SUSTAINABLE ENERGY FOR ALL

UNITY AND FREEDOM

MALAWI

Integrated Energy Plan

CLEAN COOKING

Global Energy Alliance for People and Planet

20 DECEMBER 2022

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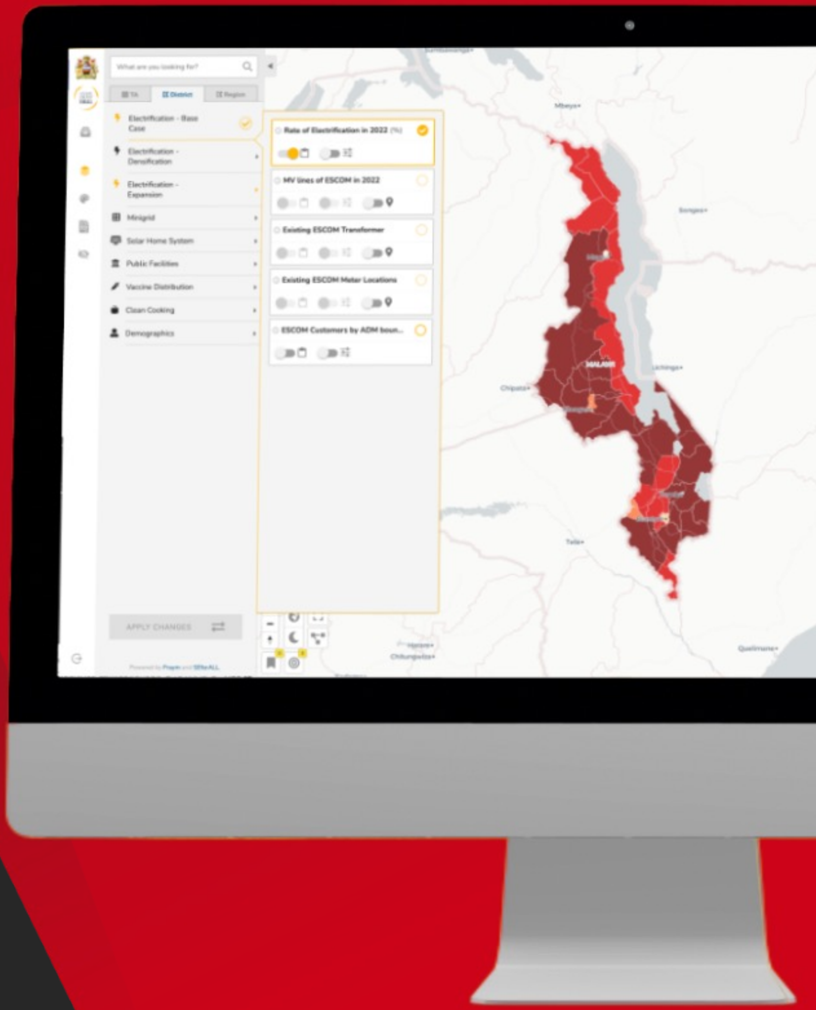

SUSTAINABLE ENERGY FOR ALL

Global Energy Alliance for People and Planet

SEFORALL SDG7 IMPACT MALAWI

Any Questions:
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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

MALAWI IEP – CLEAN COOKING

Executive Summary

SUSTAINABLE ENERGY FOR ALL

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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	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 fules 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

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).

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

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.

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%	-

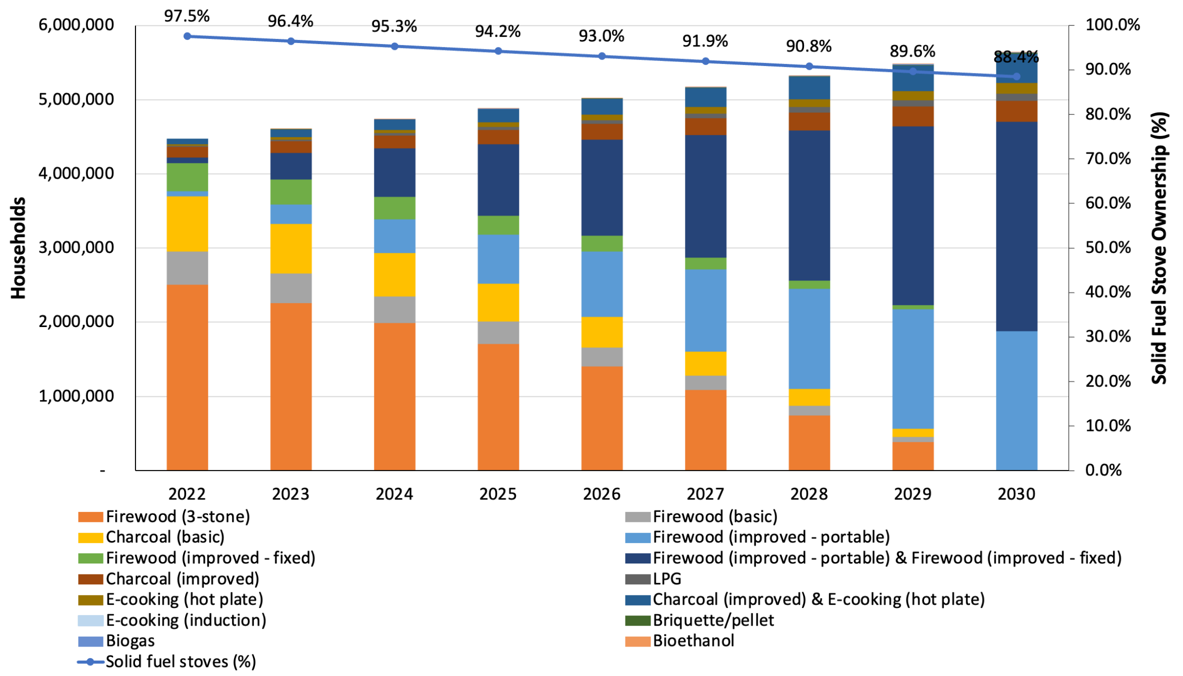
Urban			**2030**
Stove	**2022**	**2030**	**Households**
Firewood (3-stone)	0.0%	0.0%	-
Firewood (basic)	10.0%	0.0%	-
Charcoal (basic)	50.0%	0.0%	-
Firewood (improved - portable)	5.0%	0.0%	-
Firewood (improved - fixed)	0.0%	0.0%	-
Firewood (improved - portable) & Firewood (improved - fixed)	0.0%	0.0%	-
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

Meeting Compact 2030 Goals: Improved Cookstove Expansion Scenario

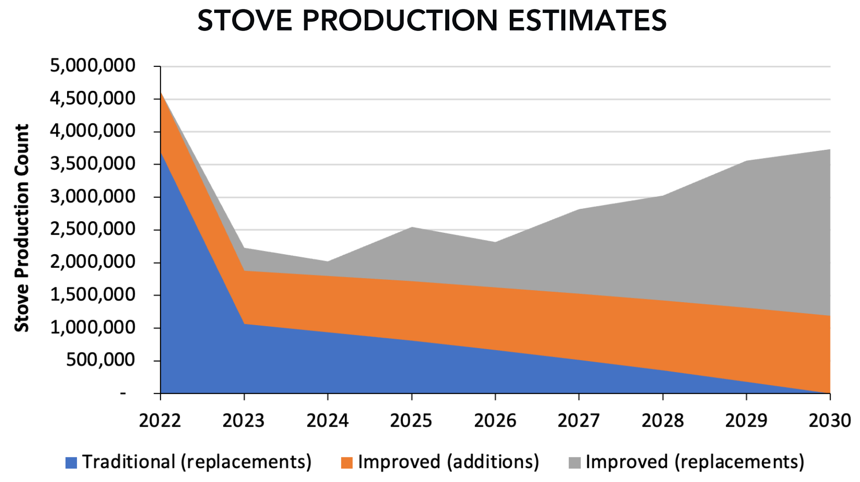
- Meeting the Compact 2030 goals will require considerable strategic planning and centralized policy incentives as well as mobilization of private sector actors to enhance multiple modalities of improved and modern cooking technologies.
- This study models an improved cookstove (ICS) expansion plan to 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".

