MALAWI

Integrated Energy Plan

CLEAN COOKING

IN PARTNERSHIP WITH:

Global Energy Alliance for People and Planet

20 DECEMBER 2022

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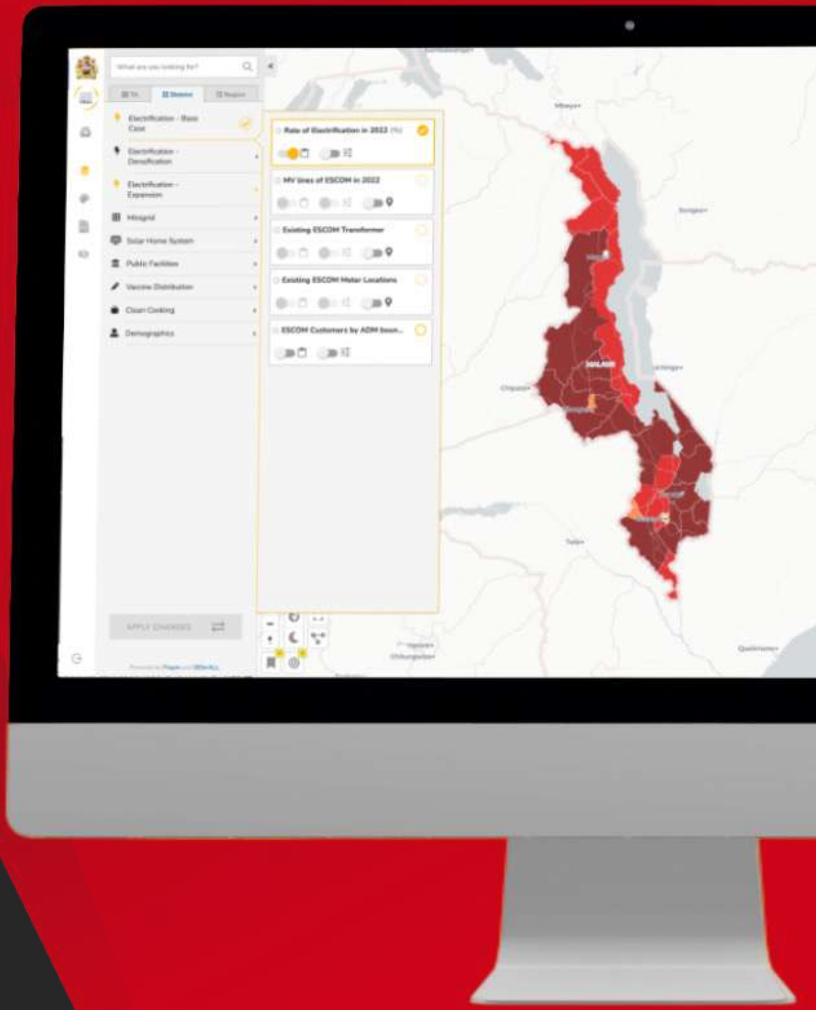

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Acronym list

CSO	Civil Society Organization
E-cooking	Electric Cooking
GIS	Geospatial Information System
HH	households
ICS	Improved Cookstove
kg	kilograms
km	kilometers
kWh	kilowatt-hour
LPG	Liquid Propane Gas
MECS	Modern Energy Cooking Services
NRECA	National Rural Electric Cooperative Association
POS	Point of Sale
SEforALL	Sustainable Energy for All
SHS	Solar Home Systems
TA	Traditional Authority
USD	United States Dollars
VAT	Value Added Tax

Goals and Motivations

- Assist the GoM in determining the tactical implementation approach for the relevant interventions towards universal energy access
- Visualize cooking information and enable users to easily view and interrogate data
- Quantify baseline (present day) cooking situation across all of Malawi, and illustrate differences by location in the country, if urban or rural household, and if have access to electricity
- Provide primary data on clean cooking characteristics from regions with minimal data on topics such as gender implications, training received, cooking location, stove costs, fuel costs, stove procurement behaviors, cooking diary, and stove stacking
- Estimate future cooking situation across all of Malawi based on population change out to 2030, and illustrate differences by location in the country, if urban or rural household, and if have access to electricity to show relationships to electrification plan
- Perform scenario modeling to estimate and visualize the effects of policy changes and other interventions, including illustrations of how to reach 2030 goals set forth in the Malawi Cleaner Cooking Compact
- Estimate environmental costs for baseline model and scenarios
- Estimate health implications for baseline model and scenarios
- Estimate biogas/bio-ethanol opportunity
- Visualize LPG access points and sales volumes
- Estimate impact of electrification on cooking and vice versa, and how e-cooking affects electrical demand
- Quantify investment requirements in improved cookstove technologies and fuels to reach 2030 targets

MALAWI IEP – CLEAN COOKING

Executive Summary

Malawi SDG7 Cleaner Cooking Energy Compact Targets

- The cookstove ownership status for 2022 in urban areas is compiled from secondary data sources[1,2,3], with 2022 cookstove ownership in rural areas representing a combined picture of secondary data and primary data collected during this project. The relative amounts of stove ownership were then compared to estimated national trends[4] from 2022 to cross-check the starting conditions for the modelling.
- The cookstove ownership status for 2030 directly follows targets set forth in the Malawi SDG7 Cleaner Cooking Energy Compact (Compact). Rural customer categories mimic Compact goals directly with 40% of homes owning a portable improved wood stove, and 60% of homes cookstove stacking with an improved portable wood stove and an improved fixed wood stove. The urban scenario is a bit more complex in 2030, and while the Compact outlines targets for 58% of users, the remaining 42% is left unspecified. This study assumes that 42% of the urban population participates in cookstove stacking with an improved charcoal stove and e-cooking. That is a trend common today that may increase based on electricity reliability and tariffs.

Rural			2030
Stove	2022	2030	Households
Firewood (3-stone)	67.0%	0.0%	-
Firewood (basic)	10.0%	0.0%	-
Charcoal (basic)	10.0%	0.0%	-
Firewood (improved - portable)	1.0%	40.0%	1,880,440
Firewood (improved - fixed)	10.0%	0.0%	-
Firewood (improved - portable) & Firewood (improved - fixed)	2.0%	60.0%	2,820,659
Charcoal (improved)	0.0%	0.0%	-
LPG	0.0%	0.0%	-
E-cooking (hot plate)	0.0%	0.0%	-
Charcoal (improved) & E-cooking (hot plate)	0.0%	0.0%	-
E-cooking (induction)	0.0%	0.0%	-
Briquette/pellet	0.0%	0.0%	-
Biogas	0.0%	0.0%	-
Bioethanol	0.0%	0.0%	-

Urban			2030
Stove	2022	2030	Households
Firewood (3-stone)	0.0%	0.0%	-
Firewood (basic)	10.0%	0.0%	-
Charcoal (basic)	50.0%	0.0%	-
Firewood (improved - portable)	5.0%	0.0%	-
Firewood (improved - fixed)	0.0%	0.0%	-
Firewood (improved - portable) & Firewood (improved - fixed)	0.0%	0.0%	-
Charcoal (improved)	20.0%	30.0%	283,691
LPG	2.0%	10.0%	94,564
E-cooking (hot plate)	3.0%	15.0%	141,846
Charcoal (improved) & E-cooking (hot plate)	10.0%	42.0%	397,168
E-cooking (induction)	0.0%	0.0%	-
Briquette/pellet	0.0%	1.0%	9,456
Biogas	0.0%	1.0%	9,456
Bioethanol	0.0%	1.0%	9,456

1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.
2. Coley, W., Galloway, S. (2020) Market assessment for modern energy cooking services in Malawi.
3. Kanaan et al. (2020) Modern Cooking for Healthy Forests in Malawi. Tetra Tech, prepared for USAID and UK Aid.
4. Mussa, K.S. (2022). Cleaner Cooking Energy Compact. GIZ EnDev-Malawi

Malawi SEforALL IEP Scenario Targets

- The additional IEP Scenario was developed using:
  - LPG – for 10% of urban households to match 2030 Compact goals
  - E-cooking – for all grid-connected households, noting that many TAs currently classified as rural will receive grid connections under the IEP universal electrification plan
  - Pellet/Briquette, Biogas, Bioethanol – for total remaining rural customers as a weighted percentage of each fuel availability
- This approach illustrates one potential scenario for completely removing fuelwood and charcoal use in Malawi

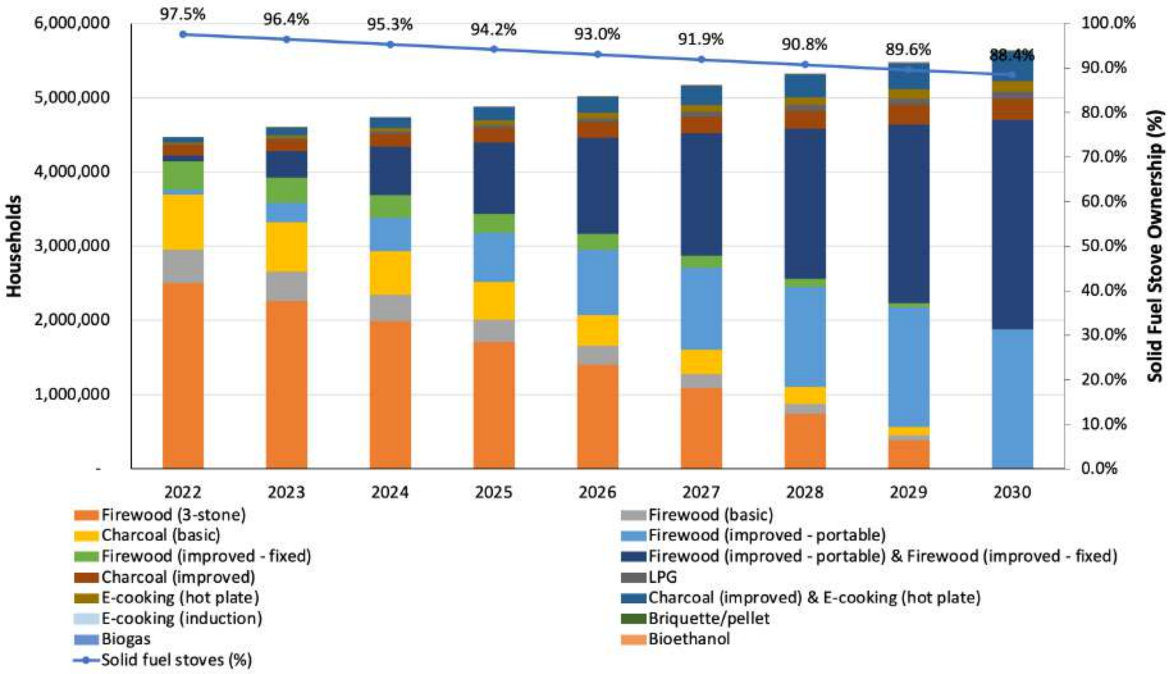
Rural 2030	Percentage		Households	
Stove	Compact	IEP	Compact	IEP
Firewood (3-stone)	0.0%	0.0%	-	-
Firewood (basic)	0.0%	0.0%	-	-
Charcoal (basic)	0.0%	0.0%	-	-
Firewood (improved - portable)	40.0%	0.0%	1,880,440	-
Firewood (improved - fixed)	0.0%	0.0%	-	-
Firewood (improved - portable) & Firewood (improved - fixed)	60.0%	0.0%	2,820,659	-
Charcoal (improved)	0.0%	0.0%	-	-
LPG	0.0%	0.0%	-	-
E-cooking (hot plate)	0.0%	0.0%	-	-
Charcoal (improved) & E-cooking (hot plate)	0.0%	0.0%	-	-
E-cooking (induction)	0.0%	69.7%	-	3,275,564
Briquette/pellet	0.0%	10.7%	-	504,469
Biogas	0.0%	3.0%	-	141,881
Bioethanol	0.0%	16.6%	-	779,185

Urban 2030	Percentage		Households	
Stove	Compact	IEP	Compact	IEP
Firewood (3-stone)	0.0%	0.0%	-	-
Firewood (basic)	0.0%	0.0%	-	-
Charcoal (basic)	0.0%	0.0%	-	-
Firewood (improved - portable)	0.0%	0.0%	-	-
Firewood (improved - fixed)	0.0%	0.0%	-	-
Firewood (improved - portable) & Firewood (improved - fixed)	0.0%	0.0%	-	-
Charcoal (improved)	30.0%	0.0%	283,691	-
LPG	10.0%	10.0%	94,564	94,564
E-cooking (hot plate)	15.0%	0.0%	141,846	-
Charcoal (improved) & E-cooking (hot plate)	42.0%	0.0%	397,168	-
E-cooking (induction)	0.0%	90.0%	-	851,074
Briquette/pellet	1.0%	0.0%	9,456	-
Biogas	1.0%	0.0%	9,456	-
Bioethanol	1.0%	0.0%	9,456	-

Improved Cookstove Expansion Scenario to Meet Compact 2030 Goals

- Meeting the Compact 2030 goals will require considerable strategic planning and centralized policy incentives as well as mobilization of private sector actors to enhance multiple modalities of improved and modern cooking technologies.
- This study models an improved cookstove (ICS) expansion plan to reach 2030 Compact goals with some consumers owning one stove and others stacking with multiple stoves.
- This will include additional fuel sources and expansion of e-cooking, LPG, and biofuels within the country. Currently available fuels and technologies in Malawi were considered (see figure legend), and if markets open to more and newer technologies, this could permit further gains by alternative fuels.
- Nevertheless, Compact goals still expect significant biomass utilization in 2030 with an estimated 88.4% of households continuing to use firewood, charcoal, or briquette/pellet fuel.
- Primary data collected from rural customers showed a high use of cookstoves for space heating, nearly two thirds of surveyed households across the three regions. This presents a challenge to shift completely away from three-stone fires and basic wood stoves in rural areas that would often be overlooked in energy plans focused just on "cooking" rather than "cooking stove uses".

PROJECTED OWNERSHIP OF CLEANER COOKING SOLUTIONS

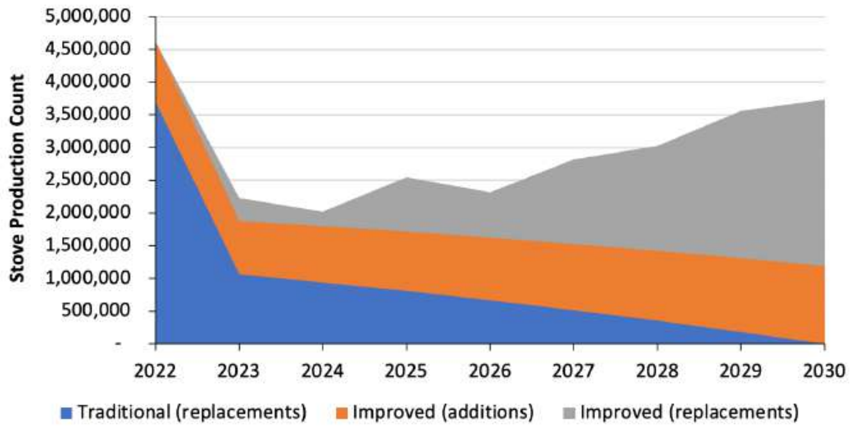


Stove Production and Financial Requirements to Meet Compact 2030 Goals

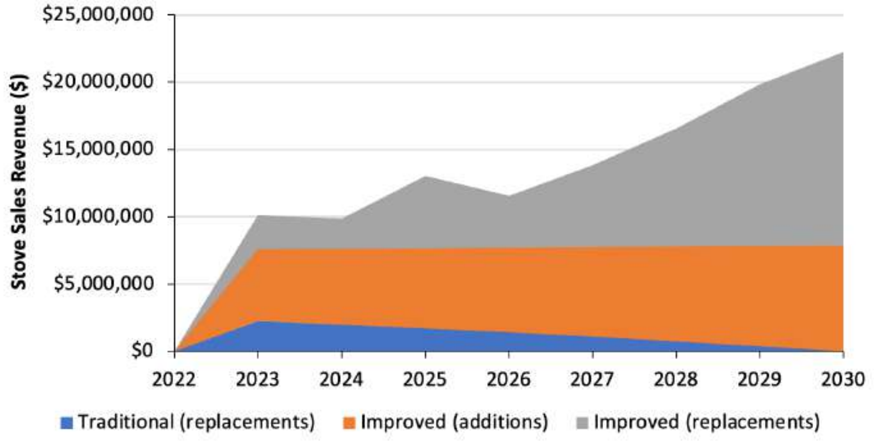
- Traditional, non-improved, biomass stoves do not phase out overnight. Consumers must replace those technologies at their own expense until production volumes, market forces, and policy drivers can enable access to improved stoves.
- Year-on-year growth targets for ICS volumes need to approach 21%, on average, over the 2030 time horizon to meet quotas for new and existing customers. This will require significant investment in local stove production and imported stoves, and enhanced supply chains to reach rural areas, to hit volume requirements and also reduce cost to address affordability challenges stated as the main barrier to ICS adoption for over half of the respondents surveyed in this project.
- There is also a significant financial challenge to reaching 100% clean cooking access due to the low durability of improved cookstoves available in Malawi[1] today. The provided scenario shows $108.8M investment is needed to reach 2030 Compact targets, comprising $52.7M for new cooking technologies and $56.1M in replacement costs for improved cookstove customers that need their device replaced due to degradation and failure at the expected end of life. This suggests emphasis is needed on more durable and longer lasting ICS, with both national and global investment and standards, to enhance manufacturing techniques and quality control that reduces costs of reaching 2030 goals and closes the affordability gaps for customers by reducing annualized costs of ICS access.
- Data collected in 2022 suggests that the distribution of improved stoves and clean fuel access in the northern region is far less than central and southern regions. This suggests the Northern region needs additional resources, strategic planning, programs, financial incentives, and systematic actions to enhance access to cleaner cooking stoves to approach 2030 goals of 100% access across the country.

1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

STOVE PRODUCTION ESTIMATES



STOVE FINANCIAL ESTIMATES

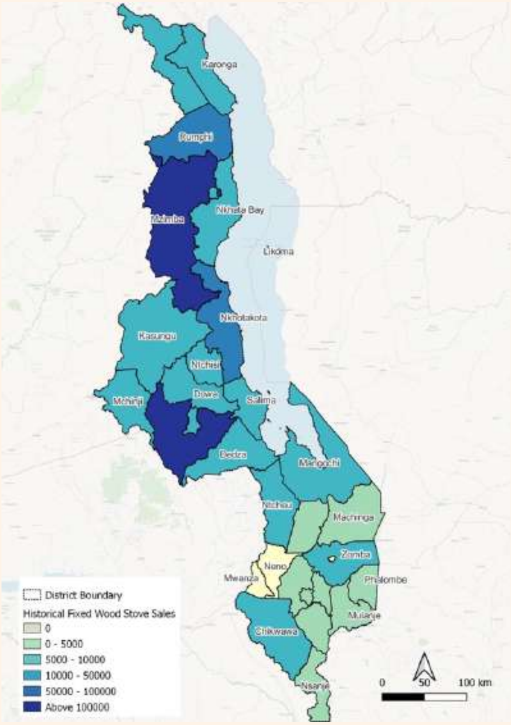


Geospatial Representation of Wood Stoves to Meet Compact 2030 Goals

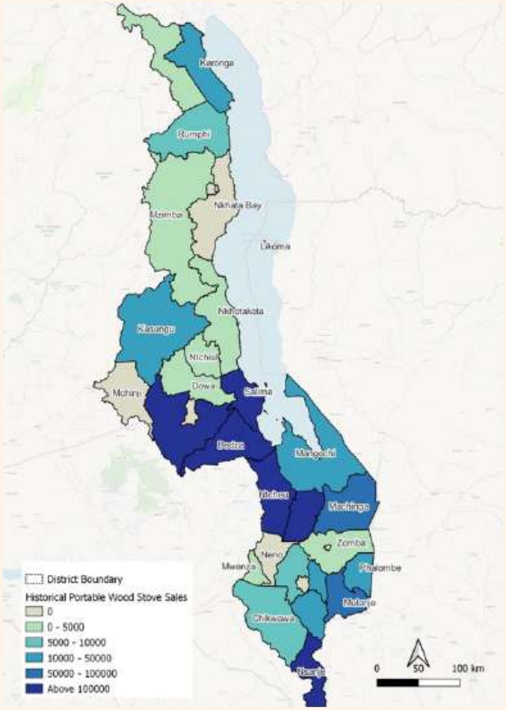
These maps shows the stove ownership of improved wood stoves per district in 2022 as well as the projection for 2030, based on the estimated 83.3% improved wood stove users in the Compact target.

Distribution of improved wood stove ownership (2022)

FIXED IMPROVED WOOD STOVE

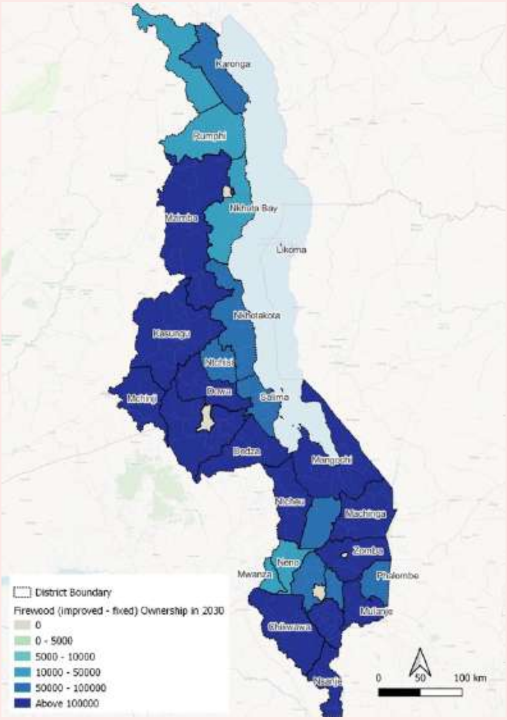


PORTABLE IMPROVED WOOD STOVE

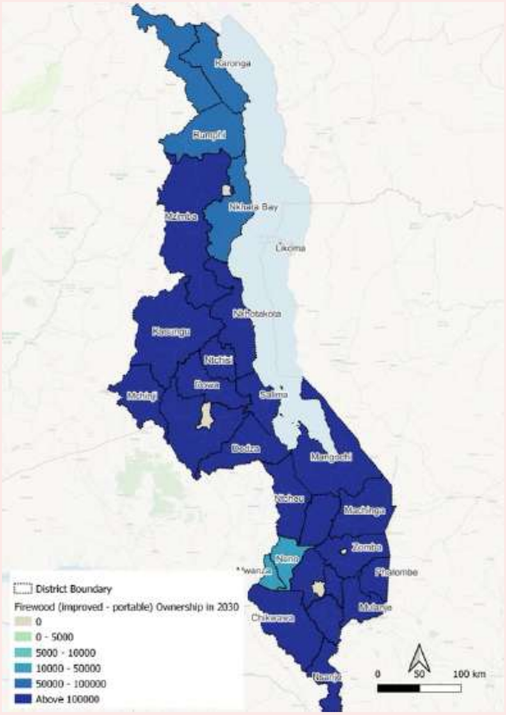


Distribution of improved wood stove ownership (2030)

FIXED IMPROVED WOOD STOVE



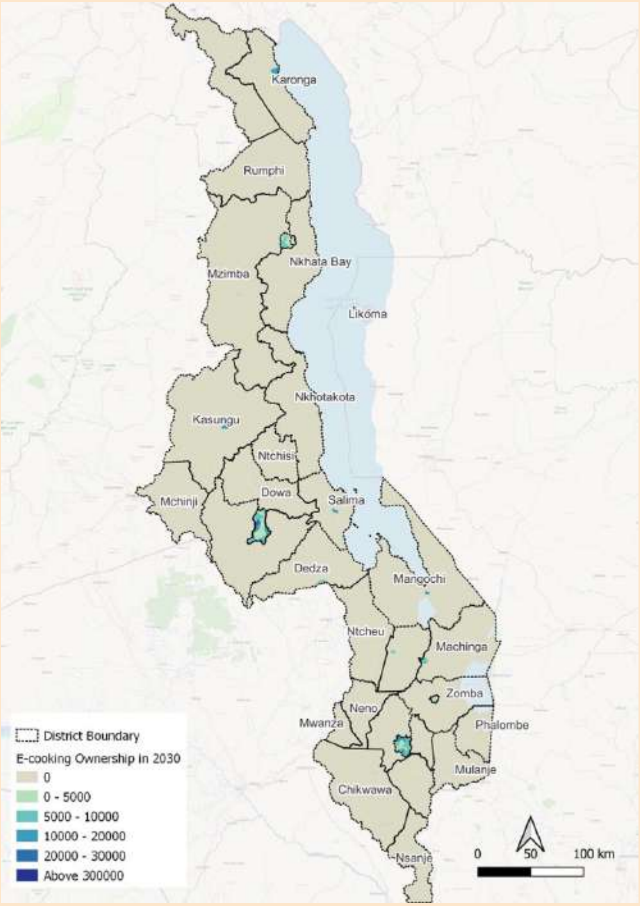
PORTABLE IMPROVED WOOD STOVE



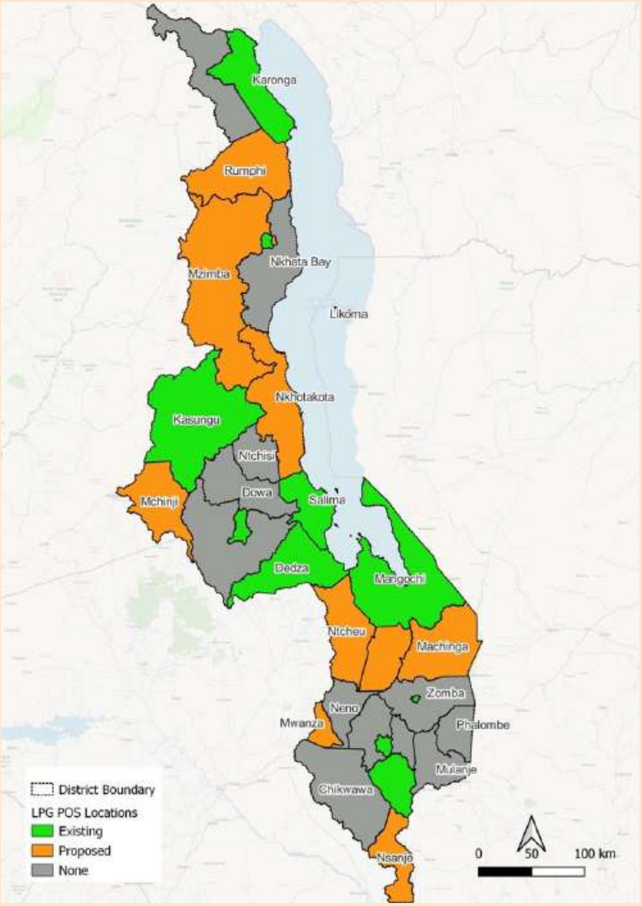
Geospatial Representation of Alternative Fuels to Meet Compact 2030 Goals (1 of 2)

- Households with e-cooking will need to increase from an estimated 95,000 today to 539,000 in 2030 to meet Compact 2030 goals. This represents 15% of urban households using only e-cooking, and 42% of urban households that use a mix of improved charcoal and e-cooking solutions.
- LPG programs can focus on densifying and expanding LPG access in urban regions with higher population density and adding capacity and marketing programs to existing points of sale. That will limit LPG distribution points to a more manageable number of districts, 10-15, rather than straining the fuel supply chain with rapid expansion from 10 districts with LPG today to all 30 districts that have a TA with urban designation.
- Total electricity use for e-cooking is subsequently estimated to increase from 218 GWh / year in 2022 to 1,324 GWh / year in 2030. As e-cooking increases, especially in urban areas without sufficient access to LPG, so will customer electrical consumption. ESCOM's revenue growth due to gains in e-cooking usage may offer synergistic value to fund the expansion of electricity access.

E-Cooking Stove Ownership



LPG Point of Sale Locations

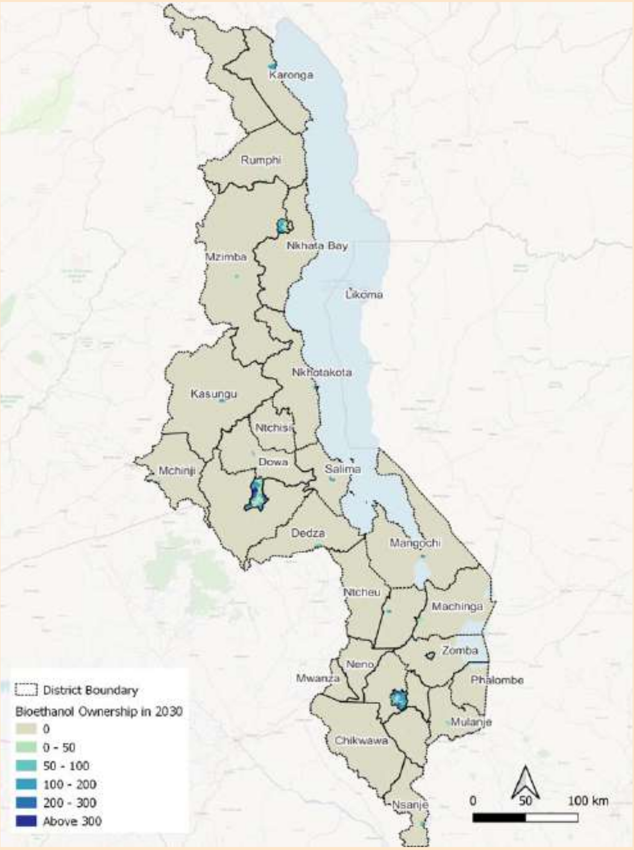


Geospatial Representation of Alternative Fuels to Meet Compact 2030 Goals (2 of 2)

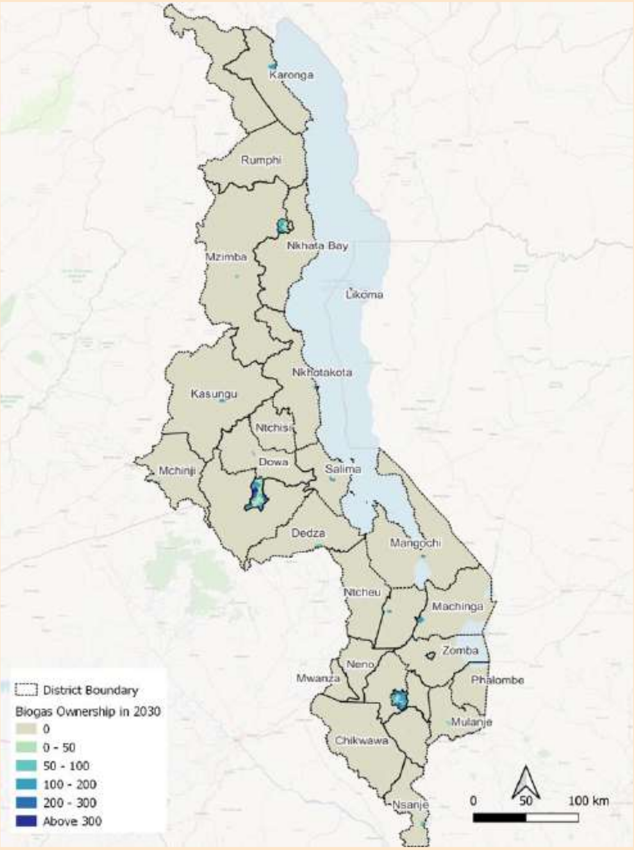
The 2030 Compact sets a 3% adoption target of urban households to use other alternative fuels such as bioethanol, biogas, and biomass pellet/briquette cooking technologies. Assuming each cooking technology is adopted evenly, a total of 9,456 households will adopt each cooking technology to reach Compact targets.

