100,000 population to indoor air pollution in the DRC in 2016.[31] The smallest particles with a diameter of 2.5 micrometers or less ($PM_{2.5}$) have the highest human health risks because they penetrate deeper into the lungs and bloodstream.

This analysis focused on the health effects of fine particulates on the households cooking with woodfuels. Cooking by other households may also contribute to ambient $PM_{2.5}$ concentrations in the neighborhood, but are relatively minor compared to the effects of a household's own cooking (Smith and Pillarisetti 2017). The analyses considered only the health effects of exposures from cooking by the household, indoors or outdoors. Many reports have focused on $PM_{2.5}$ from indoor cooking, but exposures are substantially lower if cooking is done outdoors.

The *individual intake fraction* measures an individual's absorption of $PM_{2.5}$ from an exposure (Bennett *et al.* 2002). It is an empirical relationship between the emissions from a source and the amount absorbed:

$$Individual\ intake\ fraction = \frac{Individual\ intake}{Total\ emission} = \frac{C_{personal} \cdot Q_b}{EF\ \cdot AFU}$$

where $C_{personal}$ is the average annual exposure concentration in micrograms per cubic meter ($\mu g/m^3$),

Q_b is the individual respiration rate (m^3/year),

EF is the emission factor for a stove/fuel combination (g/kg),

and AFU is annual fuel use (kg).

The MSI team estimated exposure to $PM_{2.5}$ from a stove and fuel combination by multiplying the individual intake fraction by the total emissions. The relationship between indoor particulate emissions and concentrations depends on characteristics of the building (the size, dispersion of the particulates within the building, air transferred between the inside and outside of the house) and the behavior of household members (time spent indoors and in high concentration areas).

Relatively few studies have reported individual intake fractions from indoor cooking (μg inhaled per g emitted). Grieshop, Marshall, and Kandlikar (2011) used data on indoor emissions and concentrations of particulates with a diameter of 10 micrometers or less (PM_{10}) from seven wood and charcoal stoves (Bailis, Ezzati, and Kammen 2003; Ezzati, Saleh, and Kammen 2000). The charcoal stoves included the Kenya ceramic-lined metal jiko (KCJ), an all-metal stove similar to the traditional charcoal stoves in the DRC, and two low-efficiency ceramic-lined metal stoves similar to the ones made by informal sector artisans in the DRC. Grieshop, Marshall, and Kandlikar estimated an intake fraction of 1,300 $\mu g/g$ from cooking with charcoal stoves indoors in rural Kenya, but that was based on $PM_{10,}$ which may be associated with lower health risks than $PM_{2.5}$.

[31] https://data.worldbank.org/indicator/SH.STA.AIRP.P5?locations=CG-CD&most_recent_value_desc=false.

Smith (1993) reported an intake fraction of 2,400 μg/g from cooking indoors in an enclosed kitchen with an unvented stove. However, Smith assumed a high respiration rate of 28 m^3/day (the upper end of the range for adult men) while Grieshop, Marshall, and Kandlikar (2011) assumed a respiration rate of 7.8 m^3/day for women at rest. To correct for this apparent error, the MSI team adjusted Smith's intake fraction from 2,400 μg/g to 669 μg/g to adjust for differences in assumed respiration rates. The MSI team applied this intake fraction in the analyses for Bukavu and Goma, where most households cook indoors.

To estimate exposures from outdoor cooking, which is most prevalent in Kinshasa and Kisangani, the team multiplied the indoor intake fraction by 0.615 — the midpoint of the ratio of outdoor to indoor $PM_{2.5}$ concentrations (van Vliet *et al.* (2013) and Mabonga *et al.* (2021). This yielded an intake fraction of 411 μg/g for Kinshasa and Kisangani.

The team estimated average annual exposures by multiplying the average annual weight of $PM_{2.5}$ produced by a stove and fuel combination by the individual intake fraction. The team estimated the resulting increase in the relative risk of premature death with a formula from Pope *et al.* (2009):

$$Relative\ risk = 0.1619 \times \ln(x) + 1.4573$$

where x is the exposure in milligrams per person per day

The MSI team then calculated the economic cost of the increased premature death risk multiplying the relative risk by the VSL. The VSL reflects the societal value of a small incremental reduction in the premature death risk. To estimate the VSL for the DRC, the team applied a benefit transfer approach. This approach multiplies an established VSL for one country by the ratio of the per capita gross domestic product (GDP) in another country. This approach is most valid if the two countries have a similar per capita GDP. However, most of the source data for low- and medium-income countries is for the United States or other high-income countries in the Organization for Economic Cooperation and Development (OECD). Robinson, Hammitt, and O'Keefe (2019) summarized the small number of studies that directly estimated a VSL in a low- or middle-income country and noted that many of those studies had methodological issues (which did not include DRC or Malawi).

Matek *et al.* estimated low and high VSLs for Malawi of $26,497 and $58,000 in 2019 based on value benefit transfers from developed country estimates from Robinson, Hammitt, and O'Keefe (2019) and Viscusi and Masterman (2017). The MSI team converted the 2019 values to 2020 U.S. dollars and adjusted for the difference in per capita GDP between Malawi and the DRC. The per capita GDP was $1,658 in Malawi and $1,219 in the DRC (World Bank Development Indicators for 2021). Using this information, the MSI team estimated low and high VSLs of $18,601 and $40,716, respectively, for the DRC.[32]

Table 17 summarizes $PM_{2.5}$ emission factors for the stoves and fuels used in the CBA. $PM_{2.5}$ emissions are difficult to measure and the recommended procedures and instruments have improved over time. Comparisons across studies may be questionable due to noncomparability or measurement errors in studies across countries and times using different procedures and instruments. Although LPG has low

[32] The VSL approach is also controversial for ethical reasons, which is why the USAID Global Health Bureau prefers to use cost-effectiveness analysis to estimate the efficiency of investments to reduce premature mortality risks, instead of cost-benefit analysis.

$PM_{2.5}$ emissions, it also produces concentrations of other air pollutants (nitrous oxides and methane) that can cause adverse human health effects (Clasen *et al.* 2022 and Kephart *et al.* 2021).

TABLE 17: End-Use $PM_{2.5}$ Emission Factors for Stoves and Fuels

Stove	$PM_{2.5}$ (g/kg of Fuel)	Sources
Three-stone wood stove	12.0	Johnson *et al.* (2019)
Traditional charcoal stove	2.3	Johnson *et al.* (2019) – Based on test results for the similar Benin Cloporte stove
Low-efficiency, improved charcoal stove	6.8	Johnson *et al.* (2019) – Based on test results for a similar stove in Vietnam
Medium-efficiency, improved charcoal stove	8.3	Johnson *et al.* (2019) – Based on test results for the Kenya Ceramic Jiko
High-efficiency, Jikokoa Xtra charcoal stove	7.4	Johnson *et al.* (2019)
High-efficiency, EcoZoom Jet charcoal stove	7.4	Assumed same as the Jikokoa
Single-burner LPG stove	0.1	Shen *et al.* (2017)
Single-burner, coil electric hotplate	0.0	DRC generates most grid electricity from large hydropower with negligible $PM_{2.5}$ emissions

2.5 RESULTS OF THE BASE CASE ANALYSIS OF CHARCOAL KILNS

Table 18 presents the discounted financial costs of the five kilns per ton of charcoal produced in the four locations at the three discount rates. It was based on the assumption that each kiln would be operated at an 80 percent capacity use rate. Except for the metal drum kiln, the cost-effectiveness rankings of the kilns corresponded to their relative carbonization efficiencies. Even though the more efficient kilns had higher capital costs, their greater efficiencies more than offset their higher capital costs. The large brick kiln was the least-cost alternative. The metal drum kiln was the highest-cost alternative because of its low production capacity and relatively high labor costs. Although the total discounted costs per ton of charcoal were higher at the lower discount rates, the cost-effectiveness rankings of the five kilns were the same at all three discount rates.

The economic analysis of charcoal kilns included the social costs of GHG emissions and the forest environmental services lost to unsustainably harvested wood. Table S-2 summarizes the discounted economic costs of the kilns in the four locations at the 12 percent discount rate. The social costs of GHG emissions were the main driver of economic costs for all five types of kilns in each of the locations, accounting for an average of two-thirds of the discounted costs per ton of charcoal. Except for the metal drum kiln, kilns with lower GHG emission factors were economically preferable. Even though the metal drum kiln had a lower GHG emissions factor than the traditional earth mound kiln, it had the highest discounted economic costs of all of the kilns in all locations because of its low production capacity and relatively high labor costs.

TABLE 18: Present Value of Financial Costs of Kilns by Discount Rate (U.S. Dollars per Ton of Charcoal Produced)

Kiln	Bukavu			Goma		
	3%	7%	12%	3%	7%	12%
Brick beehive	$24.12	$13.02	$7.92	$27.94	$15.07	$9.14
Casamance earth mound	$28.27	$15.21	$9.19	$32.53	$17.49	$10.56
Improved earth mound	$35.20	$18.93	$11.43	$40.59	$21.81	$13.16
Traditional earth mound	$39.99	$21.45	$12.91	$47.87	$25.68	$15.45
Portable steel drum	$41.59	$22.58	$13.80	$47.75	$25.89	$15.79
Kiln	**Kinshasa**			**Kisangani**		
	3%	**7%**	**12%**	**3%**	**7%**	**12%**
Brick beehive	$18.88	$10.21	$6.22	$7.86	$4.30	$2.66
Casamance earth mound	$21.74	$11.70	$7.08	$10.18	$5.50	$3.35
Improved earth mound	$24.25	$13.02	$7.85	$11.48	$6.18	$3.74
Traditional earth mound	$31.21	$16.74	$10.07	$13.31	$7.14	$4.30
Portable steel drum	$78.30	$42.27	$25.65	$32.28	$17.59	$10.80

TABLE 19: Present Value of Economic Costs of Kilns at a 12% Discount Rate (U.S. Dollars per Ton of Charcoal Produced)

Kiln	Bukavu	Goma	Kinshasa	Kisangani
Casamance earth mound	$1,360	$1,430	$1,300	$1,073
Brick beehive	$1,567	$1,622	$1,516	$1,302
Improved earth mound	$1,989	$2,061	$1,803	$1,573
Traditional earth mound	$2,295	$2,424	$2,218	$1,872
Portable steel drum	$2,471	$2,572	$3,108	$2,326

2.6 RESULTS OF THE BASE CASE ANALYSIS OF FUELS AND STOVES

2.6.1 FINANCIAL COSTS PER HOUSEHOLD

Table 20 contains the discounted financial costs of the nine stove and fuel combinations at a 12 percent discount rate. At the low unit price of charcoal purchased in bulk, the electric hotplate had the lowest financial costs in Bukavu, Goma, and Kinshasha. in Kisangani, the price of electricity was much higher, making the electric hotplate the second most expensive alternative for households. LPG had the highest financial costs in all four cities. The three-stone woodstove had higher financial costs than any of the charcoal stoves in Bukavu, Goma, and Kinshasa, but was the fourth least costly alternative in Kisangani, where fuelwood prices were lower. In Kisangani, the three-stone woodstove had higher financial costs than the high- or medium-efficiency charcoal stoves, but was less costly than the low-efficiency charcoal stoves. Differences in charcoal prices across the four cities affected some of the financial cost rankings.

The traditional charcoal stove had higher financial costs than the low-efficiency improved charcoal stove in Goma, Kinshasa, and Kisangani. In Bukavu, the traditional and improved low-efficiency charcoal stoves had similar costs because the price of charcoal was lower.

At the high unit price of charcoal purchased in small, daily use volumes, the annual costs of charcoal increased and the fuel cost increase was larger with the less fuel-efficient charcoal stoves. The costs of cooking with electricity, LPG, or wood did not change with charcoal price assumption, but that only changed some of the rankings of the stove and fuel combinations. The electric hotplate remained the lowest financial cost alternative in Bukavu, Goma, and Kinshasa, followed by the high- and medium-efficiency charcoal stoves. However, the high unit charcoal price made the low-efficiency charcoal stoves less financially cost-effective than the three-stone woodstove in Bukavu and Goma. In Kisangani, the three-stone woodstove had the lowest financial cost because of the relatively high prices of electricity and charcoal. The other stove and fuel combinations had the same rankings in the financial analysis at both unit prices of charcoal.

2.6.2 ECONOMIC COSTS PER HOUSEHOLD

Table 21 contains the discounted economic costs of the nine stove and fuel combinations at a 12 percent discount rate. The economic costs were substantially higher than the financial costs, mainly due to the social cost of GHG emissions and the value of statistical lives lost from $PM_{2.5}$ exposures. The differences between the financial and economic costs were highest for the three-stone woodstove and the charcoal stoves, especially the less efficient charcoal stoves because the GHG and $PM_{2.5}$ emissions were proportional to the amount of wood or charcoal burned. As noted earlier, there may be some data issues in the $PM_{2.5}$ estimates of the charcoal and wood stoves that have skewed some of the economic cost comparisons.

End-use GHG emissions also made the economic costs of the LPG stove higher than the financial costs. However, the lifecycle GHG emissions of LPG were underestimated due to lack of data on the emissions in petroleum extraction, processing, and transport. The health costs from cooking with LPG were also undercounted because the analysis only considered premature mortality risks from fine particulates and not from nitrous oxide and methane exposures.

At the low unit price of charcoal purchased in bulk, the electric hotplate was by far the least-cost alternative in the economic analysis for Bukavu, Goma, and Kinshasha. However, in Kisangani, the electric hotplate had the third highest economic costs because of higher electricity prices.