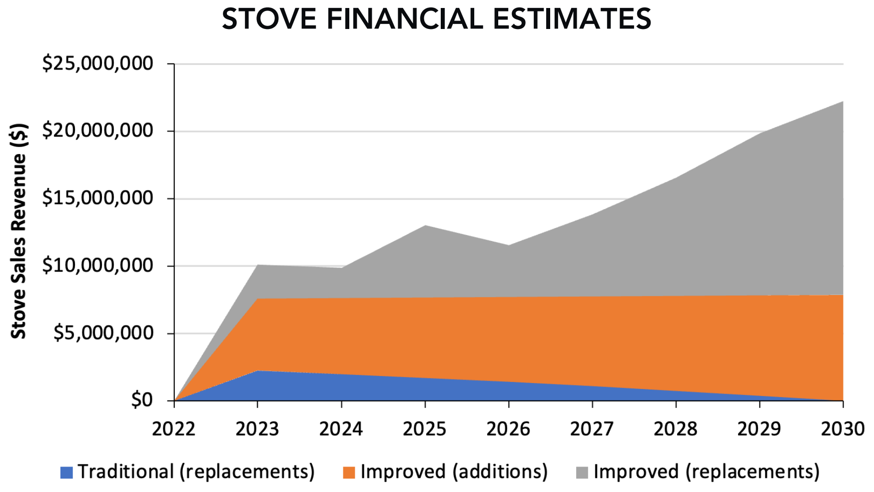
PROJECTED OWNERSHIP OF CLEANER COOKING SOLUTIONS



Meeting Compact 2030 Goals: 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 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.



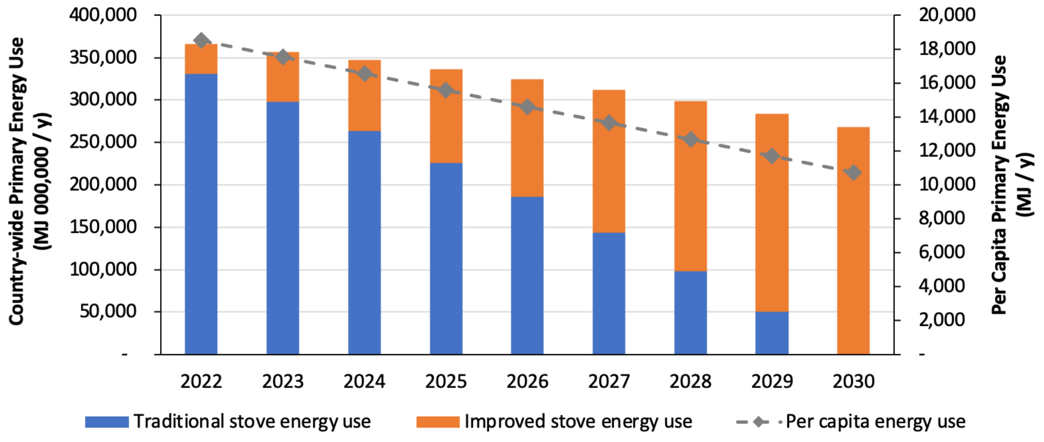


1. Matek, Benjamin; Pablo Torres; Gordon Smith; Eric Hyman; Santiago Enriquez; and Khadija Mussa. (2020) Cost-Benefit Analysis of Charcoal and Wood Use for Household Cooking and Demand- and Supply-Side Alternatives for Forest Conservation in Lilongwe, Malawi. Washington, DC: Crown Agents USA and Abt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

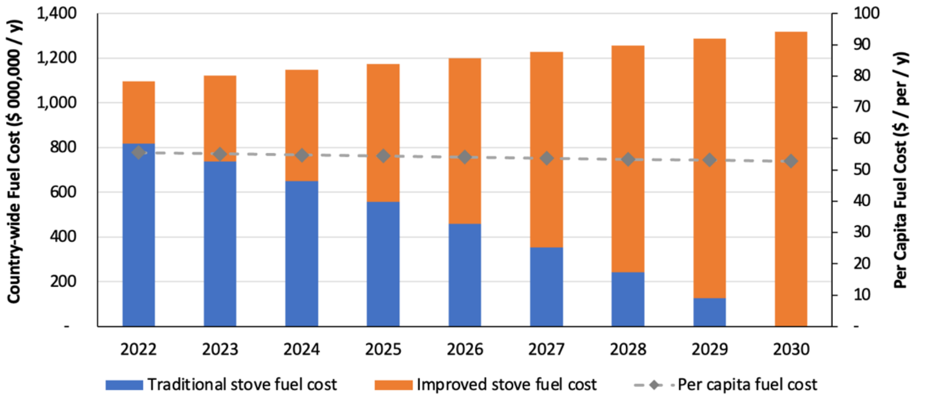
Meeting Compact 2030 Goals: Energy Use and Fuel Cost

- 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



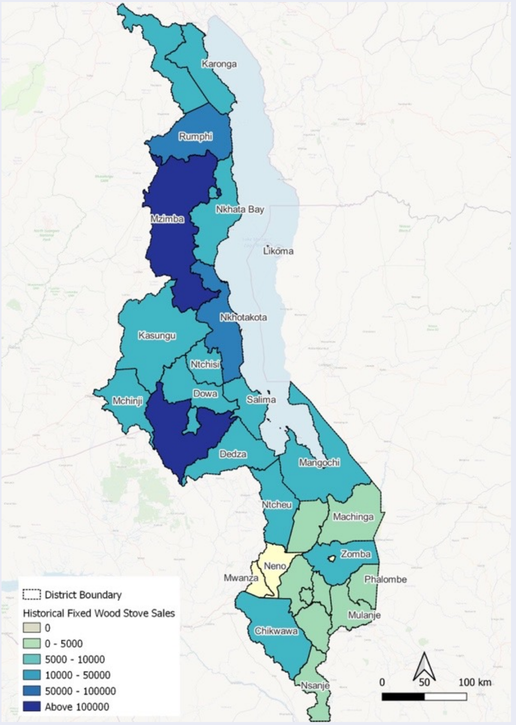
1. National Statistical Office of Malawi.

Meeting Compact 2030 Goals: Geospatial Representation of Wood Stoves

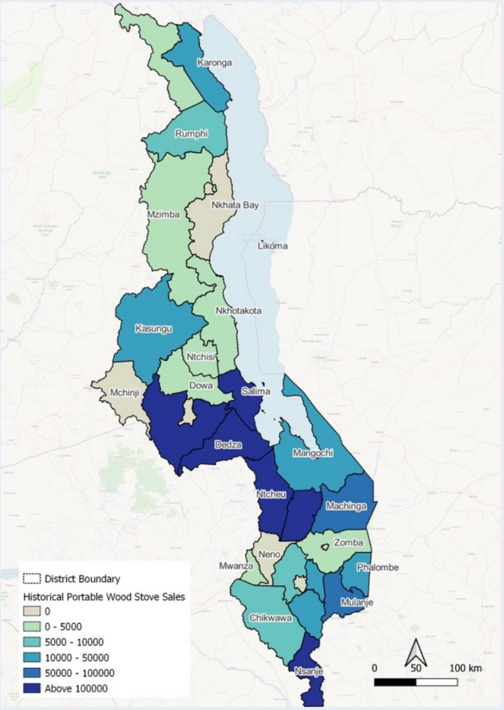
These maps shows the stove ownership of improved wood stoves per district in 2022 as well as the projection for 2030, based on the estimated 83.3% improved wood stove users in the Compact target.