No supply chain considerations are present in the Compact to bring biofuels from rural to urban customers. Rural utilization of such fuels is not targeted.

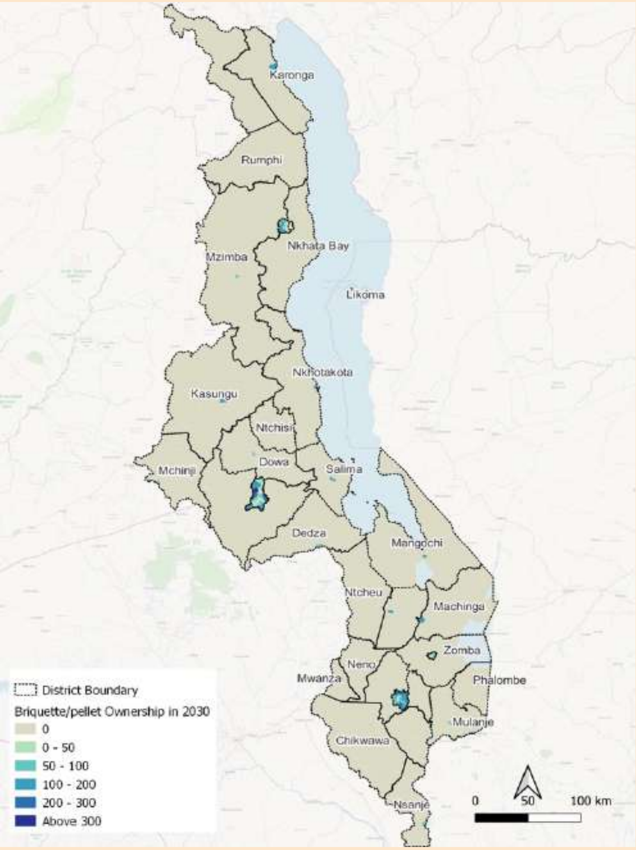
Bioethanol Stove Ownership (2030)



Biogas Stove Ownership (2030)



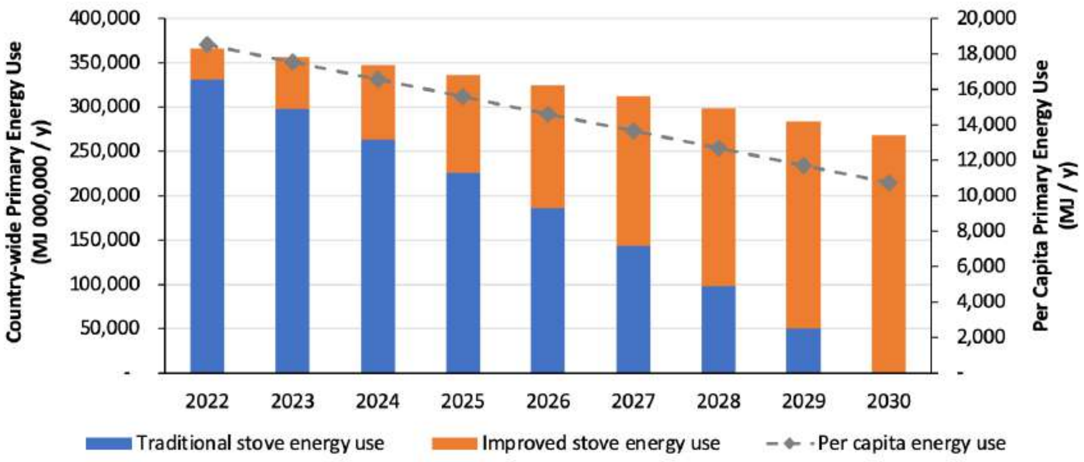
Pellet/briquette Stove Ownership (2030)



Energy Use and Gender Implications to Meeting Compact 2030 Goals

- Reaching 2030 Compact targets will reduce primary energy use for cooking by 26.8%, and per capita energy use by 42.0% (accounting for population growth[1]). This is directly attributed to fuel switching from solid fuel to alternative fuels and stoves with higher efficiency, and from efficiency improvements in improved wood stoves over traditional stoves.
- Over the same period, firewood use is reduced by 38.8% per capita and charcoal use by 68.5% per capita. This significant change occurs due to more efficient wood and charcoal stoves and switching to alternative fuels such as electricity and LPG.
- Rural women who use firewood stoves can expect to reduce 20-50% time spent collecting wood after switching to more efficient firewood stoves. This could represent a time savings of 50-125 hours per year for each household based on primary data collection in this study.
- Primary data collection and interviews with stakeholders indicated additional opportunities for job creation outside of professions to fabricate and use improved stoves, and such occupations can be targeted for women career growth. This could include more of the stove value chain activities[2] such as customer acquisition and marketing, distribution, financing plans, guidance on productive uses of stoves, maintenance of stoves, and other necessary professions to the stove industry.

PRIMARY ENERGY USE PROJECTIONS FOR COOKING TECHNOLOGIES



1. National Statistical Office of Malawi.
2. Shankar, A., & Onyura, M. A. (2019). Understanding Impacts of Women's Engagement in the Improved Cookstove Value Chain in Kenya. Global Alliance of Clean Cookstoves (GACC), Washington.

Additional Cooking Technology Opportunities (1 of 2)

- Additional opportunities were evaluated to identify the maximum potential of each modern and alternative cooking technology.
- The Malawi IEP results show that the maximum potential households that could be served with modern cooking technologies (20,291,176) exceeds the number of households estimated in the country (5,646,737) in 2030. Illustrating that there is unmet potential for each cooking technology and also opportunities for stove stacking. This suggests a deep opportunity for strategic growth of alternative fuels, as illustrated by the numbers below, showing differences between Compact targets and IEP targets[1].
- The geospatial results on the next slide go further to highlight locations in the country where single technologies or multiple technologies have potential. This information is intended to inform guided dialogue with stakeholders for potential updates or extensions to Compact targets, and suggests follow-on study with production cost modeling of stove/fuel supply chains.

Cooking Technology	Compact Target (HH count)	IEP Potential (HH count)
E-cooking	539,014	4,126,638
LPG	94,564	94,564
Bioethanol	9,456	8,783,711
Pellet/Briquette	9,456	5,686,843
Biogas	9,456	1,599,420

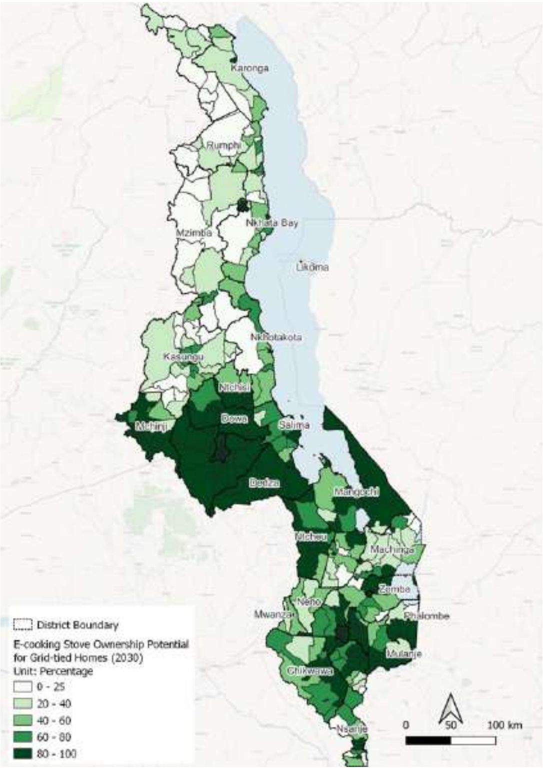
The compact e-cooking target includes households with only e-cooking and those that participate in stove stacking (e-cooking + improved charcoal).

1. Compact targets are outlined in the Malawi SDG7 Cleaner Cooking Energy Compact. IEP targets are outlined in the SEforAll Integrated Energy Plan.

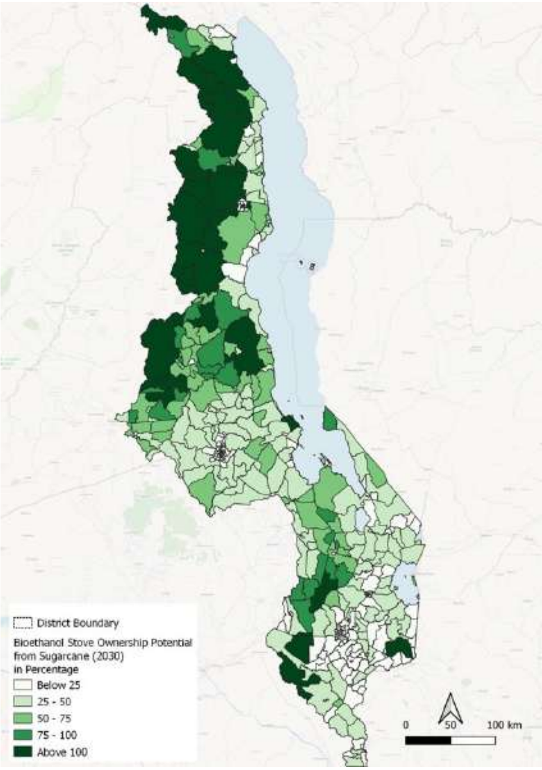
Additional Cooking Technology Opportunities (2 of 2)

E-cooking potential reaches 73.1% of all households in Malawi under the IEP universal electrification plan. Maintaining Compact targets for LPG results in a modest 1.7% of total households using LPG. The national maximum potential for bioethanol, pellet/briquette, and biogas fuels equate to a total of 155.6%, 100.7%, and 28.3% of total household energy demand in 2030, respectively. This represents an underutilized opportunity that may be explored.

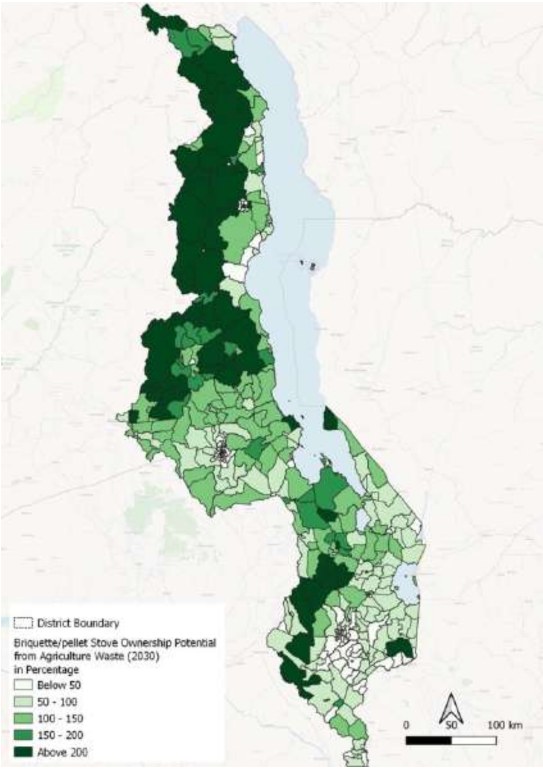
E-COOKING POTENTIAL (2030)



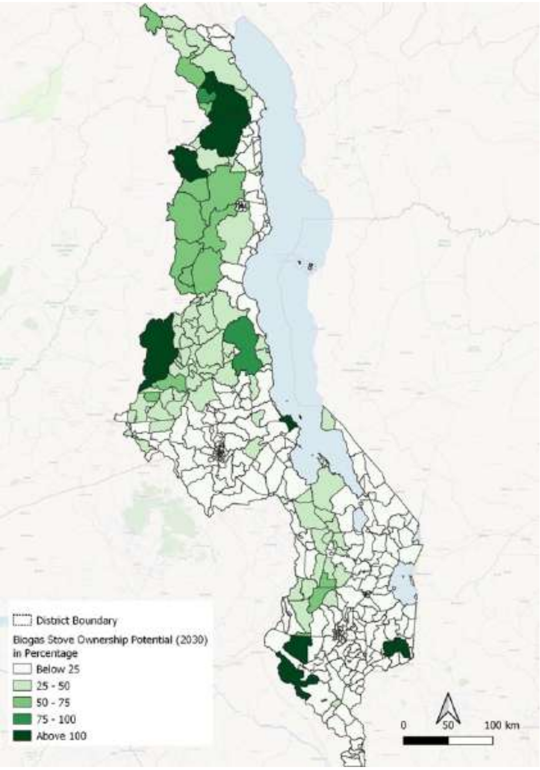
BIOETHANOL POTENTIAL (2030)



PELLET/BRIQUETTE POTENTIAL (2030)

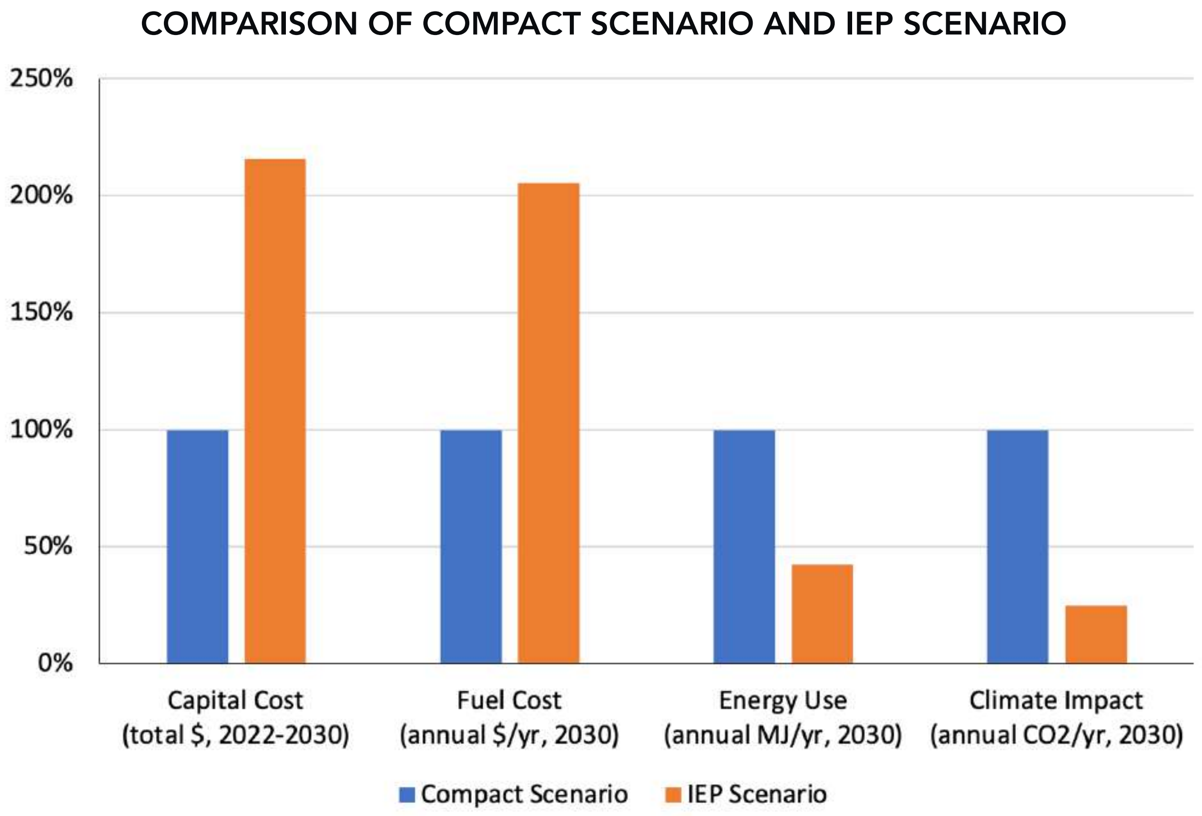


BIOGAS POTENTIAL (2030)



Comparison of Baseline Compact Scenario and IEP Scenario

- The graph on right shows a comparison of potential outcomes for the Compact Scenario and IEP Scenario, with results displayed relative to the Compact Scenario.
- Capital costs are given as the total programmatic cost for new stoves and replacement stoves over the duration of 2022-2030. Although the replacement needs are reduced under the IEP scenario with more durable stoves, the unit cost of modern stoves is higher, as reflected in the increased relative program cost.
- Fuel costs are higher in the IEP Scenario, primarily due to the increased utilization of e-cooking (assuming current tariff levels).
- Energy use (MJ/yr) and climate impact (CO2/yr) is significantly improved under the IEP scenario, with a 58% and 75% improvement, respectively.
- Gender considerations are similarly improved by transitioning from improved biomass stoves to more modern cooking technologies that require no utilization of time to collect wood or produce charcoal.



Health Impacts

- Health impacts are estimated as a function of the fine particulate matter (PM2.5) that can reach deep into the respiratory system. Reducing PM2.5 exposure can avert deaths and reduce disability-adjusted life years (DALYs).
- Each stove/fuel combination produces its own amount of PM2.5, and this value can be used to estimate a variety of health impacts[2]. PM2.5 production from stoves is assumed to yield 240 mg exposure / kg emitted for outdoor cooking and 1300 mg exposure / kg emitted for indoor cooking[2]. Exposure is given for individuals in the cooking vicinity.
- Non-solid fuels show greatly reduced PM2.5 emissions. Improved ventilation and forced draft stoves can reduce health impacts by reducing PM2.5 exposure.
- The IEP Scenario will significantly reduce PM2.5 exposure by advancing electric and LPG stoves for urban areas, and advancing briquette/pellet, biogas, and bioethanol for rural areas.

Fuel (stove)	Health Exposure (PM2.5/day/person) Outdoor	Indoor
Firewood (3-stone)	26.7	139.1
Firewood (basic)	14.9	77.6
Firewood (improved)	13.8	71.9
Firewood (improved - portable)	13.8	71.9
Firewood (improved - fixed)	12.4	64.7
Charcoal (basic)	29.8	154.7
Charcoal (improved)	17.5	91.0
Briquette/pellet	28.5	148.1
Biogas	0.1	0.5
Bioethanol	0.1	0.4
LPG	0.1	0.3
E-cooking (hot plate)	0.0	0.0
E-cooking (induction)	0.0	0.0

2030 Compact Goals will avert 16,600 deaths and 933,800 DALYs per year, relative to continued use of solid fuels and cooking technologies.

2030 IEP Goals will avert 30,609 deaths and 1,689,361 DALYs per year, relative to continued use of solid fuels and cooking technologies.

1. Pillarisetti, A; Mehta, S; Smith, KR. HAPIT, the Household Air Pollution Intervention Tool, to evaluate the health benefits and cost-effectiveness of clean cooking interventions. Ch 10 in Thomas, E., Ed, Broken Pumps and Promises: Incentivizing Impact in Environmental Health, Springer International Press, 2016, pp. 147-169.
2. Climate Economic Analysis for Development, Investment and Resilience. Burnett, Richard; Arden Pope; Majid Ezzati; Casey Olives; Stephen Lim; Sumi Mehta; Hwashin Shin; Gitanjali Singh; Bryan Hubbell; Michael Brauer; Ross Anderson; Kirk Smith; John Balmes; Nigel Bruce; Haidong Kan; Francine Laden; Annette Prüss-Ustün; Michelle Turner; Susan Gapstur; Ryan Diver; and Aaron Cohen. 2014. "An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure." Environmental Health Perspectives. 122(4): 397–403.

Recommendations and Next Steps (1 of 2)

- Commercially available improved cookstoves in Malawi are cited to have low durability. Greater emphasis on materials and durability of portable wood stoves can increase lifetime, which would yield long-term and recurring benefits for national clean cooking initiatives. Longer cookstove lifetime up to 5 years for portable and alternative fuels stoves, as opposed to 2 years, could reduce the 8-year program budget by 20-40% for stove costs.
- Household responses indicating lack of capital and lack of access to finance, suggest that purchasing plans would be a useful procurement model to enable customer behaviors towards improved stove adoption. This is further supported when noting that three-quarters of rural households observed on a payment plan are paying a friend/relative for the stove rather than obtaining vendor finance or third-party credit.
- Malawi IEP results show that the maximum potential for households that could be served with modern cooking technologies (20,291,176) exceeds the number of households in the country (5,646,737) in 2030. This suggests a significant opportunity for strategic growth of alternative fuels and technologies, as illustrated by the numbers on the right showing differences between the Compact Targets and IEP Potential.

Cooking Technology	Compact Target (HH count)	IEP Potential (HH count)
E-cooking	539,014	4,126,638
LPG	94,564	94,564
Bioethanol	9,456	8,783,711
Pellet/Briquette	9,456	5,686,843
Biogas	9,456	1,599,420

Recommendations and Next Steps (2 of 2)

- The E-cooking potential is based on the potential for grid-connected (urban and rural) households, informed by the electricity access assessment. There is also potential for LPG for urban households and significant underutilized potential of bioethanol, pellet/briquette, and biogas for both rural and urban households. These findings suggest immediate potential and action for programmatic interventions to realize this opportunity.
- Cropland covers a significant portion of rural Malawi. This presents an opportunity for district-scale pelletized biomass using agricultural waste or bioethanol production facilities that use sugarcane as feedstock. Pilot projects and early commercial trials can leverage cattle feed production facilities that use the same or similar equipment as pelletized fuel production. Existing bioethanol production facilities could be expanded to supply cooking fuel.
- Cookstoves are used for more than just cooking, such as heating water for bathing, agro-processing, medicines, tea, and even space heating. These non-meal uses can account for over 50% of solid fuel use during certain periods of the year. While a cookstove program may not focus on these additional energy requirements of a household, an integrated energy plan must consider all aspects of energy needs to resolve energy poverty.
- Rural women who use firewood stoves can expect to reduce 20-50% time spent collecting wood after switching to more efficient firewood stoves. This could represent a time savings of 50-125 hours per year for each household1. Gender programs should expand the focus beyond cooking to include other aspects of the cookstove and fuel value chain – stove production, marketing, sustainable charcoal production, financial management or micro-financer for stove purchase, liaison or program manager between electricity and cooking industries, entrepreneur utilizing improved stoves (e.g., street vendor), trainer to introduce modern cookstoves to institutional settings, and other necessary professions to the stove industry.

MALAWI IEP – CLEAN COOKING

Primary Data Summary

Energy Expenditure Survey Overview

The energy expenditure survey collected data from off-grid households to verify energy spending patterns and understand cooking practices. Only residential data was collected to match the scope of the study covering only residential cooking.

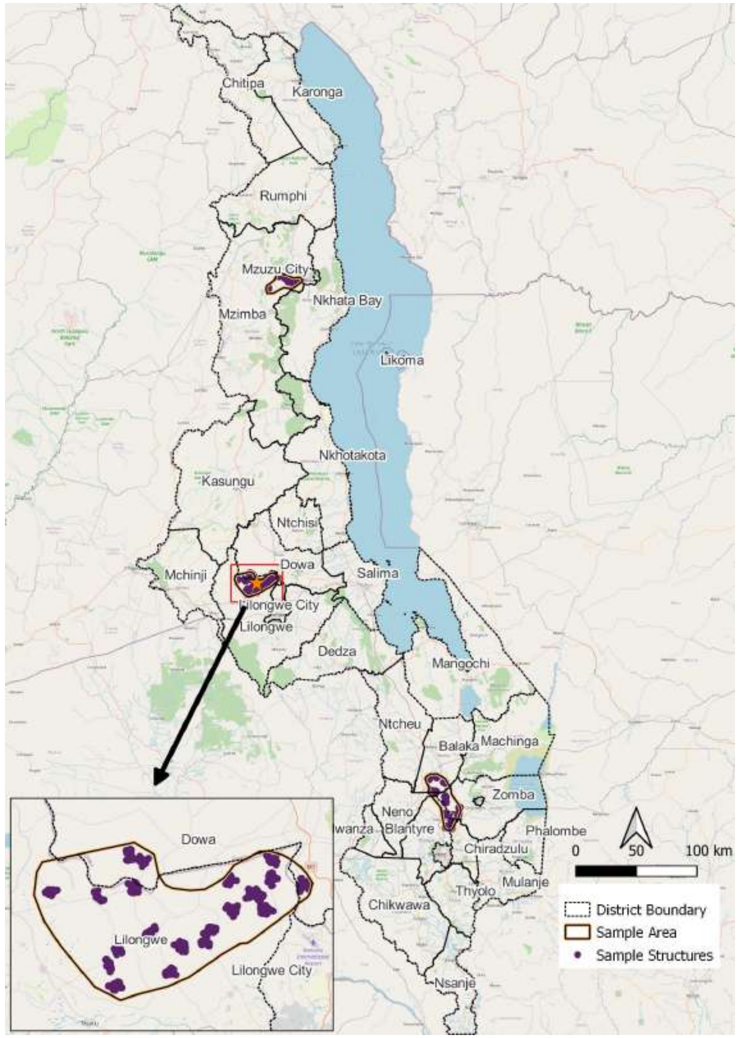
Survey locations were selected to offer a representative sample of the energy needs and economics in rural areas that are not presently served by ESCOM. These survey areas were intended to be far from the grid and represent the energy expenditures of future rural electrification customers, offering insights that are transferrable to clean cooking analysis.

Clean cooking questions were included & focused on cookstove ownership, cooking behaviors, cookstove and fuel costs, fuel collection/purchase frequency, gender issues, cookstove training, meals and non-meal activities, cooking times, and barriers to preferred cookstove use.

The survey instrument was drafted by NRECA/Atlas Energy Solutions and reviewed by SEforALL.

One survey was completed in each of the three regions, for a total of three surveys. A total of 1,265 HHs were surveyed. The results from the survey are presented on the following pages.

Survey participants were randomly selected from housing structures. The sample size was evaluated using a 95% confidence interval and a 5% error rate.



Detail: Central survey zone population centers for enumeration.

Cookstove Ownership and Preferences (1 of 2)

- Limited stove stacking with 96.5% of surveyed rural households owning only one stove.
- Only 6.2% of surveyed homes own an improved wood stove (compared to the Malawi Energy Compact goal of 100% by 2030).
- A total of 7.8% of all respondents own a basic charcoal stove (and only 1 of 1265 respondents owned an improved charcoal stove).
- No discernable difference in stove ownership types or stove stacking by region, potentially some less stacking in the southern region, but respondent counts are too low to show trend.
- No observations or negligible observations of briquette/pellet, coal, peat, crop residues, animal waste, any type of electric, any type of LPG, kerosene, ethanol, biogas, or solar (and only 2.5% want such devices).
- Rural charcoal users may continue to use charcoal (basic) stoves unless incentivized to change.

IMPLICATIONS:

- Focus on transitioning firewood (basic) to efficient firewood (improved) stoves.
- Enable stove stacking for charcoal users to add an efficient firewood (improved) stove.

CURRENT OWNERSHIP STATE OF HH SURVEYED

Stove ownership	Count	% of Total
Firewood (3-stone)	970	76.7%
Firewood (basic)	114	9.0%
Firewood (improved)	72	5.7%
Charcoal (basic)	62	4.9%
Charcoal (improved)	1	0.1%
Briquette/pellet	2	0.2%
Firewood (3-stone) & Electric (pressure cooker)	1	0.1%
Firewood (3-stone) & Charcoal (basic)	27	2.1%
Firewood (improved) & Charcoal (basic)	7	0.6%
Firewood (3-stone) & Firewood (basic)	4	0.3%
Firewood (3-stone) & Crop residues	1	0.1%
Firewood (3-stone) & Briquette/pellet	1	0.1%
Firewood (basic) & Charcoal (basic) & Electric (oven)	1	0.1%
Firewood (basic) & Charcoal (basic)	1	0.1%
Firewood (3-stone) & Charcoal (basic) & Briquette/pell	1	0.1%
Total	**1265**	**100%**

DESIRED OWNERSHIP STATE OF HH SURVEYED

Stove ownership	Count	% of Total
Firewood (3-stone)	9	0.7%
Firewood (improved)	455	36.0%
Charcoal (basic)	110	8.7%
Charcoal (improved)	661	52.3%
Coal/Lignite	7	0.6%
LPG (cylinder)	10	0.8%
LPG (portable)	1	0.1%
Piped Natural Gas	1	0.1%
Electric (hot plate)	9	0.7%
Electric (induction plate)	1	0.1%
Electric (geyser - insta boil)	1	0.1%
Total	**1265**	**100.0%**

Cookstove Ownership and Preferences (1 of 2)

- Over half of respondents (51.6%) indicated they cannot afford payments for stoves. The second most significant barrier to improved cooking technology ownership is lack of access to market (24.3%).
- Few people (3.4%) indicated lack of knowledge as a barrier to purchasing a stove. The survey instrument did not go further to ask the underlying cause to barriers, so it is unclear if this is lack of knowledge pertains to how to acquire the stove or how to use the stove.
- The response "fuel for this stove is unreliable" was attributed to no access or intermittent access to electricity and LPG.
- Nearly all households who reported "multiple reasons" cited affordability and access to market as the main barriers to purchasing a stove.

Barrier to stove ownership	Count	% of Total
Cannot afford the payment	653	51.6%
Lack of access to market	308	24.3%
Lack of knowledge	43	3.4%
Fuel for this stove is unreliable	12	0.9%
Do not need an improved cookstove	2	0.2%
Multiple reasons	247	19.5%
Total	**1265**	**100.0%**

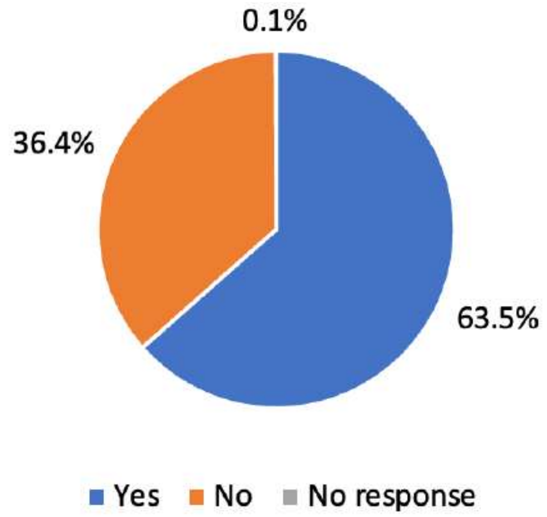
IMPLICATIONS:

- Data suggests that subsidies, reduced costs, or financing plans may be needed to enable clean cooking access for 88.3% of households that want improved stoves.
- Some stoves are not available locally to rural customers. Market access and supply chain limitations are a secondary reason for not procuring improved stoves that needs attention from suppliers and logistics companies.

Cookstove Uses

- Meal preferences in the three regions were similar.
- Stoves were used for space heating by 63.5% of households, this is not an uncommon trend but is often overlooked when studies just focus on cooking.

