ANNEX 1: LPG AND CHARCOAL COMPARATIVE GHG ANALYSIS

BACKGROUND

Charcoal production is a major contributor towards Zambia's de-forestation rate of 300,000 ha per year (Day, Gumbo, Moombe, Wijaya, & Sunderland, 2014). LPG is a cooking fuel alternative that can decrease deforestation in Zambia by reducing charcoal demand. LPG offers many advantages over charcoal including more efficient cooking time, ease of controlling heat output, and improved indoor air quality. USAID requested the Alternative to Charcoal (A2C) project to calculate and compare the respective carbon footprints of charcoal and Liquefied Petroleum Gas (LPG)LPG to inform USAID's decision to promote LPG as an alternative fuel to charcoal in Zambia.

METHODOLOGY

The A2C team calculated the carbon footprint of charcoal and LPG by calculating the CO_2e emissions[1] associated with production, transportation, and end use within the respective fuel's supply chain. The A2C team drew from our Customer Preference Survey, local interviews, and literature to provide inputs into our calculations.

The CO_2e emissions for each of these emission types were calculated based on commonly used functional units of fuel: a 33 kg bag of charcoal and a 6 kg bottle of LPG. The charcoal supply chain tracks the production of what are referred to as "50 kg bags" of charcoal, but that in reality are re-purposed 50-kg maize meal sacs that contain approximately 33kg of charcoal (Gumbo, et al., 2013) – these are the bags that we refer to in this analysis. The functional unit selection does not affect the ultimate GHG emissions comparison of charcoal and LPG, but it simplifies the application of emissions coefficients and makes A2C's modeling of the supply chains more intuitive.

A 33 kg bag of charcoal and a 6 kg bottle of LPG do not provide households with equal amounts of cooking time. To compare the CO_2e emissions of the two fuels, A2C staff subsequently normalized CO_2e emissions calculations in the Annex Conclusion using observed fuel usage by households in order to normalize the comparison.

[1] To be consistent with the IPCC direct emission data that the A2C team used to calculate LPG and charcoal combustion emissions, we defined CO_2e gases to only include CO_2, CH_4, and N_2O.

CHARCOAL

Charcoal in Zambia is primarily produced from Miombo woodland. Some of the production is from areas that are deforested, generally for the expansion of agricultural land, while other production is from areas of forest that remain forest after the charcoal is produced. Charcoal production can be sustainable if woodlands are managed such that the rates of harvest are balanced by the rates of regrowth. If production is sustainable in this way, charcoal as a fuel source is considered renewable and emissions are assumed to be zero from the perspective of greenhouse gas (GHG) accounting. However, it is well established that in many parts of Zambia, particularly surrounding the major urban centers, rates of charcoal production are much higher than is sustainable given rates of forest regrowth.

In areas where charcoal production is not sustainable, estimating GHG emissions requires an estimate of the fraction of non-renewable biomass (fNRB) – essentially, the fraction of the fuel being burned that goes beyond what the forest resource is able to supply renewably. The non-renewable fraction can therefore be assumed to lead to a loss in the total forest biomass on the landscape.

In Zambia, estimates of the fNRB value cover a wide range. Four woodfuel-focused projects in Zambia that have been verified by the Clean Development Mechanism (CDM) used fNRB values that ranged from 0.81 to 0.98 (Bailis et al., 2017). The CDM previously had accepted a default national value of 0.81 for Zambia, although this value has since expired (Bailis et al. 2017). At the other end of the spectrum, Drigo (2016) made a regional estimate of fNRB for the central part of the Zambia that was much lower: 0.19.

In cases where there is not a clearly accepted fNRB value, the CDM in its methodological tool for the calculation of fNRB[2] states that projects can use a default value of 0.3. Given the wide range in fNRB estimates that are available for Zambia, this analysis will rely on the CDM default value. It should be noted that this default is quite conservative for the purposes of this analysis comparing LPG with charcoal. Because it assumes that 70% of charcoal production is sustainable and only 30% will contribute to net emissions from biomass, the CDM value makes it relatively difficult to demonstrate that a transition to LPG would effectively result in emissions reductions.

The loss of forest biomass resulting from the non-renewable fraction of charcoal is likely to be the primary source of emissions from charcoal. In addition to those emissions that result from loss of non-renewable biomass, smaller contributions to the emissions from charcoal will result from the following:

- The manual labor at the production site;
- The production and re-use of polypropylene bags;
- Transport of charcoal from production site to end user.