In Bukavu, the EcoZoom Jet charcoal stove had the second lowest economic costs, followed closely by the LPG stove, and the Jikokoa Xtra charcoal stove, but all had about the same discounted economic costs. The medium-efficiency charcoal stove had substantially higher economic costs than the high-efficiency charcoal stoves and LPG and the economic costs were even higher for the low-efficiency charcoal stoves.

In Goma and Kinshasha, the LPG stove had lower economic costs than the high-efficiency charcoal stoves, but the medium- and low-efficiency charcoal stoves had higher economic costs than these stoves. In Kisangani, the two high-efficiency charcoal stoves had much lower economic costs than the LPG stove with the EcoZoom Jet offering a small cost advantage over the Jikokoa Xtra. The discounted economic costs of the EcoZoom Jet were less than half those of the LPG stove in Kisangani.

TABLE 20: Present Value of Financial Costs of Stoves and Fuels at Two Charcoal Prices and a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price
Single-burner, coil electric hotplate	$492	$492	$484	$484	$512	$512	$2,068	$2,068
High-efficiency, EcoZoom Jet charcoal stove	$986	$1,080	$1,277	$1,643	$1,217	$1,990	$632	$1,007
High-efficiency, Jikokoa Xtra charcoal stove	$1,010	$1,106	$1,306	$1,680	$1,245	$2,032	$655	$1,041
Medium-efficiency, improved charcoal stove	$1,167	$1,285	$1,490	$1,931	$1,495	$2,463	$735	$1,204
Low-efficiency, traditional charcoal stove	$1,557	$1,712	$2,042	$2,645	$1,939	$3,209	$971	$1,589
Low-efficiency, improved charcoal stove	$1,561	$1,718	$1,741	$2,258	$1,681	$2,774	$829	$1,359
Three-stone woodstove	$1,637	$1,637	$2,156	$2,156	$3,132	$3,132	$786	$786
LPG stove	$3,379	$3,379	$3,370	$3,370	$3,255	$3,255	$6,417	$6,417

TABLE 21: Present Value of Economic Costs of Stoves and Fuels at Two Charcoal Prices and a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price	Low Charcoal Price	High Charcoal Price
Single-burner, coil electric hotplate	$1,352	$1,352	$1,343	$1,343	$1,408	$1,408	$5,986	$5,986
High-efficiency, EcoZoom Jet charcoal stove	$4,604	$4,743	$5,410	$5,948	$5,191	$6,328	$4,173	$4,724
High-efficiency, Jikokoa Xtra charcoal stove	$4,661	$4,802	$5,479	$6,028	$5,258	$6,416	$4,248	$4,815
Medium-efficiency, improved charcoal stove	$5,232	$5,404	$6,092	$6,742	$6,055	$7,478	$4,751	$5,442
Low-efficiency, traditional charcoal stove	$5,601	$5,830	$6,846	$7,732	$6,618	$8,485	$4,968	$5,876
Low-efficiency, improved charcoal stove	$6,169	$6,400	$6,640	$7,400	$6,460	$8,066	$5,005	$5,785
Three-stone woodstove	$7,776	$7,776	$9,289	$9,289	$10,650	$10,650	$6,944	$6,944
LPG stove	$4,647	$4,647	$4,631	$4,631	$4,488	$4,488	$8,315	$8,315

The three-stone woodstove had the highest economic costs in Bukavu, Goma, and Kinshasha. However, the three-stone woodstove had lower economic costs than the LPG stove in Kisangani, where fuelwood prices were lower and LPG prices higher.

At the high unit price of charcoal purchased in small volumes, only some of the economic cost rankings changed. The electric hotplate remained the lowest economic cost alternative in Bukavu, Goma, and Kinshasha and the third lowest in Kisangani. In Kisangani, the LPG stove was still the highest economic cost alternative and the EcoZoom Jet charcoal stove remained the second lowest-cost alternative, followed by the Jikokoa Xtra charcoal stove. In Bukavu, Goma, and Kinshasha, the three-stone woodstove continued to be the most expensive alternative, but the LPG stove became less costly than the high-efficiency charcoal stoves. The medium- and low-efficiency charcoal stoves were more affected by the higher unit price of charcoal than the high-efficiency charcoal stoves.

2.7 SENSITIVITY ANALYSIS OF CHARCOAL KILNS AND STOVES AND FUELS

2.7.1 ASSUMPTIONS

Table 22 summarizes the assumptions for the base case and sensitivity analysis of charcoal kilns and stoves and fuels. Different discount rates and prices of fuelwood, charcoal, and LPG were tested for both the financial and economic analyses. In addition, the social cost of carbon, value of lost forest environmental services, and value of a statistical life varied in the economic sensitivity analysis.

The base case economic analysis used the U.S. Government's preliminary social cost of carbon, \$51/tCO_2e in 2020, which was a simple inflation adjustment of an earlier estimate (Interagency Working Group on Social Cost of Greenhouse Gases 2021). At that time, the USG announced that it would revise that estimate based on more recent scientific and economic data, different assumptions, and more sophisticated modeling. A nongovernmental analysis by Resources for the Future estimated a global social cost of \$185/tCO_2e (Rennert *et al.* 2022). The U.S. Environmental Protection Agency (2022) released a draft report with a revised estimate of \$190/tCO_2e, but the U.S. Government had not officially adopted this value by the end of March, 2023.

The sensitivity analysis also examined the effects of a 50 percent increase in LPG prices and a 25 percent increase in the price of the other cooking fuels. The sensitivity analysis considered a higher price increase for LPG because prices of this fuel vary with volatile, world market prices of petroleum in U.S. dollars as well as foreign exchange rates.

The IEA projected higher, average annual growth rates in the global demand for LPG between 2020 and 2026 than for other petroleum products. Since LPG is produced directly from natural gas or as a byproduct of gasoline refining, future supplies of this fuel may be affected by trends in production of these fuels. Natural gas is in high demand for electricity generation and industrial, commercial, and residential use. Furthermore, gasoline production may decline in relative or absolute terms as motor vehicle fuel efficiency increases and hybrid and plug-in electric vehicles gain market share. As a result, the IEA projected a larger increase in the real price of LPG than the price of petroleum (Bosoni *et al.* 2021).

Table 23 shows the assumptions for an additional sensitivity analysis based on a 50 percent higher annual household consumption of all cooking fuels. The purpose of this analysis was to address uncertainty in the data on average household consumption of cooking fuels and differences in household sizes.

2.7.2 FINANCIAL SENSITIVITY ANALYSIS

Table 24 presents the effects of a 25 percent increase in the real prices of wood and charcoal and a 50 percent increase in the real price of LPG on the financial costs of the nine stove and fuel alternatives. No increase in electricity costs was assumed because the DRC is in the process of a large expansion in low-cost hydropower capacity. At the low unit price of charcoal, the higher prices for wood, charcoal, and LPG increased the financial costs of all stoves and fuels except the electric hotplate. However, none of the rankings of the alternatives changed.

Some rankings did change when the high unit price of charcoal was combined with the higher prices of wood, charcoal, and LPG. Then, the three-stone woodstove had lower discounted financial costs than the two low-efficiency charcoal stoves in Bukavu and Goma and the low-efficiency traditional charcoal stove in Kinshasa. In Kisangani, the three-stone woodstove moved from the fourth to the second least costly alternative as the high- and medium- efficiency charcoal stoves became relatively more expensive. The electric hotplate remained the least-cost alternative in Bukavu, Goma, and Kinshasha and the second highest-cost alternative in Kisangani.

TABLE 22: Main Assumptions for the Base Case and Sensitivity Analysis of Kilns and the Stoves and Fuels

Parameter	Base Case		Sensitivity Analysis	
Real discount rate (financial and economic analysis)	12%		3% and 7%	
Social cost of carbon (economic analysis)	$51/tCO_2e$		$190/tCO_2e$	
Value of forest environmental services lost per hectare of unsustainable woodfuel harvesting (economic analysis)	$224/year		$486/year	
Value of a statistical life (economic analysis)	$18,601		$40,716	
Fuelwood prices (financial and economic analysis)	**Base case**		**25% higher**	
Bukavu	$0.11/kg		$0.14/kg	
Goma	$0.11/kg		$0.14/kg	
Kinshasa	$0.15/kg		$0.19/kg	
Kisangani	$0.04/kg		$0.05/kg	
Charcoal prices (financial and economic analysis)	**Base case**		**25% higher**	
	Low unit price	**High unit price**	**Low unit price**	**High unit price**
Bukavu	$0.29/kg	$0.31/kg	$0.36/kg	$0.39/kg
Goma	$0.28/kg	$0.37/kg	$0.35/kg	$0.46/kg
Kinshasa	$0.26/kg	$0.43/kg	$0.33/kg	$0.54/kg
Kisangani	$0.14/kg	$0.23/kg	$0.18/kg	$0.29/kg
LPG prices (financial and economic analysis)	**Base case prices**		**50% higher**	
Bukavu	$1.74/kg		$2.61/kg	
Goma	$1.74/kg		$2.61/kg	
Kinshasa	$1.66/kg		$2.49/kg	
Kisangani	$3.53/kg		$5.30/kg	

TABLE 23: Base Case and Sensitivity Analysis Assumptions on Annual Cooking Fuel Consumption Per Household

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Annual Cooking Fuel Consumption Per Household							
	Base Case	50 Percent Higher	Base Case	50 Percent Higher	Base Case	50 Percent Higher	Base Case	50 Percent Higher
Three-stone woodstove	2,649 kg	3,973 kg	3,501 kg	5,251 kg	3,648 kg	5,471 kg	3,394 kg	5,091 kg
Low-efficiency, traditional charcoal stove	950 kg	1,424 kg	1,255 kg	1,883 kg	1,308 kg	1,962 kg	1,217 kg	1,825 kg
Low-efficiency, improved charcoal stove	959 kg	1,439 kg	1,078 kg	1,617 kg	1,123 kg	1,685 kg	1,045 kg	1,567 kg
Medium-efficiency, improved charcoal stove	715 kg	1,073 kg	920 kg	1,381 kg	995 kg	1,493 kg	926 kg	1,389 kg
High-efficiency, Jikokoa Xtra charcoal stove	589 kg	883 kg	778 kg	1,167 kg	811 kg	1,216 kg	754 kg	1,132 kg
High-efficiency, EcoZoom Jet charcoal stove	569 kg	854 kg	752 kg	1,128 kg	784 kg	1,176 kg	729 kg	1,094 kg
LPG stove	247 kg	371 kg	327 kg	490 kg	341 kg	511 kg	317 kg	475 kg
Single-burner, coil electric hotplate	2,266 KWh	3,398 KWh	2,994 KWh	4,492 KWh	3,120 KWh	4,680 KWh	2,903 KWh	4,354 KWh

TABLE 24: Effects of a 25 Percent Increase in Wood and Charcoal Prices and a 50 Percent Increase in LPG Prices on the Present Value of Financial Costs of the Stoves and Fuels at a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Base Case	Higher Fuel Prices	Base Case	Higher Fuel Prices	Base Case	Higher Fuel Prices	Base Case	Higher Fuel Prices
Low unit price of charcoal								
Single-burner coil electric hotplate	$492	$492	$484	$484	$512	$512	$2,068	$2,068
High-efficiency, EcoZoom Jet charcoal stove	$986	$1,080	$1,277	$1,643	$1,217	$1,990	$632	$1,007
High-efficiency, Jikokoa Xtra charcoal stove	$1,010	$1,106	$1,306	$1,680	$1,245	$2,032	$655	$1,041
Medium-efficiency, improved charcoal stove	$1,167	$1,285	$1,490	$1,931	$1,495	$2,463	$735	$1,204
Low-efficiency, traditional charcoal stove	$1,557	$1,712	$2,042	$2,645	$1,939	$3,209	$971	$1,589
Low-efficiency, improved charcoal stove	$1,561	$1,718	$1,741	$2,258	$1,681	$2,774	$829	$1,359
Three-stone woodstove	$1,637	$1,637	$2,156	$2,156	$3,132	$3,132	$786	$786
LPG stove	$3,379	$3,379	$3,370	$3,370	$3,255	$3,255	$6,417	$6,417
High unit price of charcoal								
Single-burner coil electric hotplate	$492	$492	$484	$484	$512	$512	$2,068	$2,068
High-efficiency, EcoZoom Jet charcoal stove	$986	$1,336	$1,277	$2,040	$1,217	$2,474	$632	$1,244
High-efficiency, Jikokoa Xtra charcoal stove	$1,010	$1,367	$1,306	$2,084	$1,245	$2,524	$655	$1,286
Medium-efficiency, improved charcoal stove	$1,167	$1,602	$1,490	$2,410	$1,495	$3,068	$735	$1,502
Low-efficiency, traditional charcoal stove	$1,557	$2,133	$2,042	$3,298	$1,939	$4,003	$971	$1,980
Low-efficiency, improved charcoal stove	$1,561	$2,144	$1,741	$2,817	$1,681	$3,456	$829	$1,696
Three-stone woodstove	$1,637	$2,046	$2,156	$2,695	$3,132	$3,915	$786	$983
LPG stove	$3,379	$5,015	$3,370	$5,006	$3,255	$4,844	$6,417	$9,581

Table 25 shows the effects of increasing the average annual consumption of all cooking fuels by 25 percent. Increased fuel consumption raised the present value of the financial costs for all stove and fuel combinations by 22-25 percent over the base case. However, it did not affect the financial cost rankings of any of the alternatives in the four locations.

