SUSTAINABLE ENERGY FOR ALL

UNITY AND FREEDOM

Malawi Integrated Energy Plan

An Overview

Clean Cooking Report

October 12th, 2022

IN PARTNERSHIP WITH:

Global Energy Alliance for People and Planet

Acronyms and Abbreviations

- 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

Stove and Fuel Assumptions

- Fuel parameters use globally accepted values for clean cooking analysis[1]. Energy costs 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.

Scenario Development

- 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 study.

Government of Malawi

Ministry of Energy

Malawi SDG7 Cleaner Cooking Energy Compact – Targets and Goals

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 stacking by using more than one fixed and/or portable efficient wood stove	2030
• 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% 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	
• 3 programs implemented by government to build capacity of LPG, biogas and natural gas	Ongoing until 2023
• An additional 2,000,000 improved biomass cookstoves distributed by 2025	Ongoing until 2025
• An additional 3,000,000 improved cookstoves for both biomass and alternative cooking fuels by 2030	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	Ongoing
• Customs, excise and VAT exemptions for efficient stoves and alternative sustainable fuels in place	Ongoing until 2023

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

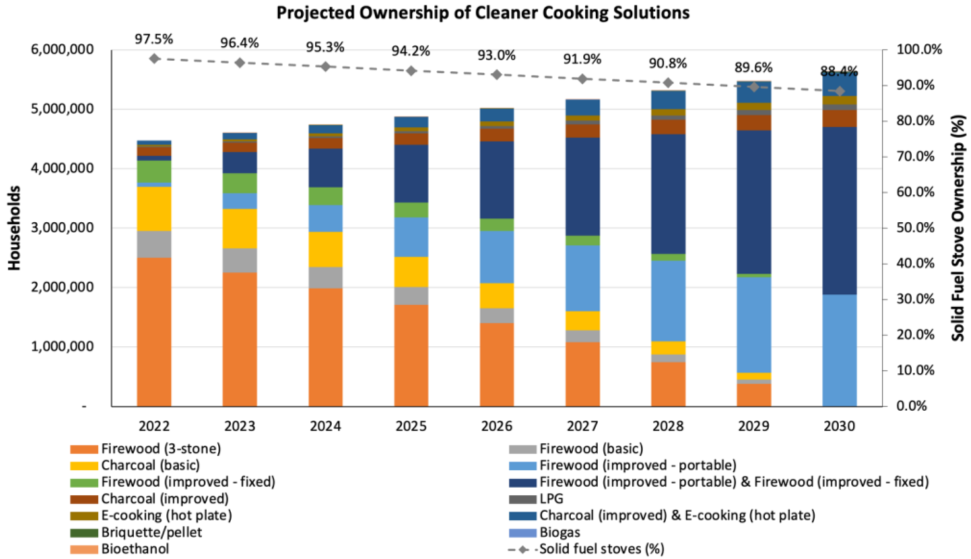
MALAWI INTEGRATED ENERGY PLAN

Results and Findings

Malawi SDG7 Cleaner Cooking Energy Compact

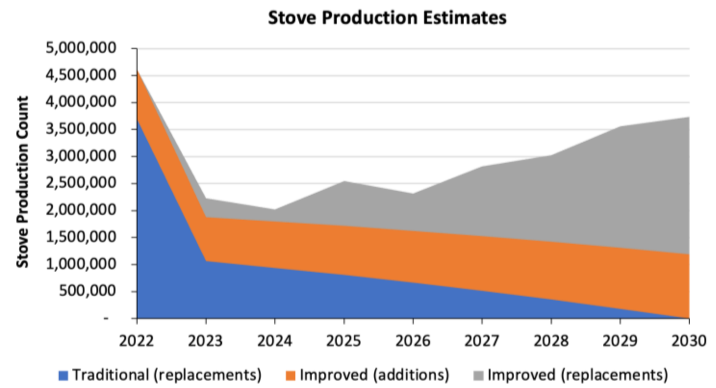
Improved Cookstove Expansion Scenario

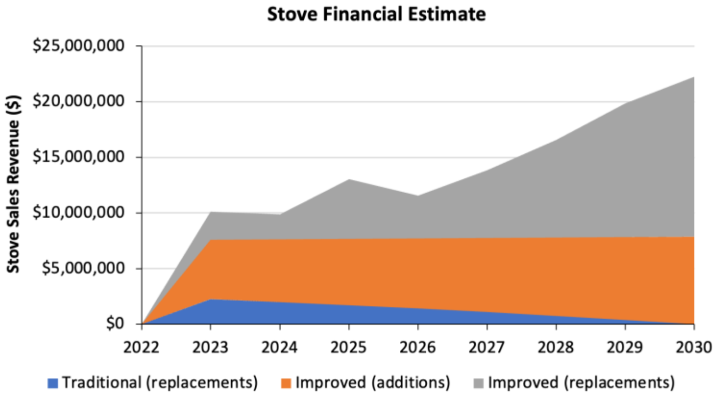
- Meeting Compact 2030 goals will require considerable strategic planning and centralized policy incentives as well as mobilization of private sector actors to enhance multiple modalities of improved cooking technology.
- This study models an improved cookstove (ICS) expansion plan to reach 2030 Compact 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 technologies in Malawi were considered[1], 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”.



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.