We will estimate each of these four components of charcoal emissions in the following section. For the largest component, emissions from non-renewable biomass, the process of estimation is shown step-wise in the following table (Table A1) for one 33kg bag of charcoal where each row of the table builds sequentially on the row above it with an associated calculation and reference.

[2] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-30-v3.0.pdf

Table A1: Calculation for emissions from charcoal production from non-renewable biomass

Quantity estimated	Value	Explanation
Mass of charcoal purchased by end user	33kg	33kg bag used as standard for this exercise
Mass of charcoal purchased by end user that was non-renewable	9.90kg	30% of charcoal used in 5 major urban centers is non-renewable (CDM, TOOL30 v3.0). Therefore, 30% of 33kg.
Mass of non-renewable charcoal that was initially produced	11.88kg	20% of charcoal is lost in transport and packaging (Gumbo et al., 2013). Therefore, 9.90kg + 20%
Mass of oven dry wood that would be needed to produce that non-renewable charcoal	51.21kg	23.2% is the charcoal yield of earthen kiln systems in Zambia relative to mass of oven dry wood (Drigo, 2016; cross-checked with Hibajene and Kalumiana, 2003 and Gumbo et al., 2013). Therefore, 11.88kg / 0.232.
Carbon stored in wood used to produce non-renewable charcoal	24.07kg	0.47 kg carbon per kg of wood dry matter per IPCC default values (IPCC, 2006).
CO2 equivalent emissions resulting from non-renewable charcoal	88.25kg	44/12 kg (3.667kg) CO2e per kg of carbon.

We therefore estimate that the emissions resulting from the loss of non-renewable biomass are **88.25 kg of CO2e** for each 33kg bag of charcoal.

EMISSIONS FROM USED POLYPROPYLENE BAGS

The used maize meal bags used by charcoal producers to package their charcoal. The manufacturing of these bags emits roughly 2.35 kg of CO2e per kg of polypropylene[3]. However, the bags are typically being reused and resold at roughly half the cost of new bags (Gumbo, et al., 2013). We attributed 33 percent of the CO_2e associated with the manufacturing of the polypropylene bags to coincide with the 33 percent of the economic value that is created by the secondary market for polypropylene bags within Zambia's charcoal industry. We attribute **0.78 kg of CO2e** emissions to the reuse of polypropylene bags to package the charcoal.

EMISSIONS FROM MANUAL LABOR AT PRODUCTION SITE.

It takes roughly 0.1 workdays for charcoal producers to fell and crosscut the 365 kg of wood required for a 33 kg bag of charcoal (Hibajene & Kalumiana, 1996). A China-based study estimated that the carbon footprint of manual labor can estimated at roughly 0.25 kg per day (Li, Wang, He, & Yang, 2020). The manual labor associated with felling and crosscutting the 365 kg of cordwood emits roughly 0.03 kg of CO_2e.

The manual labor in the *Carbonization* process includes hauling the crosscut cordwood to the kiln location, piling it into a clamp, constructing the kiln, and managing airflow into the kiln during carbonization. It is estimated that this equates to roughly 0.26 days per 33 kg bag of charcoal (Hibajene & Kalumiana, 1996). The manual labor associated with *Carbonization* emits roughly 0.07 kg of CO_2e.

[3] Data from the Eco-profiles of the European plastics industry (PlasticsEurope). http://lca.plasticseurope.org/index.htm

Taken together, emissions resulting from manual labor are estimated to be **0.10 kg of CO2e**.

FUEL TRANSPORTATION

The Fuel Transportation emission calculation encompasses the movement of packaged charcoal to the end user. (The transportation of intermediary products in between production processes is conducted by manual labor and is already accounted for in the *Fuel Production* calculations.) There are four fuel transportation calculations to account for in the Zambian charcoal supply chain.

1. Transportation from production site to a district center market
2. Transportation from the district center market to a metropolitan market
3. Transportation from the district center market to district end-users
4. Transportation from the metropolitan market to end-users

The CCaCL2 tool used by the A2C team contains two libraries of different modes of transportation that were heavily drawn on to estimate CO_2e emissions associated with charcoal transportation.

PRODUCTION SITE TO A DISTRICT CENTER MARKET

Charcoal production sites are found in rural area distant from any district center where charcoal can be distributed around the district or larger metropolitan areas. 1-ton trucks are frequently hired by producers to convey packaged charcoal from the production site to a local district center market (Gumbo, et al., 2013). It is assumed that these 1-ton trucks have to make a roundtrip of 40 km between the market and the production site. The emission coefficient of a diesel truck with cargo capacity up to 3.5 tons is $6.37*10^{-4}$ kg CO_2e/kg per km. Transporting a 33 kg bag of charcoal the 40 km to the district central market emits **0.86 kg of CO_2e**.