TABLE 25: Effects of a 25 Percent Increase in Average Annual Consumption of All Cooking Fuels on the Present Value of Financial Costs of Stoves and Fuels at a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Base Case	Higher Fuel Use	Base Case	Higher Fuel Use	Base Case	Higher Fuel Use	Base Case	Higher Fuel Use
Single-burner, coil electric hotplate	$492	$602	$484	$594	$512	$626	$2,068	$2,572
High-efficiency, EcoZoom Jet charcoal stove	$986	$1,218	$1,277	$1,582	$1,217	$1,507	$632	$776
High-efficiency, Jikokoa Xtra charcoal stove	$1,010	$1,246	$1,306	$1,617	$1,245	$1,540	$655	$803
Medium-efficiency, improved charcoal stove	$1,167	$1,455	$1,490	$1,857	$1,495	$1,858	$735	$915
Low-efficiency, traditional charcoal stove	$1,557	$1,939	$2,042	$2,544	$1,939	$2,415	$971	$1,208
Low-efficiency, improved charcoal stove	$1,561	$1,948	$1,741	$2,171	$1,681	$2,091	$829	$1,032
Three-stone woodstove	$1,637	$2,046	$2,156	$2,695	$3,132	$3,915	$786	$983
LPG stove	$3,379	$4,197	$3,370	$4,188	$3,255	$4,050	$6,417	$7,999

2.7.3 ECONOMIC SENSITIVITY ANALYSIS RESULTS

Table 26 reports the effects of increasing real fuel prices by 25 percent for wood and charcoal and 50 percent for LPG. The higher fuel price assumptions increased the economic costs of cooking with all three of these fuels. Not surprisingly, the economic cost increase was largest for the LPG stove due to the higher price differential. At the low unit price of charcoal, the LPG stove's ranking dropped from third to eighth in Bukavau, second to fifth in Goma, second to fourth in Kinshasha. In Kisangani, the LPG stove ranked last under both the base case and sensitivity analysis fuel price assumptions. In Goma and Kisangani, the low-efficiency, improved charcoal stove ranking moved up from fifth to fourth, gaining a slight advantage over the low-efficiency, traditional charcoal stove.

At the high unit price of charcoal, the higher prices for the three fuels dropped the rank of the LPG stove from third to seventh in Bukavu, second to fourth in Goma. However, it did not change the ranking of the LPG stove from second place in Kinshasha or ninth place in Kisangani. Nor did it change the rankings of the various charcoal stoves or the three-stone woodstove.

TABLE 26: Effects of a 25 Percent Increase in Wood and Charcoal Prices and a 50 Percent Increase in LPG Prices on the Present Value of Economic Costs of Stoves and Fuels at a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Base Case	Higher Fuel Prices	Base Case	Higher Fuel Prices	Base Case	Higher Fuel Prices	Base Case	Higher Fuel Prices
Low unit price of charcoal								
Single-burner, coil electric hotplate	$1,352	$1,352	$1,343	$1,343	$1,408	$1,408	$5,986	$5,986
High-efficiency, EcoZoom Jet charcoal stove	$4,604	$4,946	$5,410	$5,858	$5,191	$5,617	$4,173	$4,384
High-efficiency, Jikokoa Xtra charcoal stove	$4,661	$5,008	$5,479	$5,936	$5,258	$5,692	$4,248	$4,466
Medium-efficiency, improved charcoal stove	$5,232	$5,655	$6,092	$6,633	$6,055	$6,589	$4,751	$5,016
Low-efficiency, traditional charcoal stove	$5,601	$6,163	$6,846	$7,584	$6,618	$7,318	$4,968	$5,316
LPG stove	$4,647	$6,643	$4,631	$6,628	$4,488	$6,426	$8,315	$12,175
Low-efficiency, improved charcoal stove	$6,169	$6,737	$6,640	$7,273	$6,460	$7,062	$5,005	$5,304
Three-stone stove (wood)	$7,776	$8,378	$9,289	$10,081	$10,650	$11,801	$6,944	$7,233
High unit price of charcoal								
Single-burner, coil electric hotplate	$1,352	$1,352	$1,343	$1,343	$1,408	$1,408	$5,986	$5,986
High-efficiency, EcoZoom Jet charcoal stove	$4,743	$5,119	$5,948	$6,531	$6,328	$7,038	$4,724	$5,073
High-efficiency Jikokoa Xtra charcoal stove	$4,802	$5,185	$6,028	$6,622	$6,416	$7,139	$4,815	$5,175
Medium-efficiency, improved charcoal stove	$5,404	$5,870	$6,742	$7,444	$7,478	$8,368	$5,442	$5,879
Low-efficiency, traditional charcoal stove	$5,830	$6,448	$7,732	$8,692	$8,485	$9,651	$5,876	$6,452
LPG stove	$4,647	$6,643	$4,631	$6,628	$4,488	$6,426	$8,315	$12,175
Low-efficiency, improved charcoal stove	$6,400	$7,026	$7,400	$8,223	$8,066	$9,069	$5,785	$6,279
Three-stone woodstove	$7,776	$8,378	$9,289	$10,081	$10,650	$11,801	$6,944	$7,233

At the relatively high 12 percent discount rate, costs that occur in 28 years or more have little effect on the present value of the costs of the kilns and stoves and fuels. At a lower discount rate, the damage from the GHG emissions over the fifty-year time horizon of the analysis would be a much higher proportion of the total discounted economic costs at both social cost estimates. In addition, the difference between the discounted economic costs under the two social cost of GHG estimates would be much larger.

The economic analysis assumed a constant social cost of GHG emissions over the time horizon of the analysis. However, the U.S. Government's preliminary estimate of the social cost of GHGs increased every five years between 2020 and 2050 due to the greater economic damage from incremental GHG emissions at higher future levels of global warming. The estimated social cost rose from \$51/tCO_2 for emissions in 2020 to \$85/tCO_2 for emissions in 2050 (Interagency Working Group 2021). However, since a cost in 2050 would be discounted an additional 30 years more than a cost in 2020, this difference would not have had much effect on the present value of economic costs.

Table 27 presents the effects of the 273 percent higher social cost of GHGs on the discounted economic costs of the five charcoal kilns at the 12 percent discount rate. The higher social cost of carbon increased the discounted economic costs per ton of charcoal produced by 162-220 percent for the Casamance kiln, 186-236 percent for the brick beehive kiln, 179-224 percent for the improved earth mound kiln, 174-196 percent for the steel drum kiln, and 141-196 percent for the traditional earth mound kiln. In general, the percentage increases were highest in Kisangani and lowest in Goma. However, the higher social cost of GHGs only changed the rankings of two kilns in one location. In Kisangani, the higher GHG emissions per ton of charcoal made the traditional earth mound kiln less preferable than the steel drum kiln.

TABLE 27: Effects of the Social Cost of Greenhouse Gases on the Present Value of Economic Costs of Kilns at a 12 Percent Discount Rate (U.S. Dollars per Ton of Charcoal Produced)

Kiln	Bukavu		Goma		Kinshasa		Kisangani	
	Social Cost of Carbon (U.S. Dollars/tCO_2e)							
	\$51	\$190	\$51	\$190	\$51	\$190	\$51	\$190
Casamance earth mound	\$25.71	\$69.64	\$27.10	\$71.04	\$24.50	\$68.43	\$19.97	\$63.90
Brick beehive	\$28.70	\$84.37	\$29.95	\$85.61	\$27.81	\$83.48	\$23.54	\$79.20
Improved earth mound	\$38.11	\$109.49	\$39.86	\$111.24	\$35.61	\$106.99	\$30.54	\$101.92
Portable steel drum	\$43.14	\$122.03	\$45.15	\$124.04	\$55.87	\$134.76	\$40.24	\$119.13
Traditional earth mound	\$45.91	\$134.28	\$48.48	\$136.86	\$44.36	\$132.74	\$37.45	\$125.82

Table 28 shows the effects of the 273 percent higher social cost of GHGs on the economic analysis of the stove and fuel combinations. The social cost of GHGs was a major driver of the economic analysis results at the higher social cost of GHGs. There was no change in the discounted economic costs of the electric hotplate because of the low grid power generation emissions factor in the DRC. The higher social cost of GHGs increased the discounted economic costs by 43-53 percent for the high-efficiency charcoal stoves, 47-56 percent for the medium-efficiency charcoal stoves, 53-69 percent for the low-efficiency charcoal stoves, 67-74 percent for the three-stone woodstove, and 29-31 percent for the LPG stove. In general, the percentage increases were higher in Kinshasa and Kisangani and lower in Bukavu and Goma. The higher social cost of GHGs had the largest effect on the economic costs of the less fuel-efficient charcoal stoves and the three-stone fire because GHG emissions are proportional to the amount of woodfuels consumed in cooking. Wood and charcoal stoves with a higher thermal efficiency provide more usable heat for cooking and less waste heat.

At the higher social cost of GHGs, the electric hotplate had the lowest discounted economic costs in all four locations, even in Kisangani, where electricity cost more. The three-stone woodstove remained the highest economic cost alternative. In Bukavu, the higher social cost of GHGs improved the ranking of the LPG stove over the EcoZoom Jet charcoal stove. In the other three locations, this assumption did not change the ranking of the LPG stove. As noted, the GHG emissions of cooking with LPG were undercounted due to lack of information on the emissions in petroleum extraction, processing, and transport.

TABLE 28: Effects of the Social Cost of Carbon on the Present Value of Economic Costs of Stoves and Fuels at a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Social Cost of Carbon (U.S. Dollars/tCO_2e)							
	$51	$190	$51	$190	$51	$190	$51	$190
Single-burner, coil electric hotplate	$1,352	$1,353	$1,343	$1,344	$1,408	$1,410	$1,408	$1,410
High-efficiency, EcoZoom Jet charcoal stove	$4,604	$6,572	$5,410	$8,013	$5,191	$7,906	$5,191	$7,906
LPG stove	$4,647	$6,013	$4,631	$5,997	$4,488	$5,884	$4,488	$5,884
High-efficiency, Jikokoa Xtra charcoal stove	$4,661	$6,666	$5,479	$8,132	$5,258	$8,023	$5,258	$8,023
Medium-efficiency, improved charcoal stove	$5,232	$7,673	$6,092	$9,231	$6,055	$9,455	$6,055	$9,455
Low-efficiency, traditional charcoal stove	$5,601	$8,840	$6,846	$11,131	$6,618	$11,077	$6,618	$11,077
Low-efficiency, improved charcoal stove	$6,169	$9,445	$6,640	$10,314	$6,460	$10,296	$6,460	$10,296
Three-stone woodstove	$7,776	$13,016	$9,289	$16,191	$10,650	$17,840	$10,650	$17,840

Table 29 presents the effects of a 117 percent increase in the per hectare value of lost forest environmental services over the base case. This higher value of forest environmental services only had a small effect on the discounted economic costs of the stove and fuel combinations, 0-3 percent for the charcoal stoves and woodstove. It had no effect on the economic costs of the electric hotplate or LPG stove because they did not increase tree felling. It did not change any of the economic cost rankings of the stoves and fuels.

TABLE 29: Effects of Increasing the Value of Forest Environmental Services on the Present Value of Economic Costs of Stoves and Fuels at a 12 Percent Discount Rate (U.S. Dollars)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Value of Forest Environmental Services Per Hectare							
	$224	$486	$224	$486	$224	$486	$224	$486
Single-burner, coil electric hotplate	$705	$705	$696	$696	$734	$734	$3,022	$3,022
High-efficiency, EcoZoom Jet charcoal stove	$4,000	$4,019	$4,610	$4,637	$4,357	$4,444	$3,400	$3,432
High-efficiency, Jikokoa Xtra charcoal stove	$4,045	$4,065	$4,665	$4,692	$4,409	$4,497	$3,452	$3,484
LPG stove	$4,227	$4,227	$4,212	$4,212	$4,060	$4,060	$7,914	$7,914
Medium-efficiency, improved charcoal stove	$4,471	$4,495	$5,114	$5,147	$4,995	$5,104	$3,770	$3,809
Low-efficiency, traditional charcoal stove	$4,574	$4,606	$5,487	$5,532	$5,204	$5,347	$3,653	$3,704
Low-efficiency, improved charcoal stove	$5,126	$5,159	$5,470	$5,509	$5,239	$5,361	$3,871	$3,915
Three-stone woodstove	$6,167	$6,185	$7,169	$7,193	$8,442	$8,519	$4,889	$4,917

Table 30 shows the effects of a 119 percent higher VSL on the economic analysis of the stove and fuel combinations. The higher VSL did not change the economic costs of the electric hotplate or the LPG stove. At the higher VSL, the electric hotplate was the least-cost alternative in Bukavu, Goma, Kinshasa, and Kisangani. An electric hotplate does not generate any $PM_{2.5}$ or other air pollutants at the end-user level or in hydropower generation.

An LPG stove has low $PM_{2.5}$ emissions, but may expose household members to other indoor air pollutants that increase premature mortality risks. These other pollutants, methane and nitrous oxides, were not considered in this analysis for lack of information. In Bukavu, Goma, and Kinshasa, the LPG stove had the second lowest economic costs of the nine alternatives analyzed.

However, in Kisangani, the higher costs of premature mortality risks did not overcome the higher fuel costs for LPG fuel and the LPG stove had the second-highest economic costs.

Premature mortality risks from $PM_{2.5}$ were a major driver of the total discounted economic costs. $PM_{2.5}$ emissions were inversely proportional to the fuel-efficiencies of the various wood and charcoal stoves. Wood is a smokier fuel than charcoal and has higher $PM_{2.5}$ emissions. The higher VSL can substantially increase the costs of premature mortality risks from woodstoves and charcoal stoves if cooking is done indoors. However, $PM_{2.5}$ exposures from cooking outdoors with wood or charcoal are much lower. Whether cooking is done indoors or outdoors varied by location.