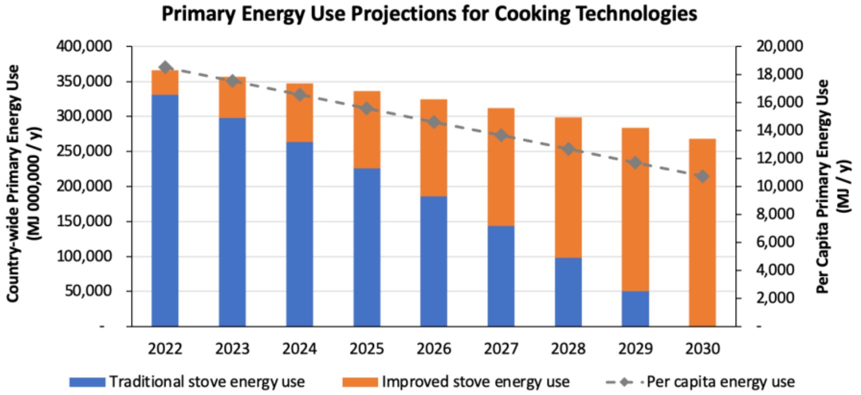


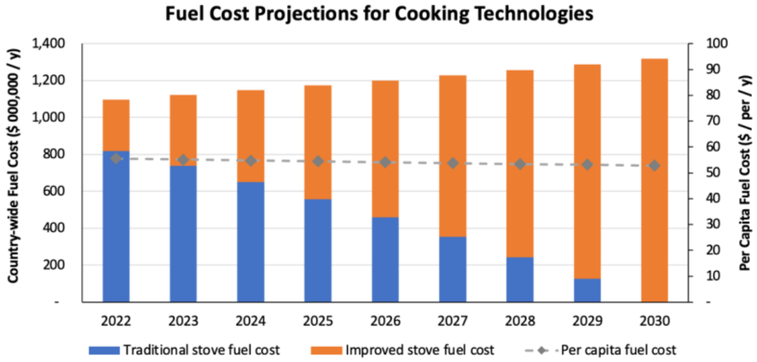
1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt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





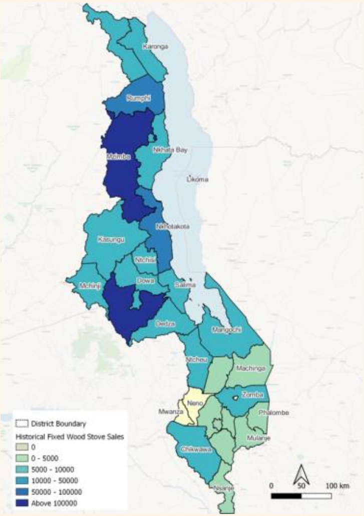
1. National Statistical Office of Malawi.

Improved Wood Stoves (per district)

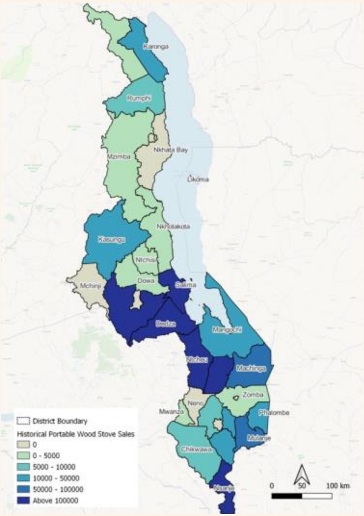
- These maps shows the stove ownership of improved wood stoves per district in 2022 as well as the projection for 2030, based on the 83.3% Compact target.

Distribution of improved wood stove ownership (2022)

FIXED IMPROVED WOOD STOVE

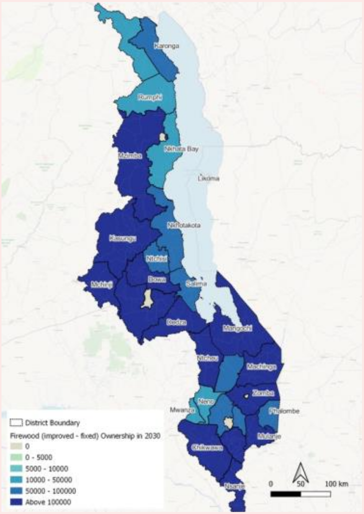


PORTABLE IMPROVED WOOD STOVE

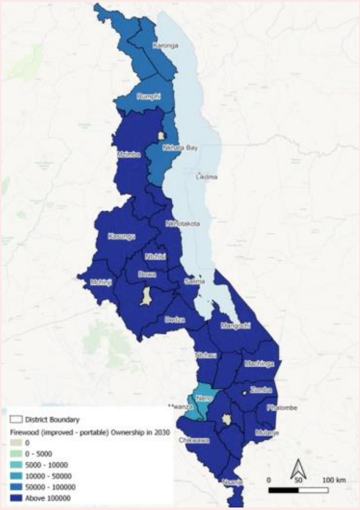


Distribution of improved wood stove ownership (2030)

FIXED IMPROVED WOOD STOVE



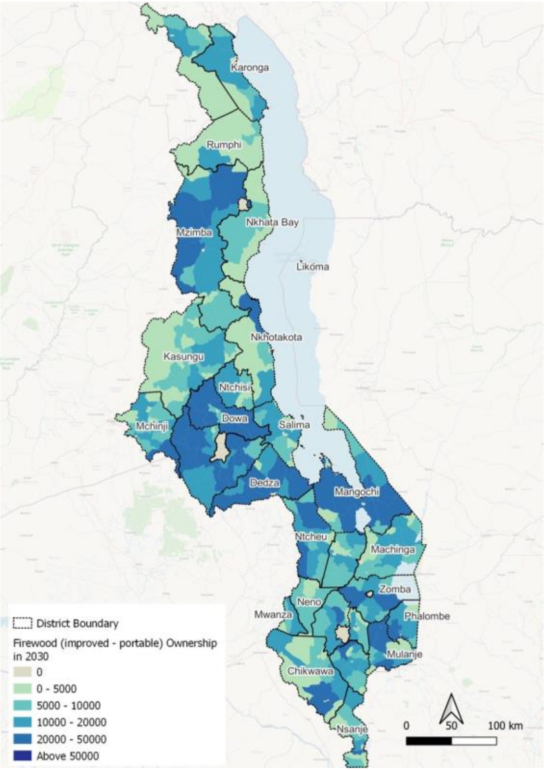
PORTABLE IMPROVED WOOD STOVE



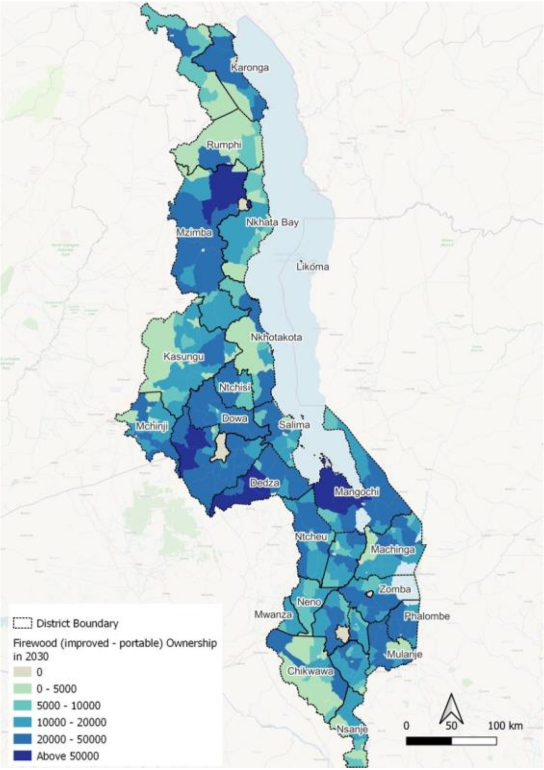
Improved Wood Stoves (per TA)