DISTRICT CENTER MARKET TO A METROPOLITAN MARKET

Only 43 percent of charcoal that reaches the district market is transported onwards to larger metropolitan markets, the rest is consumed within the district (Gumbo, et al., 2013). Larger trucks are used to cover the greater distance and larger loads between the district centers markets and metropolitan markets. A2C field research found that a common truck bringing charcoal into cities is a 15-ton truck, and we assumed that these trucks travel a roundtrip of 160 km between the district center market and metropolitan market. The emission coefficient of a diesel truck with cargo capacity between 7.5 and 17 tons is $4.68*10^{-4}$ kg CO_2e/kg per km. Transporting 43 percent of a 33 kg bag of charcoal the 160 km to the metropolitan market emits **1.08 kg of CO_2e**.

DISTRICT CENTER MARKET TO DISTRICT END-USERS

A2C's Customer Preference Survey revealed that most urban customers purchase their charcoal from markets that are within 5 km of their home (Tetra Tech, 2021). The A2C team assumed that wheelbarrows, with no associated CO_2e emissions, are the most common method to transport a 33 kg bag of charcoal across this short distance.

METROPOLITAN MARKET TO METROPOLITAN END-USERS

A2C's Customer Preference Survey revealed that most urban customers purchase their charcoal from markets that are within 5 km of their home (Tetra Tech, 2021). The A2C team assumed that wheelbarrows, with no associated CO_2e emissions, are the most common method to transport a 33 kg bag of charcoal across this short distance.

Table A2: Summarizing emissions from charcoal transport

Fuel Transportation	Vehicle	CO_2e emitted
Production Site to a District Center Market	1-ton truck	0.86 kg
District Center Market to a Metropolitan Market	15-ton truck	1.08 kg
Total		1.94 kg

Emissions from transport are estimated to be **1.94 kg of CO2e** per 33kg bag of charcoal (Table A2).

SUMMARY OF CO2E EMISSIONS FROM ONE 33KG BAG OF CHARCOAL

In Table A3 below, we summarize the emissions from charcoal. We estimate that the total emissions produced from one 33kg bag of charcoal are 91.07 kg of CO_2e. This total will be compared against emissions from LPG in the concluding section of this annex.

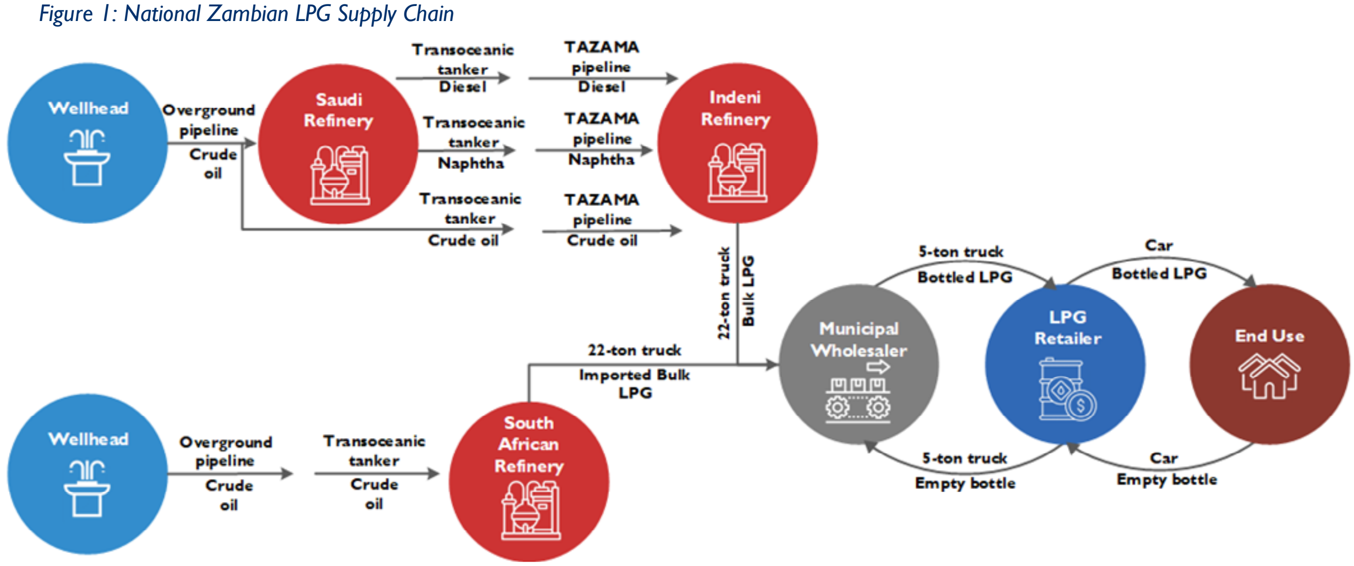
Table A3: Emissions summary for charcoal