Distribution of improved wood stove ownership (2022)

FIXED IMPROVED WOOD STOVE

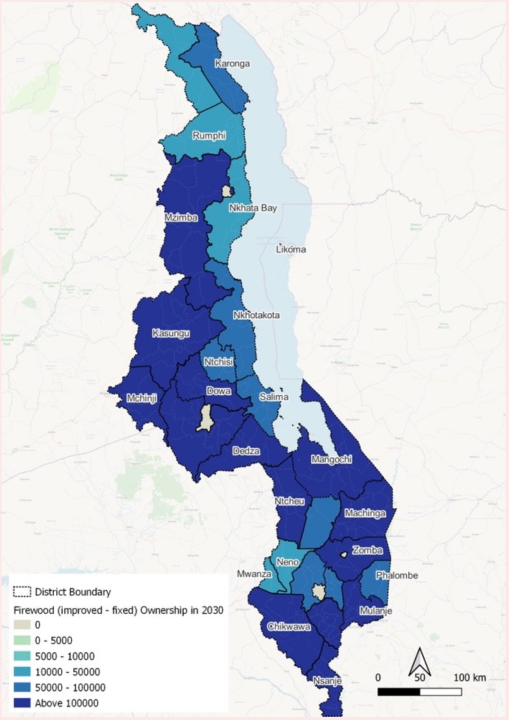


PORTABLE IMPROVED WOOD STOVE

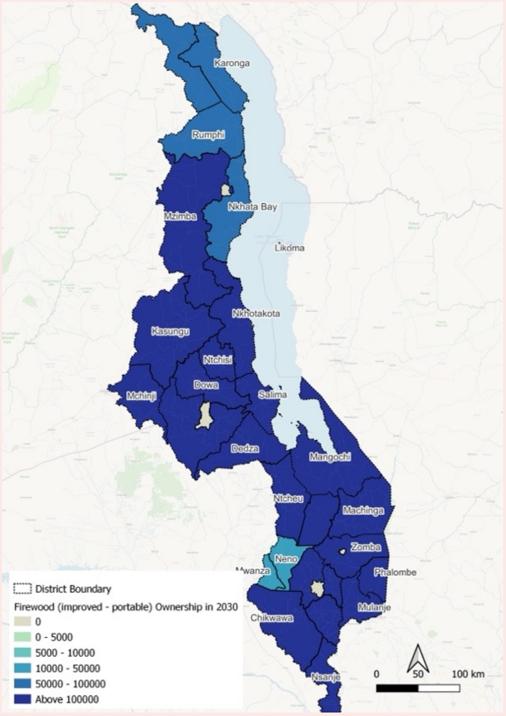


Distribution of improved wood stove ownership (2030)

FIXED IMPROVED WOOD STOVE



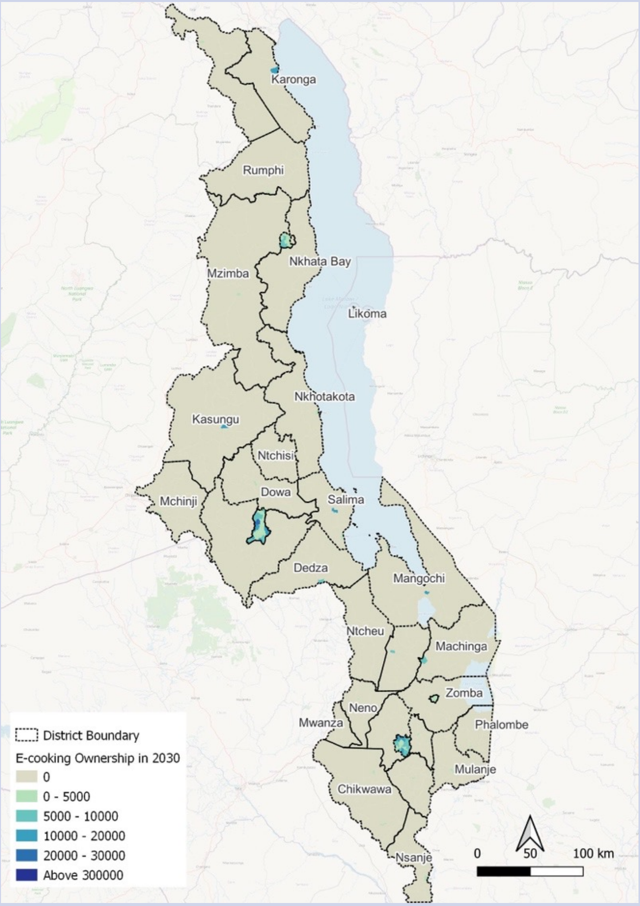
PORTABLE IMPROVED WOOD STOVE



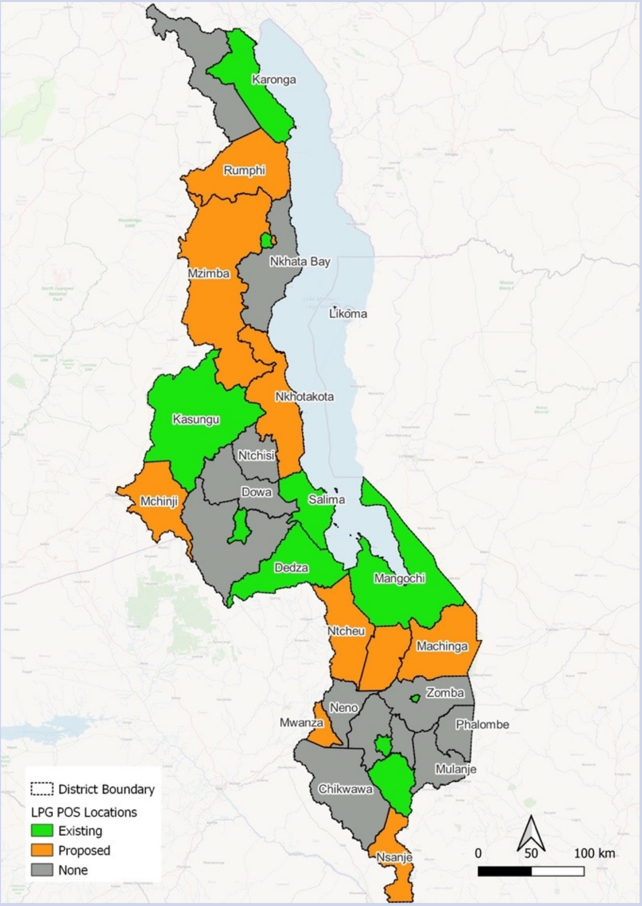
Meeting Compact 2030 Goals: Geospatial Representation of Alternative Fuels (1 of 2)

- 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

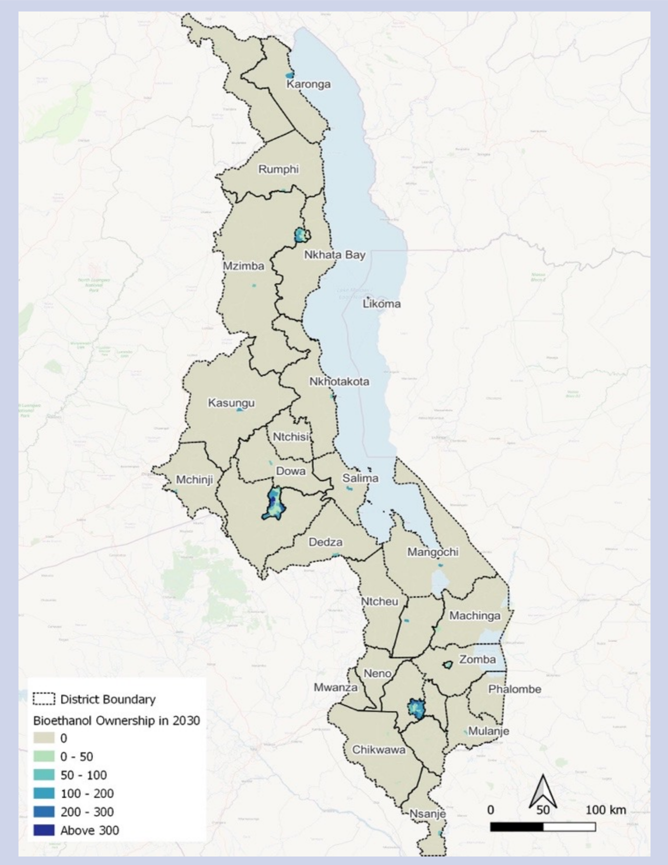


Meeting Compact 2030 Goals: Geospatial Representation of Alternative Fuels (2 of 2)