HHs USING STOVES FOR SPACE HEATING



Meal options
Breakfast - tea/coffee
Breakfast - porridge
Breakfast - potatoes
Breakfast - eggs
Breakfast - pumpkins
Lunch - tea/coffee
Lunch - nsima/rice
Lunch - beans
Lunch - vegetables
Lunch - fish
Lunch - eggs
Lunch - meat/poultry
Dinner- tea/coffee
Dinner - nsima/rice
Dinner - beans
Dinner - vegetables
Dinner - fish
Dinner - eggs
Dinner - meat/poultry

IMPLICATIONS:

- No major regional differences in cooking practices found in surveys, and hence cooking practices assumed similar in rural areas demonstrated in modeling.
- Maintaining ownership and use of solid fuel stoves in rural areas will be important for space heating.
- Non-meal uses of stoves, such as space heating and water for bathing, should be included in analyses when data is available, despite being under-analyzed in prior studies of cookstove use in Malawi and other locations.

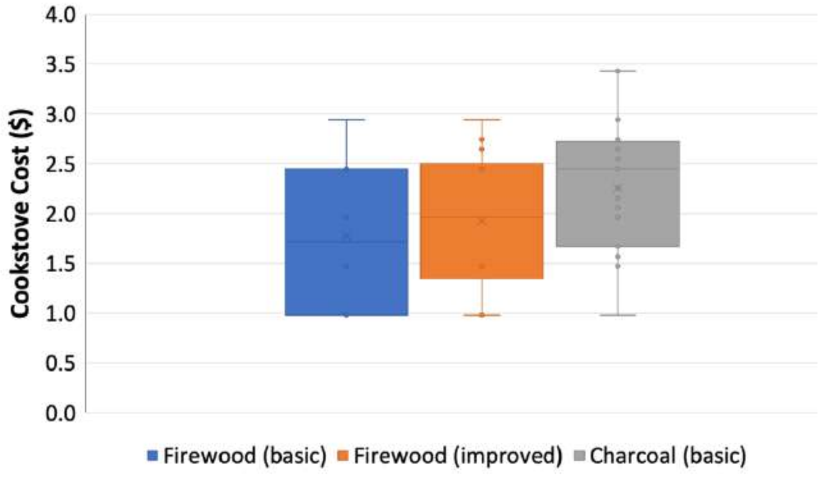
Cookstove Procurement and Costs

- Only 7.27% of households purchased stoves, and of those, 83% purchased outright and 17% had a payment plan.
- Approximately three-quarters of cookstoves on a payment plan were paid to a friend/relative, with the remaining payment plans paid to an appliance vendor/distributor.
- Stove purchase prices show no significant differences by region, likely cost differences due to stove type and supply chain markup.
- Costs of basic and improved firewood stoves show no significant difference, though this finding should be used cautiously given the low number of instances that users purchased wood stoves. Further, survey respondents may not have a consistent perception of what is a "basic" stove and "improved" stove.
- Charcoal stoves are an average of 18.7% more expensive than firewood stoves.
- There was only one observation of a household that owned a charcoal (improved) stove. That data point is omitted here due to lack of sufficient data to make statistically relevant observations.

IMPLICATIONS:

- Household responses indicate a lack of capital. Low incidence of purchasing plan options further suggest that a purchasing plan or financing plan may be a useful business model to promote increased adoption of improved stoves.

COOKSTOVE COST COMPARISON



Stove	Count	Avg Cost ($)
Firewood (basic)	8	1.8
Firewood (improved)	14	1.9
Charcoal (basic)	52	2.3

Fuel Procurement and Costs (1 of 3)

- 69.6% of households collected firewood for free, 0.1% (one response) made charcoal for self-use, and the remaining 30.3% paid for fuel. Fuel purchases almost exclusively occurred at a market (92.2% of those purchasing fuel).
- There are notable regional differences in the percentage of households that purchase fuel, with the surveyed households in the Central region 3-4x more common to purchase fuel; This is likely due to the relative price difference of firewood in the regions surveyed (as shown in the next slide).
- Charcoal users nearly always purchase fuel, whereas only one-quarter of firewood users purchase fuel.

Procurement	Location	Count	% of Total
Collected Freely	Bush	550	43.6%
	Farm	265	21.0%
	Farm and bush	9	0.7%
	Forest	9	0.7%
	Mountain	45	3.6%
	Self produce	1	0.1%
Purchased	Market	353	28.0%
	Mobile supplier	21	1.7%
	Neighbour	9	0.7%
	Total	**1262**	**100.0%**

Region	Purchased	Total surveys	% purchasing
Northern	82	414	19.8%
Southern	58	448	12.9%
Central	243	403	60.3%
Total	**383**	**1265**	

Fuel type	Purchased	Total surveys	% purchasing
Firewood	295	1156	25.5%
Charcoal	61	63	96.8%
Total	**356**	**1219**	

IMPLICATIONS:

- Fuel procurement methods and purchasing behaviors can be modeled using customer behaviors with differences by region, and the results in turn will affect overall cashflow estimates for the region and country.
- Charcoal is almost always purchased, whereas three-quarters of firewood users collect their own in rural areas.

Fuel Procurement and Costs (2 of 3)

Firewood prices on average include (sold in small bundles):

- Central (small): 0.02 $USD per kg
- Northern (small): 0.07 $USD per kg
- Southern (small): 0.05 $USD per kg

Charcoal prices on average include (sold in small bags):

- Central: 0.88 $USD per kg
- Northern: 0.68 $USD per kg
- Southern: 0.65 $USD per kg

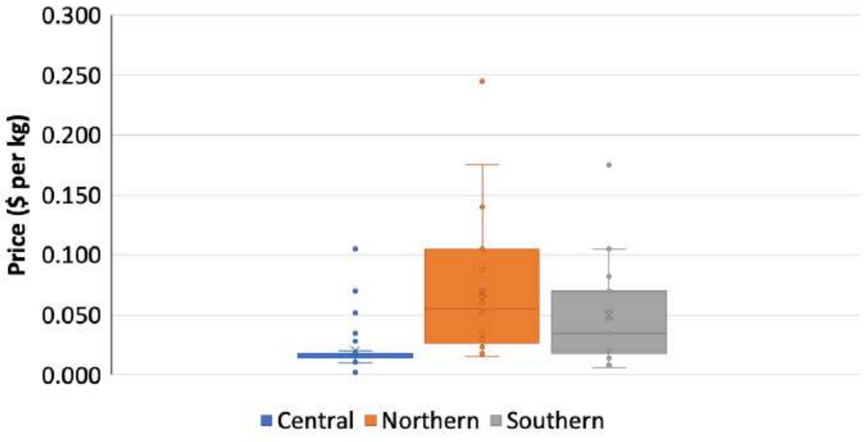
Rural firewood prices appear to be only 5-20% of the urban price in Lilongwe markets whereas charcoal is 1.5-2.0 times more expensive in rural areas than urban areas[1].

IMPLICATIONS:

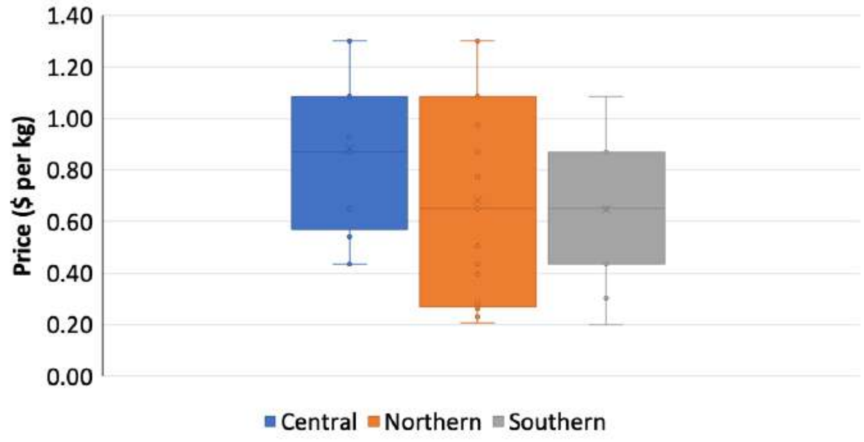
- Lower wood prices in the central region promote a higher incidence of purchasing wood rather than collecting wood. This price disparity may provide an entry point for piloting regulation and monitoring of sustainable firewood strategies in the central region.
- Charcoal prices in the central region may be higher due to lower utilization relative to other regions when noting the relative usage of each stove in each region and the lower cost of firewood in the central region.

1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

FIREWOOD PRICES



CHARCOAL PRICES



Fuel Procurement and Costs (3 of 3)

Firewood small bundle size
(average 2.8 kg)

Charcoal small bag size
(average 0.226 kg)

1. Photo Credit: Charles, Kwakye, NRECA survey team leader during primary data collection in Malawi.
   Larger firewood bundles and charcoal bags are available but not pictured.

Cooking Fuel Use (firewood)

- Average firewood use for the surveyed populations was calculated on a per capita basis from measured observations, and then translated to a per HH basis using an average family size of 4.42 people per home:

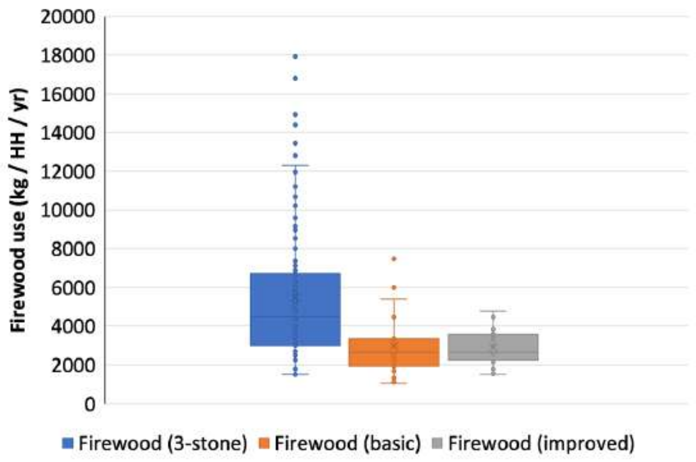
Average Recorded Firewood Use by Stove (kg/unit/y)			
Unit	3-stone	Basic	Improved
Per HH	5,507	2,984	2,919
Per person	1,246	675	660

- The table above and chart in the upper-right compare energy needed to cook, after accounting for efficiency differences in the stoves. There is a notable similarity in the firewood needs for basic and improved stoves. This could mean that improved stoves in the market have minimal efficiency difference with basic stoves, that survey respondents may not have a consistent perception of what is a "basic" stove and "improved" stove, that respondents with improved stoves use the stoves more often, or other reasons.
- Wood usage per capita recorded is comparable to other studies[1] in the region (Zambia and Zimbabwe) as shown in the lower-right chart.

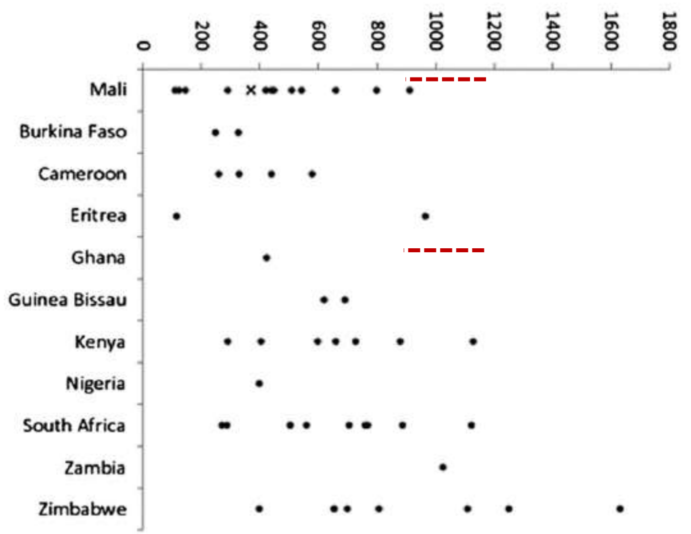
Rural firewood consumption in Malawi appears to be approximately 2-3 times larger than urban consumption[2], this is because rural households use cooking stoves for water heating and other activities whereas urban households have other heating devices[3] (such as a "geyser" water heater).

1. Johnson, N. G., & Bryden, K. M. (2012). Energy supply and use in a rural West African village. Energy, 43(1), 283-292.
2. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.
3. Coley, W., Galloway, S. (2020). Market assessment for modern energy cooking services in Malawi.

RECORDED FIREWOOD USE FOR AVERAGE SIZED HH



ANNUAL WOOD CONSUMPTION PER CAPITA (kg cap^{-1} yr-1)



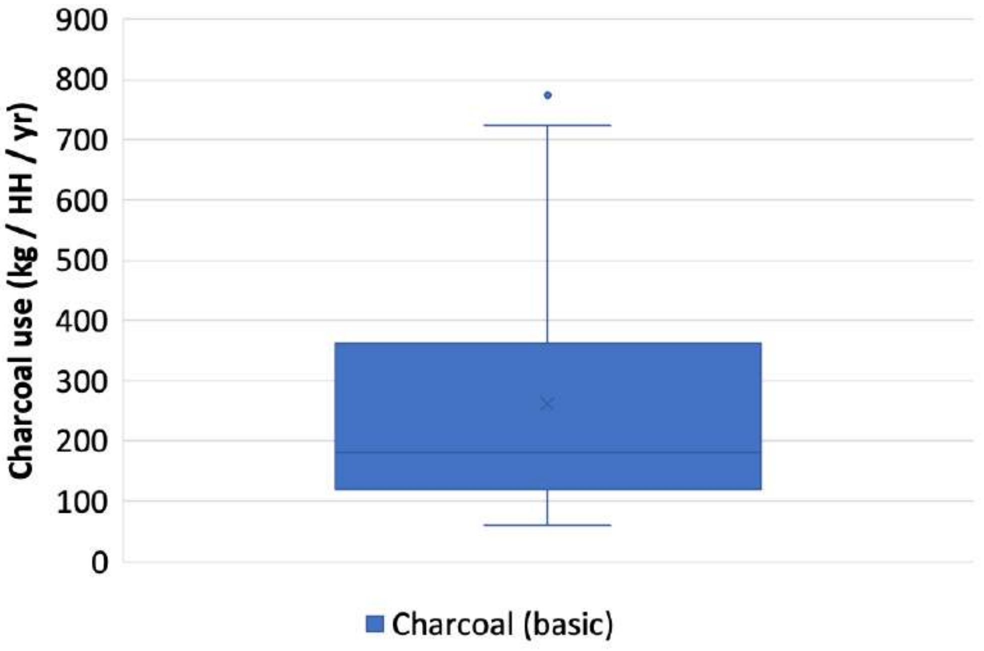
Cooking Fuel Use (Charcoal)

Average recorded annual charcoal use was calculated on a per capita basis from measured observations, and then translated to a per HH basis using an average family size of 4.42 people per household.

Average Recorded Charcoal Use by Stove (kg/unit/y)	
Unit	Basic
Per HH	262
Per person	59

Charcoal consumption by rural homes is 20-40% lower than charcoal use recorded from urban homes[1]. This difference may be attributed to urban households using charcoal for other heating needs[2] (such as water for bathing).

RECORDED CHARCOAL USE FOR AVERAGE SIZED HH



1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. 2020. Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.
2. Coley, W., Galloway, S. (2020). Market assessment for modern energy cooking services in Malawi.

Cookstove Training Received

- Approximately 23% of households reported having received training on their residential cookstove(s).
- Interestingly, of the households that purchased stoves, a slightly lower percentage of 19% received training, therefore training rates are higher on stoves received through donations or gifts.
- Incidence of training did not appear to vary significantly by stove type:
    - Some households received training on using a 3-stone fire (likely from a family member).
    - Some households that procured an improved firewood stove had received training, while the majority did not.
    - Some households that procured a charcoal stove had received training, while the majority did not.

IMPLICATIONS:

- There is some indication that the friend/relative providing a stove gives training slightly more often than a vendor, or potentially that family members train each other on how to use stoves more frequently than vendors. This result may not reflect national-level trends as vendor training could be dependent upon the regional location of stove vendors and their respective training programs.

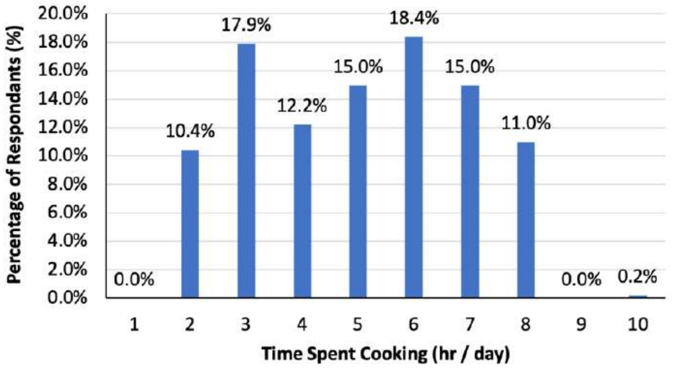
Gender Considerations

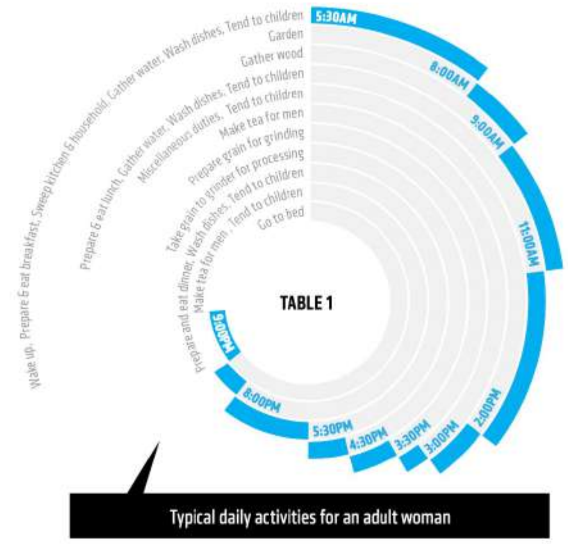
- Survey data showed an average of 5.1 hours per day is spent on "cooking" that consists of activities including meal preparation, using the stove, and cleaning. This number may seem high, but as lower right time wheel chart shows for comparison from data in Mali for similar rural communities, the time in a day, including fuel gathering and related cooking activities, can be a quarter to half of the day.
- Primary cookstove type had no major impact on average cooking time among firewood stoves. Some reduction was observed for charcoal stoves:
  - **Firewood (3-stone):** 5.1 hours per day
  - **Firewood (basic):** 5.2 hours per day
  - **Firewood (improved):** 5.1 hours per day
  - **Charcoal (basic):** 4.7 hours per day

IMPLICATIONS:

- Improved firewood stoves show no evidence of reducing the time burden of cooking, indicating time savings will not be a tangible value proposition to drive behavior. However, the reduction on fuel use with improved stoves will significantly reduce time for collecting fuel.
- LPG and e-cooking could reduce the time burden due to immediate turn-on and turn-off functionality, also leading to reduced time cleaning soot off pots.
- Secondary data shows that improved stoves can reduce the health impacts of cooking to women and children by reducing indoor air pollution and exposure to emissions.

TIME SPENT COOKING





Johnson, N. G., & Bryden, K. M. (2013). Clearing the air over cookstoves: improved cookstoves won't save fuel or reduce pollution if they can't be incorporated into daily life. Mechanical Engineering-CIME, 135(11), S8-S8.

MALAWI IEP – CLEAN COOKING

Methodological Review

SUSTAINABLE ENERGY FOR ALL

UNITY AND FREEDOM

Stove Types

Firewood (3-stone)[5]

Firewood (basic)[8]

Charcoal (basic)[8]

Briquette/pellet[7]

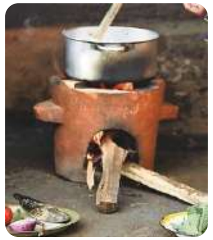
E-cooking[7]

Firewood (improved – fixed)[1,4]

Charcoal (improved)[9]

Bioethanol[10]

Firewood (improved – portable)[2,3]



Biogas[11]

LPG[6]

Sources: (1) https://energypedia.info/wiki/Total_Land_Care_Malawi_%28Cookstove_DB%29, (2) https://www.researchgate.net/figure/The-chitetezo-mbuala-in-use-in-Balaka-Malawi_fig1_257157530, (3) https://offset.climateneutralnow.org/biomass-energy-conservation-programme?searchResultsLink=%2Fallprojects%3Fspecs%3D436, (4) https://smokeandmirrors.newint.org/community.html, (5) Walker 2016, (6) 265Energy.com, (7) Khadija Mussa and http://catalog.cleancookstoves.org/stoves/309, (8) Nathan Johnson, (9) Clean Cooking Alliance, (10) http://catalog.cleancookstoves.org/stoves/78, (11) https://www.build-a-biogas-plant.com/biogas-stove-design/

Stove and Fuel Assumptions

Fuel parameters use globally accepted values for clean cooking analysis[1]. Fuel prices reflect a mix of primary data collected during this study for rural areas and secondary data from reports on urban areas[2].

Cookstove costs, lifetime, and efficiency[3] are applied to existing stoves present in the market and new stoves being added to the market. These are generalized values representative of some common technologies and should not be considered to reflect all vendor technologies. There is insufficient technical and sales data on specific vendor technologies to permit geospatial study and projections in future years. Stove lifetime is applied to existing stoves to model stove failure to present day.

Fuel price		
Fuel	Price ($/unit)	Unit
Firewood	0.046	kg
Charcoal	0.738	kg
Briquette/Pellet	0.42	kg
Biogas	0.74	kg
Bioethanol	0.905	kg
LPG	0.63	kg
Electric	0.064	kWh

Fuel Parameters			
Fuel	Energy value (MJ/kg)	PM2.5 (g/kg_fuel)	Emissions Factor (k_CO2/kg_fuel)
Firewood	18.41	7.1	1.775
Charcoal	31.98	19.7	3.662
Briquette/pellet	16.75	17.3	2.409
Biogas	22.65	0.1	1.476
Bioethanol	22.80	0.1	1.943
LPG	31.98	0.1	3.242
Electric	N/A	0.0	0.064

	Stove parameters		
Fuel (stove)	Price ($)	Lifetime (y)	Efficiency (%)
Firewood (3-stone)	0	N/A	14%
Firewood (basic)	1.8	1	25%
Firewood (improved)	2.1	2	27%
Firewood (improved - portable)	2.1	2	27%
Firewood (improved - fixed)	10	5	30%
Charcoal (basic)	2.3	1	20%
Charcoal (improved)	6	2	34%
Briquette/pellet	20	4	35%
Biogas	84	3	44%
Bioethanol	24.5	6	52%
LPG	92	6	56%
E-cooking (hot plate)	18.2	2	62%
E-cooking (induction)	40	6	90%

1. Clean Cooking Alliance 2019, Jetter and Kariher 2009, Mlotha 2019, Decker et al. 2018 (60% methane), energypedia, Benka-Coker et al. 2018, Cost-Benefit Analysis of Wood and Charcoal Use for Household Cooking and Supply- and Demand-Side Alternatives for Lilongwe, Malawi, https://www.epa.gov/sites/default/files/2015-07/documents/emission-factors_2014.pdf; Electricity emissions factor is in kg/kWh, and is low relative to other world regions due to the high proportion of hydropower in Malawi
2. Primary data (average of rural values observed); Cost-Benefit Analysis of Wood and Charcoal Use for Household Cooking and Supply- and Demand-Side Alternatives for Lilongwe; Selina Wamucii; Malawi IEP Study.
3. Cost-Benefit Analysis of Wood and Charcoal Use for Household Cooking and Supply- and Demand-Side Alternatives for Lilongwe; Modern Cooking for Healthy Forests; Malawi IEP Study; Aprovecho; cleancookstoves.org.

Administrative Levels and Geospatial Analysis

1
Country

3
Regions

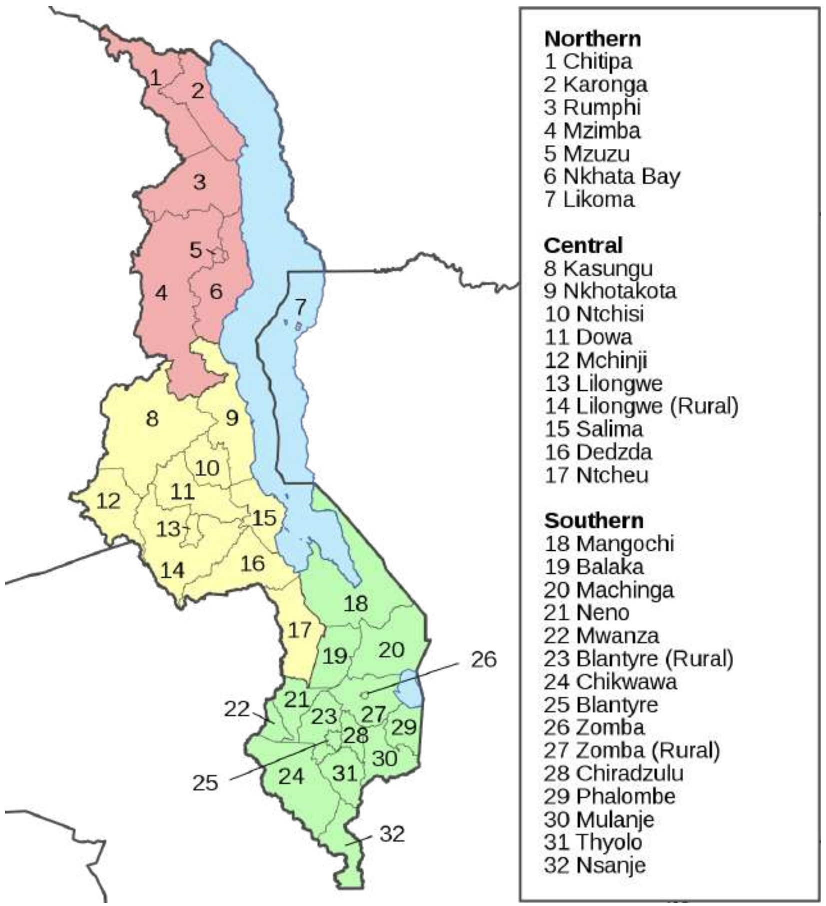
32
32 Districts and City Councils

432
Traditional authorities

4m
Households
(2018 census)

18.5m
Population
(2018 census)

TA is the highest resolution for clean cooking analysis based on the available data. Higher resolution would require further on-ground data on stove ownership and use behaviors at the HH level, and it would create inaccuracies to predict individual behavior of each separate household in the country. Rural and urban designations were given by the Ministry of Lands.



Process Flow

STEP 1: DATA COLLECTION

- Primary data (NRECA, CQuest Capital)
- Secondary data (GIZ, TetraTech, RMI)
- Goals (Cleaner Cooking Compact)
- Related studies (USAID)

STEP 2A: CATEGORIZE CUSTOMERS

- Electrification access (grid connected, mini-grid, solar home system, no access)
- Population density as proxy for access to markets (high-density vs. low-density)

STEP 2B: COOKING BEHAVIORS

- Stove ownership, costs, procurement
- Fuel use, costs, procurement
- Stove stacking, cooking diaries
- Gender, cooking location, training

STEP 3: OTHER INPUTS

- LPG distribution points
- Land use and farm holdings
- Animal ownership

STEP 4: 2030 SCENARIO CREATION

- Electrification scenarios
- Cleaner Cooking Compact goals
- SEforALL goals

STEP 5: GEOSPATIAL ANALYSIS

- Cookstove ownership and fuel use estimated for characteristic customer types
- Customer types based on electrification access and population density
- Statistics provided for each traditional authority

STEP 6: RESULTS AND VISUALIZATION

- Cookstove ownership, use, co-factors
- E-Cooking potential
- Improved solid fuel stove potential
- LPG distribution points
- Biogas potential
- Bio-ethanol potential

STEP 7: COMPARE STUDIES

- SEforALL Malawi IEP electrification study
- Malawi Sustainable Energy Investment Study
- National Charcoal Strategy
- Market assessment for modern cooking services in Malawi

STEP 8: RECOMMENDATIONS

Investment needs, stove types, effect of electrification strategies, policy or financial incentives, geospatial insights

Scenario Development (1 of 2)

The clean cooking aspect of the Malawi Integrated Energy Plan (IEP) models the progression of stove adoption and fuel use from present-day to meet 2030 goals set forth in the Ministry of Energy's Malawi SDG7 Cleaner Cooking Energy Compact. Meeting goals in the Compact is determined to be the Baseline Scenario for this project.

Malawi SDG7 Cleaner Cooking Energy Compact – Targets and Goals — Gov. of Malawi – Ministry of Energy

OUTCOME	DATE
Outcomes for Ambition 7.1 (projected population figures by 2030: ca. 25 million people in total, out of which 21 million rural, 4 million urban) • 60% of rural households transitioned to stove stacked by using more than one fixed and/or portable efficient wood stove • 40% of rural households transitioned to at least one efficient wood stove by 2030 • 30% of urban households transitioned to ultra-efficient charcoal stoves by 2030 • 10% of urban households transitioned to sustainably produced, licensed charcoal by 2030 • 10% of urban households transitioned to LPG by 2030 • 3% of urban households transitioned to self-sustaining biogas systems, pellets, briquettes and other alternative biomass fuel solutions • 15% urban households transitioned to low-consumption electric cooking by 2030 • 100 commercial users have transitioned to renewable energy including sustainable biomass	2030
• 3 programs implemented by government to build capacity of LPG, biogas and natural gas • An additional 2,000,000 improved biomass cookstoves distributed by 2025 • An additional 3,000,000 improved cookstoves for both biomass and alternative cooking fules by 2030	Ongoing until 2023 Ongoing until 2025 Ongoing until 2030
• CSO community initiatives ensuring that 55,000 rural men and women per year are trained to make and use improved cookstoves using locally available materials • Customs, excise and VAT exemptions for efficient stoves and alternative sustainable fuels in place	Ongoing Ongoing until 2023

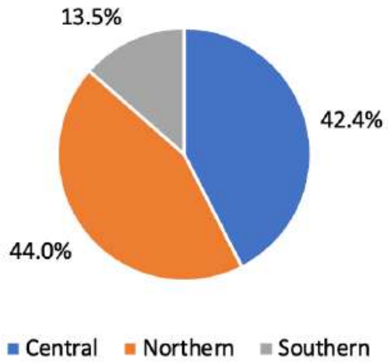
Scenario Development (2 of 2)

- The Baseline Scenario to reach Compact targets includes separate goals for rural and urban consumers:
    - **Rural:** goals describe 100% of the users as having one improved wood stove or two improved wood stoves.
    - **Urban:** goals only specify stove ownership for 58% of users, and does not mention stove stacking which is common, thus this study assumes the remaining 42% represents customers that stack stoves or other heating devices for cooking, water heating, and related.
- Analyses were completed for each traditional authority to reflect local market circumstances and user behaviors that permit identification of intervention strategies to confront localized challenges (e.g., stove subsidy vs. market incentive for mobile vendors to sell stove).
- Results are aggregated to show district, regional, and country trends to permit country-wide policy analysis, and illustrate which interventions have broad applicability in the country and which interventions should permit adaption to local circumstances.
- The geospatial study shows the trajectory of clean cooking development to 2030 for e-cooking, LPG, improved biomass, improved charcoal, bioethanol, and biogas to assess if each goal in the Malawi Cleaner Cooking Energy Compact can be met with existing market forces, needs interventions, or may not be sufficiently ambitious.
- Additional scenarios are generated to help inform more ambitious goals beyond the Malawi Cleaner Cooking Energy Compact to account for the "potential" of each fuel and technology with respect to electrification targets in the Malawi IEP and alternative fuel availability for bioethanol, biomass pellet/briquettes, and biogas. These scenarios calculate upper limits of adoption and use for each technology subject to fuel constraints (e.g., e-cooking potential is defined as the amount of grid-connected homes in the IEP).