Emissions source	Emissions from 33kg bag of charcoal (kg CO2e)
Non-renewable degradation of biomass	88.25
Polypropylene bags	0.78
Manual labor	0.10
Transportation	1.94
TOTAL	91.07

LIQUIFIED PETROLEUM GAS (LPG)

Every oil marketing company (like Puma Energy, Total, or Kobil) has a slightly different LPG supply chain, however the national Zambian supply chain can be approximated in Figure 1. This figure depicts the raw materials, production, transportation, and end-usage within the LPG supply chain.

Figure 1: National Zambian LPG Supply Chain



RAW MATERIALS

There are two raw materials that are commonly used to produce LPG: crude oil and reusable steel LPG bottles. Below we detail the CO_2e emissions associated with the production of both raw materials.

CRUDE OIL

A 6 kg bottle of LPG requires 6.73 kg of crude oil, and Zambia sources its crude oil from the Middle East via two different routes. The majority of Zambia's LPG (88 percent) is produced domestically in the Indeni Refinery while the balance (12 percent) is imported via South Africa. This dual-pronged crude oil sourcing is depicted in Figure 1. The total amount of crude oil depends on the how the crude oil is refined and the losses associated with refining and transporting interim products. The A2C team assumed the losses and equivalent quantities of crude oil leaving each process within the Zambia's supply chain listed in Table A4.

Table A4: Losses with LPG Supply Chain

Process or Transportation Mode	Process Output: *South African Leg (kg)*	Process Output: *Indeni Leg (kg)*	Losses	Source
Wellhead	0.74	5.99		
Onshore Pipeline, Middle East	0.73	5.94	0.85%	Assumed to be the same as TAZAMA Pipeline Loss
Saudi Refinery	Not Applicable	5.93	0.55%	(Triple EEE, n.d.)
Transocean Tanker	0.73	5.91	0.30%	(United Nations, 2011)
TAZAMA Pipeline	Not Applicable	5.86	0.85%	(United Nations, 2011)
South African Refinery	0.73	Not Applicable	0.55%	Same as Saudi Refinery
Indeni Refinery	Not Applicable	5.27	10%	(United Nations, 2011)

The CCaLC2 tool includes the Ecoinvest database which includes an emissions coefficient for crude oil produced within the Middle East. It includes energy use, infrastructure, and fugitive emissions associated with the production of crude oil. The CO_2e emissions associated with 6.73 kg of crude oil is **0.79 kg CO_2e**.

STEEL 6 KG LPG BOTTLE

Manufacturing a 6 kg steel canister emits 2.26 kg of CO_2e, however they can be refilled up to 240 times (Carbotainer) (Sustianable Thermal Energy Service Partnerships, 2016). The CO_2e emissions associated with a single refill cycle of LPG is **$9.42*10^{-3}$ kg CO_2e**.

Table A5: Emissions from raw materials in LPG

Raw Materials	CO_2e emitted
Crude Oil	0.79 kg
Steel 6 kg LPG Bottle	0.01 kg
Total	0.80 kg

FUEL PRODUCTION

The Fuel Production emission calculation encompasses two distinct processes in the Indeni branch, one process within the South African branch, and three processes after both are combined after LPG refining. They are:

Indeni Production Branch

- Refining Crude Oil in Saudi Arabia
- Refining Spiked Crude Oil at Indeni Refinery

South African Production Branch

- Refining Crude Oil at South African Refinery

Post-Refining Processes

- Bulk LPG Bottling
- Local OMC Staging Area
- LPG Retailer Decanting

Below we detail the CO_2e emissions associated with all six of these processes.