At the higher VSL, the high-efficiency charcoal stoves had lower discounted economic costs than the medium- and low-efficiency charcoal stoves in all four locations. Surprisingly, the low-efficiency traditional charcoal stove had lower economic costs than the medium- and low-efficiency improved charcoal stoves, but this may be due to the noncomparability or measurement errors in the secondary data on $PM_{2.5}$ emissions of the charcoal and wood stoves that were noted earlier.

TABLE 30: Effects of the Two Values of a Statistical Life on the Present Value of Economic Costs of Stoves and Fuels at a 12 Percent Discount Rate (U.S. Dollars Per Household)

Stoves	Bukavu		Goma		Kinshasa		Kisangani	
	Low VSL	High VSL	Low VSL	High VSL	Low VSL	High VSL	Low VSL	High VSL
	$19,146	$41,909	$19,146	$41,909	$19,146	$41,909	$19,146	$41,909
Single-burner, coil electric hotplate	$705	$705	$696	$696	$734	$734	$3,022	$3,022
High-efficiency, EcoZoom Jet charcoal stove	$4,000	$6,903	$4,610	$7,680	$4,357	$7,162	$3,400	$6,160
High-efficiency, Jikokoa Xtra charcoal stove	$4,045	$6,959	$4,665	$7,745	$4,409	$7,224	$3,452	$6,229
LPG stove	$4,227	$4,242	$4,212	$4,227	$4,060	$4,060	$7,914	$7,914
Medium-efficiency, improved charcoal stove	$4,471	$7,571	$5,114	$8,363	$4,995	$8,002	$3,770	$6,731
Low-efficiency, traditional charcoal stove	$4,574	$7,078	$5,487	$8,158	$5,204	$7,609	$3,653	$6,014
Low-efficiency, improved charcoal stove	$5,126	$8,282	$5,470	$8,694	$5,239	$8,198	$3,871	$6,787
Three-stone woodstove	$6,167	$10,266	$7,169	$11,432	$8,442	$12,439	$4,889	$8,843

3 CONCLUSIONS, RECOMMENDATIONS, AND FURTHER RESEARCH NEEDS

Over the long term, the Government and development assistance organizations can increase public and private investment in hydroelectric generation, solar power, and national grid and minigrid infrastructure. The coil electric hotplate produces almost no GHG emissions and $PM_{2.5}$ concentrations and does not rely on harvesting wood. The stove's environmental and health costs are therefore negligible relative to woodfuel stoves. The stove itself also outlasts woodfuel stoves. Despite the higher initial cost of the stove, it was the least cost stove alternative in both the financial and economic analyses in all cities except Kisangani, where electricity prices were relatively high.

Many households with access to other fuels prefer to cook some foods with wood or charcoal and they are unlikely to stop using woodfuels entirely. However, most households in all four cities expressed a willingness to consider using electricity for at least some of their cooking if it was available and reliable. Kinshasa had relatively high electrification rates and many households regularly used both electricity and charcoal for cooking. Despite the financial and economic benefits of electric cookstoves, limited access to reliable electricity prevents many households from adopting them.

In the near- to medium-term, the Government and development assistance organizations can increase the availability of high-quality, efficient, and cleaner charcoal stoves by facilitating imports of mass-manufactured stoves. High-quality, efficient charcoal stoves are not generally available in the DRC. Informal sector artisans produce nearly all of the traditional and improved household charcoal stoves in small batches and do not market them outside the areas where they are produced. Because of the scarcity of quality materials, limited knowledge of stove design, and inconsistent production practices, these local artisans generally produce poor quality stoves that do not last long, may be difficult to use, and may or may not be more efficient than traditional stoves. The locally-made stoves have not been tested for emissions or safety. Therefore, households lack sufficient, reliable information needed to make good purchasing decisions to protect their health or the environment.

The Worldwide Fund for Nature (WWF) and other development assistance organizations have trained some informal sector artisans to make improved charcoal stoves, especially in Goma and Bukavu. However, the approach of training informal sector producers is slow and has not had sufficient impact on stove quality. Widespread adoption of efficient improved stoves cannot be achieved by continuing the same training-based approach in the absence of financing, better raw materials, and mechanized production to replace manual jigs and fixtures.

A better solution to increasing adoption of more efficient charcoal stoves would be to replace reliance on informal sector production of improved charcoal stoves with mass production. Mass manufacturing opens up the potential for economies of scale in production, product standardization, and good quality control. A few companies marketing more efficient and durable charcoal stoves are based in Africa. BURN Manufacturing produces the Jikokoa in Kenya; Envirofit International builds its stoves in Nigeria; and EcoZoom is based in Kenya and produces its stoves in China. BURN manufacturing is expanding its marketing and distribution to more African countries.

In the near term, development assistance agencies or the Government should facilitate imports of mass manufactured stoves, such as the EcoZoom Jet and Jikokoa. A first step would be to assess the experience of the existing mass manufacturers' efforts to sell their high-efficiency stoves in other countries. Promotional campaigns to build demand will need to be combined with efforts to ensure sufficient availability of the imported stoves. The affordability of imported stoves can be improved by eliminating the value-added tax on these imports and providing supplier or third-party financing.

The DRC is a large potential market for efficient and durable household charcoal stoves. After a sufficient market for these stoves has been demonstrated, development assistance organizations or the Government could facilitate establishment of domestic, private sector operations for mass manufacturing of high-quality household charcoal stoves in the medium- to long-term. The Government could also encourage existing mass manufacturers to establish production facilities in the DRC.

International development organizations appear to have paid little attention to improving the efficiency of charcoal production, perhaps because it generates fewer benefits than improving stove efficiency. However, even marginal increases in kiln efficiency could substantially reduce the costs associated with forest resources lost to unsustainable wood harvesting. Many charcoal producers, especially in Goma and Bukavu, operate on a small scale using relatively small kilns that they construct where they harvest the wood. Anecdotal information suggests that many producers in the North and South Kivu provinces operate under the radar within the boundaries of protected national parks. Many producers also depend on wood from land cleared for agriculture. For these producers, more efficient kilns that require metal parts that they must transport to the location of the wood are not practical, even if the producers could afford the high upfront capital costs. **The substantial variability in reported conversion efficiencies suggest that training producers who use traditional kilns may contribute to improving efficiency.**

International development organizations could also play a role in promoting more efficient charcoal kilns. Even moderate increases in kiln efficiency could substantially reduce unsustainable wood harvesting for charcoal production. The substantial variability in reported conversion efficiencies in traditional kilns is due to differences in the density and moisture content of the wood used, the weather during carbonization, the size of the charcoal kilns, and artisan practices in building and operating the kilns.

Traditional earth mound charcoal kilns are generally built by local producers near the source of the wood for each production cycle. As a result, traditional kilns are often larger where wood is more available and smaller where wood is scarcer. Many charcoal producers, especially in Goma and Bukavu, use relatively small traditional kilns. Some producers in North and South Kivu Provinces operate under the radar within the boundaries of protected national parks. Farmers may produce some charcoal in traditional kilns for a short period after they clear trees from forested land being converted to agriculture. Informal sector producers cannot afford more expensive kilns and rely on their own unpaid labor. More efficient kilns that require purchased bricks or metal parts that have to be transported to production locations are not practical and the producers cannot afford high capital costs.

Nevertheless, there is some scope for improving traditional kiln efficiency through low-cost materials for a chimney and flue and worker training. The Casamance kiln is an improved earth mound kiln with a chimney and flue for better air circulation. It produces more charcoal per unit of wood and the charcoal may be better quality. However, the capital costs of the Casamance kiln are higher than the traditional kiln and simpler improved earth mound kilns. Few charcoal producers in the DRC have used the Casamance kiln and it is only likely to be adopted with development assistance organization or Government support. The WWF promoted the Casamance kiln in the DRC in its Ecomakala Project.

The cost-effectiveness analyses found that the Casamance kiln has potential advantages. Although the initial capital costs are higher, the Casamance kiln converts wood to charcoal more efficiently than a traditional earth mound kiln and the purchased raw materials can be reused in subsequent cycles. The higher initial costs are thus spread over a larger volume of charcoal in each production cycle. Production cycles are also substantially shorter, which reduces labor costs and increases the rate at which the kiln can produce charcoal. For full-time charcoal producers, the Casamance kiln produced charcoal at lower cost than all but the more expensive, and immovable, brick kiln.

When the GHG emission reductions are taken into account, the economic costs per ton of charcoal were lower for the Casamance kiln than the other alternatives in all four study locations. Since the Casamance kiln is similar to the traditional kiln, it should be easier to get informal sector charcoal producers to adopt it instead of the much more expensive alternatives. Nevertheless, it will be challenging to scale up use of the Casamance kiln due to the large number of small-scale charcoal producers in the DRC.

The Casamance kiln can be promoted in tandem with the establishment of plantations for sustainable production of wood for charcoal making. The WWF's Ecomakala Project in North Kivu Province demonstrated the potential of a private plantation-based model for growing woodfuels sustainably. This and similar projects have enabled North and South Kivu Provinces to obtain 41 percent of their woodfuels from plantations. The Ecomakala Project also promoted low-cost, but more efficient, charcoal production methods such as the Casamance kiln. The lessons learned from these experiences could help development assistance organizations scale up this work and replicate it in other provinces, particularly in areas around Kinshasa where wood is relatively scarce and the quantity demanded high.

Research on the Value of Forest Ecosystems. The DRC's forests unquestionably produce significant environmental benefits and contribute to the incomes of rural households. However, a dearth of reliable data on the characteristics of the forests and the monetary value of the goods and services they provide limits researchers' ability to make the financial and economic case for preservation. More DRC-specific research is required to map forest resources and to estimate the values of the goods and services they provide.

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ANNEX A: STATEMENT OF WORK

Cost-Benefit Analysis of Charcoal Use and Alternatives in the Democratic Republic of the Congo

This statement of work (SOW) describes a cost-benefit analysis (CBA) that USAID's Office of Economic Policy in the Bureau for Economic Growth, Education, and Environment (E3/EP) is commissioning to compare several scenarios for producing and consuming charcoal in the Democratic Republic of Congo (DRC). The analysis will also consider several alternative cooking fuels (e.g., liquified petroleum gas [LPG]) and electricity, if appropriate.

The study will determine the net present value (NPV) associated with each scenario (including both financial and economic values) to identify the most efficient way – among the scenarios considered – to produce and use charcoal to meet household demand for cooking and heating fuel. USAID's E3 Analytics and Evaluation Project will conduct the analysis, based on a study design that the Climate Economic Analysis for Development, Investment and Resilience (CEADIR) project previously developed and applied in Zambia and Malawi.

The results of this analysis will help the USAID/DRC Mission design future programming to improve the efficiency of charcoal production and use.

1. Analysis Scenarios

Cost-Benefit Analysis

CBAs compare the costs and benefits associated with alternative courses of action (scenarios) to determine which produces the greatest ratio of benefits to costs. Because actions may generate benefits and incur costs at different times over a long period, CBAs typically project future costs and benefits and then discount the stream of costs and benefits to present values for comparison. The comparison may take the form of a cost-benefit ratio, NPV (the present value of benefits minus the present value of cost), or the internal rate of return.

CBAs rely on many assumptions (e.g., about future prices, uptake of alternative charcoal production or use technologies, the availability and price of alternative fuels). These analyses typically conduct sensitivity analyses to determine the effects of these assumptions on results. For example, it is unlikely that all charcoal will be produced in the most efficient way or that all households will adopt the most fuel-efficient stoves. Sensitivity analysis can test the effect of different assumptions (e.g., a 50 percent uptake of fuel-efficient stoves) on the results of the analysis.

Alternative Charcoal Production and Use Scenarios

This analysis will examine four basic scenarios for producing and using charcoal;

1. Charcoal carbonized in a traditional kiln and used in a traditional stove;
2. Charcoal carbonized in a traditional kiln and used in more efficient stoves;
3. Charcoal carbonized in more efficient kilns and used in a traditional stove; and
4. Charcoal carbonized in more efficient kilns and used in more efficient stoves.

Scenario 1 reflects the most common current methods of producing and using charcoal in the DRC and thus represents the baseline scenario. Within scenarios 2 through 4, the analysis will consider at least one moderately efficient and one highly efficient alternative for both the kilns and stoves and may also consider other methods of producing charcoal (and the wood to produce charcoal) or alternative cooking fuels. The production and use technologies will reflect those that are practical or available in the DRC. The actual number of scenarios considered will thus depend on the number of production and use technologies considered. The analysis team and USAID will collaboratively decide on the range of production and use technologies to consider in the analysis during an inception meeting.

2. Data Collection and Analysis Approach

To initiate the study, the analysis team will consult with USAID/E3/EP and USAID/DRC to decide on analysis parameters (e.g., charcoal production and use technologies, alternative fuels, alternative wood production practices). The discussion will also provide an opportunity to clarify other aspects of the analysis to ensure that the team completely understands USAID's decision-making needs and expectations. Prior to the discussion, the team will review the datasets and study designs for the CBAs that CEADIR completed in Zambia and Malawi to align the DRC analysis with those approaches as appropriate and feasible.