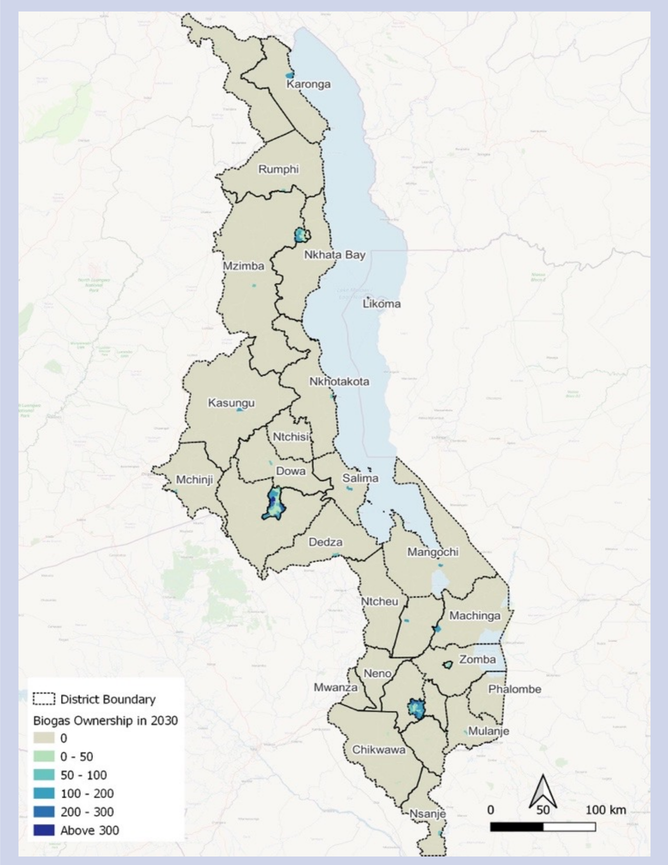
The 2030 Compact sets a 3% adoption target of urban households to use other alternative fuels such as bioethanol, biogas, and biomass pellet/briquette cooking technologies. Assuming each cooking technology is adopted evenly, a total of 9,456 households will adopt each cooking technology to reach Compact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

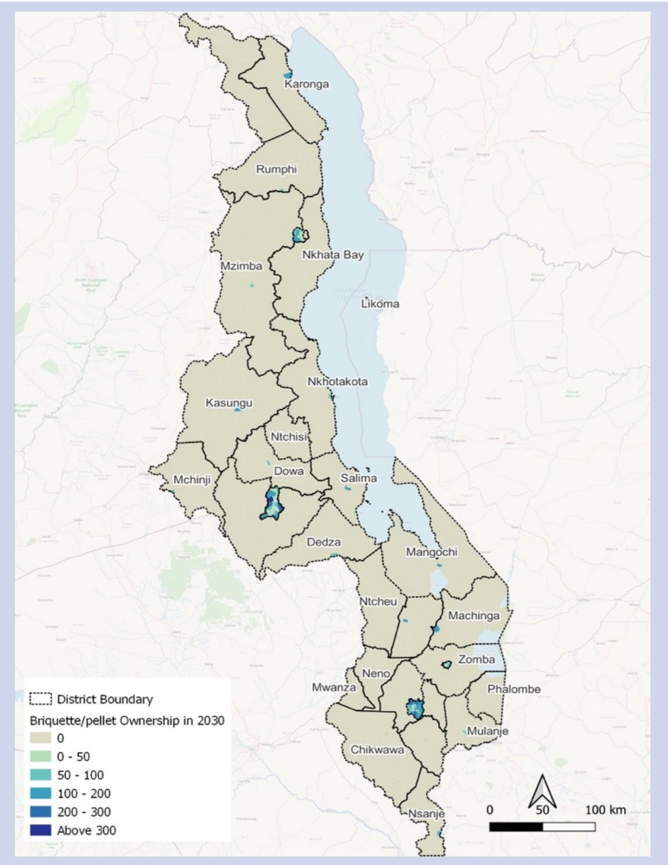
Bioethanol Stove Ownership (2030)



Biogas Stove Ownership (2030)



Pellet/briquette Stove Ownership (2030)



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	-

Meeting IEP Scenario Goals: 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.

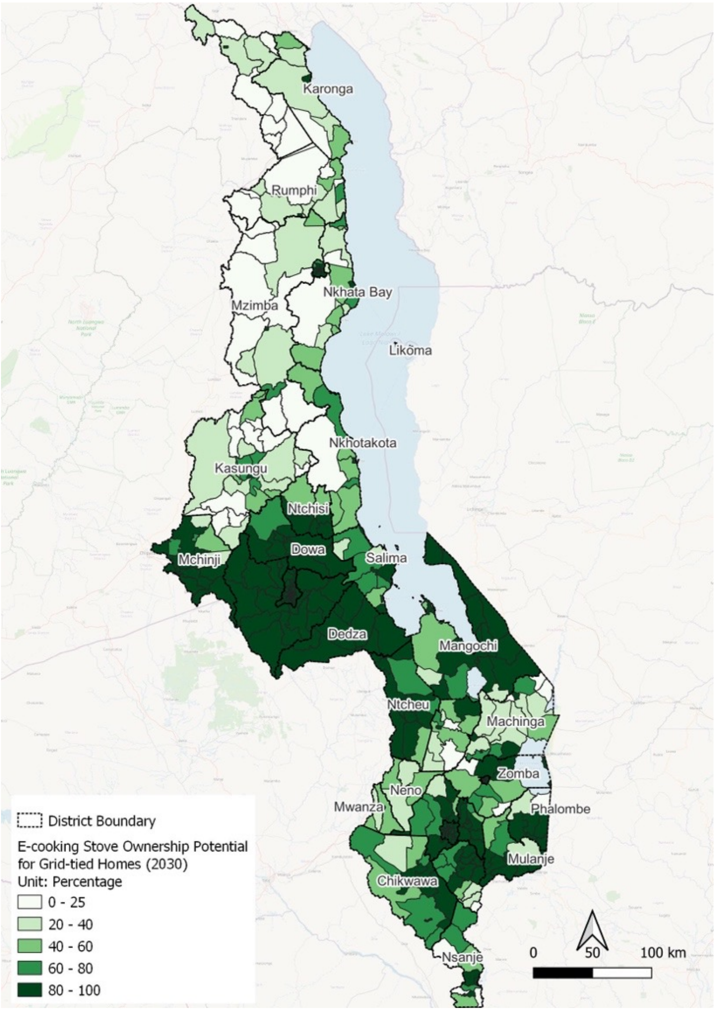
Cooking Technology	Compact Target (HH count)	IEP Potential (HH count)
E-cooking	539,014	4,126,638
LPG	94,564	94,564
Bioethanol	9,456	8,783,711
Pellet/Briquette	9,456	5,686,843
Biogas	9,456	1,599,420

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

Meeting IEP Scenario Goals: E-Cooking (Grid-connected Homes)

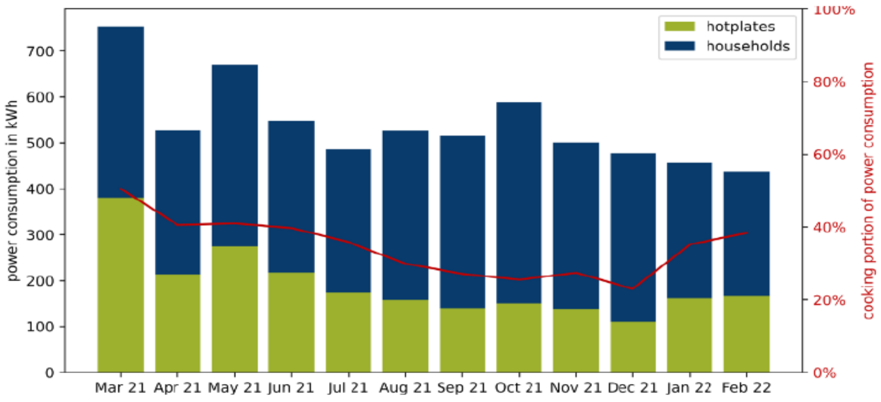
- A total of 4,126,638 households are estimated to become grid-connected by 2030 under the IEP universal electricity access scenario. The IEP Scenario assumes that all e-cooking users are grid connected due to the far lower electricity cost for those households relative to households with mini-grid or 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.