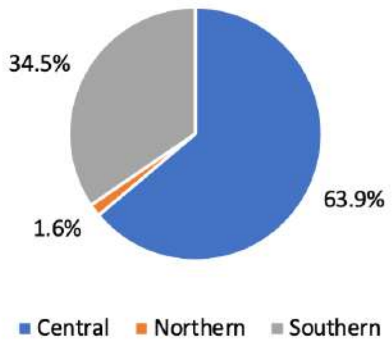
Historical Data on Improved Wood Stove Sales

- Improved wood stove sales volumes in Malawi[1] have been collected since 2013, and as of 2022, approximately 2.1M stoves have been sold. This number consists of 1.6M improved portable wood stoves and 0.5M improved fixed stoves. Data from 2021 and 2022 may not be fully reported.
- Improved fixed stove sales are reported at the district-level and are represented geospatially at the district-level. Improved portable stove sales are reported at the district-level, but may not be sold in that district, and are assumed to follow distribution channels sold within the same region as they are produced.
- Improved portable wood stoves have very little penetration in Northern region. Improved fixed stove sales are less in the Southern region.

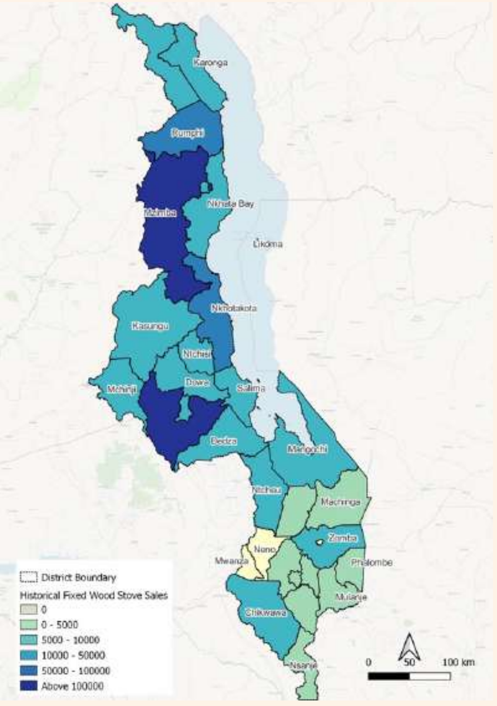
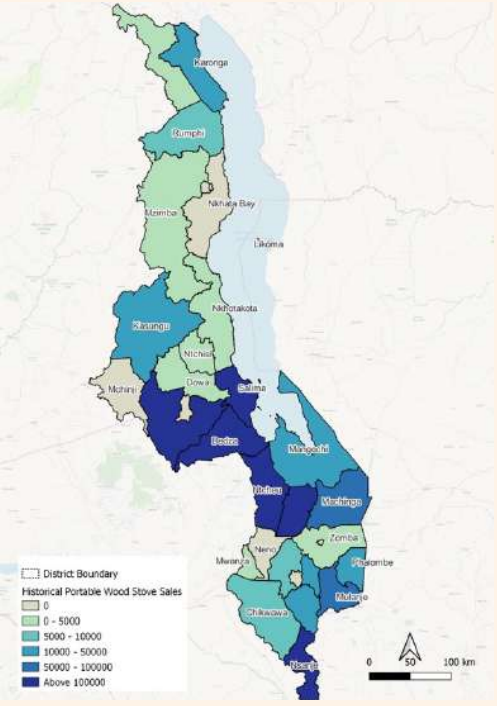
HISTORICAL IMPROVED FIXED WOOD STOVE SALES



HISTORICAL IMPROVED PORTABLE WOOD STOVE SALES



Distribution of improved wood stove ownership (2022)

Fixed improved wood stove	Portable improved wood stove
	

1. Energypedia. 2021 [Accessed: August 14, 2022] https://energypedia.info/wiki/Malawi_cookstoves_DB_Production_Centre_Overview

Current State (2022) to Universal Access (2030)

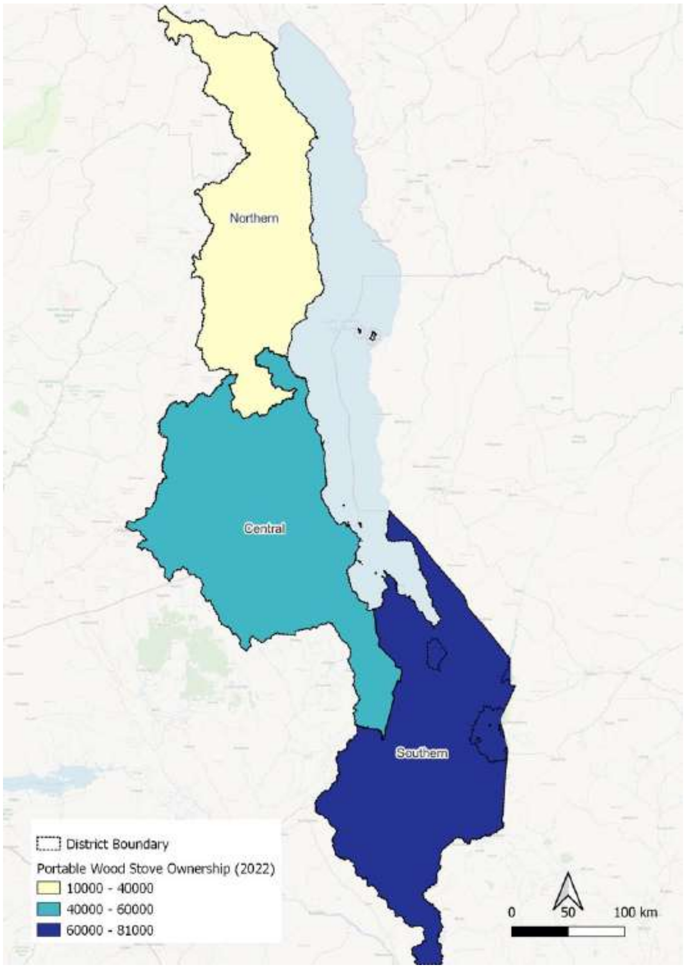
- Urban stove ownership in 2022 is compiled from secondary data sources with differences in study location and survey design[1,2,3,4] that must be consolidated to create representative customer segments that approximate actual ownership characteristics. Household surveys conducted within the Malawi IEP study focus on rural areas to understand cookstove ownership where other sources lack such data.
- Urban areas and rural TAs are modelled separately. The starting conditions for stove ownership for each TA in 2022 are based on existing regional, district, and TA data[2,4,5]. Target stove ownership in 2030 assumes consistency in urban areas and in rural areas, as such the 2030 goals do not differ city to city or community to community.
- Annual stove ownership trends are approximated for each TA as an interpolation between 2022 and 2030 values. Some vendors are increasing production, but such future vendor plans are not modelled explicitly in this study due to the inherent uncertainty.
- Stove failure is reflected by the lifetime of each stove type (see data later in the report) and is assumed to be replaced. This means that annual stove production and purchase counts include both new users and existing users (that need a stove replaced).

1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.
2. Coley, W., Galloway, S. (2020) Market assessment for modern energy cooking services in Malawi.
3. Borgstein et al. (2019) Malawi Sustainable Energy Investment Study. Rocky Mountain Institute, Prepared for Government of Malawi and UN-OHRLLS.
4. Kanaan et al. (2020) Modern Cooking for Healthy Forests in Malawi. Tetra Tech, prepared for USAID and UK Aid.
5. Energypedia. 2021 [Accessed: August 14, 2022] https://energypedia.info/wiki/Malawi_cookstoves_DB_Production_Centre_Overview

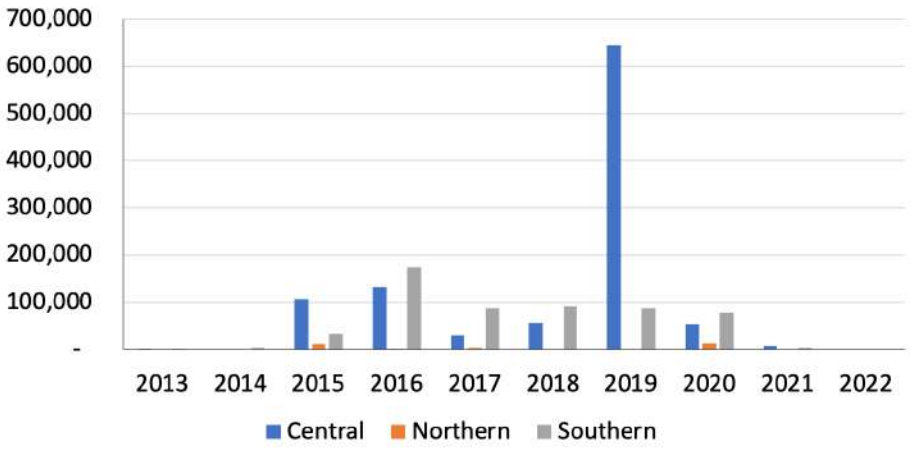
Current State (2022) – improved portable wood stoves

- Nearly all (90.6%) of the 1.6M improved portable wood stoves[1] that have been implemented to date will have failed based on the assumed 2-year life span of such stoves. The regional distribution of the remaining 9.4% of the improved wood stoves is shown on the right.
- If improved portable stoves had a longer lifetime (five years), up to 56% of the households in the central region would still have improved portable wood stoves today.
- The central region has had the most attention to date. Notably, the Dziwani stove production group sold 289,751 portable stoves in the Lilongwe District in 2019.

IMPROVED PORTABLE WOOD STOVE OWNERSHIP BY REGION (2022)



HISTORICAL PORTABLE WOOD STOVE SALES



1. Energypedia. 2021 [Accessed: August 14, 2022] https://energypedia.info/wiki/Malawi_cookstoves_DB_Production_Centre_Overview

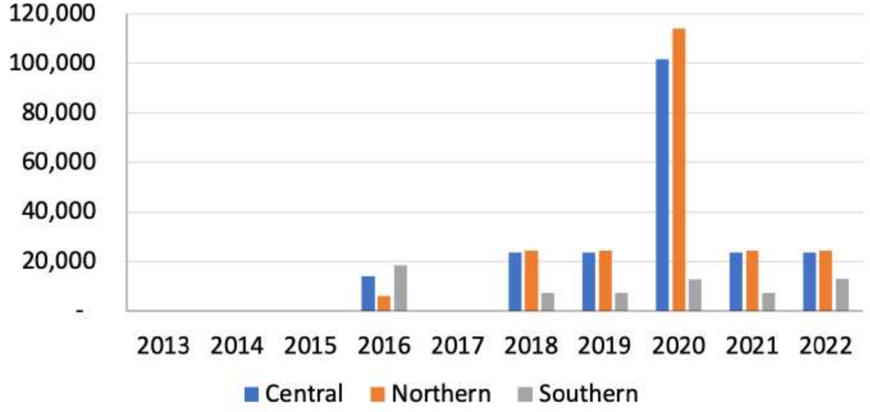
Current State (2022) – improved fixed wood stoves

- The online repository of data of the 0.5M sold fixed wood stoves[1] provides geospatial data on 0.22M stoves or 44% of those implemented. The remaining 56% of stoves are assumed to be geospatially distributed to regions using the same percentage regional distribution of the reported programs, and inside each region, distributed to the districts by relative population sizes of the districts. The implementation year of those stoves is assumed to be distributed evenly over the last five years (assumed lifetime of the fixed stove).

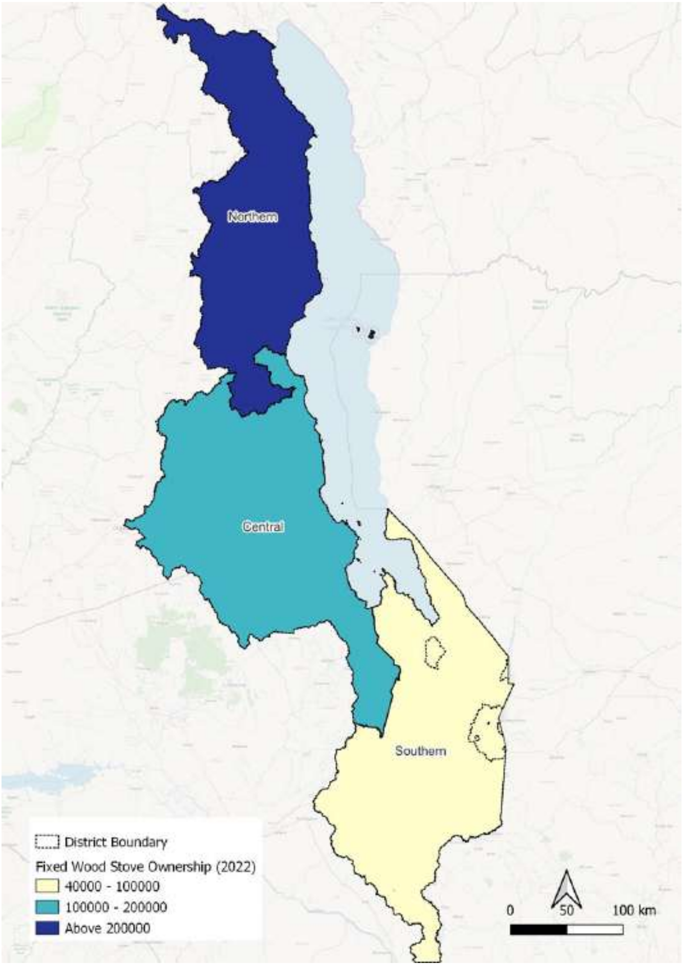
- This results in only 7.8% of the 0.5M fixed wood stoves[1] having failed using the assumed 5-year life span of such stoves. The regional distribution of the remaining 92.2% wood stoves expected to be in use today is shown geospatially on far right.

- The central region and northern region had the most attention to date. Notably, Total Land Care Malawi sold 173,169 fixed stoves in those regions in 2020.

HISTORICAL FIXED WOOD STOVE SALES



IMPROVED FIXED WOOD STOVE OWNERSHIP BY REGION (2022)



1. Energypedia. 2021 [Accessed: August 14, 2022] https://energypedia.info/wiki/Malawi_cookstoves_DB_Production_Centre_Overview

Malawi SDG7 Cleaner Cooking Energy Compact Targets

- Cookstove ownership status for 2022 in urban areas is compiled from secondary data sources[1,2,3], with 2022 cookstove ownership in rural areas representing a combined picture of secondary data and primary data collected in this work. The relative amounts of stove ownership were then compared to estimated national trends[4] from 2022 to cross-check the starting conditions for modelling.
- The cookstove ownership status for 2030 is assumed to follow the targets set forth in the Malawi SDG7 Cleaner Cooking Energy Compact (Compact). Rural customer categories are assumed to mimic Compact goals directly, with 40% of homes owning a portable improved woodstove and 60% of homes cookstove stacking with an improved portable wood stove and an improved fixed wood stove. The urban scenario is a bit more complex as the Compact outlines targets for only 58% of the users, the remaining 42% is left unspecified. This project assumes that 42% of the urban population participates in cookstove stacking with an improved charcoal stove and e-cooking. That is a trend common today that may increase based on electricity reliability and tariffs.

	Rural	
Stove	2022	2030
Firewood (3-stone)	67.0%	0.0%
Firewood (basic)	10.0%	0.0%
Charcoal (basic)	10.0%	0.0%
Firewood (improved - portable)	1.0%	40.0%
Firewood (improved - fixed)	10.0%	0.0%
Firewood (improved - portable) & Firewood (improved - fixed)	2.0%	60.0%
Charcoal (improved)	0.0%	0.0%
LPG	0.0%	0.0%
E-cooking	0.0%	0.0%
Charcoal (improved) & E-cooking	0.0%	0.0%
Briquette/pellet	0.0%	0.0%
Biogas	0.0%	0.0%
Bioethanol	0.0%	0.0%

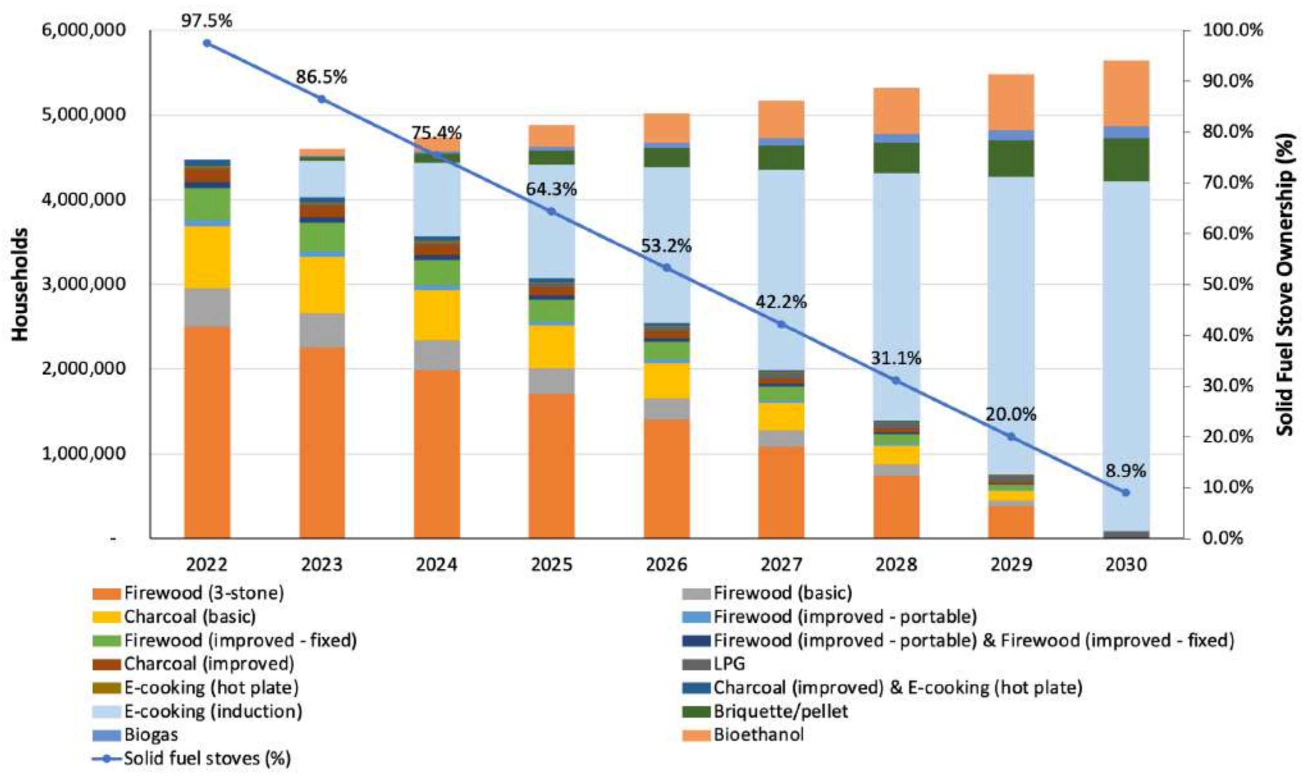
	Urban	
Stove	2022	2030
Firewood (3-stone)	0.0%	0.0%
Firewood (basic)	10.0%	0.0%
Charcoal (basic)	50.0%	0.0%
Firewood (improved - portable)	5.0%	0.0%
Firewood (improved - fixed)	0.0%	0.0%
Firewood (improved - portable) & Firewood (improved - fixed)	0.0%	0.0%
Charcoal (improved)	20.0%	30.0%
LPG	2.0%	10.0%
E-cooking	3.0%	15.0%
Charcoal (improved) & E-cooking	10.0%	42.0%
Briquette/pellet	0.0%	1.0%
Biogas	0.0%	1.0%
Bioethanol	0.0%	1.0%

1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.
2. Coley, W., Galloway, S. (2020) Market assessment for modern energy cooking services in Malawi.
3. Kanaan et al. (2020) Modern Cooking for Healthy Forests in Malawi. Tetra Tech, prepared for USAID and UK Aid.
4. Mussa, K.S. (2022). Cleaner Cooking Energy Compact. GIZ EnDev-Malawi

Improved Cookstove Expansion Scenario to Meet IEP Targets

- The IEP universal electrification plan facilitates grid-connected homes to have access to low-cost electricity and sufficient capacity to use e-cooking. In this scenario, e-cooking represents 73.1% of all households. Based on conservative design assumptions and transformer sizing in the electrification analysis, these additional customers could be accommodated in the electrification plan.
- LPG for urban households provides energy to 1.7% households.
- The remaining rural households that are not grid-connected utilize a mix of bioethanol (13.8%), briquette/pellet (8.9%), and biogas (2.5%).
- This scenario provides an example in which no fuelwood or charcoal is used for cooking.

PROJECTED OWNERSHIP OF CLEANER COOKING SOLUTIONS



Malawi SEforAll IEP Scenario Targets

- The additional IEP Scenario was developed using:
  - **LPG** – for 10% of urban households to match 2030 Compact goals
  - **E-cooking** – all grid-connected households (rural or urban) are assumed eligible for e-cooking
  - **Pellet/Briquette, Biogas, Bioethanol** – for total remaining rural customers as a weighted percentage of each fuel availability
- This approach illustrates one potential scenario for completely removing fuelwood and charcoal use in Malawi

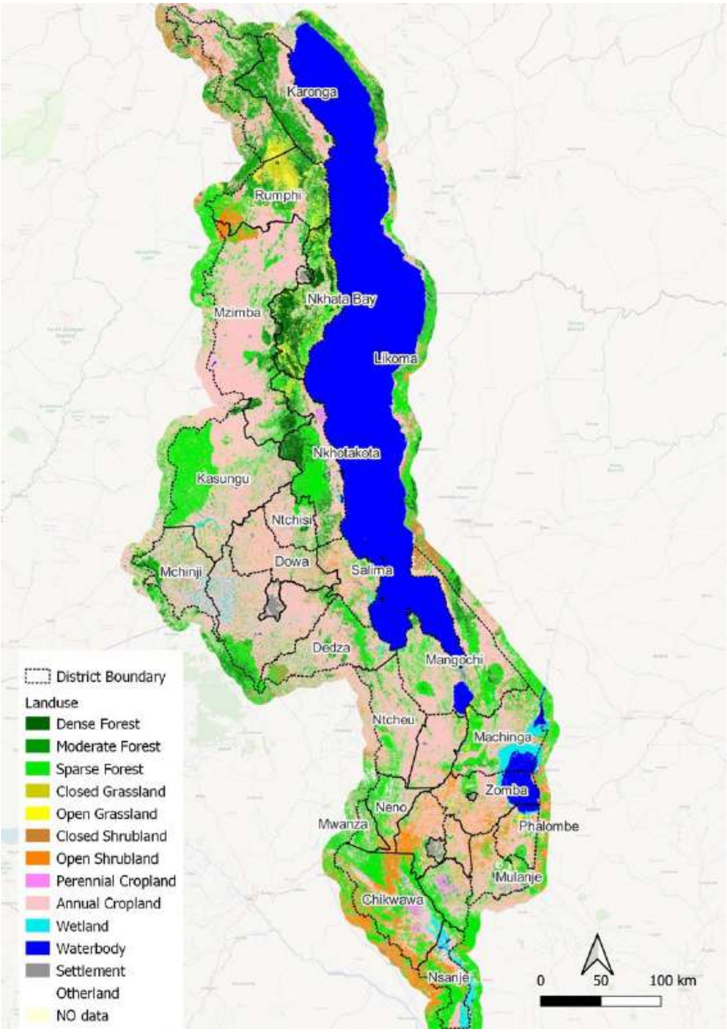
Rural 2030	Percentage		Households	
Stove	Compact	IEP	Compact	IEP
Firewood (3-stone)	0.0%	0.0%	-	-
Firewood (basic)	0.0%	0.0%	-	-
Charcoal (basic)	0.0%	0.0%	-	-
Firewood (improved - portable)	40.0%	0.0%	1,880,440	-
Firewood (improved - fixed)	0.0%	0.0%	-	-
Firewood (improved - portable) & Firewood (improved - fixed)	60.0%	0.0%	2,820,659	-
Charcoal (improved)	0.0%	0.0%	-	-
LPG	0.0%	0.0%	-	-
E-cooking (hot plate)	0.0%	0.0%	-	-
Charcoal (improved) & E-cooking (hot plate)	0.0%	0.0%	-	-
E-cooking (induction)	0.0%	69.7%	-	3,275,564
Briquette/pellet	0.0%	10.7%	-	504,469
Biogas	0.0%	3.0%	-	141,881
Bioethanol	0.0%	16.6%	-	779,185

Urban 2030	Percentage		Households	
Stove	Compact	IEP	Compact	IEP
Firewood (3-stone)	0.0%	0.0%	-	-
Firewood (basic)	0.0%	0.0%	-	-
Charcoal (basic)	0.0%	0.0%	-	-
Firewood (improved - portable)	0.0%	0.0%	-	-
Firewood (improved - fixed)	0.0%	0.0%	-	-
Firewood (improved - portable) & Firewood (improved - fixed)	0.0%	0.0%	-	-
Charcoal (improved)	30.0%	0.0%	283,691	-
LPG	10.0%	10.0%	94,564	94,564
E-cooking (hot plate)	15.0%	0.0%	141,846	-
Charcoal (improved) & E-cooking (hot plate)	42.0%	0.0%	397,168	-
E-cooking (induction)	0.0%	90.0%	-	851,074
Briquette/pellet	1.0%	0.0%	9,456	-
Biogas	1.0%	0.0%	9,456	-
Bioethanol	1.0%	0.0%	9,456	-

Biomass Potential

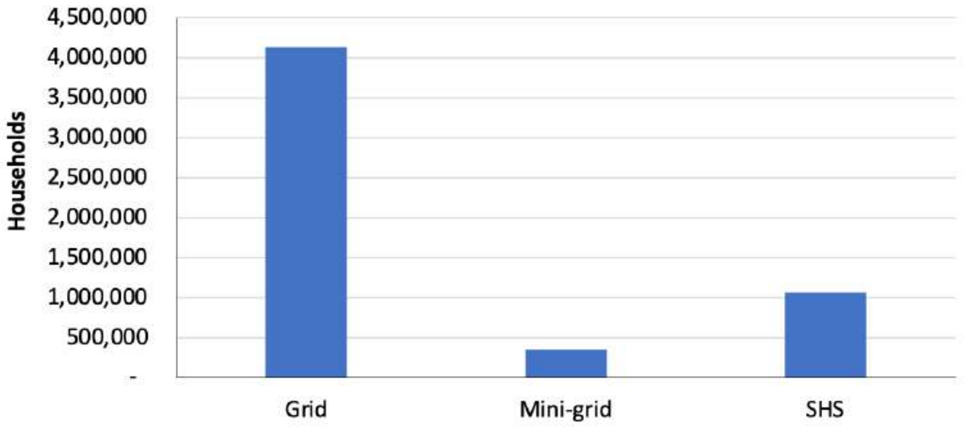
- Forest and shrubland is geospatially displayed on the right.
- There are higher amounts of forest near Lake Malawi, and near the boarders of the Malawi. This suggests districts where more wood may be available. Further, shrubland in the south is another resource.
- Much of the country is cropland with grain or agricultural residues available for utilization for bioethanol production or biomass pellets, respectively.
- Charcoal kiln designs are compared to understand how various conversion efficiencies affect overall wood consumption.
- The supply availability of biomass pellets and briquettes from agricultural wastes or wood mill wastes is not explicitly modeled geospatially.

MALAWI LAND USE AND BIOMASS POTENTIAL



E-Cooking Potential (1 of 2)

COUNTRY-WIDE ELECTRIFICATION ACCESS BY TYPE (2030)



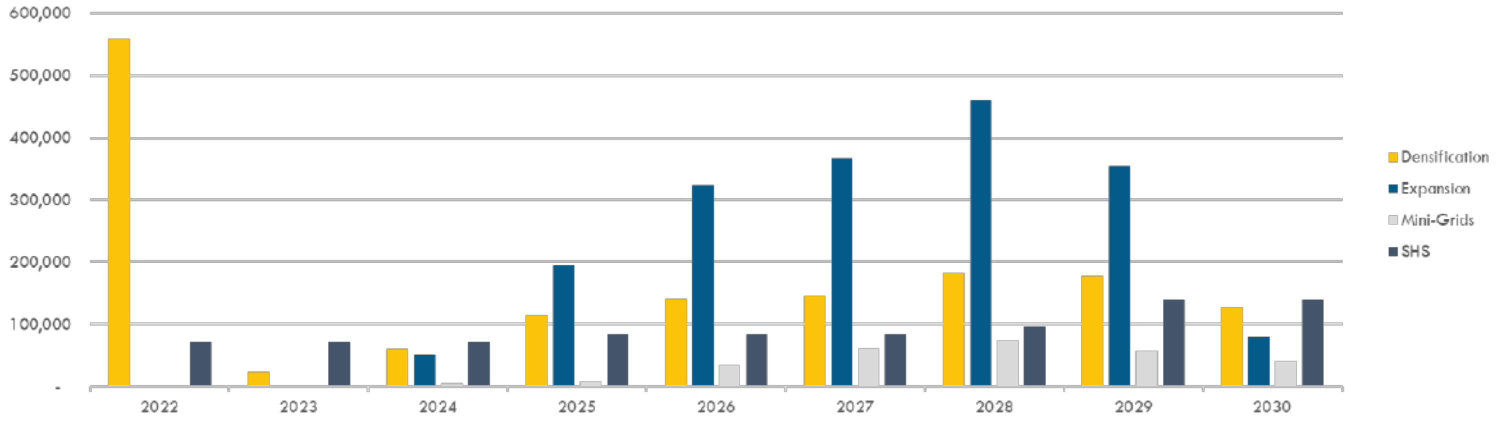
Source: Projections from Malawi IEP electrification study to meet 100% electricity access goals by 2030

- Use of e-cooking solutions is presently limited, even in electrified areas. This is primarily due to stove and fuel affordability relative to income, and also grid outages require households to have multiple cooking technologies.
- The Malawi SDG7 Cleaner Cooking Energy Compact sets a 2030 goal for 15% penetration of e-cooking in urban locations (4.1M urban people, 4.42 people/HH, 15% penetration = 141,846 HH). The Compact leaves 42% of urban households with undefined stove ownership, which is modeled here as stove stacking with improved charcoal and e-cooking (397,168 HH).
- This Compact goal was developed assuming a 10% electrification rate in the country by 2030. This is far lower than IEP goals to achieve 100% access by 2030, and the IEP scenario introduced later, assesses higher targets for e-cooking potential. Under the IEP electrification scenario, a total of 4,126,638 households would have a grid connection as the least-cost solution.
- It is assumed that all e-cooking users are grid-connected due to the far lower electricity cost for those households based on indicative electricity tariffs below. Also, mini-grids and SHS are assumed to have insufficient capacity to meet cooking loads.
- Grid: $0.064/kWh
    - Mini-grid: $0.45/kWh
    - SHS: roughly $7-10/month fixed price

E-Cooking Potential (2 of 2)

- The results of the electrification component of the Malawi IEP are summarized on the right. The overall allocation of customers by region and district in the electrification analysis was expanded to the Traditional Authorities in deriving the e-cooking potential in the clean cooking model.
- It is recommended for e-cooking campaigns to follow grid densification and grid expansion programs to achieve higher rates of adoption than un-electrified or off-grid areas. Nevertheless, affordability constraints represent a significant market barrier.
- Additional data and complete results of the national electrification analysis can be found in the electrification report of the Malawi IEP, available for download at: https://malawi-iep.sdg7energyplanning.org/

ELECTRIFICATION IMPLEMENTATION PLAN BY MODALITY



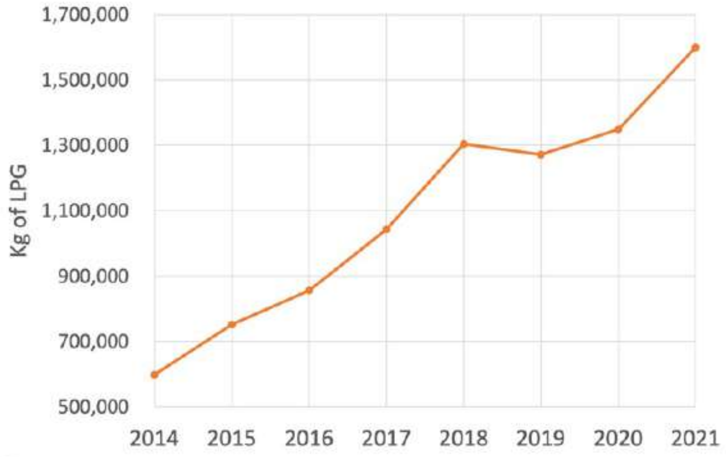
Modality	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Densification	560,220	60,159	96,254	120,317	144,381	180,476	240,634	240,634	120,317	**1,763,392**
Expansion	-	12,450	24,900	163,137	301,374	466,114	680,655	266,260	355,013	**2,269,903**
Mini-Grids	-	8,531	17,061	45,992	74,923	67,182	93,564	17,945	23,926	**349,123**
SHS	207,667	62,300	83,067	103,834	124,600	155,750	155,750	103,834	41,533	**1,038,336**
Total	**767,887**	**143,439**	**221,282**	**433,280**	**645,278**	**869,523**	**1,170,603**	**628,672**	**540,790**	**5,420,754**

Note: the "densification" connections in 2022 represents existing ESCOM grid customers at the time of the analysis.