- 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 2.35M 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

- The estimated percentage of charcoal users reduces slightly from 2022 (80%) to 2030 Compact goals (72%). The major shift occurs from 50% of urban users who swap basic charcoal stoves with improved charcoal stoves. 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 to meet 2030 Compact goals.

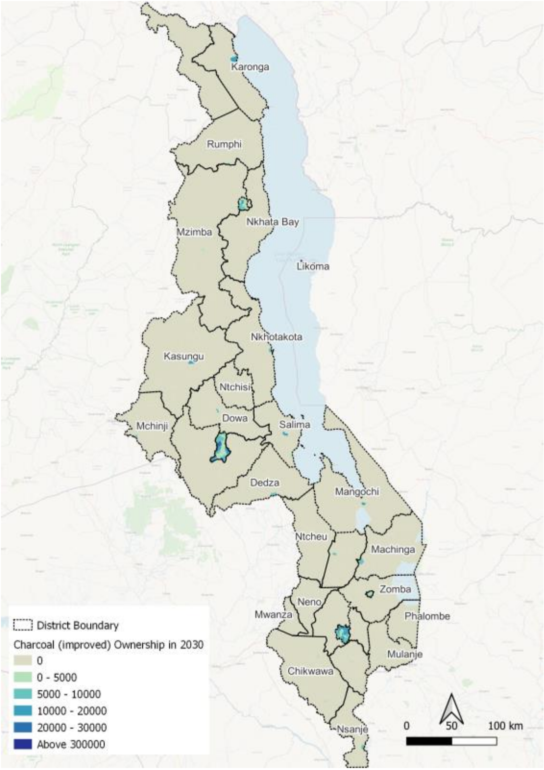
- Urban households using only improved charcoal stoves are estimated to be 275k in total. Households using both improved charcoal and e-cooking solutions is expected to be more common with an estimated 385k participating in cookstove stacking.

- 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 230k stoves per year can be produced in 2030.

- Improved, high-efficiency charcoal stoves can be paired with sustainably produced charcoal to reduce negative impact on the environment. Licensed charcoal production will also enable regulators to monitor charcoal quality, 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.

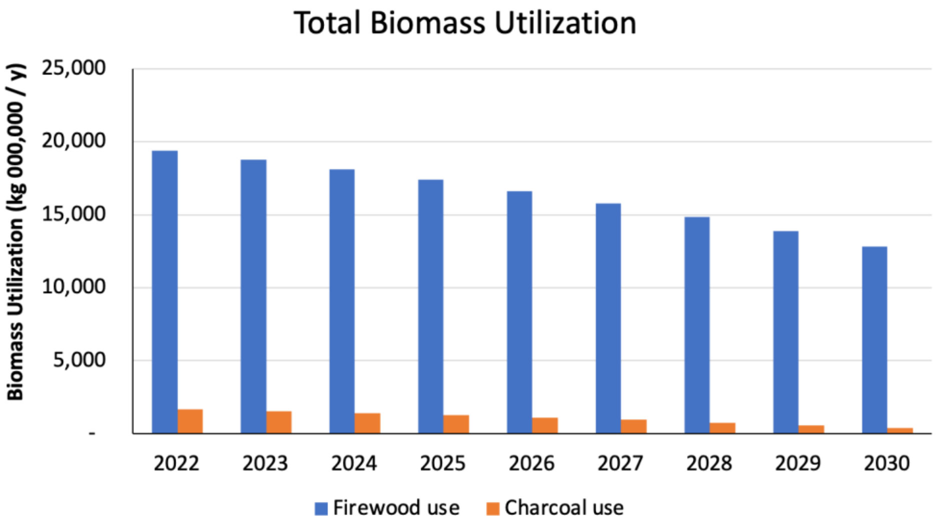
IMPROVED CHARCOAL STOVE OWNERSHIP (2030)



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 33.9% reduction in firewood utilization and a 77.7% 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-Tied Homes)

- Households with e-cooking are projected to increase from an estimated 92,000 today to 522,000 in 2030 to reach Compact targets. 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.
- Total energy use for e-cooking increases from 184 GWh / year in 2022 to 1,099 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 total increase in electricity demand due to e-cooking utilization will result in increased energy consumption 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. Nevertheless, e-cooking adoption may lead to changes in daily and seasonal load profile during mealtimes as well as increased generation requirements for the national grid.

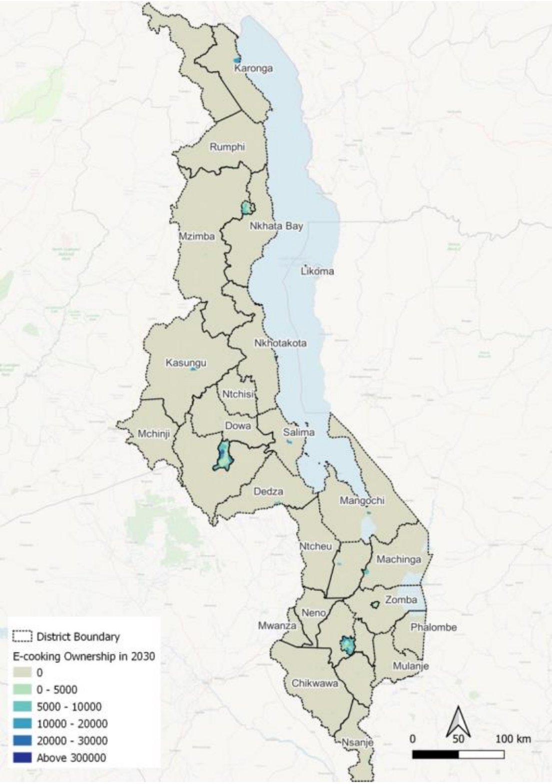
Presently, the market for electric cooking (e-cooking) in Malawi is severely constrained by the level of electricity access, quality of service, supply of e-cooking appliances, and affordability of electricity for cooking. Therefore, presently e-cooking accounts for a very small percentage of all cooking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

The Malawi Cleaner Cooking Compact envisions only 10% electricity access in Malawi by 2030 with a target of 15% of urban households utilizing e-cooking in their homes.