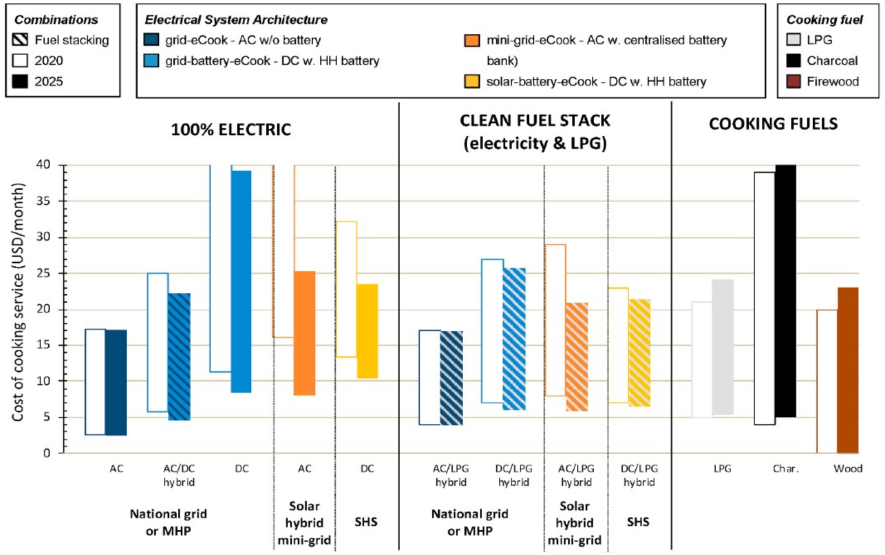
E-COOKING STOVE OWNERSHIP POTENTIAL (2030)



Meeting IEP Scenario Goals: 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.

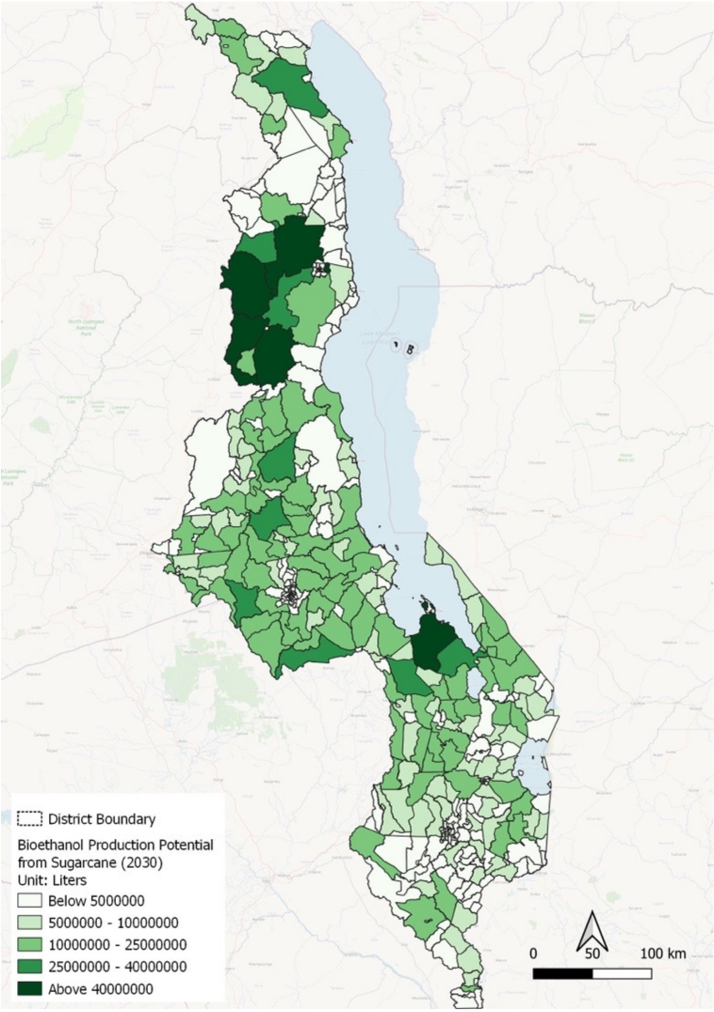
Meeting IEP Scenario Goals: Bioethanol (1 of 2)

- 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**

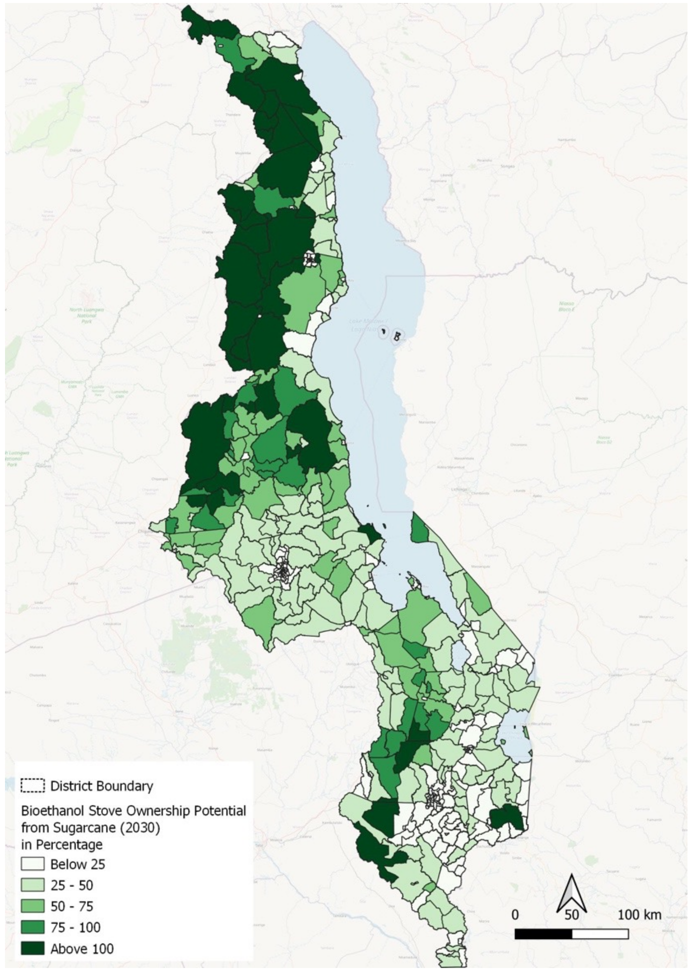
BIOETHANOL PRODUCTION POTENTIAL FROM SUGARCANE (2030)



Meeting IEP Scenario Goals: 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)



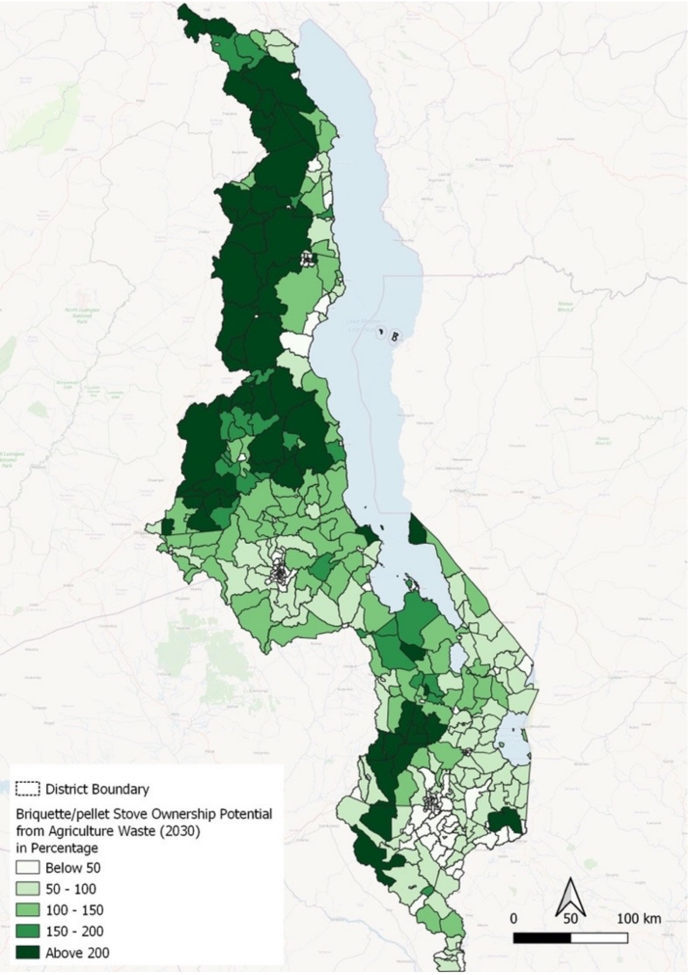
Meeting IEP Scenario Goals: Briquette/Pellet (1 of 2)