LPG Potential

- Initial sales points in 2022 use locations provided in the graphic on the right. Sales points projected out to 2030 focus on urban areas and assume no rural expansion.
- Year-on-year consumption of LPG in Malawi (lower right) represents all LPG sales, not just residential consumption. This is used as the upper viable limit for residential LPG consumption in absence of data on percent of sales for residential use.
- The historical annualized growth rate of 15% per annum is maintained to forecast future LPG supply volumes.

YEAR-ON-YEAR CONSUMPTION



Average annualized growth rate of 15% per annum

Target market:

- Youth
- Recent graduates
- New homeowners
- New neighborhood locations

Regulating Energy for Sustainable Development

Location of LPG Sales Points in 2022

Translation: "Clean cooking gas, that does not destroy the environment and is fast to use has arrived in your area. There is no Tax when you buy it and, in some places, the sellers can deliver it on your doorstep after you buy."

Bioethanol Potential – methods (1 of 2)

- Geospatial data from 2010 is latest resource available with sufficient fidelity to estimate land use by traditional authority. Land area for agriculture has remained steady 2010 to present day, and we assume this maintains to 2030.[1,2,3]
- Crops include annual cropland (sugarcane, cereals) and not perennial cropland (fruits, nuts). Did not include wheat, millet, groundnuts, cotton, pigeon peas, beans. Estimates of "potential" include all usable portions of the crop, whereas waste peels or agricultural waste is considered later for potential pelletization.
- Projections for crop growth are calculated from historical growth trends. Sugarcane datasets have 30 years of historical data[4] and other crops 5 years of historical data[5]. We assume a year over year growth rate to 2030.
- Irrigation and farming practices may vary by region and influence crop yield, but we don't have geospatial data to show this difference.
- Bioethanol uses only the grain portion crop, whereas the agricultural waste (e.g., maize stock) is used for pellets or briquettes.
- Sugarcane is presently the only crop used to produce ethanol in the country, with plant locations including:
  - Ethanol Company Ltd. (Ethco): Dwangwa, Central Region (12°29′57.84″S; 34° 9′0.39″E), has been producing ethanol since 1982.
  - PressCane: Chikhwawa District, Southern Region (16°12′18.45″S; 34°50′24.94″E), has been producing ethanol since 2004.

1. Geospatial Data 2010: https://opendata.rcmrd.org/datasets/rcmrd::malawi-land-cover-2010-scheme-ii/about
2. Agricultural land area 2010 to present. World Bank. https://data.worldbank.org/indicator/AG.LND.AGRI.ZS?locations=MW
3. Agricultural production 2010. Malawi Data Portal. https://malawi.opendataforafrica.org/fgioqkb/malawi-statistics-2011
4. Knoema 2020. https://knoema.com/atlas/Malawi/topics/Agriculture/Crops-Production-Quantity-tonnes/Sugar-cane-production
5. Agricultural production 2022. Agriculture Production Estimate Survey 2022. https://agriculture.gov.mw/index.php/downloads/category/3-report#

Bioethanol Potential – methods (2 of 2)

- Ethanol conversation rates on lower right represent commercially available technologies and near-commercial technologies.[1,2,3,4,5] Conversation rates are representative values across studies with different crop species, crop parts, technologies, etc.
  - Sugarcane is presently the only crop used to make commercial-scale ethanol in Malawi and is a conservative upper limit on ethanol potential. For illustration purposes only, the study includes estimates of bioethanol production from all crops for comparison and discussion.
  - Inedible crop waste and agro-processing waste from maize and cassava are strong options for production of bioethanol or pelletized biomass. Rice hulls tend to have a higher silica content and create accelerated wear on palletization machinery.

Crop	2022 crop production (tons)	Annual growth (%)	2030 crop production (tons)
Sugarcane	3,457,961	6.3%	3,808,183
Maize	3,716,479	3.7%	3,935,847
Rice	136,083	2.4%	141,417
Sorghum	116,918	4.9%	126,043
Cassava	6,193,001	9.7%	7,154,922
Sweet Potato	7,491,115	20.4%	9,941,355
Potato	1,392,873	21.0%	1,860,168

Crop	Conversion rate (L per kg)
Sugarcane	0.700
Maize	0.390
Rice	0.525
Sorghum	0.390
Cassava	0.500
Sweet Potato	0.219
Potato	0.208

1. Murali, P., Ram, B., Prathap, D. P., Hari, K., & Venkatasubramanian, V. (2021). Sugarcane Based Ethanol Production for Fuel Ethanol Blending Program in India.
2. Jeevan Kumar, S.P., Sampath Kumar, N.S. & Chintagunta, A.D. Bioethanol production from cereal crops and lignocelluloses rich agro-residues: prospects and challenges. SN Appl. Sci. 2, 1673 (2020). https://doi.org/10.1007/s42452-020-03471-x
3. Ademiluyi, F. T., & Mepba, H. D. (2013). Yield and properties of ethanol biofuel produced from different whole cassava flours. International Scholarly Research Notices, 2013.
4. Lareo C, Ferrari MD, Guigou M, Fajardo L, Larnaudie V, Ramírez MB, Martínez-Garreiro J. Evaluation of sweet potato for fuel bioethanol production: hydrolysis and fermentation. Springerplus. 2013 Sep 30;2:493. doi: 10.1186/2193-1801-2-493. PMID: 24130960; PMCID: PMC3795201.
5. Mostofa, M. (2019). An introduction to bioethanol and its prospects in Bangladesh: a review. Journal of Energy Research and Reviews, 2(2), 1-12.

Biogas Potential

Livestock headcount data only available for two years[1] and it is not possible to establish accurate average future-looking trends. Assumed loss and gain rate is equivalent.

Animals	2022 livestock population (heads)	2030 livestock population (heads)
Cattle	2,054,208	2,054,208
Goats	12,238,382	12,238,382
Sheep	404,956	404,956
Pigs	10,698,418	10,698,418
Chickens	230,056,331	230,056,331
Guinea fowl	2,276,913	2,276,913
Turkey	436,341	436,341
Duck	4,438,063	4,438,063

- Livestock have different waste production, solid fraction, and methane production based on diet.[2,3]
- Assumes all waste can be collected and utilized to show upper limit on biogas potential.
- Biogas is estimated to have 60% methane and 40% CO2 (and trace gases) with methane production not differentiated based on biodigester technology.

Animals	Waste production (kg wet / hd / yr)	Volatile solid fraction (kg solid / kg wet)	Methane production (m3 CH4 / kg volatile solid)	Methane production (m3 CH4 / hd / yr)
Cattle	12,911	0.17	0.19	412
Goats	960	0.17	0.19	31
Sheep	398	0.17	0.19	13
Pigs	2,933	0.15	0.34	148
Chickens	69	0.25	0.19	3
Guinea fowl	69	0.25	0.19	3
Turkey	344	0.25	0.19	16
Duck	69	0.25	0.19	3

1. Agriculture Production Estimate Survey 2022. https://agriculture.gov.mw/index.php/downloads/category/3-report#
2. Díaz-Vázquez, D., Alvarado-Cummings, S. C., Meza-Rodríguez, D., Senés-Guerrero, C., de Anda, J., & Gradilla-Hernández, M. S. (2020). Evaluation of biogas potential from livestock manures and multicriteria site selection for centralized anaerobic digester systems: The case of Jalisco, Mexico. Sustainability, 12(9), 3527.
3. Ogejo, J. A., Wildeus, S., Knight, P., & Wilke, R. B. (2010). Estimating goat and sheep manure production and their nutrient contribution in the Chesapeake Bay watershed. Applied engineering in agriculture, 26(6), 1061-1065.

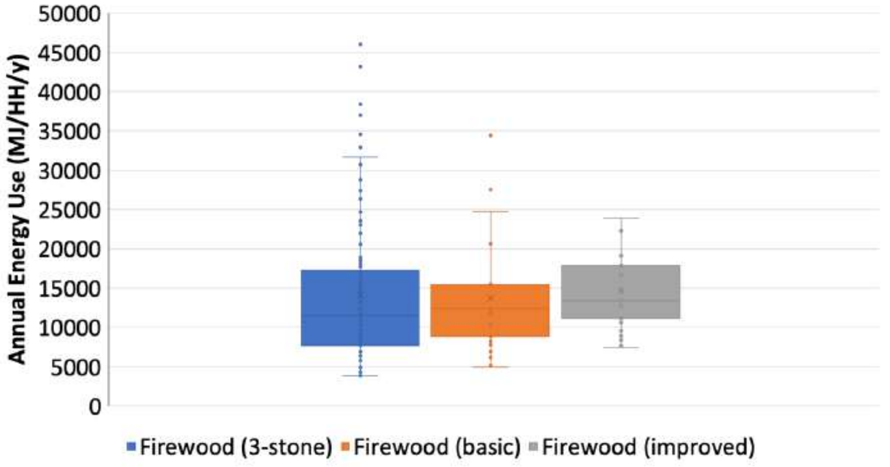
Cooking Energy and Costs

- Primary data on firewood use showed good consistency on the amount of energy required for cooking and non-cooking stove uses, after accounting for differences in efficiency between stove type. This equates to an average of 14,134 MJ/HH/y or 38.7 MJ/HH/d for an average sized household of 4.42 people. This quantity of energy demand accounts for meals and non-meal uses (e.g., water for bathing, space heating) of cookstoves to better reflect total household energy needs for thermal applications.
- Comparison between stove types and urban vs. rural households is facilitated by assuming that, regardless of location, a family has the same types of needs. All families need to cook, heat water for bathing, heat water for cleaning, and other thermal needs such as space heating. The analysis can then focus on the directionality of aggregate trends in stove adoption and fuel use for the country to give policy guidance, without needing to represent additional degrees of accuracy such as whether meal type varies by location.
- Fuel needed by the average sized family is given in the table on right using cookstove parameters[1] introduced previously.
- A scenario or sensitivity can be completed for urban areas that examines just the cooking stove portion of energy use present today.

Cookstove stacking – when households own and use multiple stoves. Stoves may be used for different purposes (e.g., stove X for cooking, stove Y for water heating).

1. Cost-Benefit Analysis of Wood and Charcoal Use for Household Cooking and Supply- and Demand-Side Alternatives for Lilongwe; Modern Cooking for Healthy Forests; Malawi IEP Study; Aprovecho; cleancookstoves.org.

USEFUL ENERGY OUTPUT FROM FIREWOOD STOVES FOR THE AVERAGE HOUSEHOLD SIZE



	Stove parameters			Fuel parameters		
Fuel (stove)	Price ($)	Lifetime (y)	Efficiency (%)	Energy use (MJ/HH/y)	Fuel use (units/HH/y)	Unit
Firewood (3-stone)	0	N/A	14%	101,258	5500	kg
Firewood (basic)	1.8	1	25%	56,502	3069	kg
Firewood (improved)	2.1	2	27%	52,317	2842	kg
Firewood (improved - portable)	2.1	2	27%	52,317	2842	kg
Firewood (improved - fixed)	10	5	30%	47,085	2558	kg
Charcoal (basic)	2.3	1	20%	70,628	2208	kg
Charcoal (improved)	6	2	34%	41,546	1299	kg
Briquette/pellet	20	4	35%	40,359	2409	kg
Biogas	84	3	44%	32,472	1434	kg
Bioethanol	24.5	6	52%	27,428	1203	kg
LPG	92	6	56%	25,224	789	kg
E-cooking (hot plate)	18.2	2	62%	22,619	6283	kWh
E-cooking (induction)	40	6	90%	15,695	4360	kWh

MALAWI IEP – CLEAN COOKING

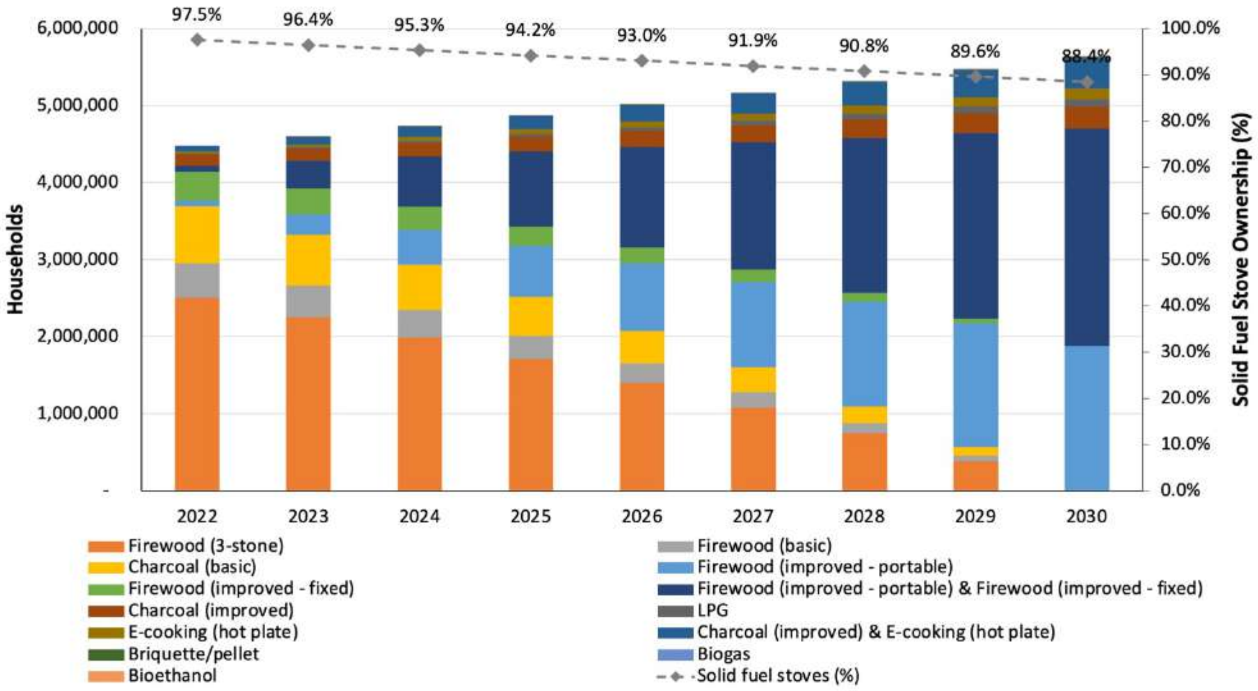
Results and Findings

Malawi SDG7 Cleaner Cooking Energy Compact

Improved Cookstove Expansion Scenario

- Meeting Compact 2030 goals will require considerable strategic planning and centralized policy incentives as well as mobilization of private sector actors to enhance multiple modalities of improved cooking technology.
- This project models an improved cookstove (ICS) expansion plan to reach 2030 Compact goals with some consumers owning one stove and others stacking.
- This will include additional fuel sources and expansion of e-cooking, LPG, and biofuels within the country. Currently available fuels and technologies in Malawi were considered, and if markets open to more and newer technologies, this could permit further gains by alternative fuels.
- Nevertheless, Compact goals still expect significant biomass utilization in 2030 with an estimated 88.4% of households continuing to use firewood, charcoal, or briquette/pellet fuel.
- Primary data collected from rural customers showed a high use of cookstoves for space heating, nearly two-thirds of surveyed households across the three regions. This presents a challenge to shift completely away from three-stone fires and basic wood stoves in rural areas that would often be overlooked in energy plans focused just on "cooking" rather than "cooking stove uses".

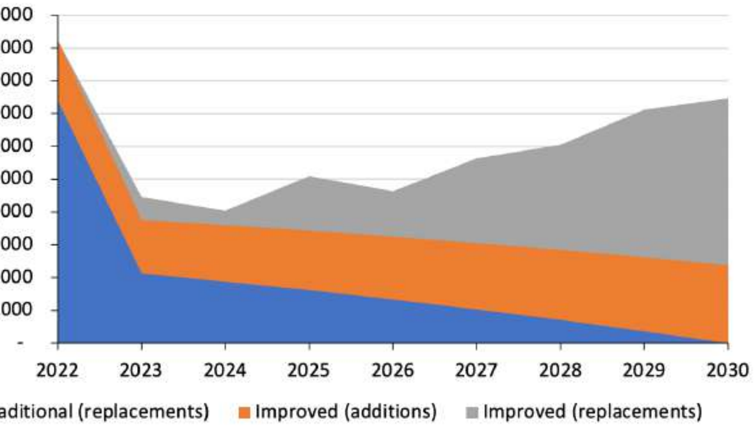
PROJECTED OWNERSHIP OF CLEANER COOKING SOLUTIONS



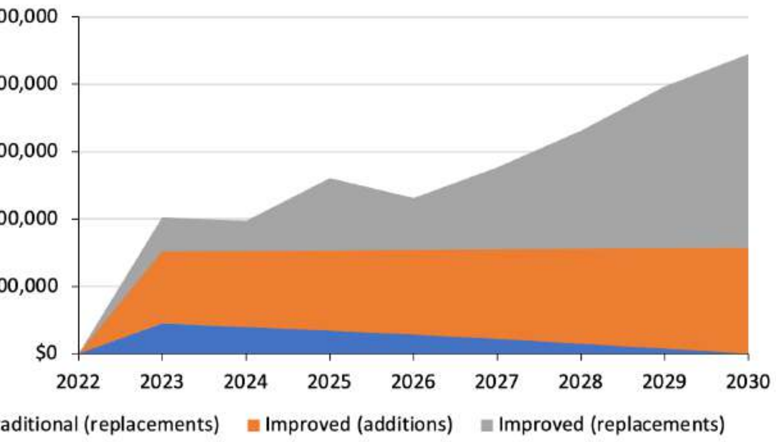
Stove Production and Financial Requirements

- Traditional, non-improved, biomass stoves do not phase out overnight. Consumers must replace those technologies at their own expense until production volumes, market forces, and policy drivers can enable access to improved stoves.
- Year-on-year growth targets for ICS volumes need to approach 21%, on average, over the 2030 time horizon to meet quotas for new and existing customers. This will require significant investment in local stove production and imported stoves, and enhanced supply chains to reach rural areas, to hit volume requirements and also reduce cost to address affordability challenges stated as the main barrier to ICS adoption for over half of the respondents surveyed in this study.
- There is also a significant financial challenge to reaching 100% clean cooking access due to the low durability of improved cookstoves available in Malawi[1] today. The provided scenario shows a $108.8M investment is needed to reach 2030 Compact targets, comprised of $52.7M for new customers and $56.1M for improved cookstove customers that need their device replaced due to degradation and failure at the expected end of life. This suggests emphasis is needed on more durable and longer lasting ICS, with both national and global investment and standards, to enhance manufacturing techniques and quality control that reduces costs of reaching 2030 goals and closes the affordability gaps for customers by reducing annualized costs of ICS access.
- For 2022 data, the distribution of improved stoves and clean fuel access in the northern region is far less than central and southern regions. This suggests the Northern region needs additional resources, strategic planning, programs, financial incentives, and systematic actions to enhance access to cleaner cooking stoves to approach 2030 goals of 100% access across the country.

STOVE PRODUCTION ESTIMATES



STOVE FINANCIAL ESTIMATES

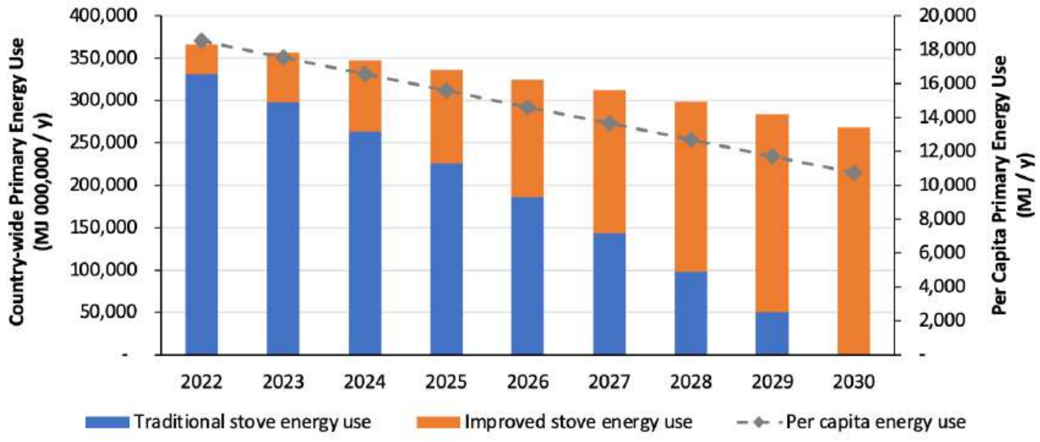


1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

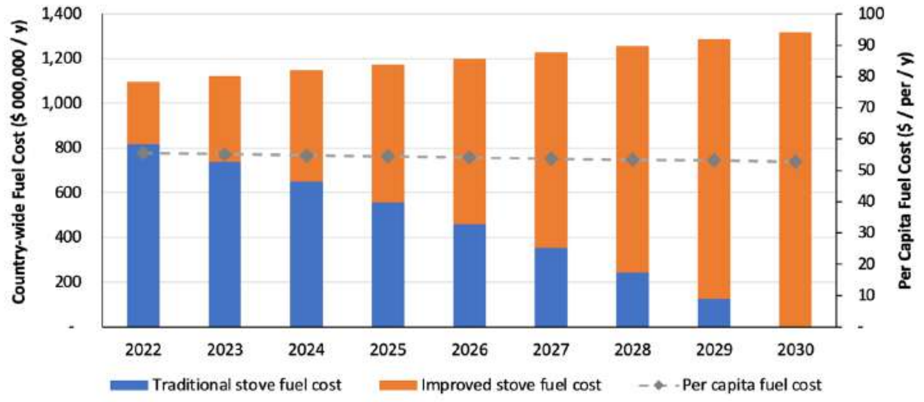
Energy Use and Fuel Cost

- Reaching 2030 Compact targets will reduce primary energy use for cooking by 26.8%, and per capita energy use by 42.0% (accounting for population growth[1]). This is directly attributed to fuel switching from solid fuel to alternative fuels and stoves with higher efficiency, and from efficiency improvements in improved wood stoves over traditional stoves.
- Over the same period, firewood use is reduced by 38.8% per capita and charcoal use by 68.5% per capita. This significant change occurs due to more efficient wood and charcoal stoves, and switching to alternative fuels such as electricity and LPG.
- Fuel cost projections assume a consistent fuel price across the region this can be updated to reflect regional differences if such data become available.
- Even after accounting for efficiency gains of e-cooking and other alternative fuel stoves, total fuel costs increase from 2022 to 2030 as households shift away from very inexpensive wood and charcoal use. This produces a near flat per capital fuel cost from 2022 to 2030 after accounting for population growth.

PRIMARY ENERGY USE PROJECTIONS FOR COOKING TECHNOLOGIES



FUEL COST PROJECTIONS FOR COOKING TECHNOLOGIES



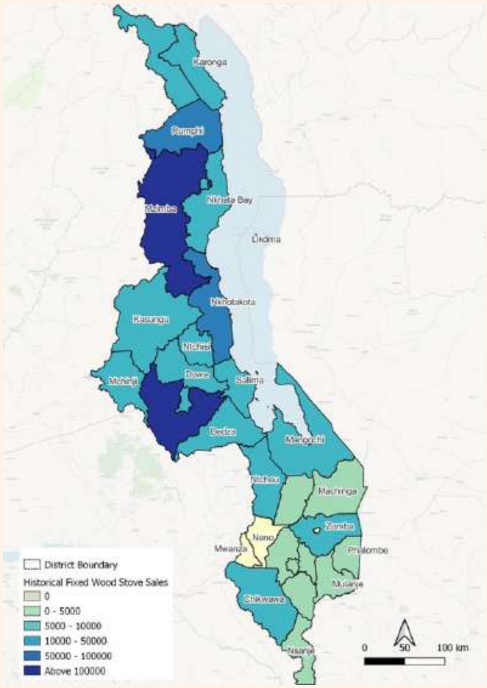
1. National Statistical Office of Malawi.

Improved Wood Stoves (per district)

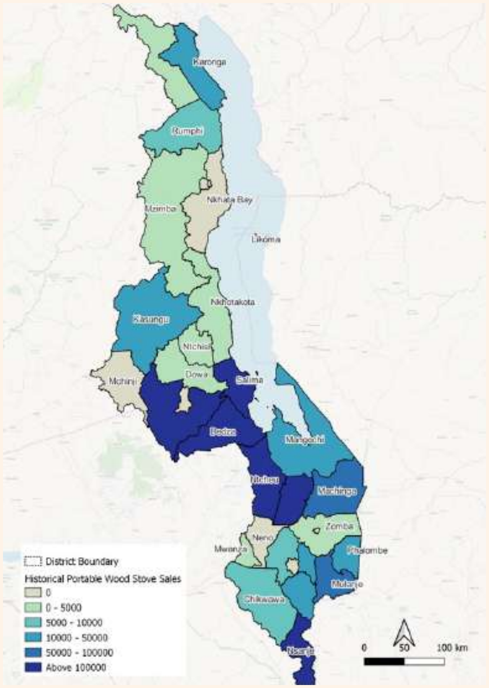
These maps shows the stove ownership of improved wood stoves per district in 2022 as well as the projection for 2030, based on the estimated 83.3% improved wood stove users in the Compact target.

