MADAGASCAR

Integrated Energy Access Planning

CLEAN COOKING REPORT

JUNE 2024

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ABBREVIATIONS

ADER	Rural Electrification Agency (Agence de Développement de l'Electrification Rurale)
AFD	French Development Agency / (Agence Française de Développement)
AfDB	African Development Bank
ASU	Arizona State University
ARELEC	Regulatory Electrification Authority (Autorité de Régulation de l'Electricité)
DALY	Disability-Adjusted Life Year
DPEBIO	Department of Ethanol and Bioenergy Promotion / (Département Promotion Ethanol et de la Bioénergie)
ESMAP	World Bank's Energy Sector Management Assistance Program
EU	European Union
FNE	National Electricity Fund (Fond National de l'Electricité)
FNED	National Sustainable Energy Fund (Fonds National de l'Énergie Durable)
GEAPP	Global Energy Alliance for People and Planet
GHI	Global Horizontal Irradiation
GIS	Geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLCEP	Geospatial Least Cost Electrification Plan
GoM	Government of Madagascar
HPAP	Health and Pollution Action Plan
IEP	Integrated Energy Plan
INSTAT	National Office of Statistics (Institut National de la Statistique)
IPP	Independent Power Producer
HV	High Voltage
JIRAMA	Jiro sy rano malagasy is the Malagasy public electric utility
JSI	John Snow Inc.
LEAD	Least-Cost Electricity Access Development Project
LPG	Liquefied Petroleum Gas
LV	Low Voltage
MECS	Modern Energy Cooking Services
MEDD	Ministry of Environment and Sustainable Development / (Ministère de l'Environnement et du Développement Durable)
MEH	Ministry of Energy and Hydrocarbons (Ministère de l'Energie et des Hydrocarbures)
MINAE	Ministry of Agriculture and Livestock (Ministère auprès de l'Agriculture et de l'Elevage)
MTF	Multi-Tier Framework
MV	Medium Voltage
NEP	New Energy Policy (Nouvelle Politique de l'Energie)
OPEC	Organization of the Petroleum Exporting Countries
ORE	Electricity Regulatory Authority (Office de Régulation de l'Electricité)
OSM	Open Street Map
PDMC	Least-Cost Power Development Plan/Plan de Développement au Moindre Coût
PRIRTEM	Power Transmission Network Reinforcement and Interconnection Project in Madagascar

PV	Photovoltaic
RBF	Result Based Finance
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SSA	Sub-Saharan Africa
SSS	Standalone Solar System
UEF	Universal Energy Facility
UN	United Nations
UNDP	United Nations Development Program
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
WWF	World Wide Fund for Nature

KEY TERMS

Biofuels: Renewable fuels made from organic matter, such as plants and plant-derived materials.

Carbon dioxide equivalent (CO_2e): All greenhouse gases have a carbon dioxide equivalent that determines their global warming potential relative to one metric ton of carbon dioxide.

Component: The components of the Integrated Energy Access Plan are the least-cost electrification plan, clean cooking plan, medical cold chain plan and agricultural cold chain plan.

Clean cooking SDG7 Energy Compact Scenario ("baseline scenario"): A scenario to achieve clean cooking targets set forth in SDG7 Energy Compact for 2030.

Clean cooking Universal Access Scenario ("IEP scenario"): A more aggressive clean cooking scenario that assumes universal access to electrification and improved cooking technologies by 2030.

CO: Carbon monoxide.

CO_2: Carbon dioxide.

Cooking devices/appliances: A device and/or appliance regardless of fuel associated, e.g., "cookstove" or "pressure cooker".

Cooking fuels: Fuels used to provide heat for cooking, which could include but are not limited to wood, charcoal, kerosene, gasoline, ethanol, propane, natural gas, butane and electricity, among others.

Cooking solutions: Potential combinations of cooking fuels and cooking appliances, e.g., "LPG cookstoves".

Disability-adjusted life year (DALY): A measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death.

E-cooking: An electric cooking stove.

Emissions factor: A term that describes the amount of a certain type of emission generated (such as carbon monoxide) relative to the amount of energy or fuel used, measured in terms of kg emission / kg fuel.

Energy access: Describes if the energy source, if available, can be accessed or obtained by the cookstove user.

Geospatial model: All spatial analysis was conducted in a geographic information system that aggregates specific geospatial and non-geospatial data and databases to conduct analysis using geospatial models and algorithms. The phrase geospatial model refers to the geospatial analysis and data models as contained within the geographic information systems' database used for the project.

Global Warming Potential (GWP): A measure of how much heat (thermal radiation) is trapped in the earth's atmosphere for a particular greenhouse gas (GHG). GWP is commonly measured over a given time frame and standardized using carbon dioxide equivalent as a basis for comparison.

Greenhouse Gas (GHG): Gases in the earth's atmosphere that trap heat. The primary GHGs include water vapor (H2O), carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O) and ozone (O3).

Grid extension: Grid extension refers to the process of connecting unserved houses and businesses with electricity service via extension of the medium voltage (MV) distribution system, new distribution transformers and extension of the low voltage (LV) to connect new service connections.

Integrated Energy Access Plan (IEP): A plan that integrates the optimal approach for achieving universal energy access for electrification and cooking, while also providing options for optimal cold storage for medical and agricultural cold chains, in support of the Government of Madagascar (GoM). The IEP is also referred to as the study or .