With the Malawi IEP projection of 100% electricity access by 2030, e-cooking opportunities will be more widespread, leading to increased adoption of e-cooking, particularly in urban areas.

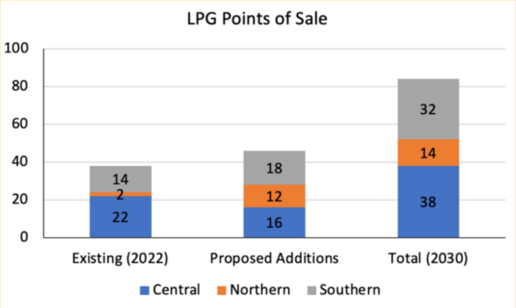
The increased e-cooking will contribute to increased electricity consumption and higher peak demand correlating with evening mealtimes. These results will, in turn, impact electrification planning.

E-COOKING STOVE OWNERSHIP (2030)



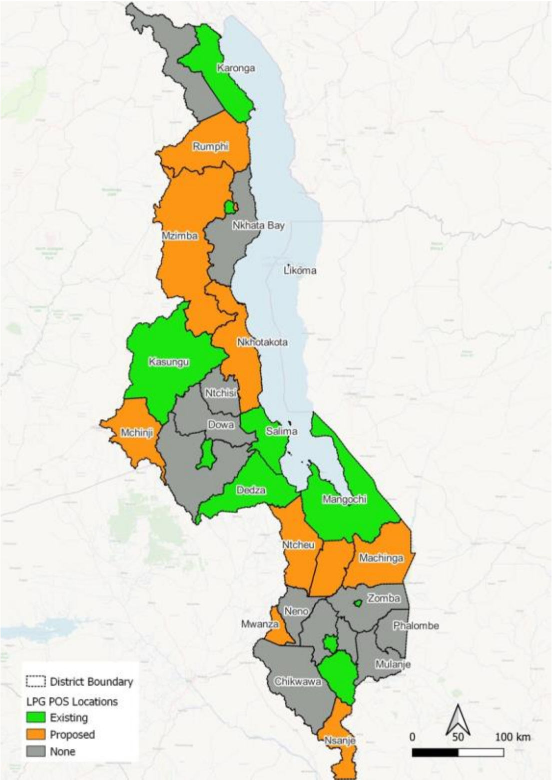
LPG (1 of 2)

- 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 272,000 local urban customers per point of sale.
- Densifying POS in existing urban areas and expanding to new urban areas can target 30,000 to 50,000 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)

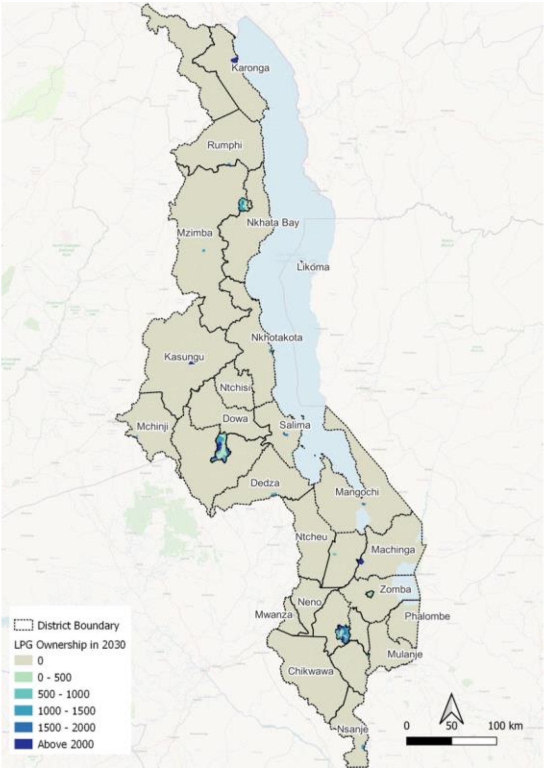


LPG (2 of 2)

- 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)

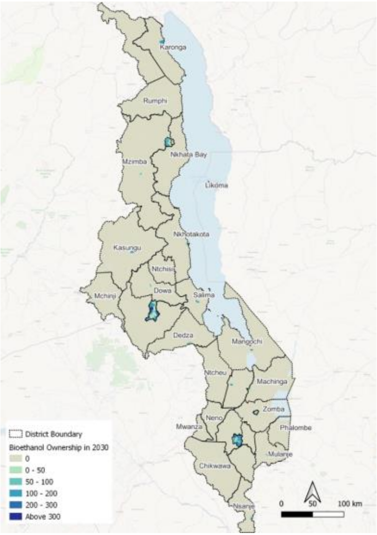


Other Alternative Fuels

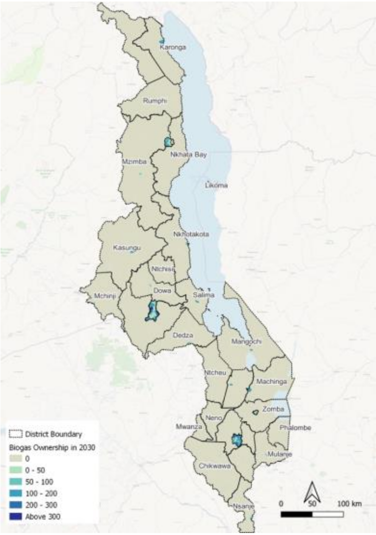
- The 2030 Compact sets a 3% adoption target of urban households to use other alternative fuels such as bioethanol, biogas, and biomass pellet/briquette cooking technologies. Assuming each cooking technology is adopted evenly, a total of 9,456 households will adopt each cooking technology to reach Compact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