Distribution of improved wood stove ownership (2022)

FIXED IMPROVED WOOD STOVE

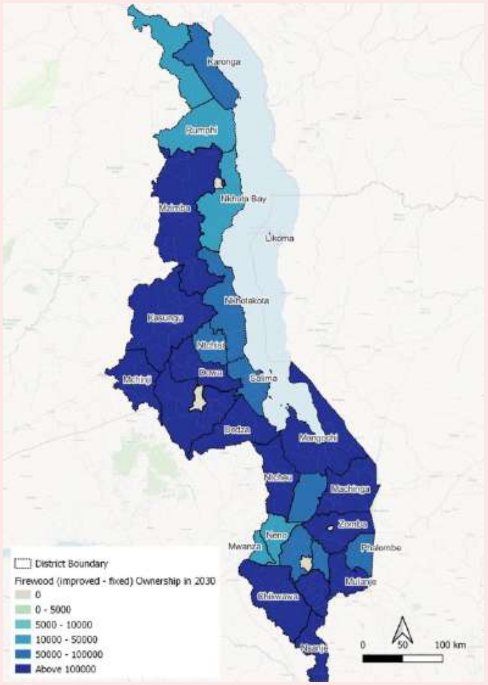


PORTABLE IMPROVED WOOD STOVE

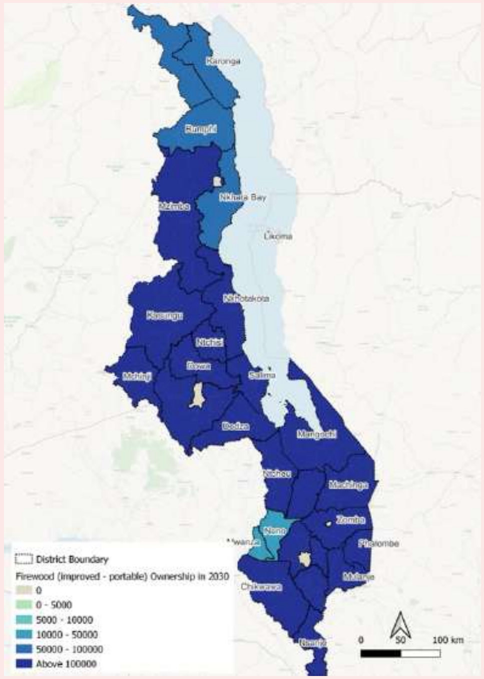


Distribution of improved wood stove ownership (2030)

FIXED IMPROVED WOOD STOVE



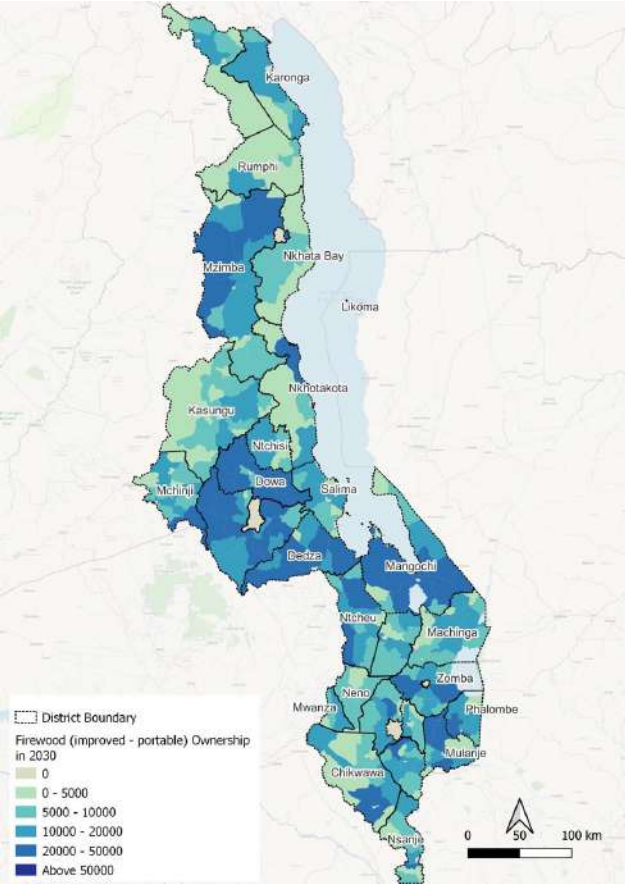
PORTABLE IMPROVED WOOD STOVE



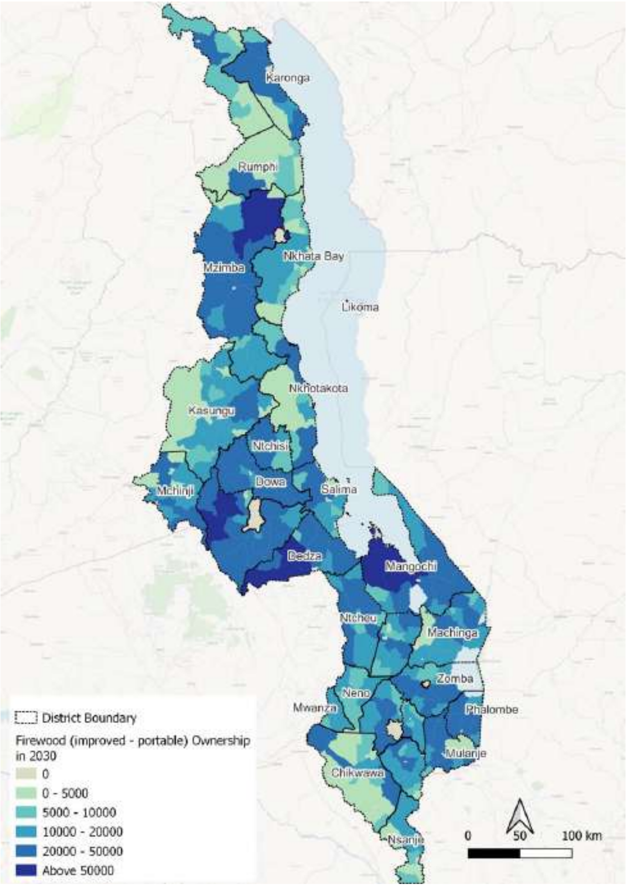
Improved Wood Stoves (per TA)

- Improved firewood stoves target rural regions per Compact goals, with an expected 4.7M households owning an improved portable firewood stove (on left) and 2.8M households owning an improved fixed firewood stove (on right).
- Cookstove stacking occurs with all fixed stove owners also owning a portable wood stove to be aligned with the Malawi SDG7 Cleaner Cooking Energy Compact.
- Replacement of portable firewood stoves will be a challenge given the low lifetime of such stoves, and by 2030, an expected 2.34M stoves will need to be replaced each year (half of the households that own portable firewood stoves) due to the low durability and two-year lifetime.

DISTRIBUTION OF FIXED IMPROVED FIREWOOD STOVE OWNERSHIP (2030)



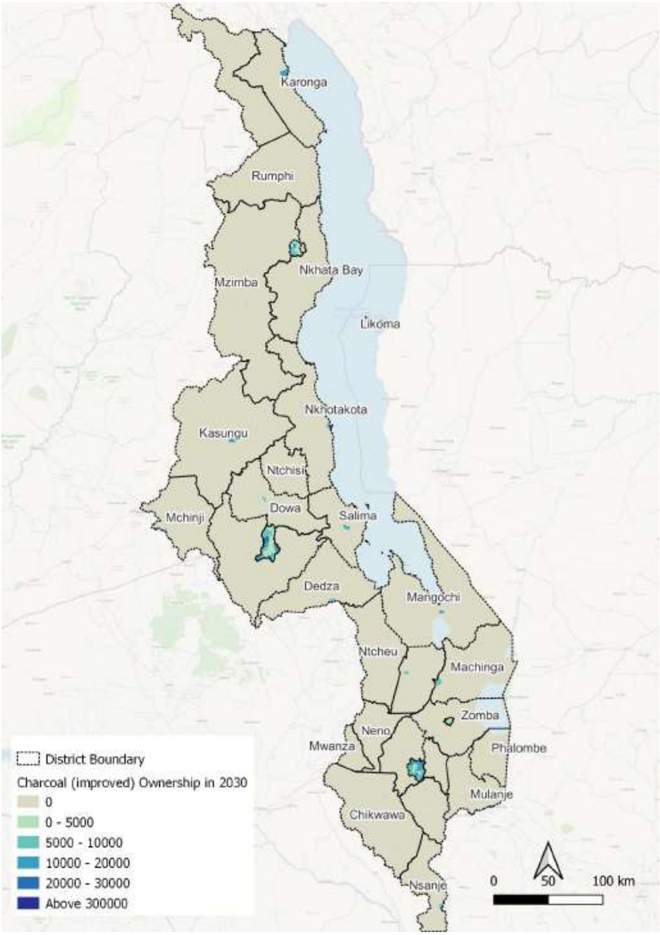
DISTRIBUTION OF PORTABLE IMPROVED FIREWOOD STOVE OWNERSHIP (2030)



Improved Charcoal Stoves

- Charcoal users in 2022 use a mix of basic and improved charcoal stoves that represent 21.5% of all households, which reduces to 12.1% of all households to meet 2030 Compact goals. All households shift from basic to improved charcoal stoves in the Compact. The higher efficiency stoves can save approximately 40% in charcoal, which has direct and positive benefits to reducing wood harvesting. Rural households are expected to shift completely away from meeting 2030 Compact goals.
- Urban households using only improved charcoal stoves are estimated to be 284k in total. Households using both improved charcoal and e-cooking solutions is expected to be more common, with an estimated 397k practicing cookstove stacking.
- Similar to portable wood stoves, portable charcoal stoves have a two-year lifetime and existing production volumes and import targets should be evaluated to discern if stove production can be ramped up to reach 237k replacements each year by 2030.
- Improved, high-efficiency charcoal stoves can be paired with sustainably produced charcoal to reduce the negative impact on the environment. Licensed charcoal production will also enable regulators to monitor charcoal quality and wood harvesting practices and potentially collect taxes or fees.
- Improved kilns can reduce input wood use by up to 30% over traditional earthen or soil covered kilns[1]. Training programs on kiln fabrication and subsidies for improved kilns can have an immediate and long-term impact on wood usage for charcoal production.

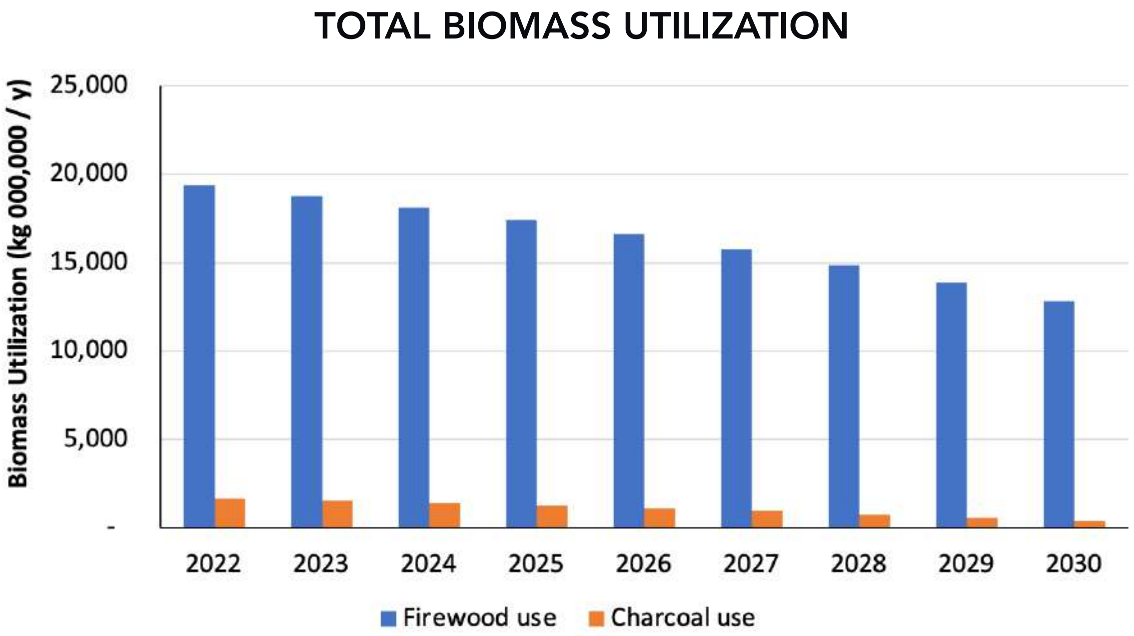
IMPROVED CHARCOAL STOVE OWNERSHIP (2030)



1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

Biomass Utilization

- Reaching the 2030 goals outlined in the Malawi Cleaner Cooking Compact will create a 34.1% reduction in firewood utilization and a 77.3% reduction in charcoal utilization.
- Charcoal use is reduced more significantly as existing urban customers on a basic charcoal stove switch to an improved charcoal stove or alternative cooking fuels such as e-cooking, LPG, bioethanol, biogas, and briquette/pellet fuel.
- These fuel savings will have multiple co-benefits including end user affordability, improved public health (air quality), reduced deforestation, less time spent gathering/purchasing fuel, and reduced emissions.
- These substantial reductions in fuel expenditures and biomass consumption represent a material positive impact on economic productivity for Malawi and its residents.



E-Cooking (Grid-connected Homes)

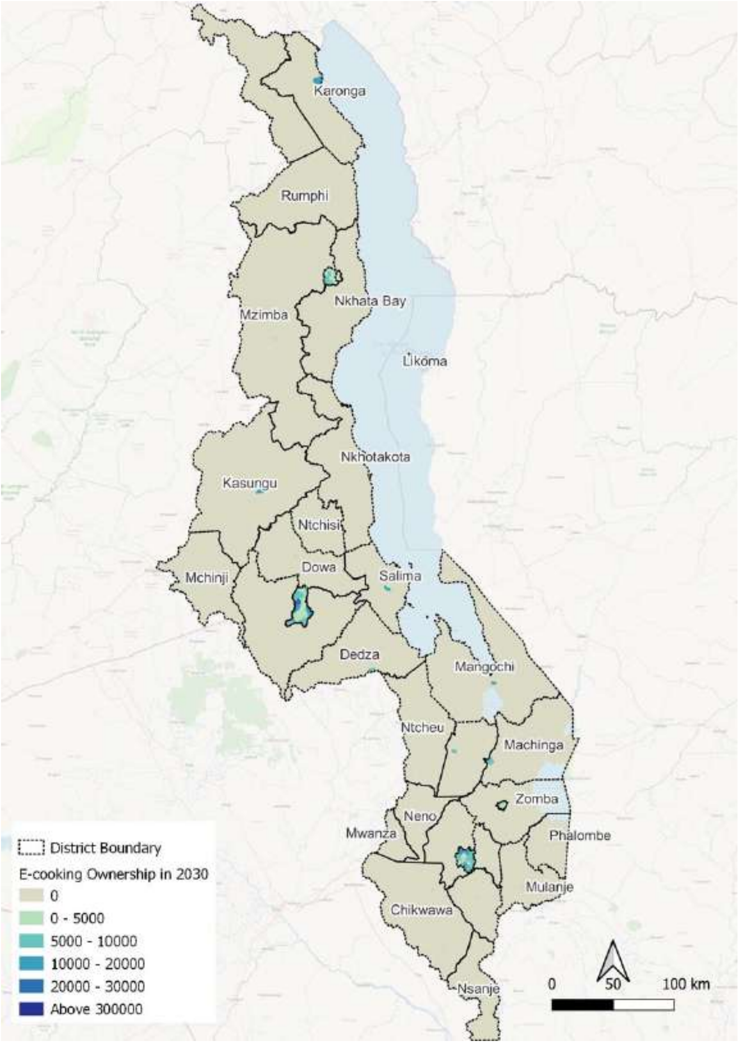
- The Compact envisions 10% electricity access in Malawi by 2030 and sets a target for 15% of urban households utilizing only e-cooking in their homes. In also considering the assumption that 42% of urban households may use both improved charcoal and e-cooking solutions, the number of households with e-cooking would have to increase from the estimated 95,000 households in 2022 to 539,000 in 2030 in order to reach the Compact targets.
- Similarly, the total energy use for e-cooking would increase from 218 GWh / year in 2022 to 1,324 GWh / year in 2030. While this number accounts for efficiency differences between stove types and stove stacking behaviors, the numbers do not reflect differences in energy use behaviors (e.g., meal preferences, using less energy to heat water, purchasing ready-to-go items in the city that don't require energy in the home, waste heat co-benefit for space heating) between urban vs. rural and hence should be used as an order of magnitude estimate.
- The increase in electricity demand due to e-cooking utilization will occur in urban and peri-urban areas. These increases are anticipated to be accommodated within the proposed grid densification and grid expansion capacity of the ESCOM network. Electricity demand increases associated with e-cooking are within the design tolerance of distribution transformers and LV conductors selected in the electrification analysis and design. Specifically, new distribution transformers in the model are designed not to exceed 50% loading based on 2030 load projections. Nevertheless, e-cooking adoption may lead to changes in daily and seasonal load profiles during mealtimes as well as increased generation requirements for the national grid.

Presently, the market for electric cooking (e-cooking) in Malawi is severely constrained by the level of electricity access, quality of service, supply of e-cooking appliances, and affordability of electricity for cooking. Therefore, presently e-cooking accounts for a very small percentage of all cooking in urban areas, and very little cooking activities in rural areas.

The Malawi IEP projection of 100% electricity access by 2030 shows far greater e-cooking potential than the 10% electrical access assumed in the Compact.

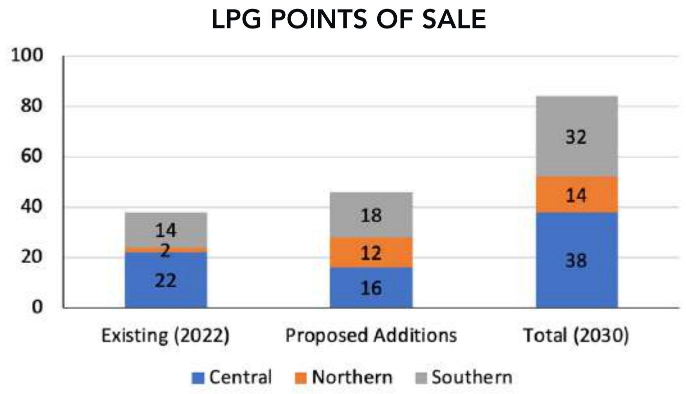
The increased e-cooking will contribute to increased electricity consumption and higher peak demand correlating with evening mealtimes. These results will, in turn, impact electrification planning.

E-COOKING STOVE OWNERSHIP (2030)



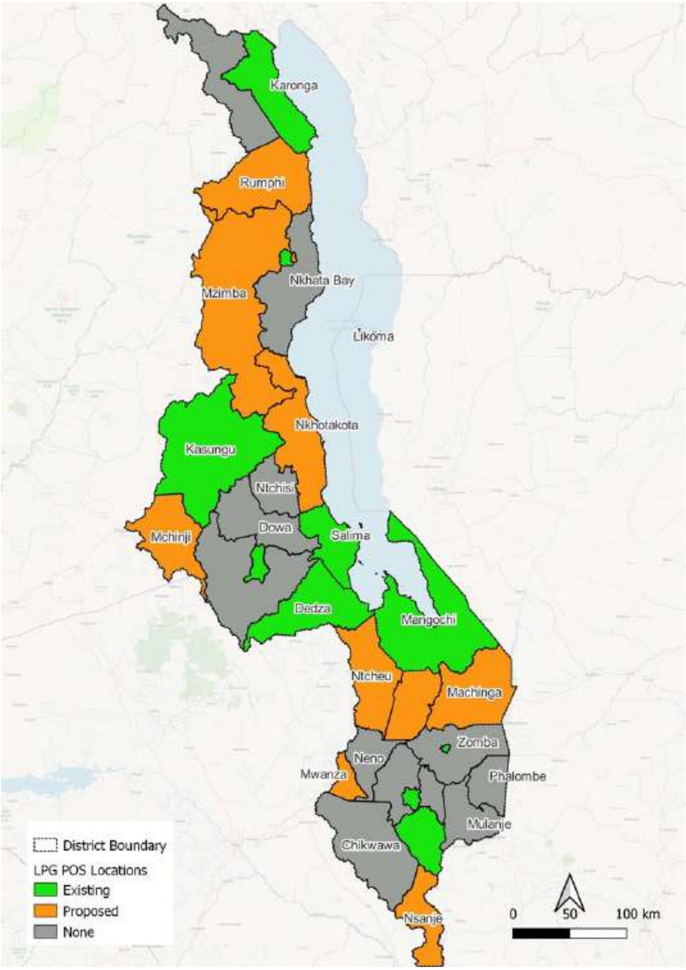
LPG (1 of 2)

- Currently there are 38 LPG points of sale (POS). Assuming that POS locations increase linearly with the 15% annual growth in LPG sales, this would require an additional 46 points of sale (84 in total) to be distributed across the country to maintain the same volumes sold per sales point.
- Reaching all urban customers would require LPG distribution points in 30 districts. This is far greater than the 10 districts today that have LPG points of sale. A more efficient approach would be to densify and expand LPG access in more densely urban regions to (1) add capacity and (2) improve marketing and incentive programs in districts with existing points of sale. This approach will keep LPG distribution points to a more reasonable number of 19 districts total to simplify supply chain considerations to spread LPG adoption across the country.
- POS additions are similar in each region, though the Northern region needs the most attention to increase from 2 in 2022 to 14 in 2030.



- Existing points of sale in 2022 have a potential market size of between 31,000 and 274,000 local urban customers per point of sale.
- Densifying POS in existing urban areas and expanding to new urban areas can target 30,000 to 70,000 urban customers per point of sale.
- This approach would provide LPG access to 9 additional districts, bringing the total to 19 districts, and provide a similar level of LPG accessibility (or coverage) as shown on next slide.

EXISTING AND PROPOSED LPG POINT OF SALE LOCATIONS (2022)

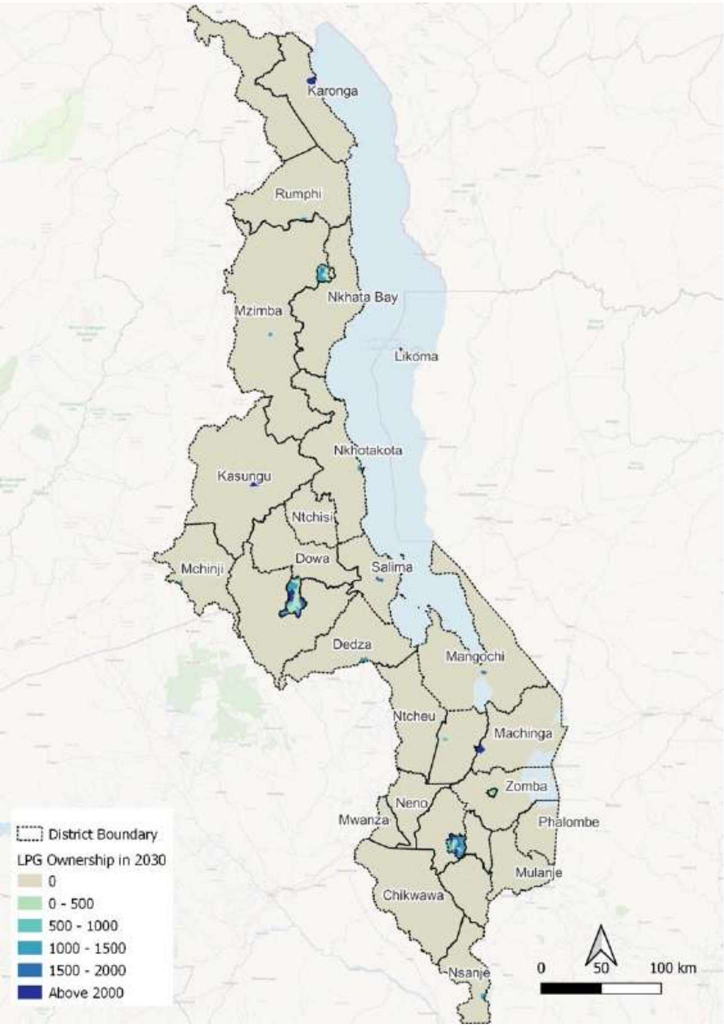


LPG (2 of 2)

- LPG ownership expands from 14,657 households in 2022 to 94,564 households in 2030 as districts add proposed LPG sales capacity.
- Priority is first given to expanding urban markets with existing LPG sales and supply chain in years 2022-2026, and then subsequently adding new supply chain capacity and POS to regions of the country that do not presently have LPG access.

							LPG POS additions (2022 is existing numbers)								
Region	District	Existing POS	Additional POS	Total POS	Market Potential 2022 (people / POS)	Market Potential 2030 (people / POS)	2022	2023	2024	2025	2026	2027	2028	2029	2030
Central	Lilongwe City	19	11	30	60,965	52,034	19	1	2	2	1	2	1	1	1
Southern	Blantyre City	11	10	21	78,744	48,327	11	1	1	2	1	1	1	2	1
Northern	Mzuzu City	1	8	9	273,338	46,258	1	3	2	2			1		
Southern	Zomba City	1	2	3	122,494	49,749	1	1				1			
Southern	Mangochi	1	1	2	76,799	50,957	1				1				
Southern	Thyolo	1		1	25,077	29,382	1								
Central	Salima	1	1	2	71,544	46,742	1				1				
Southern	Machinga		2	2		25,456	-	1				1			
Central	Ntcheu		1	1		29,080	-						1		
Central	Mchinji		1	1		36,460	-						1		
Central	Kasungu	1	1	2	66,226	41,622	1				1				
Central	Dedza	1		1	31,882	39,764	1								
Southern	Balaka		1	1		69,945	-			1					
Southern	Nsanje		1	1		34,818	-					1			
Northern	Mzimba		1	1		32,154	-						1		
Central	Nkhotakota		1	1		41,290	-			1					
Northern	Rumphi		1	1		29,884	-				1				
Northern	Karonga	1	2	3	71,679	30,740	1			1			1		
Southern	Mwanza		1	1		30,985	-			1					
Totals		**38**	**46**	**84**			**38**	**7**	**5**	**10**	**6**	**6**	**7**	**3**	**2**

LPG STOVE OWNERSHIP (2030)

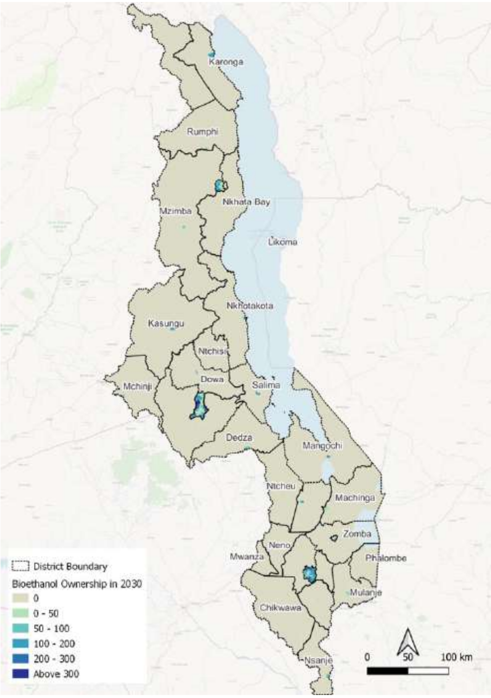


Other Alternative Fuels

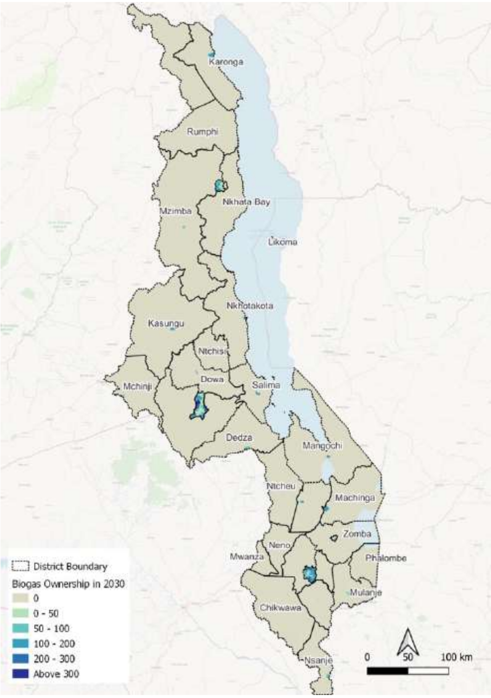
The 2030 Compact sets a 3% adoption target of urban households to use other alternative fuels such as bioethanol, biogas, and biomass pellet/briquette cooking technologies. Assuming each cooking technology is adopted evenly, a total of 9,456 households will adopt each cooking technology to reach Compact targets.

No supply chain considerations are present in the Compact to bring biofuels from rural to urban customers. Rural utilization of such fuels is not targeted and underutilized.

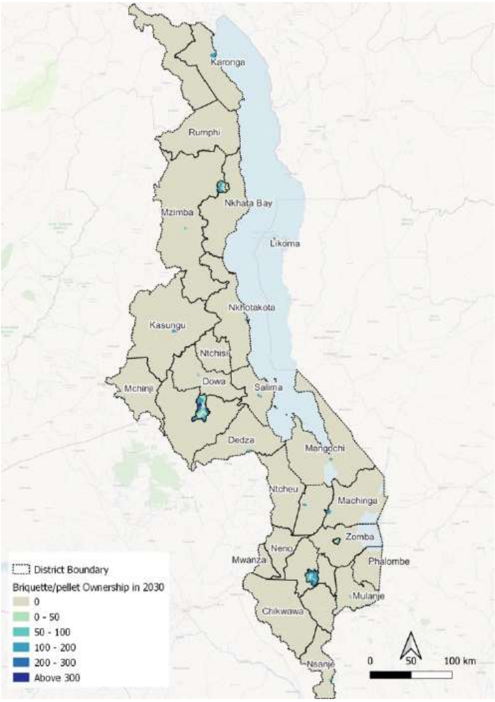
BIOETHANOL STOVE OWNERSHIP (2030)



BIOGAS STOVE OWNERSHIP (2030)



PELLET/BRIQUETTE STOVE OWNERSHIP (2030)



MALAWI IEP – CLEAN COOKING

Results and Findings

Additional Malawi IEP Scenario

Additional Cooking Technology Opportunities

- Additional opportunities were evaluated to identify the potential for each modern and alternative cooking technology. Results are summarized here and detailed in the following slides. Results are not an optimization or least-cost illustration, and instead show the potential for each technology separately, to guide future study on production- cost modelling, market study, and location-specific deployment plans.
- If summing the potential for each technology separately, the total potential households that could be served with modern cooking technologies (20,291,176) exceeds the number of households in the country (5,646,737) in 2030. This suggests a deep opportunity for strategic growth of alternative fuels, as illustrated by the numbers on the right showing differences between Compact Targets and IEP Potential.
- The geospatial results on the next slides go further to highlight the spatial distribution of the potential (for a single technology or multiple technologies).
- This information informs guided dialogue with stakeholders for potential updates or extensions to the Compact targets, and suggests additional assessment, including production cost stove/fuel supply chains.

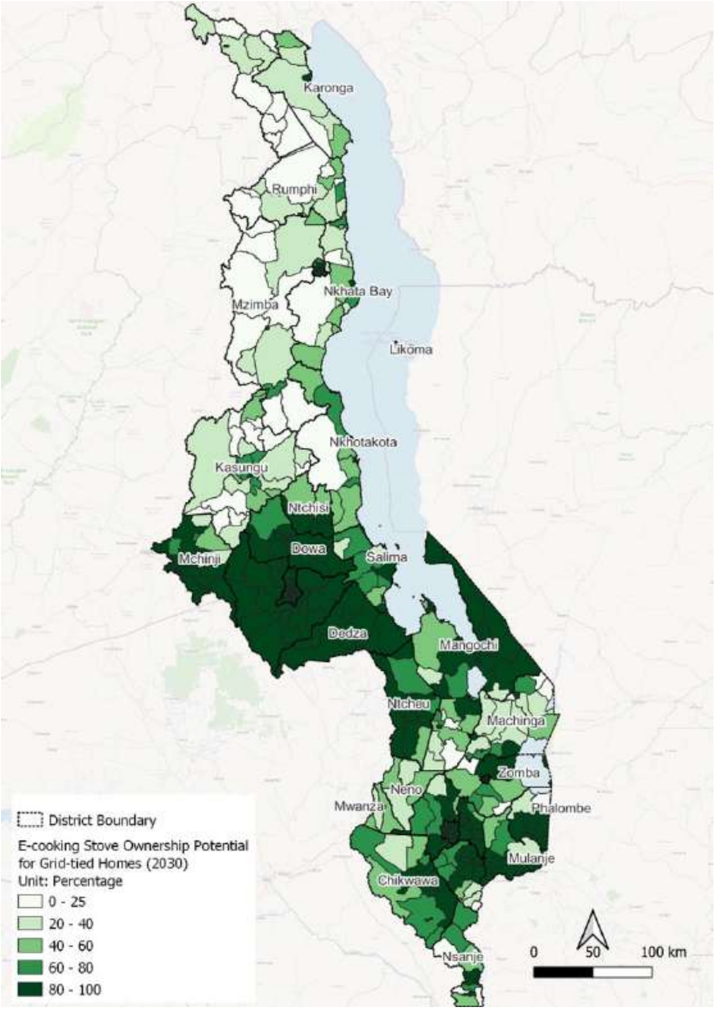
Cooking Technology	Compact Target (HH count)	IEP Potential (HH count)
E-cooking	539,014	4,126,638
LPG	94,564	94,564
Bioethanol	9,456	8,783,711
Pellet/Briquette	9,456	5,686,843
Biogas	9,456	1,599,420

The compact e-cooking target includes households with only e-cooking and those that participate in stove stacking (e-cooking + improved charcoal).