The analysis team will utilize local specialist(s) as needed to collect primary data in the DRC. DRC-based team members will take all measures necessary to protect their health and that of people with whom they interact. Depending on the nature of COVID-19-related restrictions, this may require conducting interviews remotely via telephone or similar technology. Most primary data should be able to be collected by telephone, but reaching some respondent types (e.g., small-scale charcoal sellers or consumers) may require different remote approaches.

The analysis will incorporate both financial and economic values. Financial values are the direct monetary costs and benefits associated with the various scenarios. Economic costs and benefits are those experienced by others (e.g., the monetized costs of forest degradation associated with charcoal production or the monetized costs of the health consequences of urban or indoor air pollution due to using charcoal for cooking).

The analysis team's design proposal will detail the proposed data collection and analysis approach for this study, for USAID's approval. The analysis approach and report will adhere to the requirements documented in "USAID Guidelines: Cost-Benefit Analysis (CBA)" (August 2015).

Data Collection

The data required for the analysis will consist primarily of data on the financial and economic costs and benefits associated with alternative charcoal production and use technologies and practices, as well as those associated with alternative fuels. The analysis will also require data on the technical parameters of production and use technologies and practices. These include data on the efficiency of stoves and kilns, their emissions (and monetized values of the associated health and environmental consequences), the efficiency and economic consequences of alternative wood production practices (e.g., natural forests, plantations, or alternative sources), and the characteristics of alternative fuels.

The analysis team will rely primarily on outreach to local producers and consumers of charcoal to gather information on financial costs and benefits. The team will validate and triangulate these data from available secondary sources. The team will use estimates of economic costs and benefits gleaned from secondary data sources.

The analysis team will collect data from local markets and secondary sources on how charcoal prices vary between rural and urban areas within the DRC, by season, and by volume. The team will seek information on the national supply of charcoal, including how much is sourced domestically versus imported.

The analysis team will consult official data sources and databases from organizations such as the World Bank to collect data on income distribution levels in the country, information about the relationship between household income and what fuel the household uses, demographic and economic forecasts, exchange rates, inflation rates, and electricity prices.

Charcoal Production and Use Technologies and Practices

For the technical parameters (e.g., efficiency, emissions) of kilns and stoves, the team will rely largely on secondary sources such as the Clean Cooking Alliance's database of information on stoves, fuels, and testing (http://catalog.cleancookstoves.org/).

Tables 1 and 2 present the characteristics of some available production (Table 1) and use (Table 2) technologies the analysis may consider. These tables are illustrative. At the beginning of the analysis, the team will identify and collect data on the technologies and practices relevant to the DRC context (e.g., types of stoves available in the DRC).

TABLE 1: TYPES OF KILNS AND THEIR EFFICIENCY LEVELS

Kiln	Efficiency range (%)
Earth mound or pit	10-20[a]; 12-30[b]; 15-20[c]
Portable metal kiln	30-35 [a]; 20-38 [b]; 25%[c]
Half orange kiln (made of brick)	50-60 [a]; 27-35 [b]

Sources: [a] Camco Advisory Services (2013); [b] van Dam (2017); [c] BEFS (2018).

TABLE 2: CHARCOAL STOVES & KILNS TO BE INCLUDED IN THE ANALYSIS

Stove (*Common Name*)	Lifespan (yrs.)	Efficiency (IWA high-power thermal efficiency)	Retail Price (USD)	Fuel Consumption (IWA low-power specific consumption)	Emission Factors	Reference
Three-Stone Stove (Open Fire)	n/a	14%	0	TBD	TBD	TBD
Clay Stove (*Chitetezo Mbaula*)	4	29%	2	0.0262 MJ/min/L	106 (CO g/kg), 1.5 (OC g/kg), 6.7 (PM2.5 g/kg), 1666.8 (CO2g/kg), 1.5 (EC g/kg)	Clean Cooking Alliance 2019
Jikokoa	2	44%	40	0.004 MJ/min/L	0.28 (BC g/kg), 3.9 (OC g/kg), 0.01 (BC g/kg)	Clean Cooking Alliance 2019
Kenya Ceramic Jiko	*	~25%	6	0.014 MJ/min/L	1.6 $PM_{2.5}$ g/kg fuel to 3.4 $PM_{2.5}$ g/kg fuel	Clean Cooking Alliance 2019; Jetter et al., 2012

The analysis team will use national estimates of population, fuels used in residences, fuels used in non-residential settings, and production to estimate the fraction of total national fuelwood use that could be avoided by replacing existing inefficient residential energy technologies (such as burning wood in traditional three stone hearths) with the most cost effective of the efficient technologies. The analysis will separately report reductions for residential and non-residential uses.

Alternatives to Substitute Charcoal with Other Fuels

The analysis may also consider options for substituting other fuels for charcoal. As with the charcoal production and use technologies and practices, the team – in collaboration with USAID – will identify a set of alternatives relevant to the DRC to include in the analysis. A preliminary list of alternative fuels for consideration includes:

1. LPG used in a relatively efficient stove (may include both butane and propane);
2. Electric cooking for grid-connected households;
3. Small-scale biomass gasification (biodigesters) and gas stoves (may include ethanol or methane);
4. Briquettes produced from bamboo; and
5. Briquettes produced from sawdust, agricultural residuals, cow dung, and/or tree branches.

Tables 3 and 4 summarize the characteristics of some alternative cooking stoves and fuels. The analysis team will refine this list in collaboration with USAID at the start of the analysis.

TABLE 3: NON-CHARCOAL STOVES TO BE INCLUDED IN THE ANALYSIS

Stove (*Common Name*)	Fuel	Lifespan (yrs.)	Efficiency (IWA high-power thermal efficiency)	Retail Price (USD)	Fuel Consumption (IWA low-power specific consumption)	Emission Factors	Source
LPG Stove	LPG	6	49%	50	0.01742445 MJ/min/L	58−78 (CO2g/MJ), 0.57−3.1 ($PM_{2.5}$ mg /MJ)	Shen et al. 2018; Clean Cooking Alliance 2019
Electric Infrared Stove *(Geepas Digital Cooker)*	Electric	TBD	n/a	~75	2200 Watt	n/a	Geepas 2019
Nikai Gas Cooking Range - NG843	Biogas or natural gas	TBD	TBD	~35	TBD	TBD	TBD

TABLE 4: HOUSEHOLD COOKING FUELS ADVANTAGES AND DISADVANTAGES

Cooking Fuel Type/Technology	Uses	Advantages	Disadvantages	Relative Costs	Greenhouse Gas Emissions	Local Air Pollutants
Fuelwood (open fire or traditional stoves)	Household cooking, heating	Principal cooking fuel for low and middle income households in rural areas of LDCs; often collected for free; preferred for food flavor	High transport cost due to bulk	Low (opportunity cost of time if collected for free); some marketed in rural and especially urban areas	Mostly contributes to forest degradation since often from fallen wood or cutting of tree branches. Depends on whether tree branches are cut or whole, live trees; potential for increased farm forestry and agroforestry, with environmental co-benefits	High for users
Fuelwood (improved stoves)		Improve fuel efficiency by up to 56% over open fire	Need to consider user preferences in design and achieve scale through modern mass production	Relatively low cost, but incentive for purchase depends on whether fuelwood is purchased or free; quick payback period if fuelwood purchased	Reduce carbon emissions by up to 65% over traditional woodstove	Similar to reduction in GHG emissions
Charcoal (traditional stoves)	Household cooking	Principal cooking fuel for low and middle income households in urban areas of LDCs; preferred for food flavor; lower transport costs than for wood, making long-distance trade feasible	Contributes to poor air quality, morbidity, and mortality and relatively high GHG emissions	Lower fuel cost than many alternatives, but can be a substantial share of low-income household budgets; low cost for stoves	Often contributes to more deforestation than fuelwood since whole, live trees are often cut for artisanal or industrial production and energy loss in charcoal production	Moderately high; less smoky than wood
Charcoal (improved kilns for production)		More efficient than traditional kilns	Approximately half the energy value of wood is lost in conversion to charcoal via traditional kilns (after accounting for higher combustion efficiency of traditional charcoal stoves vs. traditional woodstoves); traditional kilns for converting wood to charcoal yield 10–22% but	Moderate cost; may be easier through new commercial enterprises than by changing traditional artisanal production technology	Reduced carbon emissions by 67-76%	Similar to reduction in GHG emissions

Cooking Fuel Type/Technology	Uses	Advantages	Disadvantages	Relative Costs	Greenhouse Gas Emissions	Local Air Pollutants
			a low-cost retort/kiln can yield 30–42% (DOI: 10.1016/j.renene.2008.12.009)			
Charcoal (improved stoves for use)		Increase fuel efficiency from 15% to as much as 46% for Kenya BURN stove (EU-UNEP 2018)	Need to consider user preferences in design; importance of achieving scale through modern mass production	Relatively low cost and quick payback period, but households may need financing	Reduce carbon emissions up to 67% over traditional charcoal stove	Similar to reduction in GHG emissions
Kerosene	Lighting and household cooking	Fast cooking; often only a partial replacement for charcoal	High fire and safety risk; disliked for food flavor due to odor	Moderately high cost fuel and stove	GHG emissions from whole fuel production and distribution cycle need to be considered	Moderate
LPG	Household cooking	Fast cooking; often only a partial replacement for charcoal	Moderately high safety risk	High cost fuel and moderately high cost stove	GHG emissions from whole fuel production and distribution cycle need to be considered	Moderately low
Grid electricity	Lighting, household cooking, appliances in urban areas	Fast cooking; often only a partial replacement for charcoal	Low safety risk	Grid access constraints in urban informal sector settlements and rural areas; high capital cost of grid extension; grid electricity may be unreliable; renewable energy is often cheaper now than conventional generation	Need to consider lifecycle GHG emissions from the mix of power generation sources. cheaper now	Low
Beyond-the-grid electricity	Lighting, household cooking, and appliances in rural areas	Fast cooking; often only a partial replacement for charcoal	Low safety risk	Can be feasible through community minigrids or household PayGo financing		Low
Biogas	Cooking, but more likely to be viable for large institutional users than households	Some successes in India and China; environmental benefits from cleaning up animal manure	Moderately high safety risk; technology reliability problems, especially on small-scale; mixed performance and cultural taboos on handling animal manure in many countries	High capital cost of biogas digesters		Moderately low

Cooking Fuel Type/Technology	Uses	Advantages	Disadvantages	Relative Costs	Greenhouse Gas Emissions	Local Air Pollutants
Bioethanol	Household cooking	Fast cooking	High fire and safety risk; may need to be imported in many countries and may require changes in tariff and VAT policies; domestic production may involve setting up an entirely new industry	High capital cost of growing sugarcane specifically for bioethanol; waste bagasse is already often used as a boiler fuel in sugar processing; lower opportunity cost if other agricultural wastes are available; high cost of ethanol production facilities and mechanized distribution system, transport, and custom stove production; higher stove and/or fuel costs for households than charcoal, kerosene, LPG, or electricity	Lifecycle emissions of growing sugarcane (including land conversion and high nitrogen fertilizer requirement); energy used in conversion process and raw material and fuel transport; more objective analysis is needed	

Commercial Plantations for Sustainable Charcoal Production

The analysis will consider at least two alternatives to the usual practice of producing wood from natural forests:

1. Establishing tree plantations for charcoal production (considering several different species); and
2. Establishing bamboo plantations for charcoal production.

The analysis team will collect three categories of data to conduct the CBA for the establishment of plantations:

1. **Yield of wood.** This may be in volume such as cubic meters, or by weight. If by weight, the analysis team will indicate if this is green weight, air dry weight, or dry weight. Ideally, yield information will be net of disease losses, and actual growth of operational plantations, not modeled and not from test plots. Other associated data that the analysis team will try to collect include: (1) when harvests typically occur in years since establishment of the plantation; (2) harvesting practices (e.g., there may be multiple harvests, such as thinnings and then a final harvest where all trees are removed, or there may be coppicing, where a tree is cut and new stems grow from the stump/roots. If there is coppicing, how many cycles of harvest are possible before the production has to be restarted, with site preparation and new planting?); (3) tree species; (4) price and quality of the product (e.g., piece size, bark content, heartwood content); and (5) whether any other products can be produced from plantations while wood is being grown.
2. **Costs**. These will include costs of: (1) acquiring or leasing land; (2) site preparation and management (including planting and planting stock, management during growth, and harvesting); (3) transportation (typically per truckload or per unit of production, and this may vary depending on distance); (4) taxes or fees; and (5) those associated with what happens to the land after a cycle of wood production (i.e., if the land is rented, an estimate of the cost of restoring the land to its prior condition – typically the cost of removing stumps so the land can be used for agriculture; if the land is purchased, the residual value of the land – which might be the price at which the land could be sold).
3. **Timing of yields and costs, by year**. In particular, when do harvests occur and what are the costs of each harvest? Typically, site preparation and planting costs occur in the first year (modeled as year 0 in the analysis) and the analysis team will confirm if this is the case in the DRC. The analysis team will also confirm if plantation managers pay taxes and if so, whether they pay them annually or at the time of harvest.

The analysis team will try to collect the data needed to estimate the costs and benefits of plantations by engaging with local companies and other development assistance organizations. A local specialist will attempt to collect these data through surveys, interviews (by telephone or in person, whichever is efficient and feasible), or a combination of the two. If these organizations are unable to provide the needed data, the analysis team will use information from similar countries and will discuss any uncertainty associated with the use of such data with USAID.

The analysis team will construct CBAs of establishing plantations for charcoal, estimating the cost of production per cubic meter of charcoal and comparing production costs (including transportation, where applicable) to charcoal prices in the capital city. The analysis will also require similar data (e.g., costs of production, quantities) for the baseline scenario of producing charcoal from natural forests.