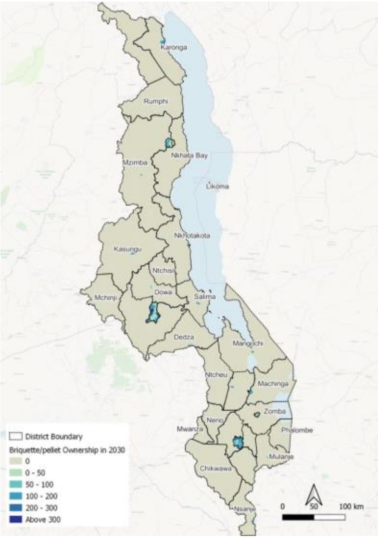
BIOETHANOL STOVE OWNERSHIP (2030)



BIOGAS STOVE OWNERSHIP (2030)



PELLET/BRIQUETTE STOVE OWNERSHIP (2030)



MALAWI INTEGRATED ENERGY PLAN

Results and Findings

Additional Malawi IEP Scenario

SUSTAINABLE ENERGY FOR ALL

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Additional Cooking Technology Opportunities

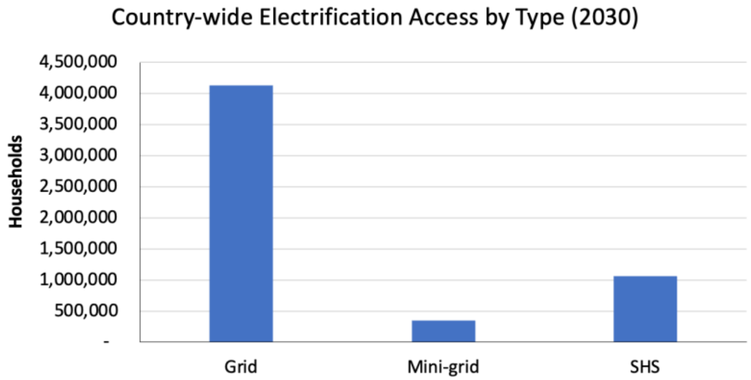
- Additional opportunities were evaluated to identify the maximum potential of each modern and alternative cooking technology. Results are summarized below and detailed in following slides.
- Malawi IEP results show that the maximum potential households that could be served with advanced cooking technologies (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 right showing differences between Compact Targets and IEP Potential.
- Geospatial results on the next slide go further to highlight locations in the country where single technologies or multiple technologies have potential. This information informs 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).

E-Cooking Potential

- Use of e-cooking solutions is presently limited, even in electrified areas.
- 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 = 141,848 HH). The Compact gives allowance for a further 42% of urban population to stove stack 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 become grid-tied.
- 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-grid and SHS are likely to have insufficient capacity to meet cooking loads.
  - Grid: $0.064/kWh
  - Mini-grid: $0.45/kWh
  - SHS: roughly $7-10/month fixed price

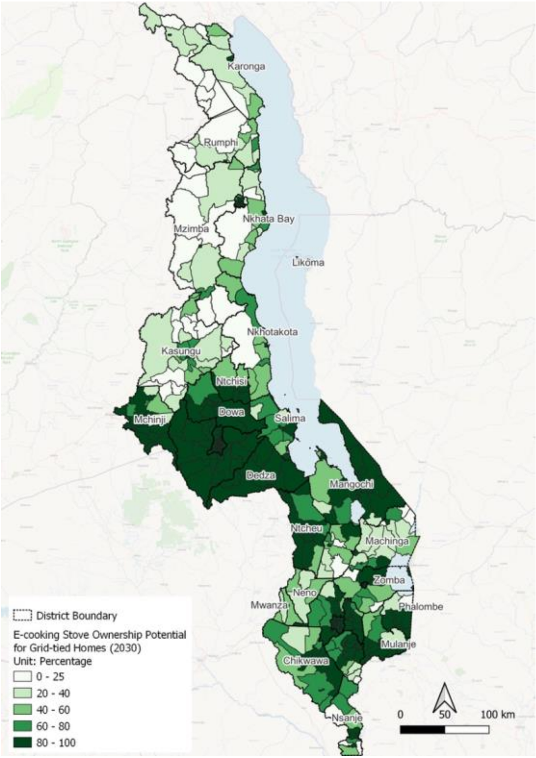


Source: Projections from Malawi IEP electrification study to meet 100% electricity access goals by 2030

E-Cooking (Grid-Tied Homes)

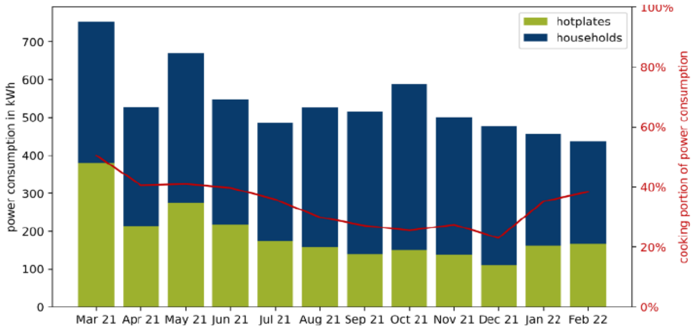
- A total of 4,126,638 households become grid-tied by 2030 under the IEP universal electricity access scenario.
- The graph on the right shows the percentage of grid connected homes relative to all homes.
- Central and Southern regions show a higher amount of homes that are grid connected in 2030.
- Alternative fuels could have more impact in northern regions. 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.

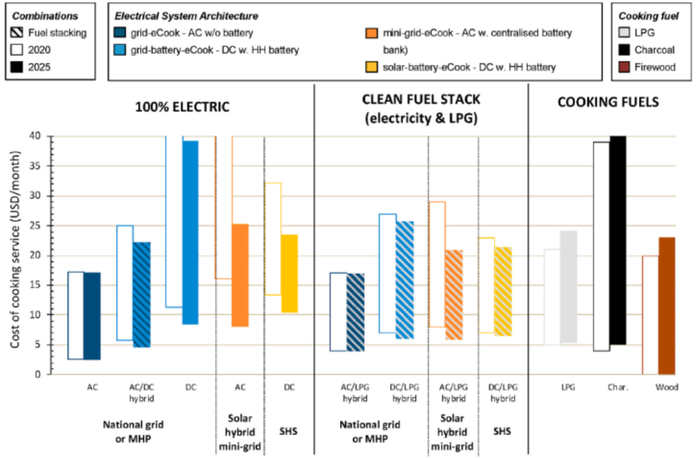
E-COOKING STOVE OWNERSHIP POTENTIAL (2030



E-cooking (Off-Grid Considerations)

- In the Malawi Cleaner Cooking Compact, there is no target for e-cooking among non-urban households. This is expected given the high cost of e-cooking on mini-grid tariff. Some emerging opportunities for off-grid e-cooking do exist, however.
- 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. In order 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. 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. 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.