REFINING CRUDE OIL IN SAUDI ARABIA

The Indeni Refinery requires spiked crude oil — a mixture of crude oil (46 percent), diesel (43 percent), and naphtha (11 percent) — in order to produce petroleum products in the ratio required by the Zambian economy. The diesel and naphtha are refined from crude in the Middle East before transported to Africa. The A2C team assumes that the Saudi Refinery's losses are 0.55 percent, and that that losses equally affect all of the refinery's outputs. The Indeni refinery must order 2.55 kg of diesel and 0.65 kg of naphtha from the Saudi Refinery to supplement 2.73 kg of crude oil and create 5.93 kg of spiked crude oil. The CCaLC2 tool includes the Ecoinvest database which includes separate emissions coefficients for diesel and naphtha that accounts for the energy consumption, fugitive emissions, and co-products that result from petroleum product refining. Diesel production releases 0.4862 kg CO_2e per kg of diesel produced and 0.4228 kg of CO_2e per kg of naphtha produced resulting in **1.24 kg and 0.27 kg of CO_2e** being released from diesel and naphtha production, respectively.

The Saudi Refinery inefficiencies are also a source of CO_2e emissions; the 0.55 percent loss in the Saudi refinery results in $1.767*10^{-2}$ kg (or 0.761 MJ) of lost refinery products being consumed during the refining of diesel and naphtha. The CCaLC2 tool includes a database that includes an emissions coefficient of $8.07*10^{-2}$ kg of CO_2e for every MJ of refinery products burned during refinery operation. The resulting emissions due to Saudi refinery losses are **0.06 kg of CO_2e**.

Table A6: Emissions from refining crude oil in Saudi Arabia

Process	CO_2e emitted per 6kg canister
Diesel Production	1.24 kg
Naphtha Production	0.27 kg
Refinery Losses	0.06 kg
Total	1.58 kg

REFINING SPIKED CRUDE OIL AT INDENI REFINERY

The Indeni Refinery converts spiked crude oil into LPG, but, due to the age of the refinery and lack of appropriate maintenance, with significant refinery losses (10 percent.) The CCaLC2 tool includes the Ecoinvest database which includes emissions coefficients for LPG that accounts for the energy consumption, fugitive emissions, and co-products that result from petroleum product refining. LPG production releases 0.605 kg CO_2e per kg of LPG produced resulting in **3.19 kg of CO_2e** being released from Indeni's LPG production.

The Indeni Refinery inefficiencies are also a significant source of CO_2e emissions; the 10 percent loss in Indeni refinery results in 0.5858 kg (or 25.18 MJ) of refinery products being consumed during the refining of LPG. The CCaLC2 tool includes a database that includes an emissions coefficient of $8.07*10^{-2}$ kg of CO_2e for every MJ of refinery products burned during refinery operation. The resulting emissions due to Indeni refinery losses are **2.03 kg of CO_2e**.

After the LPG is refined, it is pumped to LPG storage tanks on the refinery properly until bulk LPG carrier trucks arrive to transport the LPG to the Ndola and Lusaka bottling plants. The total pumping load for 6 kg of LPG is 0.01 kWh[4]. The carbon intensity of the Zambian grid is 0.9644 kg of CO_2e per kWh of electricity consumed (Institute for Global Environmental Strategies, 2021). The electricity associated with pumping LPG emits **0.01 kg of CO_2e**.

Table A7: Emissions from refining crude oil in Indeni Refinery

Process	CO_2e emitted per 6kg canister
LPG Production	3.19 kg
Refinery Losses	2.03 kg
Indeni pumping	0.01 kg
Total	5.23 kg

REFINING CRUDE OIL AT SOUTH AFRICAN REFINERY

Twelve percent of Zambia's LPG supply is imported from South Africa. The South African refinery must order 0.73 kg of crude oil from the Middle East to produce 0.73 kg of LPG. The A2C team assumes that the South African refinery's losses are 0.55 percent, and that losses equally affect all of the refinery's outputs. The CCaLC2 tool includes the Ecoinvest database which includes the emissions coefficient for LPG production that accounts for the energy consumption, fugitive emissions, and co-products that result from petroleum product refining. LPG production releases 0.605 kg CO_2e per kg of LPG produced resulting in **0.44 kg of CO_2e** being released from LPG production within South Africa.

The South African refinery inefficiencies are also a source of CO_2e emissions; the 0.55 percent loss in the Saudi refinery results in $4.02*10^{-3}$ kg (or 0.173 MJ) of refinery products being consumed during the refining of LPG. The CCaLC2 tool includes a database that includes an emissions coefficient of $8.07*10^{-2}$ kg of CO_2e for every MJ of refinery products burned during refinery operation. The resulting emissions due to Saudi refinery losses are **0.01 kg of CO_2e**.