Economic Benefits and Costs

In all scenarios, the analysis team will discuss, quantify, and monetize where possible the positive externalities associated with the use of cleaner cookstoves, and the negative externalities associated with inefficient stoves. Cookstoves have quantifiable and measurable environmental and health impacts due in large part to emissions of air pollutant created during the incomplete combustion of traditional fuels such as wood or charcoal. During the combustion process, these stoves may release air pollutants and GHGs such as carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), methane (CH_4), polycyclic aromatic hydrocarbons (PAHs), black carbon (BC), and carbon dioxide (CO_2).

The analysis team will seek data to estimate the annual lifecycle GHG emissions of each energy source for each scenario, including transport of each fuel. GHG emissions will be stated for both sustainable and unsustainable wood sourcing (assuming all charcoal consumed is replaced by growth with no net loss of terrestrial carbon stock versus assuming wood used to produce charcoal is emitted without replacement of terrestrial carbon stock). The analysis team will not conduct a lifecycle assessment of GHG emissions, but will reference existing sources that document lifecycle assessments of the production and transport of different technologies.

Long-term exposure to $PM_{2.5}$ in household environments can result in health risks including ischemic heart disease, cerebrovascular disease (stroke), lung cancer, chronic obstructive pulmonary disease, diabetes, and acute lower respiratory infections. Women and young children are most at risk from household air pollution because they tend to spend more time indoors. By switching to alternative fuels or upgrading to more efficient stoves, households can reduce their exposure to these air pollutants, thereby reducing the morbidity and mortality associated with this air pollution. For instance, upgrading stoves to charcoal with improved efficiency or LPG may reduce household exposure to $PM_{2.5}$ by 64 to 75 percent (Anenberg et al. 2017). A study in Mozambique found that expanding the use of LPG stoves to 10 percent of households in 5 major cities could avoid an estimated 160 premature deaths and 11,000 disability adjusted life years from reduced $PM_{2.5}$ exposure for a 3-year intervention, assuming 60 percent of households use the new stove (Anenberg et al. 2017).

The analysis team will review the literature of health effects of indoor air quality from cooking using the methods considered in this analysis. Upon determining the avoided air pollution emissions for each scenario, the team will be able to estimate the mortality and morbidity reductions on households from the use of cleaner cookstoves. The team will then monetize these effects with a value of statistical life estimated by Viscusi *et al.* (2017) and updated to the current-year value. Value of statistical life is a well-established method used to monetize the fatality risks from health impacts in CBAs by measuring workplace compensation.

As a part of the charcoal CBA, the analysis team will estimate reductions in CO_2 emissions per household per year for selected cooking technology improvements, taking into account both the potential penetration of the new technologies and the estimated charcoal use reduction by each household that adopts the new technology. The team will then estimate the amount of wood needed to produce the reduced amount of charcoal consumption. To this end, the team will seek data on the wood utilization ratio of charcoal makers, which is the fraction of tree biomass (above and below ground) that is put in the kiln to make charcoal. The team will use this rate to estimate the total amount of wood biomass killed or extracted for charcoal, which will in turn be used to estimate the avoided forest emissions.

The CBA will also estimate potential reductions in forest degradation associated with lower charcoal use. Harvesting wood to make charcoal generally results in forest degradation, not deforestation. This is because only trees that are suitable for making charcoal are harvested, and other trees are left to grow. If land is being cleared for conversion to agriculture, sometimes pre-existing trees are used for timber, fuel wood, or making charcoal, and sometimes the trees are burned on site to dispose of them. The analysis team will seek measurements of the average number of tons of wood extracted per hectare during charcoal production. The team will estimate hectares of avoided degradation per year by dividing the total number of tons of reduced wood consumption nationally each year by the tons of wood extracted per hectare.

The value of reduced GHG emissions due to cleaner cooking practices will be based on a survey of carbon prices from the voluntary carbon market and U.S. mandatory carbon markets, including the California cap-and-trade program and the Regional Greenhouse Gas Initiative. The team will conduct the analysis with four separate carbon prices of $0, $8, $15, and $25 per metric ton of carbon dioxide equivalent (tCO_2e).

3. Cost-Benefit Analysis Approaches

For the baseline (i.e., current practices) and each alternative scenario, the analysis team will estimate the financial and economic costs and benefits. The financial analysis will include the direct costs associated with the purchase or construction of the stove and kiln, and its operation and maintenance (e.g., fuel costs). The economic analysis will include additional nonmarket benefits such as reduced GHG emissions, reduced morbidity and mortality, and deforestation impacts.

The projected costs and benefits will be discounted to determine the present value. The analysis team will use a discount rate of 12 percent per annum for the analyses and will also conduct a sensitivity analysis using discount rates of 3 percent and 7 percent. The team will conduct the analysis using a 30-year time horizon – the harvest cycle for pine species, which is the alternative that requires a longer timeframe. The other alternatives considered in the analysis can be integrated into the 30-year time horizon by considering the costs of replacing the stoves or kilns. The team will compare the NPV of each alternative scenario to the baseline.

The team will report the analysis and results in local currency and converted to U.S. dollars. The analysis will be conducted on a per household basis and aggregated to a national level.

Sensitivity Analysis

The results of CBAs are highly sensitive to the number of benefits included in the analysis and the assumptions made. For instance, the benefits of each scenario will be driven in large part by the efficiency of different fuels and technologies and other factors, such as assumptions about the adoption of such technologies and whether households use them to completely or partially substitute stoves. A sensitivity analysis will help assess the conditions under which each alternative makes economic and financial sense.

A first step to address uncertainty is the incorporation of three different types of kilns and three kinds of charcoal stoves with different levels of efficiency, as discussed above. In addition, the analysis team will attempt to collect information on key uncertain parameters to determine the shape and size of their probability distributions, or at least to estimate a range of values. If enough information on the distribution or range can be found, the team will conduct a Monte Carlo analysis, which may require use of the Crystal Ball software package, to estimate the uncertainty around the NPV of each scenario.

Alternatively, the team will at least conduct a sensitivity analysis using different point estimates of each parameter to determine how important each parameter is to the NPV of each scenario.

4. Strengths and Limitations of the Study Design

If properly conceived and implemented, CBA is a reliable and credible analytic approach for comparing alternatives. However, it requires a lot of detailed data that may sometimes be difficult to find. In its design proposal, the analysis team will identify the primary strengths and limitations of the proposed CBA approach, along with proposed mitigation strategies for any identified limitations. The key strengths and limitations associated with this study are likely to include:

Strengths

- Established analysis approach: CBA is a well-developed approach to explore the financial and economic consequences of alternative courses of action. With good data, it can produce robust and reliable estimates of the NPV associated with adopting alternative charcoal production and use technologies.

Limitations

- Limited data: A CBA is a data-heavy exercise and it is possible that the analysis team may find few data points, or unreliable data, for some of the data required for the analysis. In these instances, the analysis will note the limitation and conduct sensitivity analysis to explore the effects of a range of likely values.
- Sensitive information: The analysis requires some information that businesses may view as proprietary or sensitive (e.g., financial information on business enterprises such as tree plantations or charcoal production technologies). The team will mitigate this limitation by triangulating data from multiple primary and secondary sources.
- Remote data collection: Restrictions on domestic travel or human interaction imposed by DRC's response to COVID-19 will likely restrict options for collecting primary data. The analysis, however, will rely largely on secondary data and interviews with individuals who are likely easily identifiable and have access to telephones or other communication technology. If necessary, the analysis team expects to be able to collect much of the required data using remote communication technologies. When this is not possible, the team will seek alternative sources of information

5. Deliverables and Reporting

The analysis team will be responsible for the following deliverables, and will provide a final list of proposed deliverables and due dates in its design proposal for USAID's approval.

Deliverable	Due Date
1. Draft Design Proposal	o/a four weeks following USAID approval of this SOW
2. Revised Design Proposal	o/a two weeks following receipt of all written USAID feedback on the Draft Design Proposal
3. Draft Analysis Report	To be proposed in the Design Proposal
4. Final Analysis Report	To be proposed in the Design Proposal
5. Slide Deck for Presentation to USAID on Key Analysis Results	To be proposed in the Design Proposal

The analysis team will provide all documents and reports electronically to USAID. All debriefs will include a formal presentation with slides delivered both electronically and in hard copy for all attendees.

Prior to the submission of the design proposal, the analysis team will discuss with USAID whether its preliminary dissemination plan for this CBA indicates other deliverables that should be prepared. Such additions as agreed with USAID will then be included in the design proposal.

The analysis team's design proposal will include a proposed outline for the final report, for USAID's approval. The analysis and report will adhere to the requirements documented in "USAID Guidelines: Cost-Benefit Analysis (CBA)" (August 2015). Following receipt of USAID's comments on the draft report, the analysis team will prepare a final version that incorporates and responds to this feedback. The final report should not exceed 30 pages, excluding references and annexes. The analysis team will deliver a copy of the final report to USAID's Development Experience Clearinghouse (DEC) within 30 days of COR approval to post it on the DEC.

Data Management and Transfer

The storage and transfer of data collected for this analysis will adhere to the requirements laid out in ADS 579.[33] Final datasets are expected to be submitted to USAID's Development Data Library as required in a format consistent with Automated Directives System (ADS) 579.

6. Team Composition

USAID anticipates that the analysis team will include a team leader, research specialist, and local specialists to carry out the CBA. The team's design proposal will include proposed team members including their roles and their CVs, for USAID's approval.

Team Leader: The team leader will be primarily responsible for the quality of the analysis design and its execution. The team leader should have a minimum of a master's degree in a relevant discipline and experience conducting financial and economic analyses. He/she should also have excellent team management and analytical and report writing skills. The team leader will be responsible for the drafting of all analysis deliverables.

Research Specialist: The research specialist will support the team leader with developing and implementing the CBA approach. In coordination with the team leader, the research specialist will be responsible for developing the methods and data collection instruments, as well as supporting data collection and analysis. The research specialist should have a graduate degree and at least five years of relevant experience.

Local Specialist(s): One or more local specialists will be responsible for collecting primary data in the DRC and otherwise supporting development of the data collection and analysis activities. The specialist(s) should have a graduate degree in a relevant social science field, familiarity with the charcoal sector in the DRC, and some experience with similar analyses. Additional local country research specialists may support field data collection activities, as required.

Home Office Support: Home Office support will be provided by the firm(s) that will be implementing this analysis, as required, including quality assurance, research and analysis support, financial management, administrative oversight, and logistics.

[33] See http://www.usaid.gov/sites/default/files/documents/1868/579.pdf

7. USAID Participation

Regular communication between the analysis team and the designated USAID activity manager for this analysis will be essential to the successful execution of activities. An interactive and collaborative process is envisioned between the analysis team and USAID to carry out the study. USAID/E3/EP and USAID/DRC will be engaged during the design process to ensure agreement on analysis approach and design proposal. The analysis team will keep the USAID activity manager apprised of changes and developments that necessitate/require any significant decision-making or modification of the approved design proposal. Possible USAID participation in the data collection phase of the analysis will be determined prior to the start of field work.

8. Schedule and Logistics

The analysis team's design proposal will include a detailed schedule and proposed delivery dates for conducting the analysis and producing the study deliverables. The overall period of performance for completion of the analysis is expected to last from approximately August 2020 to March 2021.

The analysis team will be responsible for all logistics, including coordinating all in-country travel, lodging, printing, office space, equipment, car rentals, etc. USAID will provide support to set up initial meetings with USAID-affiliated stakeholders and implementing partners, and other stakeholders as appropriate.

9. Estimated Budget

The analysis team's design proposal will include a detailed estimated budget for USAID's review and approval prior to commencing implementation of the study.

10.References

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ANNEX B: DATA COLLECTION INSTRUMENTS

INTERVIEW GUIDE FOR CHARCOAL PRODUCERS

Instructions: Select the respondent who is most familiar with the process of producing charcoal, especially the financial details.

Presentation and Informed Consent

Good morning/afternoon. Thank you for agreeing to talk with me today. My name is [name] and I work for Management Systems International. We are conducting a study of charcoal production in various regions of DRC. The information we collect will help the United States Agency for International Development (USAID) decide how to better support the charcoal sector in DRC.

We want to talk to you because you produce charcoal. Your knowledge, opinions, and experience are very important for this study. The interview will take about 45 minutes to one hour.

Before we start the interview, I would like to ask for your formal consent, including the following:

- You have the right to not participate, this is completely voluntary
- You have the right to stop at any point
- If there is anything you do not understand, please ask me to clarify
- You have the right to decline to answer any question
- You will not receive any direct benefit from participating in this study. However, your responses will help to improve the support that USAID provides in DRC
- The information you provide is only for our study and your responses will be anonymous. You will not be named directly in our report or in any information we share with USAID or other stakeholders. We will not use your name should we choose to quote something you say.

Do you have any questions?

Do you agree to participate in this study?

[ ] YES [ ] NO

May I record our conversation for my notes? Only members of the research team will listen to the recording. We will not share it with anyone else and we will destroy the recording when we are finished with the study. Only the research team will have access to the notes and they will not be shared with anyone else.

[ ] YES [ ] NO

Respondent Contact Information

Name: ___________________________

Location: _________________________

Gender: [ ] Male [ ] Female

How can I reach you if I have other questions?