- 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**

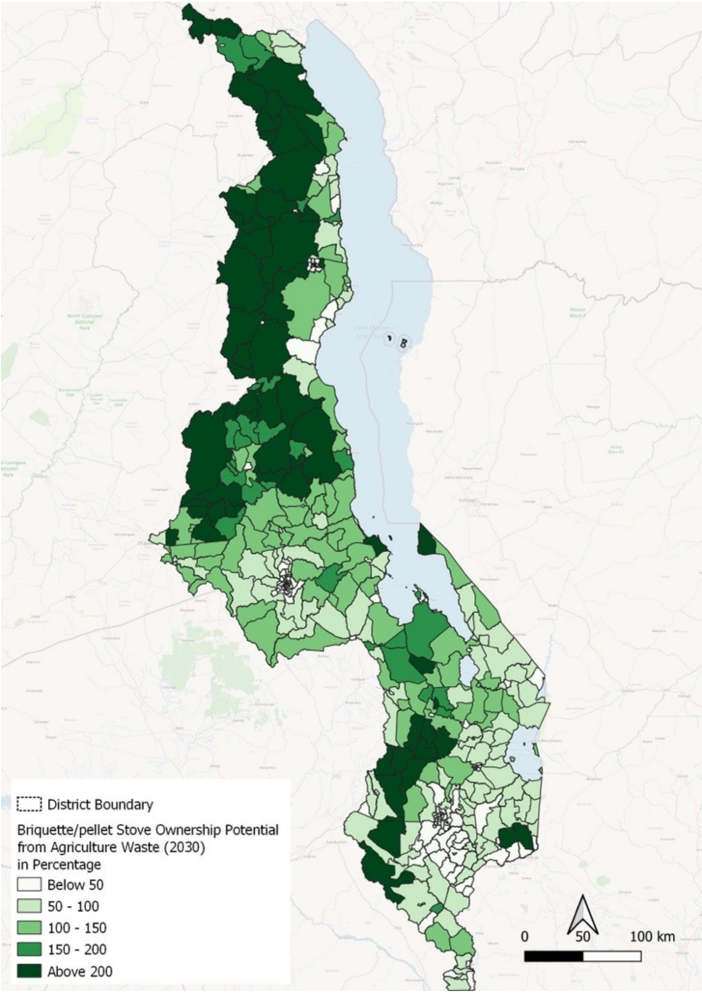
BRIQUETTE/PELLET PRODUCTION POTENTIAL FROM AGRICULTURE WASTE (2030)



Meeting IEP Scenario Goals: 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)

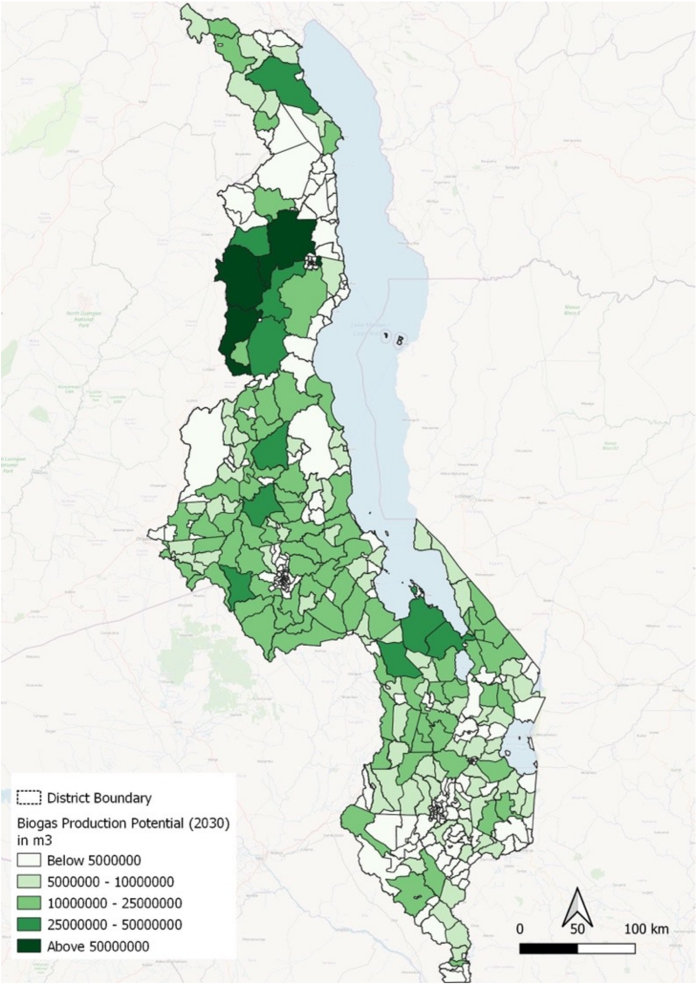


Meeting IEP Scenario Goals: Biogas (1 of 2)

- 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**

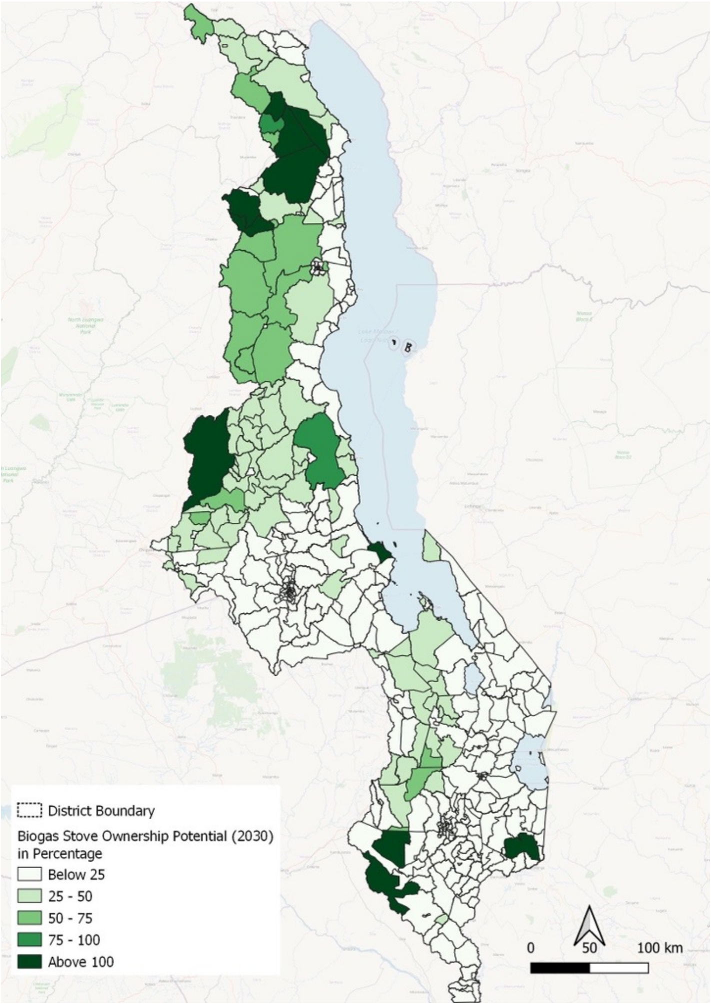
BIOGAS PRODUCTION POTENTIAL FROM LIVESTOCK WASTE (2030)



Meeting IEP Scenario Goals: Biogas (2 of 2)

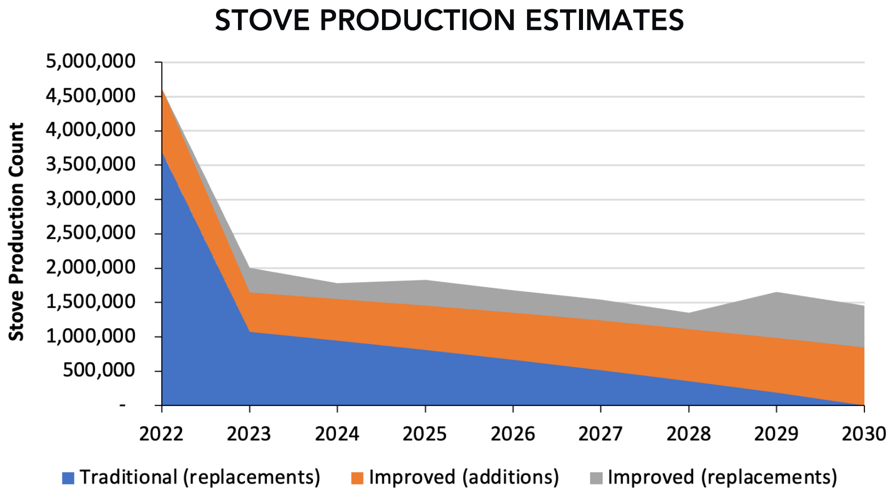
- The Compact assumes biogas use in cities but none in rural areas, presenting supply chain challenges to migrate gas from rural areas to urban areas.
- Total households that can be served biogas from livestock waste exceeds the target set forth in the 2030 Compact of 9,456 HH, though it is not as extreme 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.