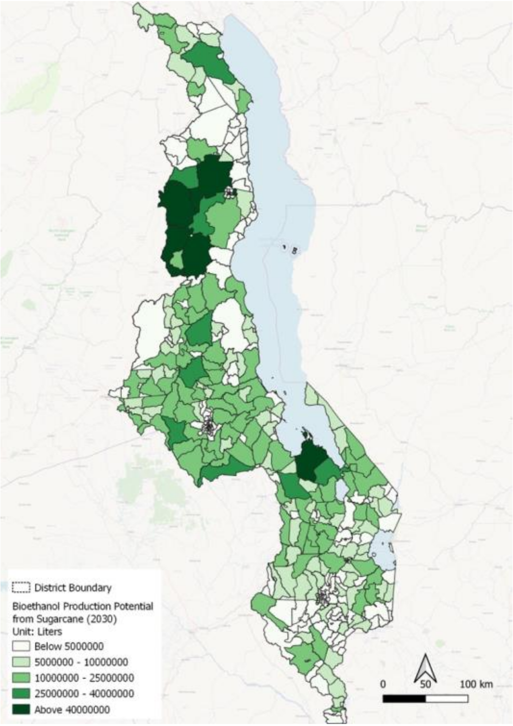
Bioethanol (1 of 2)

- 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**

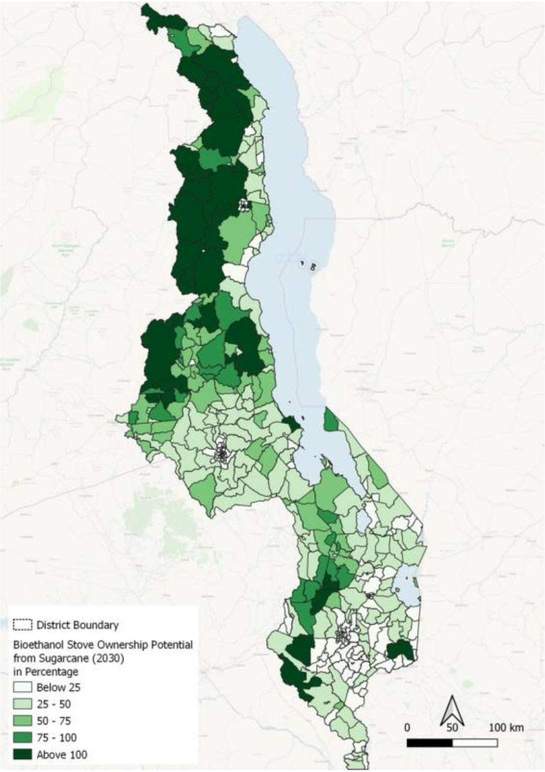
BIOETHANOL PRODUCTION POTENTIAL FROM SUGARCANE (2030)



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)



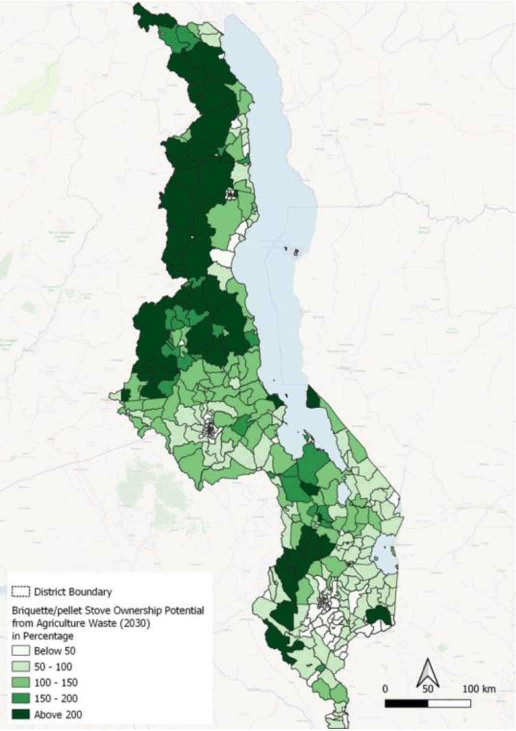
Briquette/Pellet (1 of 2)

- 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**

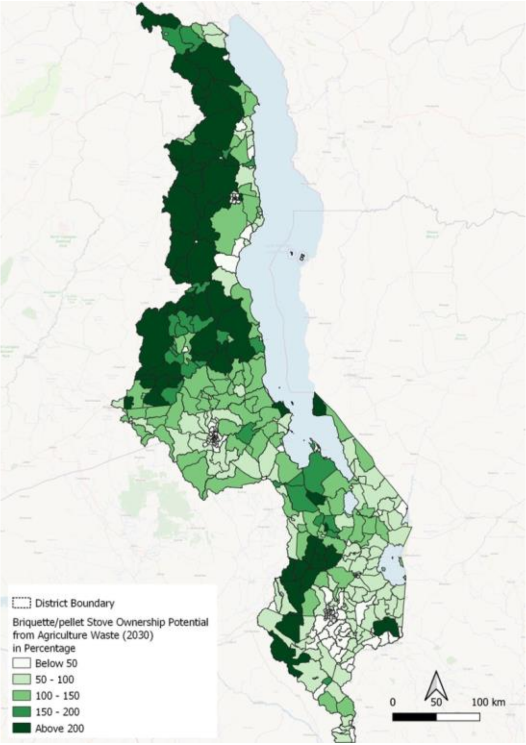
BRIQUETTE/PELLET PRODUCTION POTENTIAL FROM AGRICULTURE WASTE (2030)



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)