Contact phone number(s): _________________________ ***(collect as many as possible)***

Whatsapp number (if different and available) ______________________

Email address if available _________________________

Interviewer: ______________________

Interview Date: ___________________

General Information

1. To start, can you please tell me how long you have been producing charcoal in this area?

   Number of years __________

2. About how much of your income comes from producing charcoal? ***(Circle one number)***

   1. Some
   2. About half
   3. Most
   4. All

3. Thinking of the past year, about how much charcoal did you produce during the entire year of 2020?

   Instructions: Ask about the number of sacks of charcoal and the weight of a typical sack. The interviewee may need assistance estimating the total amount for the year. If they answer number of sacks for a kiln load, then probe about the number of kiln loads for the entire year. Write down notes on any calculations done.

   Number of kiln loads produced in 2020 ________________

   Average number of sacks for each kiln load ________________

   Weight of one sack _________________ (kg)

Notes on calculation of total amount of charcoal produced

4. Do you usually buy a permit or license to produce charcoal? ***(Circle one number)***

   1. Yes
   2. No ***(Go to question 7)***

5. How much does the permit or license cost?

   ______________ CDF

6. How often does the permit or license have to be renewed?

Instruction: Record the frequency and units, e.g., once per year.

Frequency ___________________

Unit _______________

7. Other than licenses or permits, do you usually pay any other official or unofficial taxes or fees to produce charcoal?

Instruction: This question is about fees for producing charcoal and does not include fees to purchase wood or taxes to sell charcoal.

a. Describe type of tax or fee	b. Is this an official or unofficial tax or fee?	c. How often, and when, do you pay the tax or fee?	d. What is the amount of the tax or fee? (CDF)	e. How is the amount of the tax or fee determined (e.g., by quantity produced)?

Cost of Sourcing Wood

8. Thinking about the past year (2020), how did you obtain wood to produce charcoal?

Probe for all the ways they obtained wood. Circle all that apply.

1. Used wood from land cleared for agriculture
2. Used wood gathered from forest
3. Bought wood from plantation
4. Bought wood from someone else, not a plantation (Specify ___________________)
5. Other (Specify ____)

***(If multiple answers are recorded, ask)*:** Of these options, which one provided most of the wood you used to produce charcoal?

Most common wood source ______________________________

Now I want you to think about the <u>last time</u> you produced charcoal from ***[most common wood source].***

9. When you made charcoal this time, did you use wood from only one tree species or more than one? ***(Circle one number)***

    1. Single species (Specify ______________________________________)
    2. Multiple species
    3. Don't know

10. Still thinking about the <u>last time</u> you made charcoal from ***[most common wood source]***, how much wood did you put in the kiln?

    Instructions: Ask about the volume (e.g., cubic meters) or weight (tons or kilograms). If by weight, record whether the wood was wet/green or dried. Record data for either volume or weight.

    Volume
    - Volume of wood _______________
    - Units (e.g., cubic meters) _____________

    Weight
    - Weight of wood ________
    - Units (e.g., tons, kg) _________
    - Type of wood (e.g., wet/green, dry) _________

Write explanatory notes here

11. This last time you made charcoal, how much did it cost you to get the wood?

Instructions: Ask about all costs (cash or in-kind) to obtain the wood for this time. This may include paying someone for wood, paying labor to collect or harvest the wood, input costs, and any taxes or fees to collect/buy the wood. If respondent does not report labor costs for collecting wood (e.g., used unpaid family labor or other reason), ask question 12 after the table.

Type of cost	Amount (CDF)
Collecting or harvesting the wood	
Cost of hand labor	
Cost of hiring equipment and operator ***(if applicable)***	
Cost of renting equipment ***(if applicable)***	
Cost of inputs	
Taxes or fees (Specify ______________________________)	
Other costs (Specify ______________________________)	
Buying the wood	
Cost of wood	
Taxes or fees (Specify ______________________________)	
Other costs (Specify: ______________________________)	

12. ***Ask if respondent did not pay for hand labor:*** If you did not pay for the labor to collect wood (for example, you or family member(s) collected wood), how much would it have cost you to hire someone to collect the wood?

Ask for the total number of hours or days—the total amount of time all workers together spent collecting the wood—of labor required to collect the wood and the wage rate for this labor.

Total amount of time required to collect the wood ____ days or hours ***(Circle days or hours)***

Wage rate for this type of labor ________ (CDF per day or hour) ***(Circle day or hour)***

13. Still thinking of the last time you made charcoal from ***[most common wood source],*** what type of kiln did you use? ***(Circle one number)***

Show respondent photographs of kilns to identify kiln type. Ask for permission to take a picture of the kiln if possible.

1. Traditional earth mound kiln
2. Improved earth mound kiln
3. Other (Specify: _________________________________)

14. In addition to the cost of obtaining the wood we previously discussed, what did it cost you to make charcoal that time?

Instructions: If respondent does not report labor costs (e.g., collected the wood themselves or used unpaid family labor), ask columns 3 and 4 in table below.

a. Type of cost	b. Amount (CDF)	***If unpaid labor:*** c. How much time did this task take? ***(total hours for all people involved in the task)***	***If unpaid labor:*** d. How much would you have paid if you hired people to do this task? (CDF) ***(total amount for all people involved)***
Labor Costs			
Cost to stack wood			
Cost to build kiln and operate it			
Cost to gather or package charcoal			
Other labor costs (Specify ____________________)			
Other Costs			
Cost of bags			
Cost of inputs			
Cost of equipment			
Taxes or fees (Specify ____________________)			
Other costs (Specify ____________________)			

15. How many sacks of charcoal did you produce from this kiln load?

Instructions: Ask about the number of sacks of charcoal and the weight of one sack. The interviewee may need assistance estimating this amount. Record notes on any calculations done. Calculate the total weight of charcoal produced by multiplying number of sacks by the weight of the sacks and confirm with the respondent that the total weight is accurate. If necessary, show respondent photographs of sacks to identify packaging.

Number of sacks of charcoal ______________

Weight of one sack _______________ (kg)

Notes/explanation

Transportation and Sales Costs

	16. How have you sold the charcoal you make during the past 12 months? ***(Circle all that apply)***	17. How did you sell most of the charcoal you made in the last 12 months ***(Circle one number)***
1	Agent or middleman	1
2	Local wholesale market	2
3	Local retail market	3
4	Directly to consumer in town	4
5	Direct to consumers in some other place (Specify: ____________________)	5
6	Delivered to retailers or wholesalers in town	6
7	Other (Specify: ____________________)	7

The next questions ask about the last time you sold charcoal in the way you said you sell most of the charcoal you make.

18. When did this sale take place?

Month __________ Year __________

19. How much charcoal did you sell at that time?

Quantity sold __________________ (kg)

20. In what kind of packages did you sell this charcoal? ***(describe all the different types of packaging used the last time they sold charcoal)***	21. What is the weight of one of these packages? (kg)	22. What price did you get for a single bag (CDF)	23. How many of these packages did you sell?

24. What was the distance between where you produced the charcoal and where you sold it?

Number of kilometers __________

25. How did you transport this charcoal from where you produced it to where you sold it? ***(Circle one number)***

    1. Bus
    2. Motorcycle
    3. Bicycle
    4. Car
    5. Small truck or van
    6. Foot
    7. Boat
    8. Not applicable, did not have to transport the charcoal ***(Go to question 28)***

26. How much did you pay for this transportation? ***(If they transported it themselves, ask for the cost of labor and fuel if applicable)***

    Transportation cost _____________ (CDF)

27. If you transported the charcoal yourself, how much time did it take?

    Confirm that the respondent is referring to the most recent sale to their most common buyer.

    Time ***(specify minutes, hours, or days)*** ______________

28. What is the total amount of money you received for selling the charcoal?

    Confirm that the respondent is referring to the most recent sale to their most common buyer.

    Income from selling the charcoal ___________ (CDF)

29. Did you pay any taxes or fees to sell the charcoal that time?

    Confirm that the respondent is referring to the most recent sale to their most common buyer.

    1. Yes
    2. No ***(Go to question 31)***

30. How much did you pay in taxes or fees to sell the charcoal?

List all taxes or fees and describe how it is calculated (e.g., by weight, volume, value, or flat fee)	Amount of tax or fee. (CDF)

31. Did you have any other costs associated with selling the charcoal that time?

    1. Yes
    2. No ***(Go to question 30)***

32. What and how much were those other costs?

List all types of cost	Amount of cost (CDF)

Notes on other costs

33. Would you say that the COVID-19 pandemic affected how much charcoal you produced and sold?

    1. Yes, produced and sold more charcoal during COVID pandemic
    2. Yes, produced and sold less charcoal during COVID pandemic
    3. No, produced and sold about the same amount of charcoal as before COVID pandemic

34. In what other ways did the COVID-19 pandemic affect your charcoal production business?

Describe

INTERVIEW GUIDE FOR PLANTATION OPERATORS

Instructions: Select the respondent who is most familiar with the operation and management of the plantation, especially the financial details.

Presentation and Informed Consent

Good morning/afternoon. Thank you for agreeing to talk with me today. My name is [name] and I work for Management Systems International. We are conducting a study of charcoal production in various regions of the country. The information we collect will help the United States Agency for International Development (USAID) decide how to better support the charcoal sector in DRC.

We want to talk with you because you operate a plantation to provide a sustainable source of wood for charcoal. Your knowledge, opinions, and experience are very important for this study. The interview will take about 45 minutes to one hour.

Before we start the interview, I would like to ask for your formal consent, including the following:

- You have the right to not participate, this is completely voluntary
- You have the right to stop at any point
- If there is anything you do not understand, please ask me to clarify
- You have the right to decline to answer any question
- You will not receive any direct benefit from participating in this study. However, your responses will help to improve the support that USAID provides in DRC
- The information you provide is only for our study and your responses will be anonymous. Neither you nor your organization will be named directly in our report or in any information we share with USAID or other stakeholders. We will not use your name or specific title should we choose to quote something you say.

Do you have any questions?

Do you agree to participate in this study?

[ ] YES [ ] NO

May I record our conversation for my notes? Only members of the research team will listen to the recording. We will not share it with anyone else and we will destroy the recording when we are finished with the study. Only the research team will have access to the notes and they will not be shared with anyone else.

[ ] YES [ ] NO

Respondent Contact Information

Name: ___________________________

Location: _________________________

Gender: [ ] Male [ ] Female

How can I reach you if I have other questions?

Contact phone number(s): _________________________ ***(collect as many as possible)***

Whatsapp number (if different and available) ______________________

Email address if available _________________________

Interviewer: ______________________

Interview Date: ___________________

General Information

1. Who owns this plantation? ***(Circle one number)***

    1. Owned by respondent

    2. Owned by respondent's family

    3. Other (Describe)_____________________

2. When was this plantation established? ***(Enter four-digit year)***

    Year _______

3. What is the current size of this plantation?

    Number of hectares ____________

4. What species of trees do you currently grow? ***(Ask about each row sequentially)***

Do you grow...	How many hectares are planted to this species?	How is most of this species used? (for example: charcoal, poles, firewood, other)
Eucalyptus?		
Acacia?		
Terminalia?		
Other commercial species (Specify ______________)?		
TOTAL (Add rows for total hectares)		

Instruction: Compare the total area reported in question 4 with the area reported in question 3. Probe to reconcile discrepancies.

5. Do you own any equipment, such as tractors, that you use on this plantation? ***(Circle one number)***

   1 Yes

   2 No ***(Go to question 7)***

6. Please tell me about all the equipment that you own that you use on this plantation. ***(Enter information about each piece of equipment on a separate row.)***

List types of equipment owned	How much did it cost you to buy this equipment? (CDF)	When did you buy this equipment? (Year)	About how much did it cost to maintain the equipment in 2020? (CDF)	About how much did you spend on fuel for this equipment in 2020? (CDF)	How long do you expect the equipment to last? (Years)

Cost of Acquiring the Right to Use the Land

Instructions: The questions in the section capture only the costs associated with acquiring the right to use the land. They do not refer to recurring taxes or fees associated with holding the land (e.g. property taxes) or taxes associated with what is produced on the land.

7. Do you own the land used for this plantation, rent/lease the land, or use the land under some other arrangement? ***(Circle all that apply)***

    1 Own

    2 Rent/lease

    3 Used under some other arrangement

Describe

8. How much would this land be worth now if you sold it?

    Value of land ____________ (CDF or USD)

Instruction: Ask questions 9-16 based on the answer to Q7

9. **[If "1" to question 7]** Did you buy this land?

    1 Yes

    2 No ***(Go to question 17)***

10. **[If "1" to question 7]** When did you buy the land?

    Year land was purchased _________

11. **[If "1" to question 7]** How much did you pay for the land?

    Instructions: ***Probe for all types of cost associated with the purchase. This refers only to one-time costs associated with buying the land. It does not include recurring taxes or fees associated with holding the land or producing wood. Confirm that the reported cost applies to all of the land mentioned in question 3. If it does not, ask about the cost of the most recent purchase of land.***

Type of cost	
How many hectares did you buy?	________ hectares
What was the cost of this land?	________ CDF/USD
Did you pay any taxes associated with the purchase? ***(Explain)***	________ CDF
Did you pay any fees associated with the purchase? ***(Explain)***	________ CDF
Did you pay any other one-time costs associated with buying the land ***(Explain)***	________ CDF
Cost per hectare ***(Instruction: Calculate per hectare cost and confirm with respondent.)***	________ CDF

12. **[If "1" to question 7]** Did you borrow money to buy the land?

    1 Yes

    2 No ***(Go to question 17)***

13. How do you repay the loan? ***(Circle one number and fill in associated table)***

    1 Periodic/regular payments ***(Complete following table and go to question 17)***

How much did you borrow?	What is the interest rate?	How often do you make a payment?	What is the amount of each payment?