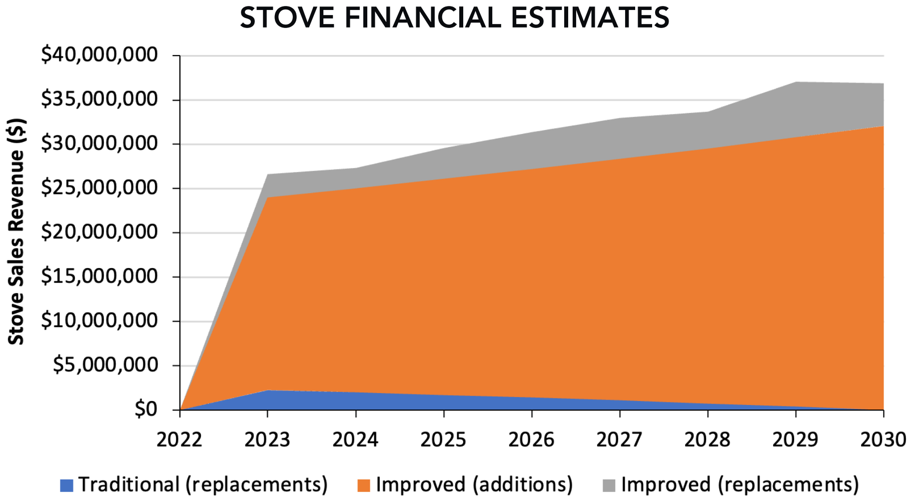
BIOGAS STOVE OWNERSHIP POTENTIAL OF TOTAL HOUSEHOLDS (2030)



Meeting IEP Scenario Goals: 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.

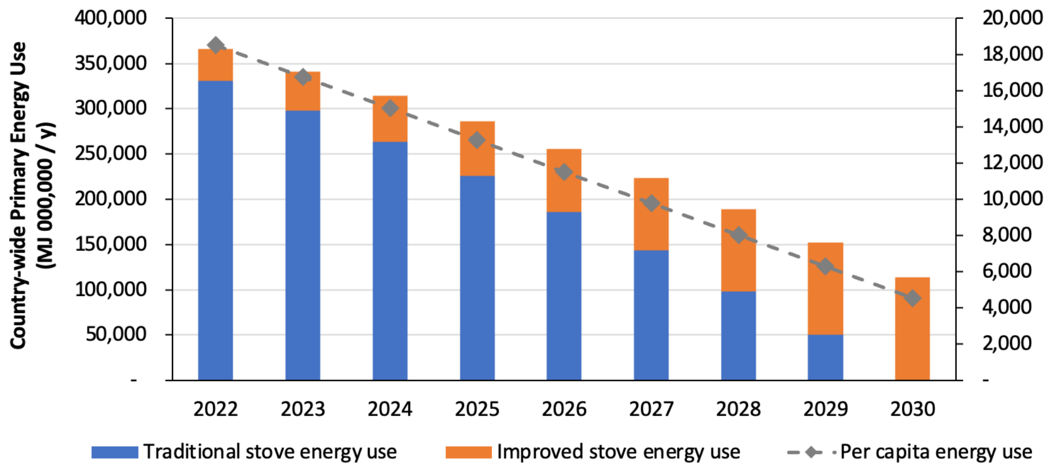




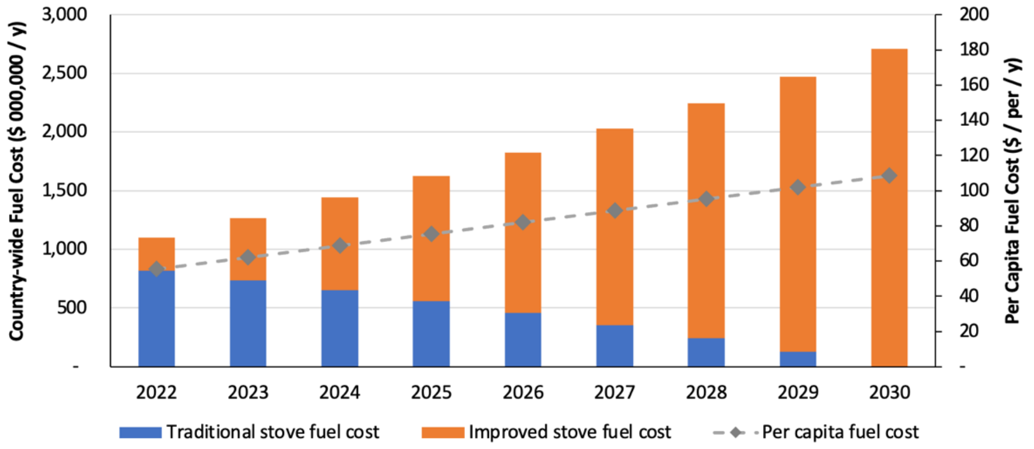
Meeting IEP Scenario Goals: Energy Use and Fuel Cost

- 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]).