[4] Source: Interviews with Indeni staff

Table A8: Emissions from refining crude oil in South Africa

Process	CO_2e emitted
LPG Production	0.44 kg
Refinery Losses	0.01 kg
Total	0.45 kg

LPG RETAILER DECANTING

LPG retailers purchase LPG from the OMC in bottles that carry more than 6 kg of LPG. When customers want to refill their 6 kg bottles, retailers must pump LPG from the larger bottles they keep on premise into the 6 kg bottles. This process consumes 0.02 kWh of electricity that have CO_2e emissions associated with it. The carbon intensity of the Zambian grid is 0.9644 kg of CO_2e per kWh of electricity consumed (Institute for Global Environmental Strategies, 2021). LPG retailer decanting emits 0.02 kg of CO_2e per 6 kg bottle of LPG.

Table A9: Emissions from LPG retailer decanting

Process	CO_2e emitted
LPG Decanting	0.02 kg
Total	0.02 kg

Table A10: Summary of emissions from LPG fuel production

	CO_2e emitted
Refining Crude Oil in Saudi Arabia	1.58 kg
Refining Spiked Crude Oil at Indeni Refinery	5.23 kg
Refining Crude Oil at South African Refinery	0.45 kg
LPG Retailer Decanting	0.02 kg
Total	7.28 kg

FUEL TRANSPORTATION

The Fuel Transportation emission calculation encompasses the movement of intermediate LPG production products between production processes and bottled LPG to the end user. There are six fuel transportation calculations to account for in the Zambian LPG supply chain.

1. Transportation of crude oil from wellhead to the Saudi refinery
2. Transportation of crude oil from wellhead to South African refinery
3. Transportation of spiked crude oil to Indeni refinery
4. Transportation of South African LPG to the Indeni Tank Farm
5. Transportation of bottled LPG to the end users
6. Transportation of empty bottles to bottling plants

The CCaCL2 tool used by the A2C team contains two libraries of different modes of transportation that were heavily drawn on to estimate CO_2e emissions associated with LPG transportation.

CRUDE OIL FROM WELLHEAD TO SAUDI REFINERY

In the Indeni Branch, crude oil is transported from the wellhead to a nearby refinery via onshore pipeline. The A2C team assumed that the distance between the wellhead and refinery is 100 km. Transporting crude oil via pipeline is very efficient; the emissions factor for onshore pipeline transportation is $1.57*10^{-5}$ kg CO_2e/kg per km. Transporting 5.99 kg of crude oil the 100 km to a Saudi refinery emits **$9.43*10^{-3}$ kg of CO_2e**.

Table A11: Emissions from transportation of crude oil from wellhead to Saudi refinery

Transport Segment	CO_2e emitted
Onshore Pipeline	0.01 kg
Total	0.01 kg

CRUDE OIL FROM WELLHEAD TO SOUTH AFRICAN REFINERY

In the South African Branch, crude oil is transported from the wellhead to a nearby shipping terminal via onshore pipeline. The A2C team assumed that the distance between the wellhead and the shipping terminal is 100 km. Transporting crude oil via pipeline is very efficient; the emissions factor for onshore pipeline transportation is $1.57*10^{-5}$ kg CO_2e/kg per km. Transporting 0.74 kg of crude oil the 100 km to a Saudi shipping terminal emits **$1.16*10^{-3}$ kg of CO_2e**.

The crude oil is then loaded onto a transoceanic oil tanker to ship the crude to a South African refinery. The round trip between the largest Saudi ports — Ras Tanura and Yanbu— and South African ports — Durban and Cape Town— is 12,907 km. The emissions factor for transoceanic tanker transportation is $5.64*10^{-6}$ kg CO_2e/kg per km. Transporting 0.74 kg of crude oil the 12,907 km to South Africa emits **0.05 kg of CO_2e**.

Table A12: Emissions from transportation of crude oil from wellhead to South African refinery

Transport segment	CO_2e emitted
Onshore Pipeline	0.00 kg
Transoceanic oil tanker	0.05 kg
Total	0.05 kg

SPIKED CRUDE OIL TO INDENI REFINERY

In the Indeni Branch, spiked crude oil is produced in a Saudi Refinery then loaded onto a transoceanic oil tanker to ship the spiked crude to Dar Es Salaam. The round trip between the largest Saudi ports — Ras Tanura and Yanbu— and Dar Es Salaam is 9,600 km. The emissions factor for transoceanic tanker transportation is $5.64*10^{-6}$ kg CO_2e/kg per km. Transporting 5.93 kg of spiked crude oil the 9,600 km to Dar Es Salaam emits **0.32 kg of CO_2e**.