    2 Lump sum ***(Complete following table and go to question 17)***

How much did you borrow?	What is the interest rate?	When is/was the lump sum payment due?	What is/was the amount of the lump sum payment?

    3 Other arrangement ***(Describe and go to question 17)***

Describe ***(Note the details of payment amount, payment dates, and interest rate.)***

14. **[If "2" to question 7]** How much do you pay to rent/lease the land?

Type of cost	Amount (CDF)	Frequency of payment (e.g., monthly, yearly, etc.)
How many hectares do you rent/lease?	_________ hectares	
What is the amount of the rental payment	_________ CDF	
What other recurring costs associated with renting the land do you pay? (Explain) ***(Note: Do not include recurring taxes, fees, or other regulatory costs.)***	_________ CDF	
Rent per hectare ***(Instruction: Calculate per hectare rent and confirm with respondent.)***	_________ CDF	

(Enter explanations for question 14 here)

15. **[If "2" to question 7]** Does the rent change over time? Explain.

Instructions: ***Probe for monetary or in-kind value of changes in rent/lease cost and timing of changes, e.g., annual percentage increase.***

Explain ***(Describe how the rent changes with time or circumstances and go to question 17)***

16. **[If "3" to question 7]** Please describe the other arrangement under which you use the land.

    Instructions: Probe to understand the current and anticipated future costs associated with the arrangement. Probe for the total annual cost associated with the arrangement. This may include financial or in-kind costs. Include recurring taxes, fees, etc. If the respondent, or the respondent's family, owns the land under this arrangement, ask about the value of the land, i.e., what it would be worth if sold today, and record it in the explanation.)

Explain arrangement

Cost of Establishing the Plantation

17. Of the species that you grow, which on is used mostly for charcoal? ***(Circle one number)***

    1. Eucalyptus
    2. Acacia
    3. Terminalia
    4. Other (Specify__________________________)

For the rest of this interview, I want to ask only about your experience growing [***name of most common species used for charcoal***].

18. When did you first plant ***[name of primary species used for charcoal]*** on this plantation?

    Year __________

19. How much land did you plant to ***[name of primary species used for charcoal]*** at that time?

    Number of hectares __________

20. Thinking about the time you established this plantation, how much did it cost you to prepare this land and plant the trees?

Instructions: Clarify that this refers only to the first time they planted trees and to the amount of land specified in question 17. When finished filling this table, calculate the total cost per hectare for preparing and planting the land and verify with the respondent that the per hectare cost is accurate. "Cost of hiring equipment and operator" refers to hiring someone with equipment to perform a task. "Cost of renting equipment" refers to renting the equipment itself, using the equipment, and then returning it. If the respondent reports no cost for hand labor, ask how much it would have cost to hire labor for the task and then ask for the hourly or daily rate for this type of labor.

Type of cost	Amount (CDF)	If no cost, how much would it have cost you to hire labor for this task? (CDF)	What is the usual hourly or daily wage rate for this type of labor? (CDF)
Preparing the land			
Cost of hand labor			
Cost of hiring equipment and operator ***(if applicable)***			
Cost of renting equipment ***(if applicable)***			
Taxes or fees (Specify ______________________________)			
Other costs (Specify ______________________________)			
Costs of planting trees			
Cost of seed or seedlings			
Cost to transport seed or seedlings to the plantation			
Cost of hand labor			
Cost of hiring equipment and operator ***(if applicable)***			
Cost of renting equipment ***(if applicable)***			
Taxes or fees (Specify ______________________________)			
Other costs (Specify ______________________________)			

Instruction: Add all the costs in question 20 together and calculate the per hectare cost by dividing by the answer to question 19. Ask the respondent whether this sounds reasonable. Probe to reconcile differences if necessary.

21. Did you use any of the equipment you own to prepare this land or plant the trees? ***(Circle one number)***

   1 Yes

   2 No ***(Go to question 23)***

22. What equipment that you own did you use to prepare land or plant trees.

Instructions: Make sure that the respondent mentioned this equipment in question 6. If the respondent did not mention the equipment in question 6, go back to question 6 and add the equipment to the list in question 6.

List types of equipment owned

Tending the Plantation

Still thinking only about your experience with ***[name of primary species used for charcoal]***, the next questions ask about the costs you incur to tend the trees while they are growing and any income you get from the land while the trees are growing.

23. What do you do to tend the plantation while the trees are growing? ***(Note: The purpose of this question is to document all the costs incurred to tend the plantation during the rotation period. It does not include commercial activities such as commercial thinning.)***

- ***For column 1: Probe for weeding, watering, fertilizing, replacing dead trees, or other activities. Keep probing until the respondent cannot think of other activities. Respondents may also mention thinning. Record thinning here but only if it is a non-commercial thinning (i.e., does not generate income).***
- ***For column 2: Probe for the timing and frequency of the task during the rotation period. We need to know the years (since year 0 when the trees were planted) that the task is performed, and the per hectare cost. For example, you might describe the timing and frequency as "Two times per year for the first five years", "One time per year for the first five years, and then once every three years after that", or "once every five years".***
- ***For column 3: Probe for costs associated with hand labor (i.e., not using equipment).***
- ***For column 4: Probe for costs of purchasing any inputs for this task.***
- ***For column 5: Probe for costs associated with hiring equipment (e.g., tractors). This refers only to situations where the operator hires equipment and an operator OR rents equipment without an operator.***
- ***If the cost of any task is different in different years, note that as well. For example, if weeding costs more in the first two years than in subsequent years, explain.***

Description of task	How often, and when, do you need to do this?	What is the cost of hand labor for this task? (CDF)	What is the cost of inputs for this task? (CDF)	What is the cost of hiring/renting equipment for this task? (CDF)

24. Did you use any of the equipment you own to tend the plantation? ***(Circle one number)***

    3 Yes

    4 No ***(Go to question 26)***

25. What equipment that you own that did you use to tend the plantation. ***(Make sure that the respondent mentioned this equipment in question 6. If the respondent did not mention the equipment in question 6, go back to question 6 and add the equipment.)***

List types of equipment owned

26. Do you earn any income from the land from any activities other than producing wood for charcoal? This may include income from harvesting other forest products or selling some wood for other uses? I will ask about agricultural activities in the next question. ***(Probe for the source, timing relative to when the plantation was established, and amount of income during the entire rotation period).***

Description of source of income (e.g., sold wood for construction)	How often, and when, do you obtain this income? ***(Enter calendar years. Note all of the years in which they earn the income from a source.)***	Did this involve harvesting wood? If "yes" ask...			How much did you earn from this activity? (CDF)	Did you pay any taxes or fees associated with this income? Please record the amount.
		How much wood did you harvest? (Record quantity and units)	Did you harvest the wood or did the buyer harvest the wood?	How much did it cost to harvest this wood? (If the respondent harvested the wood, ask what it would have cost him to hire someone else to harvest it.)		

27. If you earn some income from agricultural activities on the land planted to ***[name of primary species used for agriculture]***, I'd like to ask for more detail about these activities. ***(Complete the following table.)***

List all the crops normally produced on a separate row.	How often do you plant this crop with your trees? ***(Note all the years during the rotation period)***	The last time you planted this crop with your trees, how many hectares did you plant?	What is the cost of producing these crops ***(ask about cost of preparing land, buying inputs, planting, tending, and harvesting)***	How much was the production worth ***(If sold, ask for the price. If consumed by the respondent, probe for the value.)***

28. Do you pay any recurring taxes or fees while the trees are growing (e.g., an annual property tax based on the area of land)?

Describe type of tax or fee.	How often, and when, do you pay the tax or fee?	What is the amount of the tax or fee? (CDF)	How is the amount of the tax or fee determined (e.g., size of property or value of property)?

Harvesting/selling

These questions ask about how you usually harvest and sell ***[name of primary species used for charcoal].***

29. How do you harvest ***[name of primary species used for charcoal]***? Do you... ***(Ask for each of the options and circle all that apply)***

1 Wait until the trees are mature and harvest them all (clear-cut)?

2 Thin, or partially cut, the trees periodically?

3 Thin, or partially cut, the trees periodically during the rotation period and then clear-cut the remaining trees?

4 Coppice the trees periodically and then clear-cut the remaining trees?

30. Do you sell the ***[name of primary species used for charcoal]*** that you grow, or do you use it to make charcoal that you then sell? ***(Circle one number)***

1 Sell the wood

2 Make charcoal yourself

3 Both of the above

31. When you sell ***[name of primary species used for charcoal]***, do you sell the harvested wood, or do you sell the trees to someone else who harvests them? ***(Circle one number)***

1 Sell the harvested wood

2 Sell the trees to someone else who harvests them

3 Both of the above

The next questions ask about when you harvest and sell ***[name of primary species used for charcoal]***. I'd like to know when you thin/coppice **[ask as appropriate]** the stand and when you clear-cut the stand to start over **[ask as appropriate]**. For each harvest, I'll ask when you harvested; the quantity of wood you harvested; how you sold or used it; and, if you sold it, how much you received.

Instructions: Ask about a plot of *[name of primary species]* that the respondent has managed through an entire rotation. Walk them through the table below. Ask about the year of each harvest, the type of harvest, and the quantity of wood harvested in volume (e.g., cubic meters) or weight (tons wet/green, air dried, or dried). Ask about the cost of each harvest (i.e., labor, inputs, equipment). If the respondents sells the wood, ask about the value. Record responses in the table below.

Please think about a plot of ***[name of primary species]*** that you have managed through an entire rotation. If you have not managed a plot through an entire rotation, then think about the plot that you have managed the longest.

32. How large is this plot?

Number of hectares __________

33. In what year did you plant the trees on this plot?

Year ___________

In what year did you harvest or sell this wood from this plot (Enter calendar year)?	Type of harvest (thinning, coppicing, clear-cut)	How much wood did this harvest yield?	Units (cubic meters, weight (wet/green or dried)	Did you harvest the wood or did the buyer harvest this wood?	If you harvested the wood, about how much did it cost you to harvest it? (Consider labor, inputs, renting equipment. If the respondent performed the labor, ask what it would have cost to hire someone else to do it.) (CDF)	How much did you sell this wood for? (If the respondent used the wood, ask what it would have sold for if he had sold it.) (CDF/unit) (Record units)	Did you pay any taxes or fees associated with the harvest or sale of the wood? (Explain amount and basis (i.e., value, quantity, other))
2016	Thinning	50	tons (dry weight)				
2019	Thinning	50	tons (dry weight)	EXAMPLE			
2020	Clear-cut	150	cubic meters				

Instruction: For each row, calculate costs per hectare and confirm with the respondent that it sounds accurate.

34. Did you use any of the equipment you own when you harvested wood? ***(Circle one number)***

1 Yes

2 No ***(Go to question 36)***

35. What equipment that you own did you use to harvest this wood. ***(Make sure that the respondent mentioned this equipment in question 6. If the respondent did not mention the equipment in question 6, go back to question 6 and add the equipment.)***

List types of equipment owned

Cost of Replanting Trees or Restoring the Land

36. Do you ever clear-cut the plantation, or plots within the plantation?

1 Yes

2 No ***(Go to question 45)***

37. When you finish a rotation of ***[name of primary species used for charcoal],*** do you replant the trees immediately?

1 Yes ***(Go to question 40)***

2 No

38. Do you fallow the land before you replant the trees?

1 Yes

2 No ***(Go to question 40)***

39. How many years to you let the land fallow?

Number of years ________

40. When did you last replant a plot of ***[name of primary species used for charcoal]?***

Year _________

41. How large was the plot?

Number of hectares _________

42. How much did it cost you to replant the plot? ***(If the respondent reports no cost for hand labor, ask what it would have cost if he/she had to hire labor to perform the task.)***

Type of cost	Amount of cost (CDF)	If no cost, how much would it have cost you to hire labor for this task? (CDF)	What is the usual hourly or daily wage rate for this type of labor? (CDF)
Cost of seeds or seedlings			
Cost of transporting seeds or seedlings to the plantation			
Cost of hand labor			
Cost of hiring equipment and operator ***(if applicable)***			
Cost of renting equipment ***(if applicable)***			
Cost of inputs			
Other costs			

Instructions: Calculate the cost per hectare and confirm with the respondent that it sounds accurate.

43. Did you use any of the equipment you own (e.g., tractors) to replant the trees? ***(Circle one number)***

    1 Yes

    2 No ***(Go to question 45)***

44. What equipment that you own did you use to replant these trees? ***(Make sure that the respondent mentioned this equipment in question 6. If the respondent did not mention the equipment in question 6, go back to question 6 and add the equipment.)***

List types of equipment owned

Restoring the Land

45. When you are finished growing trees on this plantation, are you responsible for restoring the land?

    1 Yes

    2 No ***(Go to question 49)***

46. What do you think it will cost to restore the land?

Type of cost	Amount of cost (CDF)
Cost of hand labor	
Cost of hiring equipment and operator ***(if applicable)***	
Cost of renting equipment ***(if applicable)***	
Cost of inputs	
Other costs	

47. Would you use any of the equipment you own (e.g., tractors) to restore the land? ***(Circle one number)***

    1 Yes

    2 No ***(Go to question 49)***

48. What equipment that you own would you use to restore the land? ***(Make sure that the respondent mentioned this equipment in question 6. If the respondent did not mention the equipment in question 6, go back to question 6 and add the equipment.)***

List types of equipment owned

Charcoal Production

49. Do you produce charcoal?

    1. Yes ***(Administer charcoal producer questionnaire)***

    2. No ***(Thank and finish interview)***