PRIMARY ENERGY USE PROJECTIONS FOR COOKING



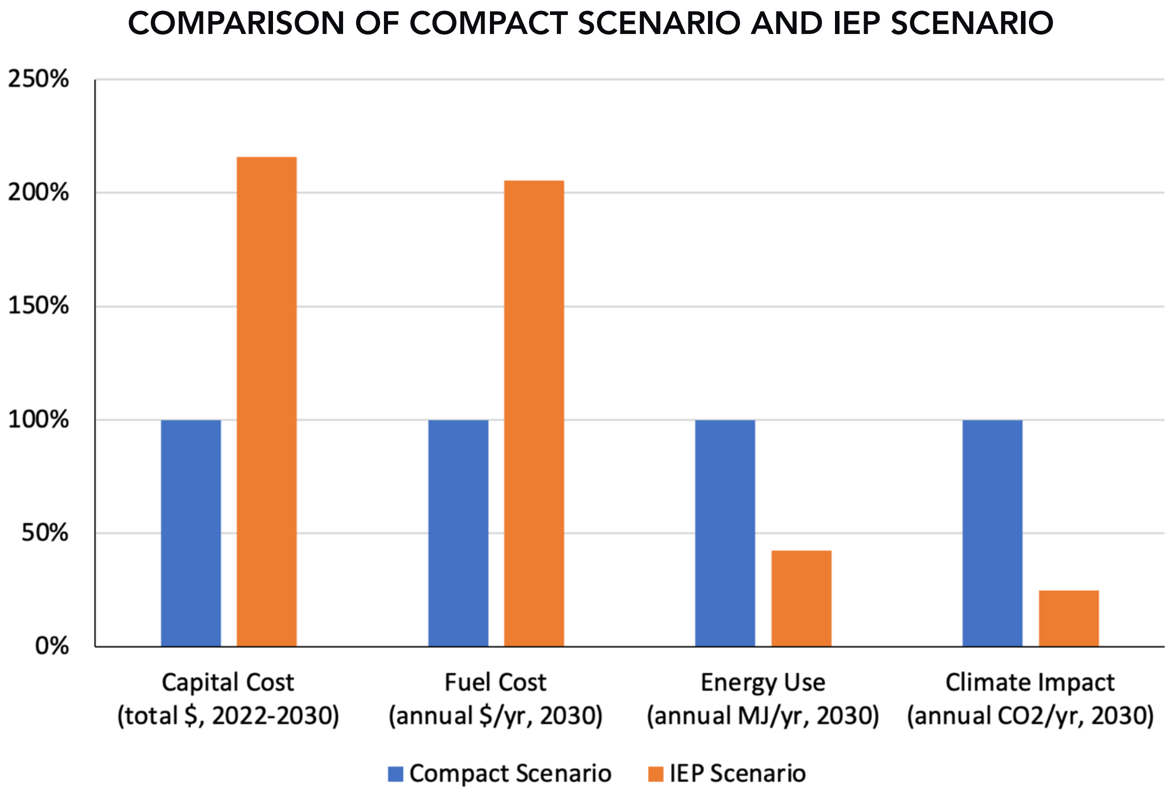
FUEL COST PROJECTIONS FOR COOKING



1. National Statistical Office of Malawi.

Comparison of Baseline Compact Scenario and IEP Scenario

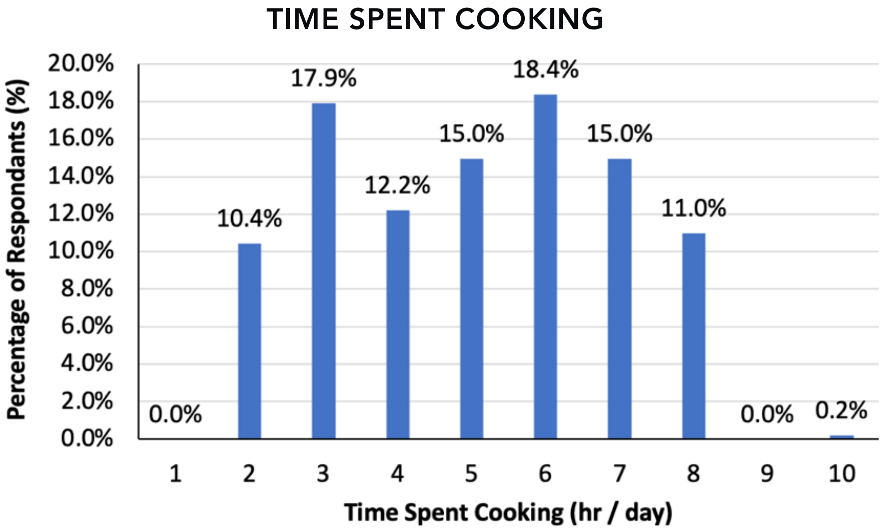
- The graph on right shows a comparison of potential outcomes for the Compact Scenario and IEP Scenario, with results displayed relative to the Compact Scenario.
- Capital costs are given as the total programmatic cost for new stoves and replacement stoves over the duration 2022-2030. Although replacement 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.



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.

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

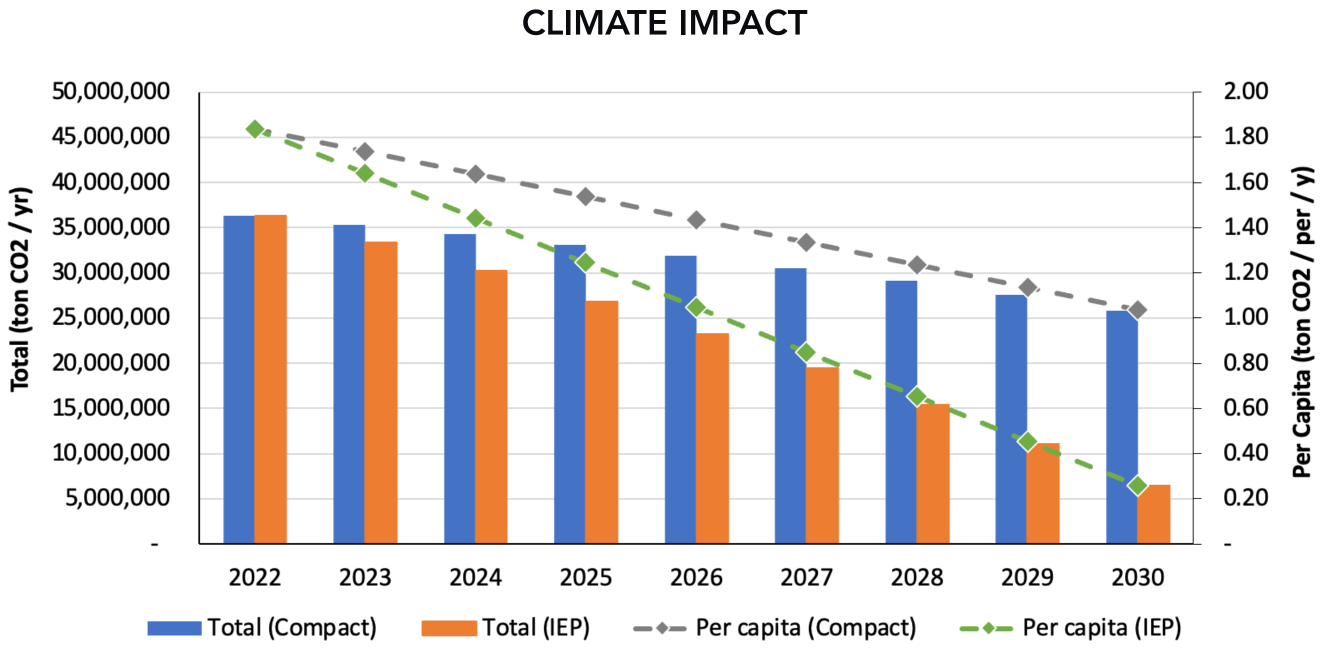
2030 Compact Goals will avert 16,600 deaths and 933,800 DALYs per year, relative to continued use of solid fuels and cooking technologies.
2030 IEP Goals will avert 30,609 deaths and 1,689,361 DALYs per year, relative to continued use of solid fuels and cooking technologies.

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.

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.



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.

INTEGRATED ENERGY PLANNING TOOL

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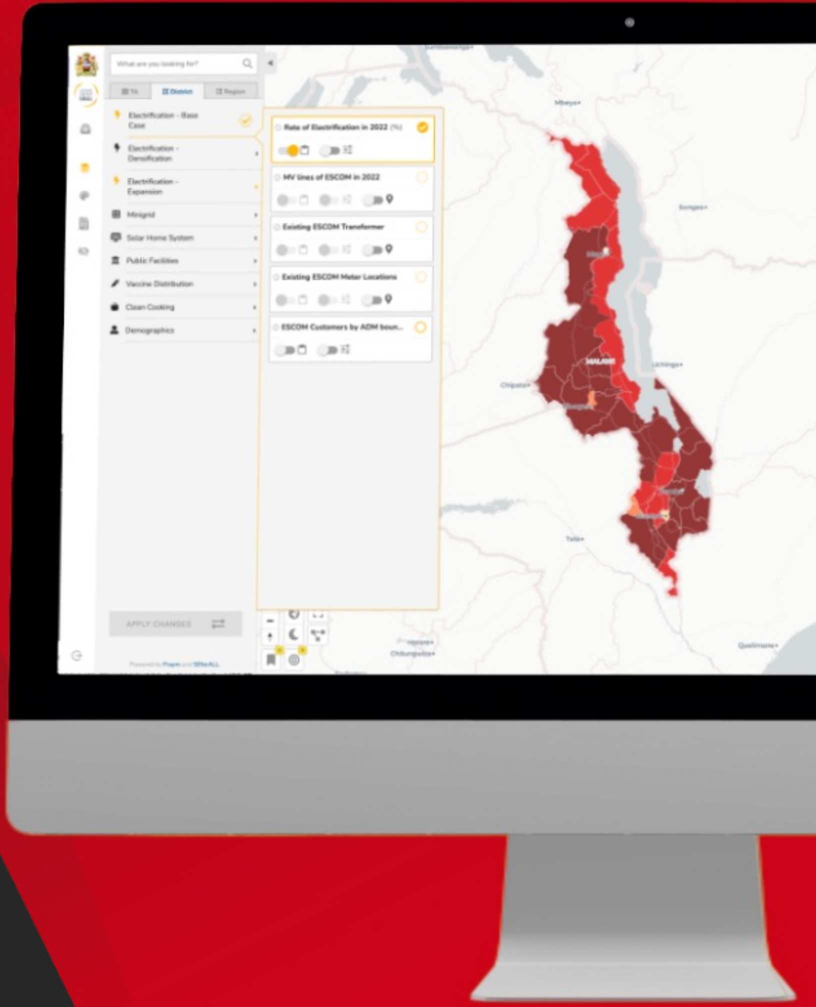

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