Between Dar Es Salaam and the Indeni Refinery, the spiked crude oil is pumped through the TAZAMA pipeline. The TAZAMA pipeline is 1,704 km long. Transporting crude oil via pipeline is very efficient; the emissions factor for onshore pipeline transportation is $1.57*10^{-5}$ kg CO_2e/kg per km. Transporting 5.91 kg of crude oil the 1,704 km to the Indeni refinery emits **0.16 kg of CO_2e**.

Table A13: Transport of spiked crude to Indeni refinery

Transport segment	CO_2e emitted
Transoceanic oil tanker	0.32 kg
TAZAMA onshore pipeline	0.16 kg
Total	0.48 kg

LPG TO THE MUNICIPAL WHOLESALER

The domestic and imported South African LPG streams are blended within the Municipal Wholesaler. Physically this is typically a bottling plant within a major city like Kitwe or Lusaka. Nationally, an average of 5.27 kg (88 percent) of a 6 kg LPG bottle is supplied by the Indeni refinery and the remaining 0.73 kg (12 percent) comes from a South African refinery. The Indeni-produced LPG is pumped from the refinery to the tank farm while the South African LPG is imported via 22-ton bulk LPG carrier.

The 0.73 kg of LPG being imported from South Africa is also transported on a 22-ton bulk LPG carrier, but over a much longer distance. The weighted average distance between South Africa's major refineries and ports — Durban, Cape Town, and Sasolburg — is 2,600 km from Zambia's major cities, like Ndola. It is assumed that the South African LPG carrier returns to South Africa empty which increases CO_2e emissions by roughly 60 percent. The emissions associated with the transportation of LPG between South Africa and the Ndola bottling plant is **0.57 kg CO_2e**.

Table A14: Transport of LPG to municipal wholesaler

Transport segment	CO_2e emitted
22-ton truck	0.57 kg
Total	0.57 kg

LPG TO END USERS

The Indeni Tank Farm stores LPG until bulk LPG carriers (22-ton trucks) empty the tanks and transport the LPG 7 km to the Ndola bottling plant or 308 km to the Lusaka bottling plant. The split of LPG supply stream going to the Ndola and Lusaka bottling plants are 42 percent and 58 percent, respectively. The emissions coefficient for a 22-ton truck is $1.85*10^{-4}$ kg CO_2e/kg per km, and the weight of LPG used is 6 kg. We assume that the LPG carriers return to the refinery empty, increasing the emissions of the 22-ton truck journey by roughly 60 percent. The emissions associated with the transportation of LPG between the Indeni Tank Farm and the Ndola bottling plant is **$5.27*10^{-3}$ kg CO_2e**. Transporting LPG between the Indeni Tank Farm and the Lusaka bottling plant is **0.31 kg of CO_2e**.

A2C confirmed that retailers typically use a 5-ton truck to transport bottled LPG between 35 and 40 km from the OMC staging area to their retail location[5]. The A2C team assumed that the method of transportation between bottling plants and the end user are the same in Ndola and Lusaka. This assumption allowed us to simplify the calculations. The emission coefficient of a diesel truck with cargo capacity between 3.5 and 7.5 tons is $4.86*10^{-4}$ kg CO_2e/kg per km. Even though the LPG retailer does not transport 6 kg bottles of LPG between the OMC and the retail store location, most LPG bottles

[5] Source: Interviews with 3rd-party Afrox distributors

weigh the same as the quantity of LPG they hold. If a retailer wants to transport 6 kg of LPG between the OMC staging area and the retail store, they will also haul an additional 6 kg of steel LPG bottle equivalent. Transporting the combined weight of 12 kg the average distance of 37.5 km between the OMC and the retail store emits **0.22 kg of CO_2e**.

A2C's Customer Preference Survey revealed that most urban customers purchase their LPG from markets that are within 5 km of their home (Tetra Tech, 2021). Based on socio-economic status of typical LPG customers identified by A2C's Customer Preference Survey, we assumed that customers collect LPG using petrol-powered car, with an emission coefficient of $1.02*10^{-3}$ kg CO_2e/kg per km. Transporting LPG the 5 km to end users emits **0.06 kg of CO_2e**.