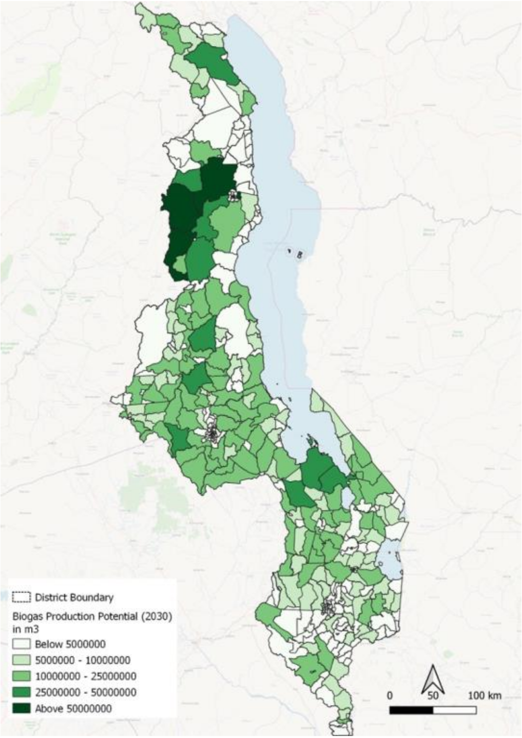


Biogas (1 of 2)

- 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**

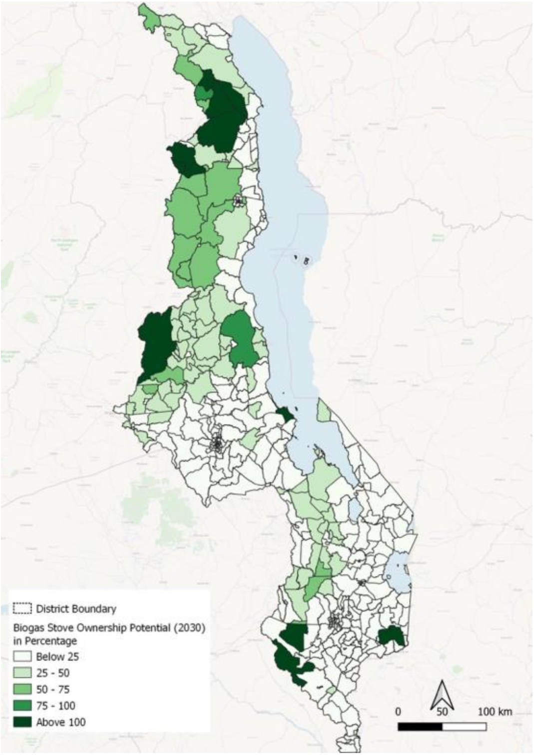
BIOGAS PRODUCTION POTENTIAL FROM LIVESTOCK WASTE (2030)



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)



IEP Scenario

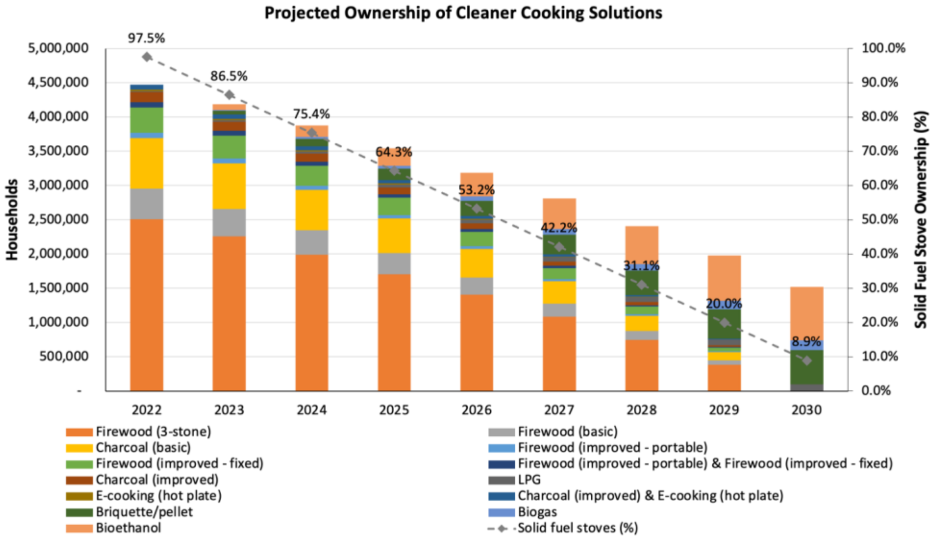
- The additional IEP Scenario was developed using:
  - LPG – for 10% of urban households to match 2030 Compact goals
  - E-cooking – for all grid-connected households, noting that many TAs currently classified as rural will receive grid connections under the IEP universal electrification plan
  - Pellet/Briquette, 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	-

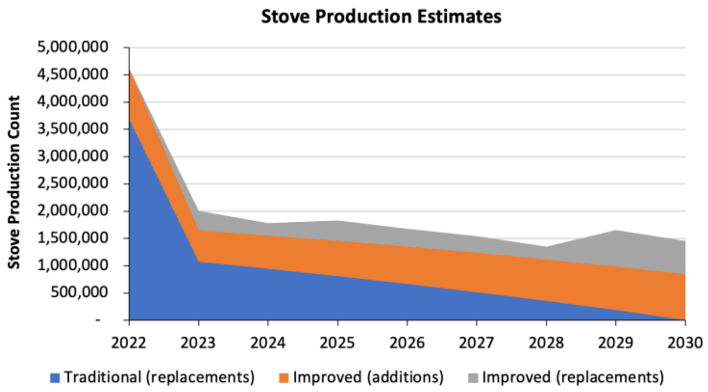
Improved Cookstove Expansion Scenario

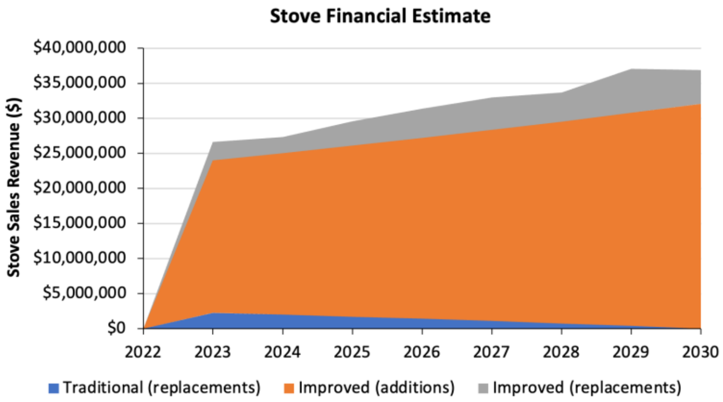
- The IEP universal electrification plan facilitates grid-tied homes to have access to low-cost electricity and sufficient capacity to use e-cooking. In this scenario, e-cooking represents 73.1% of all households.
- LPG for urban households provides energy to 1.7% households.
- The remaining rural households that are not grid-tied 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.