E-Cooking (Grid-connected Homes)

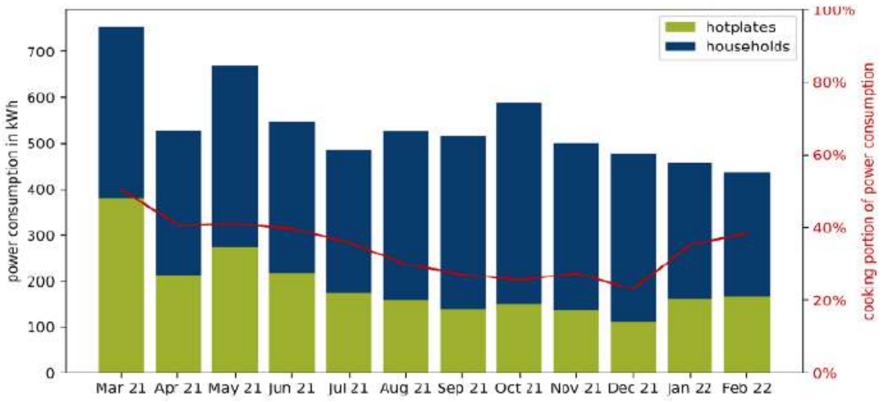
- A total of 4,126,638 households are estimated to become grid-connected by 2030 under the IEP universal electricity access scenario. The IEP Scenario assumes that all e-cooking users are grid connected due to the far lower electricity cost for those households relative to households with mini-grid or SHS systems.
- The graph on the right shows the share of HH per TA with a higher potential for e-cooking.
- Central and Southern regions show a higher amount of homes that are grid-connected in 2030. This represents potentially promising trends for e-cooking prevalence and scale.
- Alternative fuels could have more impact in northern regions, where population density is lower and electrification is potentially more reliant on off-grid technologies, at least in the near term. This is further supported when noting the potential of bioethanol and briquette/biomass, which concentrate largely in the north and north-central, as illustrated in future slides.

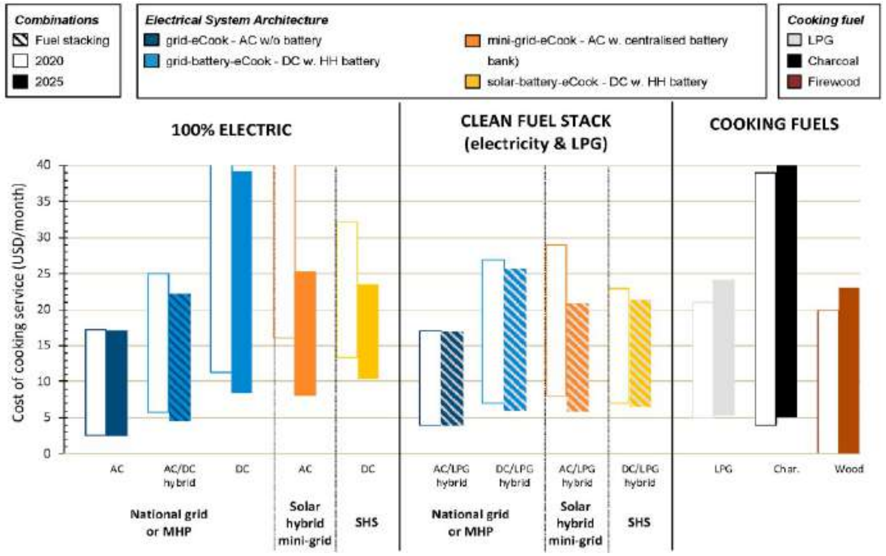
E-COOKING STOVE OWNERSHIP POTENTIAL (2030)



E-Cooking (Off-grid Considerations)

- There is no target for e-cooking among rural households in the Compact because the Compact assumes rural households do not become electrified, and while the IEP electrification study plans 100% electrical access, there are customers with mini-grids and SHS that are expensive for e-cooking relative to improved solid fuel stoves. Yet some emerging opportunities for off-grid e-cooking do exist.
- Based on a recent study from 2021-2022, e-cooking on a mini-grid in Malawi varied from 22% - 50% of total household energy consumption[1]. To accelerate off-grid e-cooking, it would be possible to subsidize incremental increases to mini-grid generation infrastructure to support clean cooking demand and/or to modify mini-grid tariffs for e-cooking users.
- Another innovation in Malawi is a standalone solar kit optimized for e-cooking[2]. The SHS utilizes Lithium-Ion Titanate (LTO) battery to provide more rapid charging/discharging with less degradation and better performance in higher temperatures. The costs of SHS E-cooking remains higher than many conventional fuels, but will decline over time. Costs of high-performance batteries such as LTO are also expected to decrease and may become accessible for low-income off-grid customers. Pay-as-you-go systems may also enhance access to customers stating affordability constraints to ICS use.
- For the IEP Scenario, this study continues to assume that no mini-grid or SHS utilize e-cooking due to the cost of cooking relative to firewood or other alternative fuels such as bioethanol, biogas, pellets/briquettes.





1. Earles et al. “Opportunities and challenges for eCooking on mini-grids in Malawi: case study insight.” Atmosfair and University of Strathclyde, Glasgow, UK, 2022.

2. Leary et al. “Battery-supported e-cooking: A transformative opportunity for 2.6billion people who still cook with biomass.” Energy Policy, vol 159, 2021.

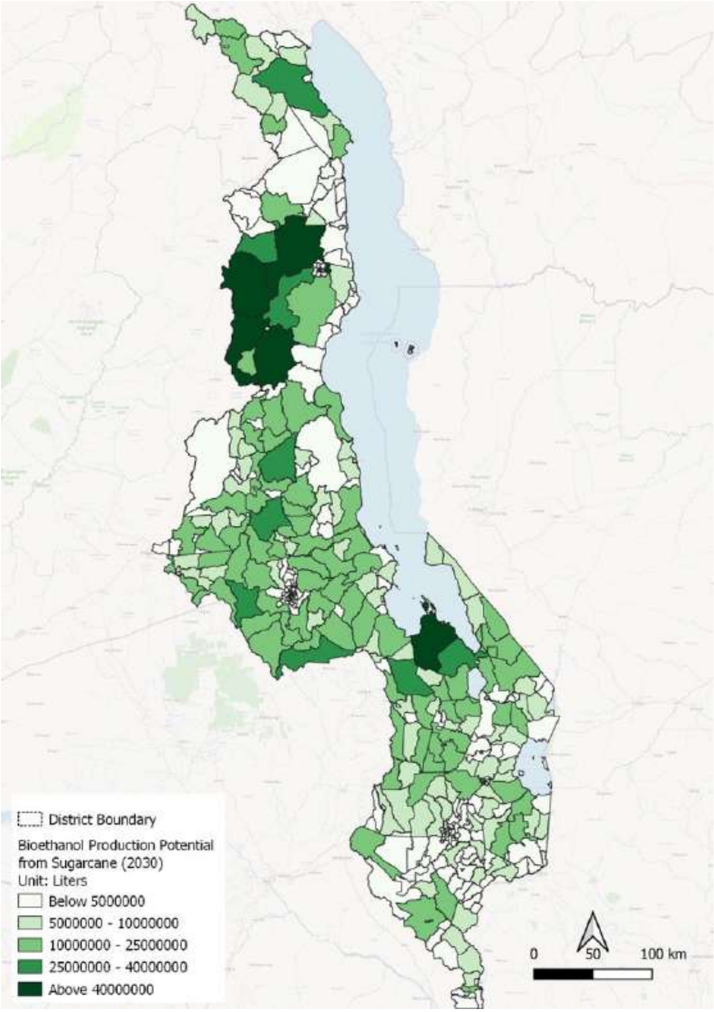
Bioethanol (1 of 2)

- Rural areas have the highest density of cropland. Ethanol potential for the country is sizable, with most dense concentrations in the Northern region and remaining sugarcane output spread across Central and Southern regions.
- Sugarcane is presently the only crop used to produce ethanol and is considered here as the upper limit in ethanol supply (figure on left). Other crops are shown in table as theoretical illustrations for ethanol potential but are prioritized as food staples in Malawi and many regions of the world and are hence not allowed or uncommonly used to produce ethanol.

2022 Ethanol Potential				
Crop	**Volume (liters)**	**Energy (MJ)**	**Percentage (%)**	**Households (count)**
Sugarcane	2,420,572,821	55,189,060,322	26.9%	2,031,667
Maize	1,449,426,810	33,046,931,268	16.1%	1,216,552
Rice	71,443,575	1,628,913,510	0.8%	59,965
Sorghum	45,598,020	1,039,634,856	0.5%	38,272
Cassava	3,096,500,500	70,600,211,400	34.4%	2,598,995
Sweet Potato	1,639,655,251	37,384,139,727	18.2%	1,376,217
Potato	290,210,104	6,616,790,369	3.2%	243,583
Total	**9,013,407,081**	**205,505,681,452**	**100.0%**	**7,565,251**

2030 Ethanol Potential				
Crop	**Volume (liters)**	**Energy (MJ)**	**Percentage (%)**	**Households (count)**
Sugarcane	2,665,728,436	60,778,608,352	25.5%	2,237,434
Maize	1,534,980,330	34,997,551,517	14.7%	1,288,360
Rice	74,243,896	1,692,760,827	0.7%	62,315
Sorghum	49,156,858	1,120,776,361	0.5%	41,259
Cassava	3,577,461,001	81,566,110,823	34.2%	3,002,682
Sweet Potato	2,175,963,767	49,611,973,887	20.8%	1,826,358
Potato	387,572,708	8,836,657,745	3.7%	325,303
Total	**10,465,106,996**	**238,604,439,512**	**100.0%**	**8,783,711**

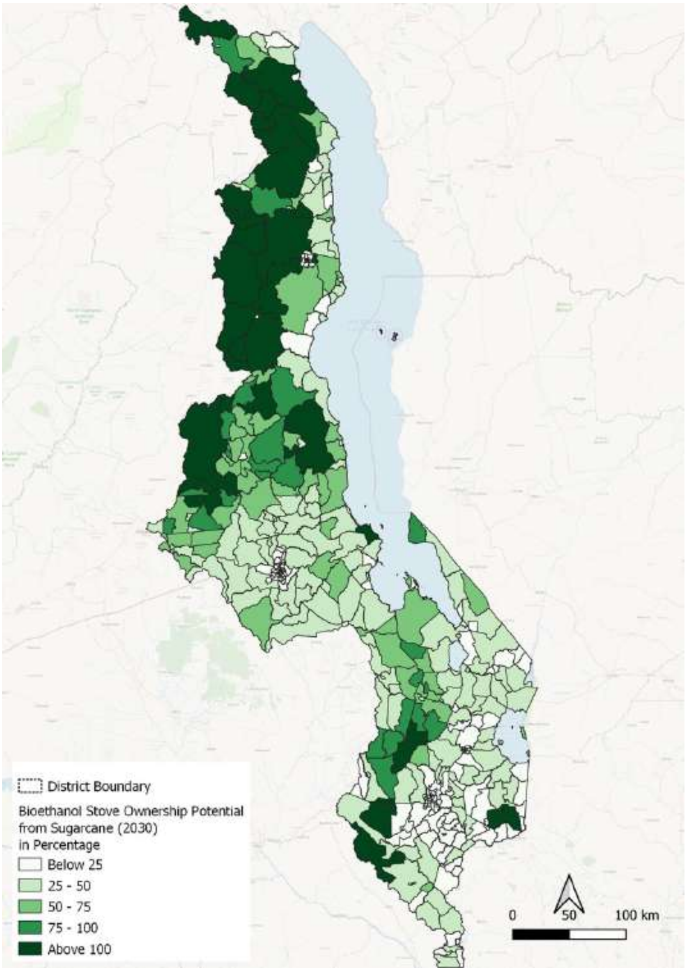
BIOETHANOL PRODUCTION POTENTIAL FROM SUGARCANE (2030)



Bioethanol (2 of 2)

- The Compact assumes ethanol use in cities but none in rural areas, presenting supply chain considerations that need to be addressed alongside the review of production volumes completed here. The figure on left does not constrain use to cities, and instead illustrates what percentage of households could be served by briquette/pellet within the TA boundary that sugarcane is available to produce ethanol.
- Total households that can be served with ethanol fuel far exceeds the target set forth in the 2030 Compact of 9,456 HH, illustrating potential to expand the bioethanol fuel sector and use of alternative fuels to meet 2030 goals.
- Nevertheless, bioethanol expansion may be challenged due to costs relative to other national energy priorities, or may not be permissible to divert food stuffs away from addressing food insecurity and nutritional needs.
- Geospatial information (on left) can inform placement of production facilities in which supply availability meets or exceeds demand for cooking energy.
    - Northern region can be prioritized with a bioethanol facility to match location of sugarcane availability with potential demand.
    - Central and Southern regions can follow next noting some TAs with high agricultural waste output relative to population.

BIOETHANOL STOVE OWNERSHIP POTENTIAL OF TOTAL HOUSEHOLDS (2030)



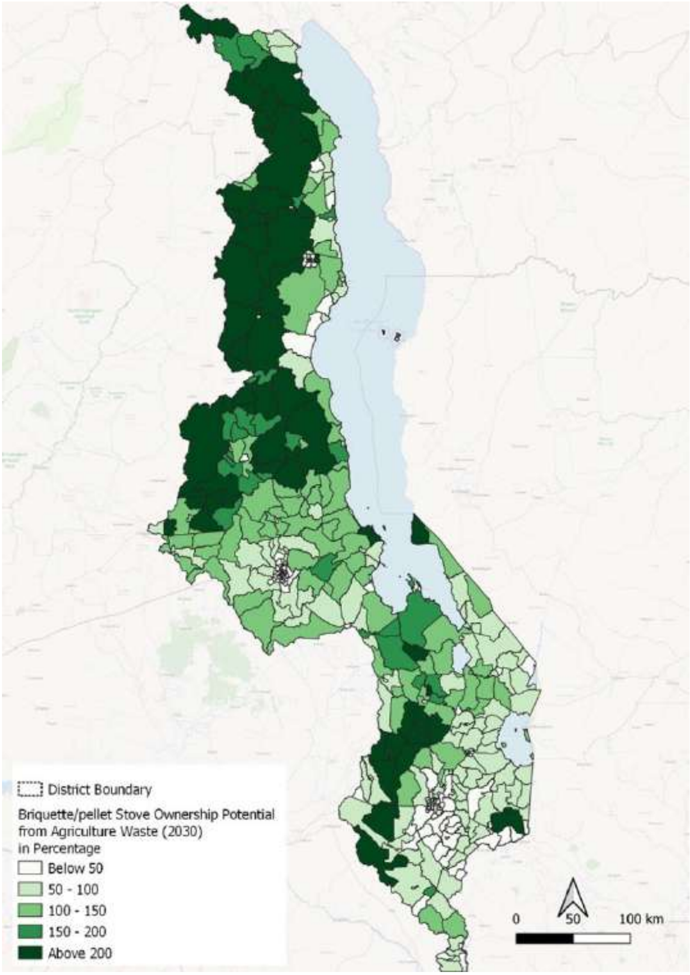
Briquette/Pellet (1 of 2)

- Rural areas have the highest density of cropland with a variety of crops (noted below). Maize produces a considerable amount of ag waste in the stalk, husk, and cob.
- Depending on the crop, agricultural waste is available on the farm or at an agro-processing facility. Production models can be designed to capture, transport, and pelletize different agricultural wastes based on the location of waste, volume, weight, as well as the scale of the operation needed to match demand with available supply.

	2022 Ag Waste Potential		
Crop	**Energy (MJ)**	**Percentage (%)**	**Households (count)**
Sugarcane	33,707,513,923	16.6%	835,201
Maize	88,326,761,839	43.5%	2,188,550
Rice	2,631,569,788	1.3%	65,205
Sorghum	688,820,919	0.3%	17,068
Groundnut	2,380,478,464	1.2%	58,983
Cassava	42,982,112,225	21.2%	1,065,006
Sweet Potato	27,267,658,600	13.4%	675,635
Potato	5,070,057,720	2.5%	125,625
Total	**203,054,973,478**	**100.0%**	**5,031,273**

	2030 Ag Waste Potential		
Crop	**Energy (MJ)**	**Percentage (%)**	**Households (count)**
Sugarcane	37,121,410,933	16.2%	919,790
Maize	93,540,316,126	40.8%	2,317,731
Rice	2,734,717,481	1.2%	67,761
Sorghum	742,582,070	0.3%	18,400
Groundnut	2,758,009,925	1.2%	68,338
Cassava	49,658,261,068	21.6%	1,230,427
Sweet Potato	36,186,531,944	15.8%	896,626
Potato	6,771,011,672	3.0%	167,771
Total	**229,512,841,218**	**100.0%**	**5,686,843**

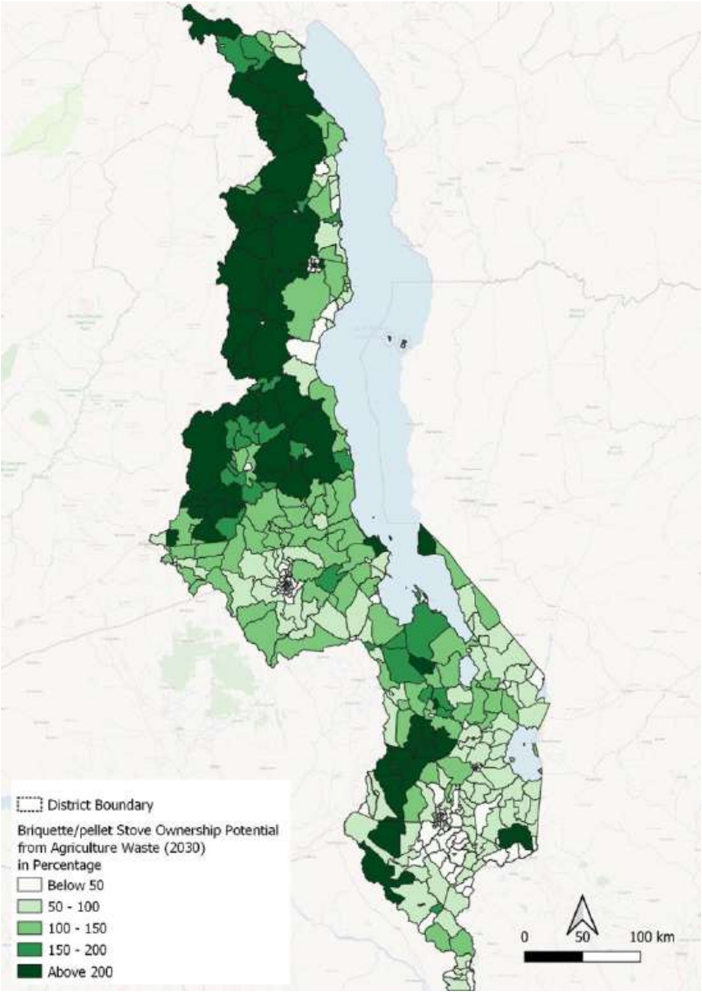
BRIQUETTE/PELLET PRODUCTION POTENTIAL FROM AGRICULTURE WASTE (2030)



Briquette/Pellet (2 of 2)

- The Compact assumes briquette/pellet use in cities but none in rural areas, presenting supply chain considerations that need to be addressed alongside the review of production volumes completed here. The figure on left does not constrain use to cities, and instead illustrates what percentage of households could be served by briquette/pellet within the TA boundary that agricultural waste is available.
- Total households that can be served with pellets or briquettes made from agricultural waste far exceeds the target set forth in the 2030 Compact of 9,456 HH, illustrating potential to expand the ag waste fuel sector and use of alternative fuels to meet 2030 goals. Noting this upper limit assumes all agricultural waste could be diverted.
- These fuels are potentially readily available with less capital-intensive supply chains than biogas, for example, and can contribute materially towards clean and renewable cooking solutions by diverting agricultural byproducts, generally without impacting food supply.
- Geospatial information (on left) can inform placement of production facilities in which supply availability meets or exceeds demand for cooking energy.
  - Northern region can be prioritized with a palletization or briquette facility
  - Central can follow next noting some TAs with high agricultural waste output relative to population
  - South has limited amounts of agricultural waste to serve the population in the region.

BRIQUETTE/PELLET STOVE OWNERSHIP POTENTIAL OF TOTAL HOUSEHOLDS (2030)

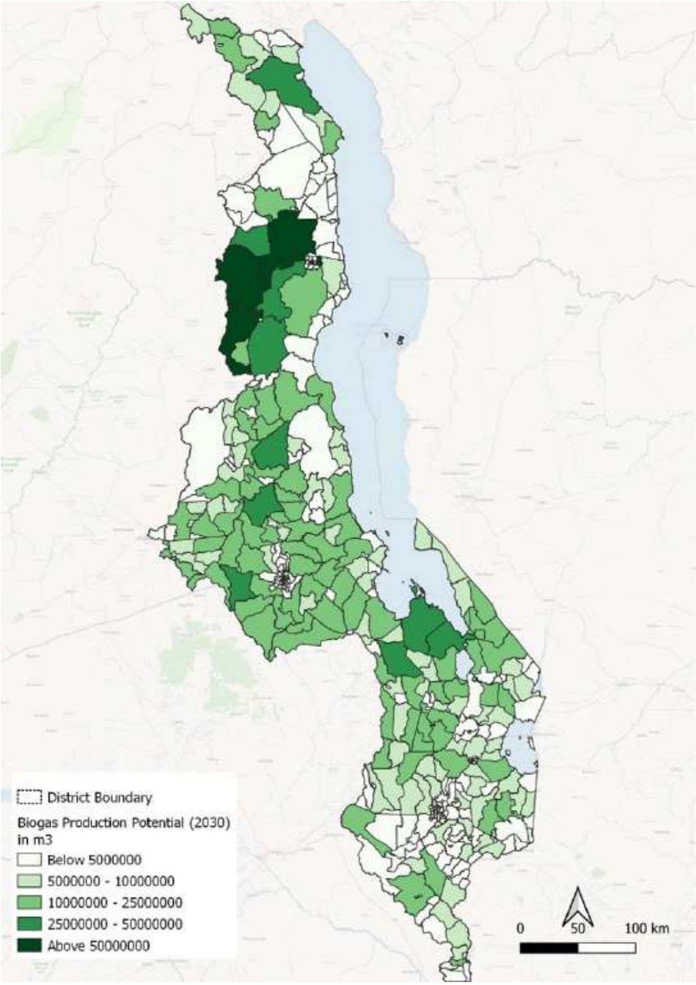


Biogas (1 of 2)

- Presently, biogas availability will be limited to rural areas where livestock is located, but the 2030 Compact states that biogas be used only in urban areas and not rural areas. The specific target for urban households in the Compact is 3% alternative fuels, including biogas. The goal could be adapted to also prioritize biogas in rural areas, while focusing on LPG adoption and other alternative fuels for urban areas. That would avoid supply chain challenges of transfer biogas from a rural producer to an urban consumer.
- Livestock concentrations are expected to follow similar geospatial trends as pellet fuel and bioethanol, all concentrated in regions with greater farmland area.
- Cattle and pigs provide the greatest biogas production potential. Other animals, though numerous, contribute far fewer amounts of methane.

2022-2030 Biogas Potential				
Crop	Volume (m3)	Energy (MJ)	Percentage (%)	Households (count)
Cattle	846,578,393	33,641,332,191	65.5%	1,047,905
Goats	62,947,507	2,501,408,017	4.9%	77,917
Sheep	26,096,987	1,037,042,074	2.0%	32,303
Pigs	303,177,601	12,047,671,495	23.5%	375,277
Chickens	6,678,805	265,402,368	0.5%	8,267
Guinea fowl	6,678,805	265,402,368	0.5%	8,267
Turkey	33,297,233	1,323,165,431	2.6%	41,216
Duck	6,678,805	265,402,368	0.5%	8,267
Total	**1,292,134,136**	**51,346,826,313**	**100.0%**	**1,599,420**

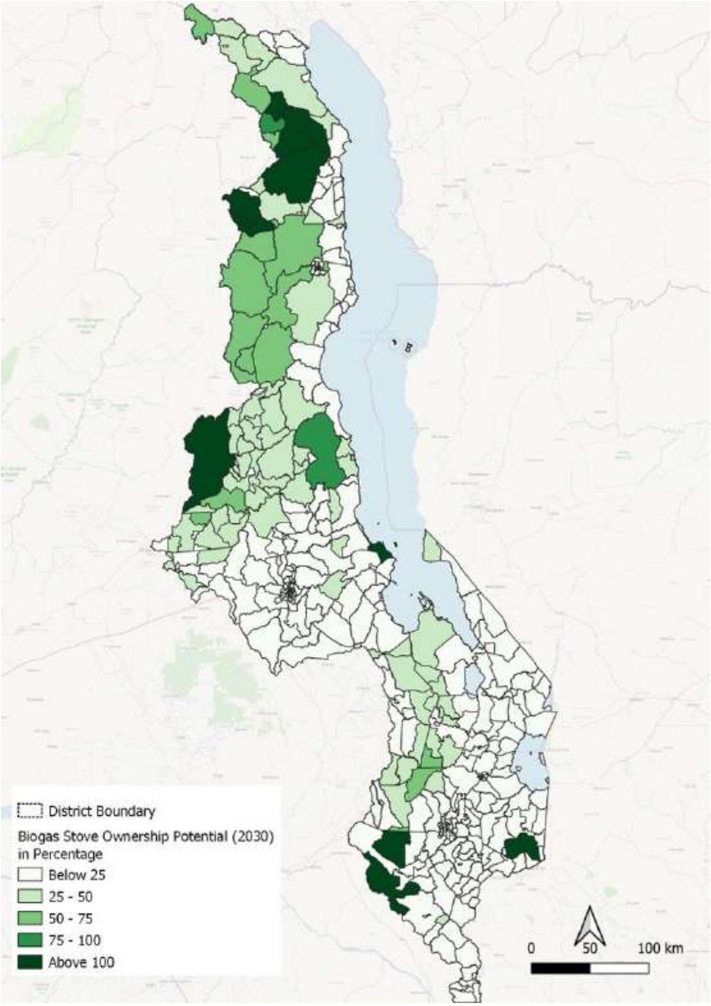
BIOGAS PRODUCTION POTENTIAL FROM LIVESTOCK WASTE (2030)



Biogas (2 of 2)

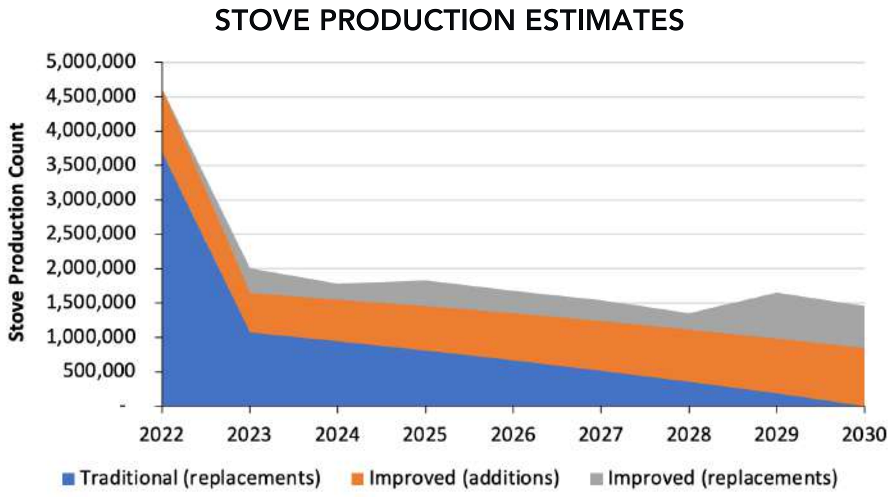
- The Compact assumes biogas use in cities but none in rural areas, presenting supply chain challenges to migrate gas from rural areas to urban areas.
- Total households that can be served biogas from livestock waste exceeds the target set forth in the 2030 Compact of 9,456 HH, though it is not as extreme as for bioethanol or pelletized fuels.
- A few TAs in each region contain sufficient livestock relative to population to suggest focused, local efforts could target those areas for family-sized or town-sized biogas units. These are spaced across all regions, with slightly higher concentrations observed in northern and central regions.

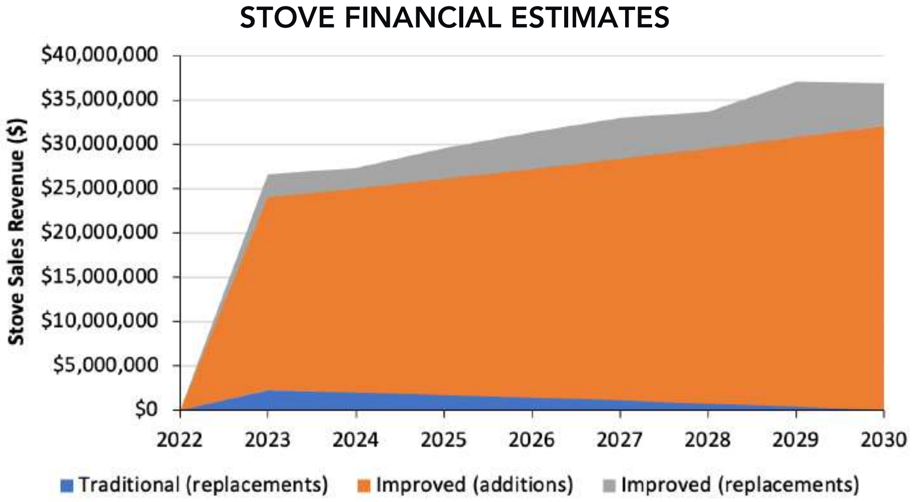
BIOGAS STOVE OWNERSHIP POTENTIAL OF TOTAL HOUSEHOLDS (2030)



Stove Production and Financial Requirements

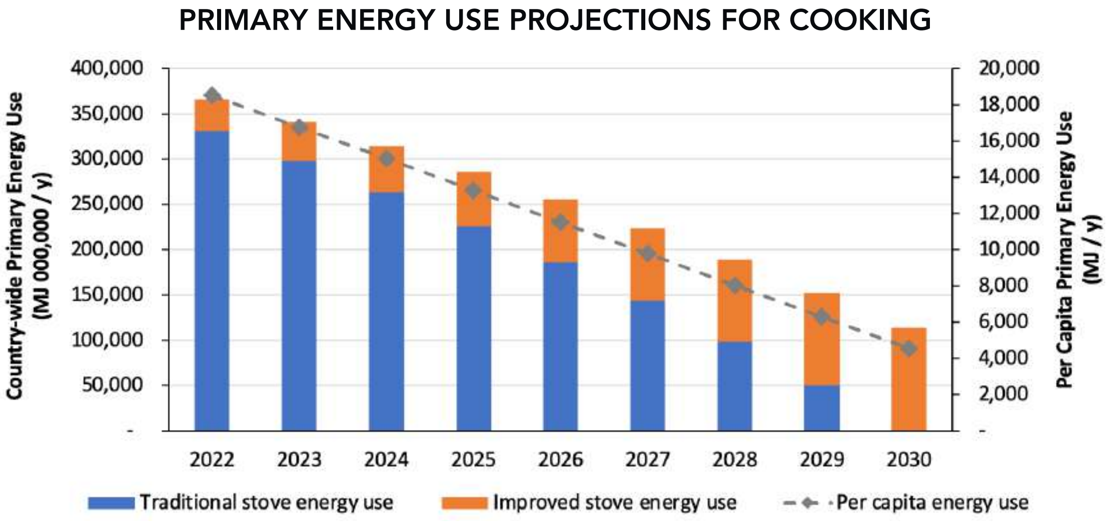
- The IEP scenario shows far fewer stove production volumes per annum because of the preference for modern cooking technologies that have longer lifetimes (durability). This means that the replacement of cooking stoves is greatly decreased.
- Stove financial estimate for sales price is higher than the baseline Compact scenario. The newer and modern cooking technologies have a higher unit price, and as such, the addition of modern cooking technologies in the IEP scenario creates a higher program cost of $246.0M as compared to $108.8M in the Compact Scenario.
- The improved durability of stoves in the IEP scenario presents a cost breakdown of $213.5 for new stoves and only $32.5 for replacements over the 8-year period from 2022 to 2030.