Table A15: Transport of bottled LPG to end users

Transport segment	CO_2e emitted
22-ton truck	0.32 kg
5-ton truck	0.22 kg
Petrol car	0.06 kg
Total	0.60 kg

EMPTY BOTTLES TO RESPECTIVE BOTTLING PLANT

Transporting an empty 6 kg LPG bottle from the end-user back to the retail location within a petrol car emits **0.03 kg of CO_2e**.

When the retailer transports steel LPG bottles back to their respective bottling plant, either Ndola or Lusaka, for refilling, 6 kg of the steel bottles on the 5-ton truck is associated with containing 6 kg of LPG. Transporting 6 kg of steel bottles the average distance of 37.5 km between the retail store and the bottling plant emits **0.11 kg of CO_2e**.

Table A16: Transport of empty bottles to Ndola bottling plant

Empty Bottles to Ndola Bottling Plant	CO_2e emitted
5-ton truck	0.11 kg
Petrol Car	0.03 kg
Total	0.14 kg

Table A17: Summary of emissions from transport of LPG

Fuel Transportation	CO_2e emitted
Crude Oil from Wellhead to Saudi Refinery	0.01 kg
Crude Oil from Wellhead to South African Refinery	0.05 kg
Spiked Crude Oil to Indeni Refinery	0.48 kg
LPG to Municipal Wholesaler	0.57 kg
LPG to End Users	0.60 kg
Empty Bottles to Bottling Plant	0.06 kg
Total	1.77 kg

END-USE

When an end user burns a 6 kg bottle of LPG in a stove, the carbon within the LPG is released into the atmosphere. The IPCC provides emissions coefficients that allows the A2C team to calculate the CO_2e emission for residential stationary combustion of LPG. These emission coefficients are listed in Table A18**Error! Reference source not found.**.

Table A18: Charcoal Combustion Emission Coefficients

Greenhouse Gas	Coefficient *(kg/TJ)*	Global Warming Potential
CO_2	63100	1
CH_4	5	23
N_2O	0.1	290

A 6 kg bottle of LPG contains $2.84*10^{-4}$ TJ. The product of the emission coefficients, global warming potentials, and energy content yields **17.95 kg of CO_2e** emitted when a 6 kg bottle of LPG is burned.

Table A19: Emissions from stationary residential combustion of LPG

End-Use	CO_2e emitted
Stationary Residential Combustion	17.95 kg
Total	17.95 kg

SUMMARY OF CO2E EMISSIONS FROM ONE 6 KG BOTTLE OF LPG

In Table A20 below, we summarize the emissions from LPG and estimate them to be 27.8kg CO_2e per 6kg bottle. In the following section we will compare those emissions with emissions from charcoal.

Table A20: Summary of emissions from LPG use in Zambia per 6 kg canister

Emissions Type	Emissions from 6 kg canister of LPG (*kg CO2e*)
Raw Material	0.80
Fuel Production	7.28
Fuel Transportation	1.77
End-Use	17.95
Total	**27.80**

COMPARING LPG AND CHARCOAL

In order to compare emissions from LPG to those from charcoal, we need to standardize the values to reflect actual expected fuel usage by households. In order to do so, we relied on data from the Food and Agriculture Organization (FAO) and the Ministry of Energy of Zambia (MEZ) that estimates urban households who rely on LPG for their cooking use 365kg of fuel per year while urban households who rely on charcoal with a traditional Mbaula stove use 1460kg of charcoal per year (FAO and MEZ, 2020).

Given the estimate of 91.07kg CO_2e emissions from one 33kg bag of charcoal (Table A3), 1460kg of annual charcoal use would result in annual emissions of 4029.2kg for one household – more than four metric tons. Given the estimate of 27.8kg CO_2e emissions from one 6kg canister of LPG (Table A20), 365kg of annual LPG use would result in annual emissions of 1691.2kg.

Table A21: Summarizing comparison of emissions estimates for charcoal and for LPG

Fuel	Unit of fuel consumption analyzed	Emissions attributed to one unit of fuel consumed (*kg CO_2e*)	Amount of fuel used per household per year (*kg; FAO*)	Emissions per household per year (*kg CO_2e*)
Charcoal	33kg bag	91.07	1460	4029.2
LPG	6kg canister	27.80	365	1691.2

CONCLUSION

Emissions from charcoal-based cooking are estimated to be 4029.2kg CO_2e per household per year while emissions from LPG-based cooking are estimated to be 1691.2kg CO_2e per household per year (Table A21). This suggests that ***replacing charcoal-based cooking with LPG results in an overall reduction in emissions of 2.34 tons CO_2e per household per year*** which is equivalent to a ***reduction of 58%.***

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