Stove Production and Financial Requirements

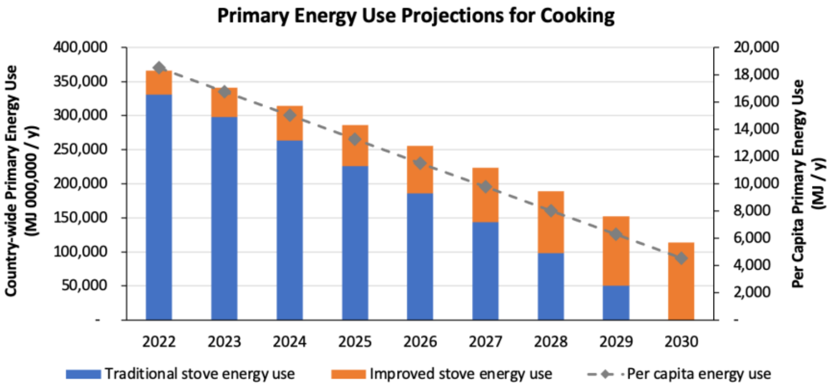
- The IEP scenario shows far fewer stove production volumes per annum because of the preference for modern cooking technologies that have longer lifetimes (durability). This means that the replacement of cooking stoves is greatly decreased.
- Stove financial estimate for sales price is higher than the 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.

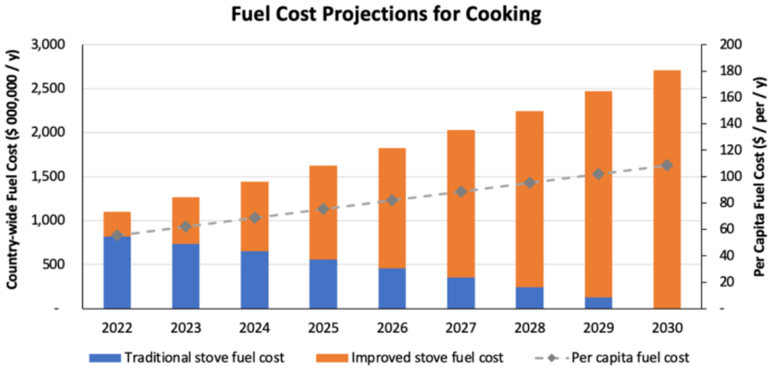




Energy Use and Fuel Cost

- Reaching 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]).

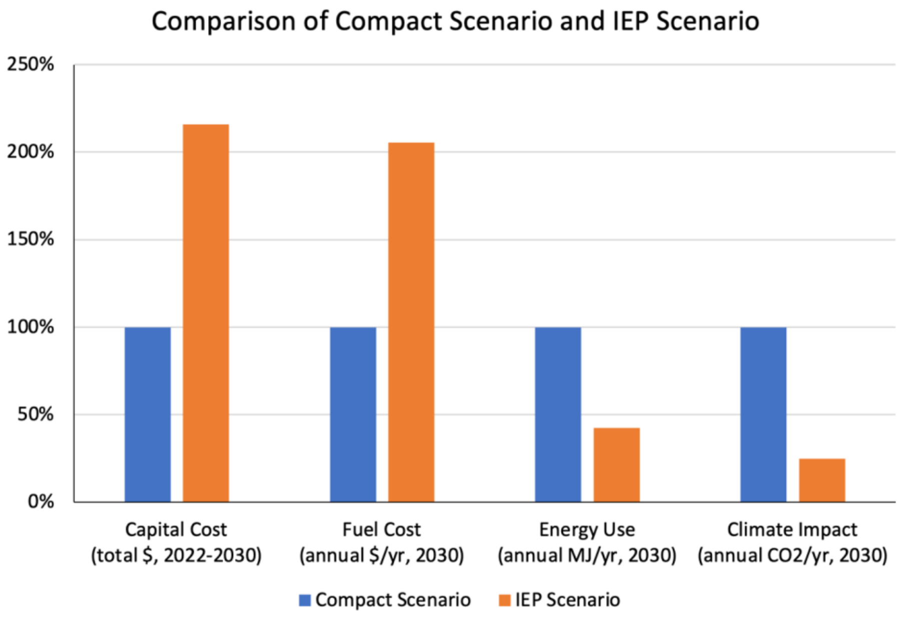




1. National Statistical Office of Malawi.

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 INTEGRATED ENERGY PLAN

Co-Benefits

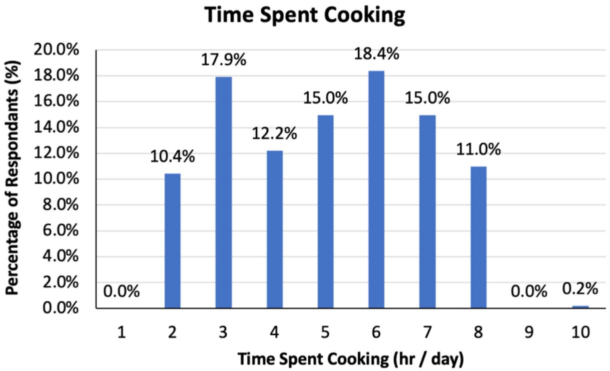
SUSTAINABLE ENERGY FOR ALL

UNITY AND FREEDOM

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.
- Each stove/fuel combination produces its own amount of PM2.5 production, 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[1]. 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

1. 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

- Total CO2 emissions from residential cooking and heating applications reduce by 28.8% under the Compact Scenario as households switch to cleaner burning fuels and cooking technologies. The associated per capita improvement is 43.6%.

- 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 improve by 82.3% and 85.9% from 2022 to 2030.