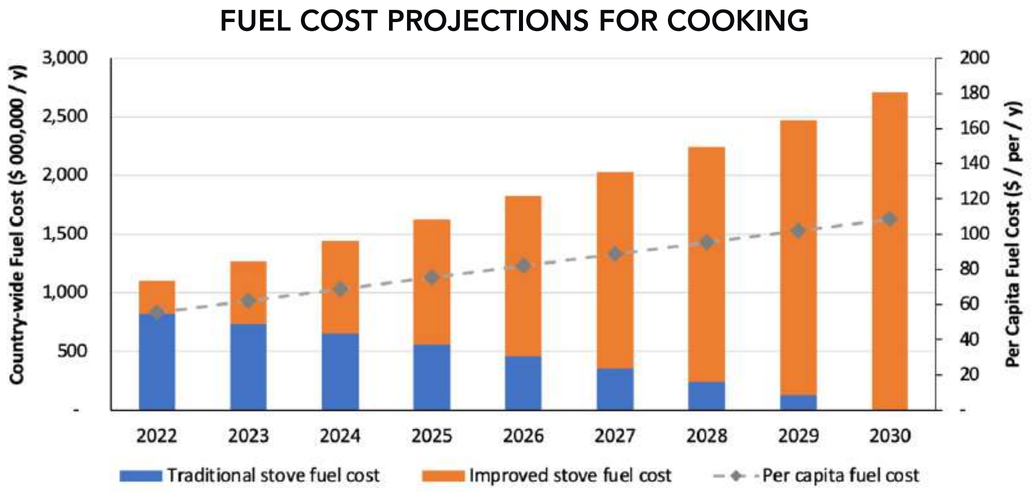




Energy Use and Fuel Cost

- Reaching the IEP Scenario targets will reduce primary energy use for cooking by 69.0% and per capita energy use by 75.4% (accounting for population growth[1]). This is directly attributed to fuel switching from solid fuel to alternative fuels and stoves with higher efficiency, and from efficiency improvements in improved wood stoves over traditional stoves.
- Over the same period, firewood use and charcoal use is completely phased out in favor of e-cooking, LPG, bioethanol, pellets/briquettes, and biogas.
- Fuel cost projections are higher under the IEP scenario because customers use cleaner, modern fuels that cannot be collected freely and are higher priced than wood or charcoal. The per capita fuel cost increases by approximately 50% over the 8-year program period (accounting for population growth[1]).

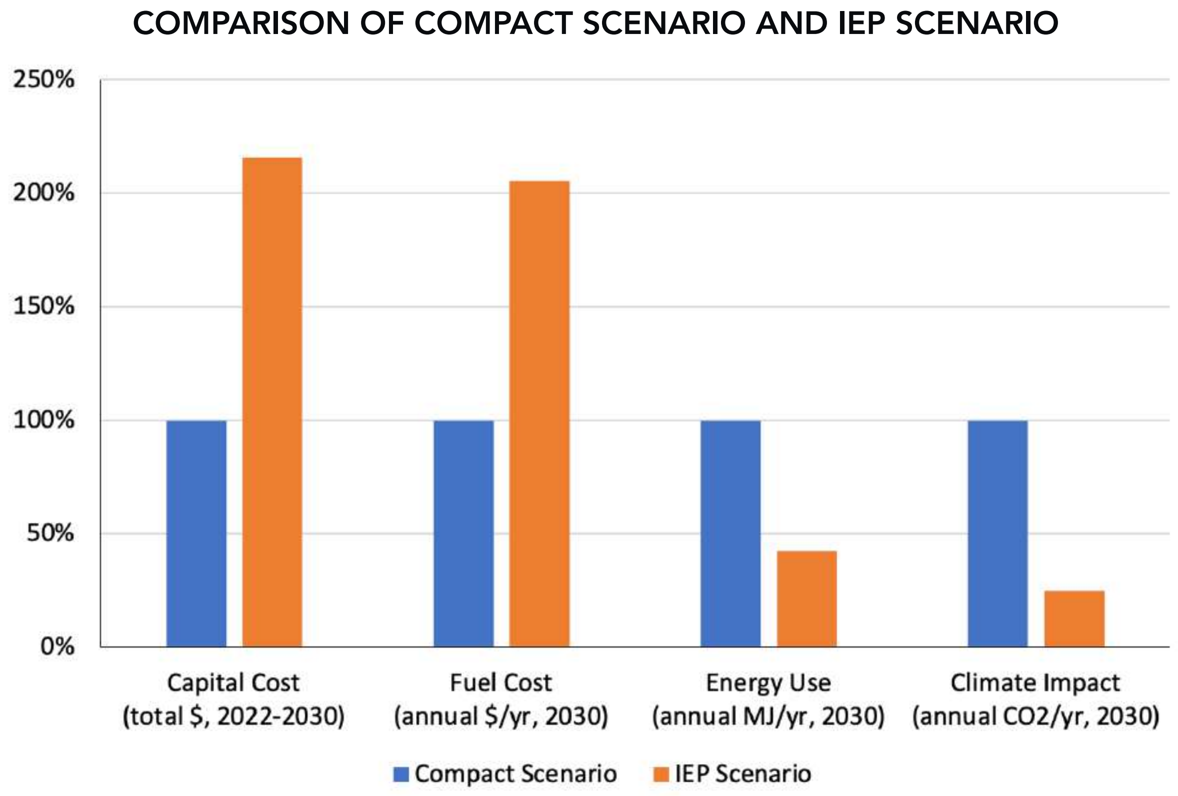




1. National Statistical Office of Malawi.

Comparison of Baseline Compact Scenario and IEP Scenario

- The graph on right shows a comparison of potential outcomes for the Compact Scenario and IEP Scenario, with results displayed relative to the Compact Scenario.
- Capital costs are given as the total programmatic cost for new stoves and replacement stoves over the duration 2022-2030. Although replacement stoves occur far less under the IEP scenario, the cost of modern stoves are higher, as reflected in the increased relative program cost.
- Fuel costs are higher in the IEP Scenario primarily due to the increased utilization of e-cooking.
- Energy use and climate impact is significantly improved under the IEP scenario, with a 68% and 75% improvement, respectively.
- Gender considerations are similarly improved by transitioning from improved biomass stoves to more modern cooking technologies that require no utilization of time to collect wood or produce charcoal.



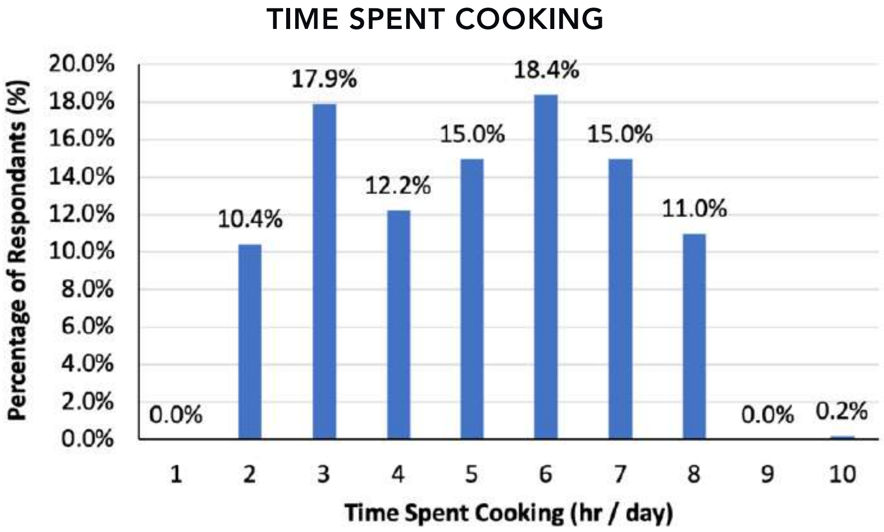
MALAWI IEP – CLEAN COOKING

Co-benefits

Gender Considerations

Time savings

- Rural women who use firewood stoves can expect to reduce 20-50% time spent collecting wood after switching to more efficient firewood stoves. This could represent a time savings of 50-125 hours per year for each household[1].
- Alternative fuels that have an instant ignition (LPG, bioethanol, biogas) or faster ignition process (e-cooking) than solid fuel stoves can also reduce cooking time.



Reduced illness and morbidity

- The reduction in cooking exhaust will improve indoor air quality for improved health of women and children as a result of cleaner and safer cooking technologies.

Income generation and entrepreneurship

- Gender programs should expand focus beyond cooking to include other aspects of the cookstove and fuel value chain – stove production, marketing, sustainable charcoal production, financial management or money lender for stove purchase, liaison or program manager between electricity and cooking industries, entrepreneur utilizing improved stoves (e.g., street vendor), trainer to introduce improved cookstoves to institutional settings, and other necessary professions to the stove industry.
- Gender inclusion programs in the workforce can also significantly enhance country GDP[2].

Photo Sources: (top) https://offset.climateneutralnow.org/biomass-energy-conservation-programme?searchResultsLink=%2Fallprojects%3Fspecs%3D436, (bottom) Nathan Johnson

1. Johnson, N. G., & Bryden, K. M. (2012). Energy supply and use in a rural West African village. Energy, 43(1), 283-292.
2. Woetzel, J. (2015). The power of parity: How advancing women's equality can add $12 trillion to global growth (No. id: 7570).

Health Impacts

- Health impacts are estimated as a function of the fine particulate matter (PM2.5) that can reach deep into the respiratory system. Reducing PM2.5 exposure can avert deaths and reduce disability-adjusted life years (DALYs).
- Each stove/fuel combination produces its own amount of PM2.5, and this value can be used to estimate a variety of health impacts[1]. PM2.5 production from stoves is assumed to yield 240 mg exposure / kg emitted for outdoor cooking and 1300 mg exposure / kg emitted for indoor cooking[2]. Exposure is given for individuals in the cooking vicinity.
- Non-solid fuels show greatly reduce PM2.5 emissions. Improved ventilation and forced draft stoves can reduce health impacts by reducing PM2.5 exposure.
- The IEP Scenario will significantly reduce PM2.5 exposure by advancing electric and LPG stoves for urban areas, and advancing briquette/pellet, biogas, and bioethanol for rural areas.

	Health Exposure (PM2.5/day/person)	
Fuel (stove)	Outdoor	Indoor
Firewood (3-stone)	26.7	139.1
Firewood (basic)	14.9	77.6
Firewood (improved)	13.8	71.9
Firewood (improved - portable)	13.8	71.9
Firewood (improved - fixed)	12.4	64.7
Charcoal (basic)	29.8	154.7
Charcoal (improved)	17.5	91.0
Briquette/pellet	28.5	148.1
Biogas	0.1	0.5
Bioethanol	0.1	0.4
LPG	0.1	0.3
E-cooking (hot plate)	0.0	0.0
E-cooking (induction)	0.0	0.0

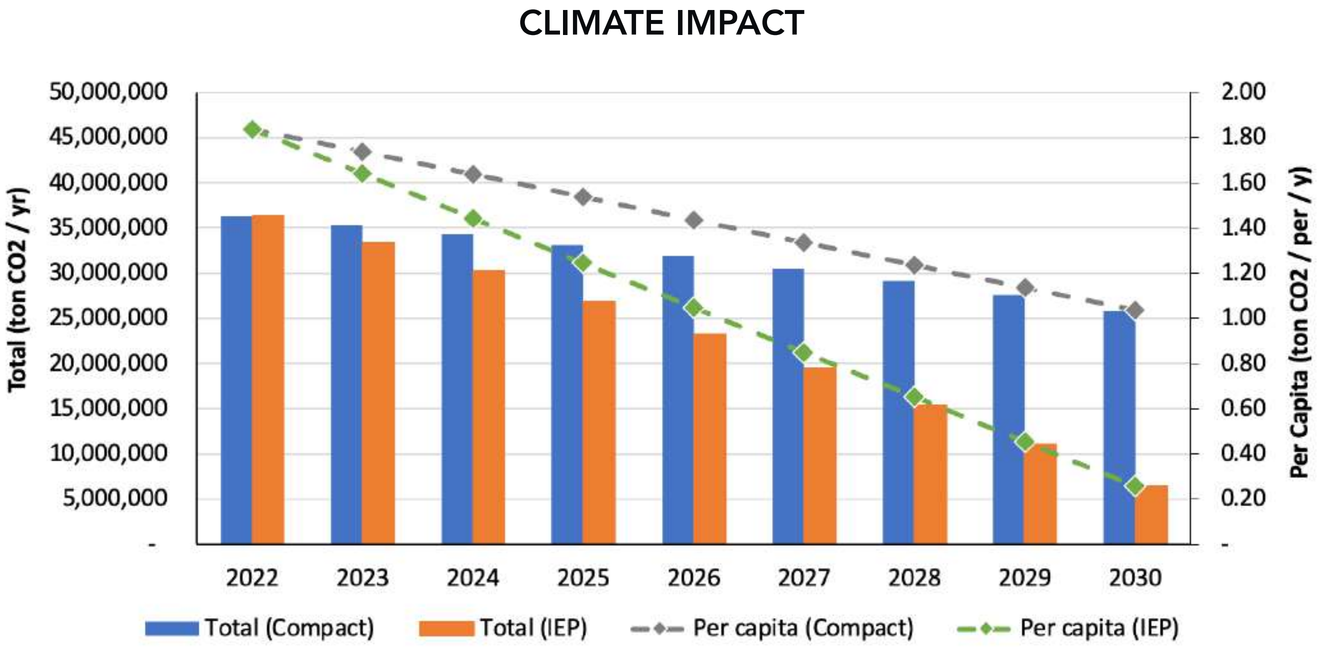
2030 Compact Goals will avert 16,600 deaths and 933,800 DALYs per year, relative to continued use of solid fuels and cooking technologies.
2030 IEP Goals will avert 30,609 deaths and 1,689,361 DALYs per year, relative to continued use of solid fuels and cooking technologies.

1. Pillarisetti, A; Mehta, S; Smith, KR. HAPIT, the Household Air Pollution Intervention Tool, to evaluate the health benefits and cost-effectiveness of clean cooking interventions. Ch 10 in Thomas, E., Ed, Broken Pumps and Promises: Incentivizing Impact in Environmental Health, Springer International Press, 2016, pp. 147-169.
2. Climate Economic Analysis for Development, Investment and Resilience. Burnett, Richard; Arden Pope; Majid Ezzati; Casey Olives; Stephen Lim; Sumi Mehta; Hwashin Shin; Gitanjali Singh; Bryan Hubbell; Michael Brauer; Ross Anderson; Kirk Smith; John Balmes; Nigel Bruce; Haidong Kan; Francine Laden; Annette Prüss-Ustün; Michelle Turner; Susan Gapstur; Ryan Diver; and Aaron Cohen. 2014. "An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure." Environmental Health Perspectives. 122(4): 397–403.

Carbon and Emissions Impacts

- The total CO_2 emissions from residential cooking and heating applications would reduce by 28.8% from 2022 to 2030 under the Compact Scenario as households switch to cleaner burning fuels and cooking technologies. The associated per capita improvement is 43.6%, after accounting for population growth.

- The climate impact is further improved under the IEP scenario due to increased utilization of e-cooking, LPG, and cleaner burning bio-based fuels. Total and per capita emissions are estimated to improve by 82.3% and 85.9%, respectively, from 2022 to 2030.



MALAWI IEP – CLEAN COOKING

Recommendations

Recommendations for Malawi (1 of 6)

Recommendations resulting from the primary data collection:

- The responses from the surveyed households indicate a lack of capital and lack of access to finance as barriers for improved cookstove adoption. Suggesting that purchasing plans would be a useful and enabling procurement model to enhance adaptation. This is further supported when noting that three-quarters of rural households observed on a payment plan are paying a friend/relative for the stove rather than obtaining vendor finance or third-party credit.
- Mobile vendors distributing improved cook stoves could play a vital role in reducing this barrier for about one-quarter of rural customers that report market access the main barrier to adopting improved stoves.
- The 2030 Compact goals outline the importance of regulated charcoal for urban customers but provide no guidance for rural customers. Rural district-level or TA-level regulation and business models also deserve attention, as rural customers are likely to maintain some charcoal use.
- Any stove that requires specialized training or sophisticated monitoring could benefit from knowledge reinforcement from peers, advertising materials (e.g., calendars with instructions), or vendor support. The survey suggests that the incidence rate among users that have received training is presently fairly low, even when primarily offered by relatives rather than specialists or technicians.
- Lower fuel prices in the central region promote a higher incidence of purchasing fuel rather than collecting fuel. This could provide an entry point for piloting regulation and monitoring of sustainable firewood and charcoal strategies.
- Stove use for heating occurs in 63.5% of rural homes, and hence a biomass or charcoal stove may be perceived as necessary for heating in addition to ICS unless another solution for heating is provided.
- Heating water for bathing in rural areas is commonly done on a cook stove. Improved stoves need to be capable of holding extra large pots for water heating, or alternative (potentially solar) water heaters need to be implemented to address hot water needs for sanitation.

Recommendations for Malawi (2 of 6)

Recommendations on stoves:

- Commercially available improved cookstoves in Malawi are cited to have low durability[1]. This creates significant waste and supply chain requirements. Year-on-year growth targets for improved cookstoves would need to approach 21%, on average, over the 2030-time horizon to meet stove quotas for new and existing customers. Advancing technical standards and production quality for low-cost improved solutions could greatly reduce program costs and produce significant co-benefits such as stove waste diversion and avoided capital cost. Longer lifetime up to 5 years for portable and alternative fuels stoves, as opposed to 2 years, could reduce the 8-year program budget by 20-40% of total costs. These savings would need to be contrasted against the potentially higher cost of stoves with longer lifetimes.
- Greater emphasis on materials and durability of portable wood stoves can increase lifetime, which would yield long-term and recurring benefits for national clean cooking initiatives. The production volumes needed to meet the demand for stoves for new customers and replace stoves for existing customers is significant. For example, using the 2-year lifetime assumption for portable stoves, a total of 2.55M stoves would need to be replaced annually by 2030, accounting for population growth. This annual replacement need exceeds the total amount of 1.6M portable stoves sold in the last 10 years. To satisfy this exclusively by scaling production is improbable.
- As e-cooking increases, especially in urban areas without sufficient access to LPG, so will customers' electrical consumption. ESCOM's revenue growth due to gains in e-cooking usage may offer synergistic value to fund expansion of electrical access. Nevertheless, tariff analysis will be necessary to ensure that residential electricity rates are affordable for e-cooking households and ESCOM tariffs are cost-reflective. ESCOM may consider offering customized e-cooking tariffs to incentivize electrification of clean cooking. Innovative tariff strategies for e-cooking could also be considered for mini-grid and SHS customers to facilitate e-cooking adoption.
- Stove stacking behaviors exist and are increasingly common. Studies that do not reflect cookstove stacking may significantly underestimate capital costs in cash flow models because they do not reflect common behaviors of owning and using more than one stove. Fuel use and operating costs may similarly have inaccuracies if stove stacking is not considered.

1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

Recommendations for Malawi (3 of 6)

Recommendations on fuels:

- The IEP Scenario with expanded electrical access shows great potential for e-cooking for grid-connected customers, increasing from 539,014 households in the Compact Target to 4,126,638 in the IEP Scenario.
- In addition to the existing sugarcane feedstock for bioethanol production, additional crop sources should be considered and evaluated.
- Inedible crop waste and agro-processing waste from maize and cassava are strong options for production of bioethanol or pelletized biomass. Rice hulls tend to have a higher silica content and create accelerated wear on palletization machinery, which makes rice a less viable feedstock for bioethanol diversification, despite significant rice production potential in Malawi.
- The total households that can be served by sugcarcane ethanol fuel far exceeds the target set forth in the 2030 Compact of 9,456 HH, based on the IEP assessment. Illustrating potential to expand the bioethanol fuel sector and use of alternative fuels to meet 2030 goals, subject to supply chain, public policy, and affordability constraints.
- Cropland covers a significant portion of Malawi. This presents an opportunity for district-scale pelletized biomass using agricultural waste in cropland or from local mills that process grains. Using agricultural waste to make pelletized fuels could be prioritized over biogas and bioethanol options in the near-term to avoid competing with grains as food staples. Pilot projects and early commercial trials can leverage cattle feed production facilities that use the same or similar equipment as pelletized fuel production.
- Training programs on kiln fabrication and subsidies for improved kilns can have an immediate and positive long-term impact on wood usage for charcoal production. Improved kilns can reduce input wood use by up to 30% over traditional earthen or soil-covered kilns[1].
- Crop production and livestock counts were only available as national totals. District-level or TA-level counts would allow higher fidelity estimates to be completed for bioethanol, pellet/briquette fuels, and biogas. At present, the national statistics for crop production and livestock are represented at the TA level to correspond with the amount of farmland in each TA.

1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

Recommendations for Malawi (4 of 6)

Geospatial recommendations for stove adoption and alternative fuels:

- Urban areas with grid access and market access will be best suited for driving the adoption of e-cooking or LPG, with improved charcoal stoves likely to be included with cookstove stacking practices.
- Other alternative fuels such as biogas, bioethanol, and pellet/briquette would be recommended for rural areas where the fuel is available and customers are present, and thereby reducing supply chain challenges and costs of translating those fuels from rural to urban centers. The geospatial analysis show priority districts for alternative fuels and give valuable insights to the private sector and MoE to further investigate with production cost modeling to guide stove and fuel production planning.
- Rural areas show a significant opportunity to benefit from alternative fuels not included in the Compact (bioethanol, pellet/briquette, biogas), and while fixed wood and portable wood improved stoves will continue to have market shares, results of the geospatial study show strong evidence for alternative biofuels to be expanded:
  - Bioethanol: Northern region can be prioritized with a bioethanol facility to match the location of sugarcane availability with potential demand. Central and Southern regions can follow, with some TAs showcasing high agricultural waste output relative to population.
  - Pellet/briquette: Northern region can be prioritized with a palletization or briquette facility. Central can follow next, noting some TAs with high agricultural waste output relative to population. South has limited amounts of agricultural waste to serve the population in the region.
  - Biogas: A few TAs in each region contain sufficient livestock relative to the population to suggest focused, local efforts could target those areas for family-sized or town-sized biogas units. These are spaced across all regions, with slightly higher concentrations observed in northern and central regions.

Recommendations for Malawi (5 of 6)

Recommendations on business models and policy:

- LPG programs can focus on densifying and expanding LPG access in urban regions with higher population density and adding capacity and marketing programs to existing points of sale. This approach will keep LPG distribution points to a more reasonable number of 19 districts total to simplify supply chain considerations to spread LPG adoption across the country, expanding from the 10 districts today.
- Single vendors or programs can have a significant impact on stove production and sales. This suggests that strategic partnerships with a small number of vendors could dramatically increase stove utilization across multiple fuel types – such as observed with a few firewood stove vendors – while reducing administrative burden when compared to overseeing many smaller programs. A single effort may also make it easier to systematize other goals such as job creation for women. However, this approach could create single points of failure in supply networks and reduced inclusion of local staff if not set up to incentive these attributes.
- For 2022 data, the distribution of improved stoves and clean fuel access in the northern region is far less than central and southern regions. This suggests the Northern region needs additional resources, strategic planning, programs, financial incentives, and systematic actions to enhance access to cleaner cooking stoves to approach 2030 goals of 100% access across the country.

Recommendations on gender:

- Rural women who use firewood stoves can expect to reduce 20-50% time spent collecting wood after switching to more efficient firewood stoves. This could represent a time savings of 50-125 hours per year for each household[1].
- Gender programs should expand focus beyond cooking to include other aspects of the cookstove and fuel value chain – stove production, marketing, sustainable charcoal production, financial management or money lender for stove purchase, liaison or program manager between electricity and cooking industries, entrepreneur utilizing improved stoves (e.g., street vendor), trainer to introduce improved cookstoves to institutional settings, and other necessary professions to the stove industry.

1. Johnson, N. G., & Bryden, K. M. (2012). Energy supply and use in a rural West African village. Energy, 43(1), 283-292.

Recommendations for Malawi (6 of 6)

Recommendations related to the Malawi Cleaner Cooking Energy Compact:

- Rural goals may benefit from stipulating potential options for non-wood cooking solutions such as biogas, pellets, or briquettes. It is unlikely that other cleaner fuels, such as e-cooking and LPG, will be accessible to rural customers in the near future, particularly in off-grid areas as designated by the IEP electrification plan.
- Urban goals in the cleaner cooking compact do not fully reflect 100% of customer groups. This study showed the effect of cookstove stacking for customers using e-cooking and charcoal, a common approach today, particularly given the high incidence of grid outages on prospective e-cooking households. It would be valuable to hold a stakeholder discussion on the projected percentage customers who may engage in cookstove stacking, and the types of stoves they could use. That discussion could be refined annually or bi-annually as the local energy market changes over time (e.g., grid power becomes more or less reliable, LPG costs change, pellet supply chain expands).
- Government financial incentives for efficient stoves and alternative fuels could more heavily target regions of the country where there has been little uptake of improved stoves, such as in the Northern region.
- Sustainable charcoal production could be more aggressive in promoting higher efficiency methods that reduce wood use. An additional goal could be added to state programming requirements to parallel wording already in the Compact for LPG, biogas, and natural gas statements (e.g., implement 3 sustainable charcoal programs).
- Targets for training men and women currently only talk about professions to fabricate and use improved stoves. This could be expanded to include more of the stove value chain, including activities such as customer acquisition and marketing, distribution, financing plans, guidance on productive uses of stoves, maintenance of stoves, and other necessary professions to the stove industry. Training also has an expense to include in program planning.
- Although commercial cookstoves were not included in this study, the Compact goal commercial users seems low for the population of Malawi, and this goal could also benefit from distinguishing between commercial cooking locations and small-scale food vendors or entrepreneurs along the street. Further, targets can be set for public or municipal institutions such as schools, universities, hospitals, prisons, and related.
- The target penetration rate of alternative biomass fuels (pellet, biogas, bioethanol) is so small that the aggregate impact to Malawi is only 0.5% of total households. Attention and funding to those programs should be minimal, commensurate with the impact, or the target number of households could be increased and given greater resources to offset the use of LPG, e-cooking, and wood stoves.
- Add recommendations specifically for women health and wellness, and also gender inclusion in the stove value chain including marketing, production, distribution, sales, financing, fuel supply, and more.
- Consider adopting targets for e-cooking in off-grid (mini-grid, SHS) homes.

Recommendations for Clean Cooking Studies and Integrated Energy Planning

- Data gaps are commonplace in clean cooking – stove ownership, stove use, geospatial representation, urban vs. rural differences, gender impacts, stove costs, fuel costs, fuel accessibility, and more.
- Cookstoves are used for more than just cooking, such as heating water for bathing, agro-processing, medicines, tea, and even space heating. These non-meal uses can account for over 50% of solid fuel use during certain periods of the year. Studies that just focus on the "cooking" aspects of cookstove use underrepresent energy needs, and misrepresent the variety of household energy uses that need to be explicitly represented for comprehensive integrated energy planning.
- Clean cooking studies require cross-sectoral data from several ministries, private sector, and non-governmental organizations. The absence of part or most data from these organizations, differences in geospatial fidelity and accuracy, discrepancies in data values, and competing objectives or viewpoints between organizations prevents more comprehensive analyses needed for integrated energy planning. Dataset sourcing, curation, vetting, and gap filling for datasets across so many sectors is an underrepresented time commitment and challenge to perform such studies.
- Geospatial representation of current cookstove situation is challenging due to limitations in data availability, no single organization has those data, private sector stove vendors protect sales data as part of business intelligence, and stove implementation volumes mispresent what stoves are being used due to stove attrition/failure and stove stacking.
- Biomass and biogas production potential is highly dependent on location, farmland (e.g., irrigation) and livestock care methods (e.g., feed), agro-processing, food quality control measures, and other factors that require site assessments with primary data for accurate estimations.
- Build evidence and share data on how clean cooking addresses gender equality and women's empowerment, as well as how gender-informed approaches provide a return on investment for clean cooking businesses.

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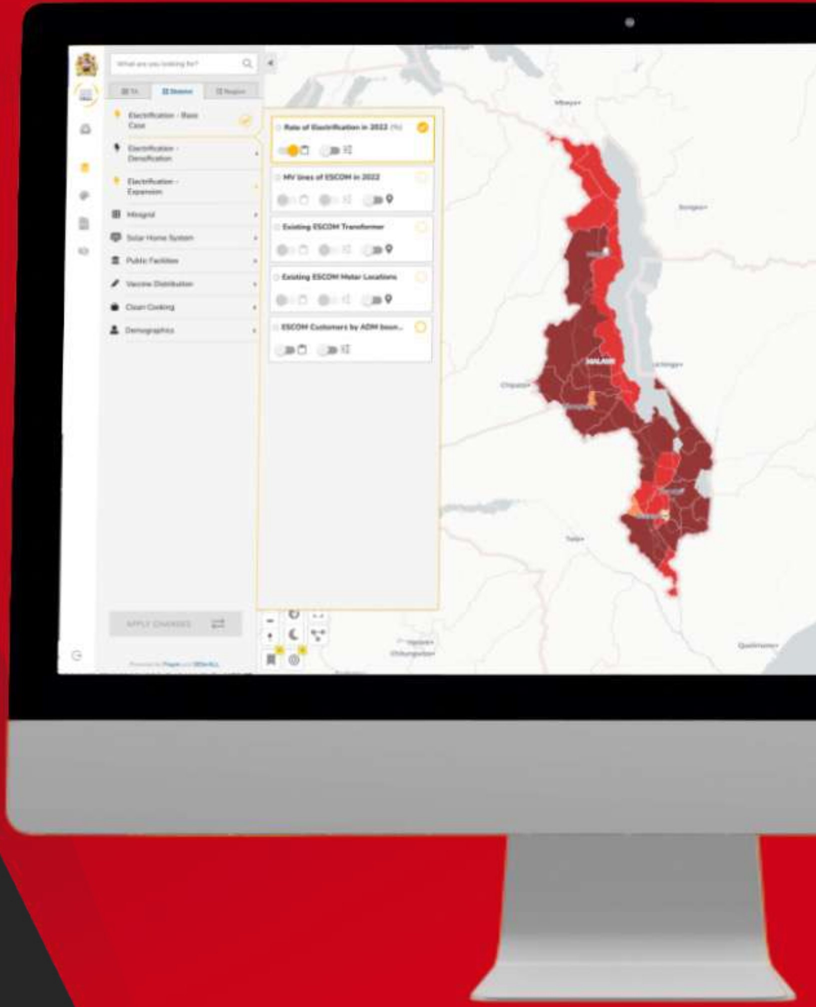

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