Isolated grids: Existing non-interconnected national utility operated distribution grids, which may also contain their own source of power, via renewable, thermal, hydro or other sources.

Mini-grid: Distribution systems (either LV or MV) that are not interconnected to other national or substation distribution systems and contain their own source of power, via renewable, thermal, hydro or other sources.

On-grid: Connected to the national interconnected electricity grid network.

Off-grid electrification: Encompassing mini-grids and standalone solar solutions for households, businesses and public institutions. These do not include grid-tied renewable energy generation systems.

PM2.5: Particulate matter with a diameter of 2.5 microns or less, also called "fine inhalable" particles. Fine inhalable particles can get into deeper parts of the lungs and may also enter the blood.

PM10: Particulate matter with a diameter of 10 microns or less, also called "inhalable" particles. Inhalable into the lungs and can induce adverse health effects.

Scenario: A description of one possible set of outcomes based on an assumed set of input conditions.

Solid fuel: A fuel in a solid form that is used as a source of energy to produce heat or electricity, e.g., wood, coal, charcoal, and peat.

Stove additions: Stoves that are newly acquired that users did not previously own or use. These are additions to the total stove count for a user and country.

Stove replacements: Stoves that are replacements for the same stove type and are replaced at the end of the original stove's useful lifetime. These do not affect the total annual stove count for a user and country.

Visualization Platform (platform): An online, publicly available, interactive, and user-friendly data visualization platform that equips policymakers and energy practitioners with data and insights to make informed decisions on strategies and operations to advance energy access in the country.

INTRODUCTION

Madagascar is the world's second largest island country with an area of 572,000 square kilometers and a population of approximately 29.6 million people.[1] It also has the unfortunate distinction of having one of the highest poverty rates in Southern Africa. Agriculture employs nearly 80 percent of all adults and accounts for almost 43 percent of GDP.[2] The primary crops grown in Madagascar include rice, cassava, potatoes and sweet potatoes. An estimated 2,600 health clinics provide immunization.[3] The rate of routine vaccine coverage has declined recently due to COVID-19 disruptions and is currently estimated at 51 percent for BCG and 70 percent for the first dose of DPT.[4] Low coverage numbers are more pronounced in more rural and remote areas.[5]

Electricity service is managed by JIRAMA, the state-owned electricity and water company that operates a series of small generation-distribution service networks that serve major population centres with limited service to rural areas. The Agency for the Development of Rural Electrification (ADER) coordinates off-grid electrification planning, as several mini-grid and standalone solar distributors implement and operate over 100 mini-grid systems. The current reported electrification rate is approximately 35 percent[6] (2023, Tracking SDG7 Report) while access to clean cooking devices is far lower at just 5 percent of Malagasy households. In light of the challenges facing Madagascar's energy, health and agricultural sectors, Sustainable Energy for All (SEforALL) and the Government of Madagascar (GoM) have agreed to sponsor and develop the Madagascar Integrated Energy Access Plan (IEP). The IEP will provide integrated electrification, clean cooking and cold chain analysis to support increased access to modern energy and associated services for urban, peri-urban and rural communities throughout Madagascar. The cold chain access plan will evaluate the means to improve refrigeration service to support vaccine storage and distribution, as well as refrigeration services for agricultural and food products. The IEP is intended to support improved energy and electrification policy development as well as to provide a public-facing point of reference for investment in energy resources for Malagasy businesses and communities to help public and private stakeholders identify optimal pathways to improved energy access and service delivery.

Madagascar IEP overview

SEforALL engaged a consortium of experts led by NRECA International (NRECA) to develop the IEP. The IEP consortium members include JSI, Arizona State University (ASU), DGrid Energy, and Fraym. The Madagascar IEP results are derived from a detailed geospatial analysis that uses a dynamic geospatial modelling framework designed by the NRECA team. The geospatial modelling framework integrates data from numerous sources including JIRAMA generation-distribution network infrastructure data and characteristics, road networks, hydrologic data, population and

[1] World Bank, 2022. https://data.worldbank.org/country/madagascar

[2] FIDA 2021. Programme d'options stratégiques pour le pays 2022-2026.

[3] Madagascar Vaccine Supply Chain Network Analysis, 2019, JSI.
[4] Performance de la Vaccination de Routine, Janvier 2023. Direction du Programme Elargi de Vaccination.
[5] SEforALL, Consultancy Services for Integrated Energy Planning (IEP) Madagascar, 2023
[6] In 2020, Tracking SDG7 report (2022)

demographic data, clean cooking data, health centre and vaccine infrastructure data and agricultural production and value chain data, among others. The geographically referenced data were used to evaluate electrification, cold chain and clean cooking solutions for all urban, peri-urban and rural communities in Madagascar using models developed by NRECA consortium team members.

This ambitious project builds upon experiences from previous SEforALL integrated energy planning projects in Nigeria (2021) and Malawi (2022). The Madagascar IEP includes the following goals and objectives:

- Prepare and present a gender-responsive integrated energy plan that synthesizes a least-cost geospatial electrification approach to service expansion building on the recently completed electrification analyses undertaken in 2018 and 2021[7] to evaluate the least-cost pathway to universal electrification in Madagascar. The IEP places a particular emphasis on electrification of public facilities and opportunities to enhance productive use potential using existing and new data on affordability analysis. The electrification modelling framework evaluates technology options based on least-cost supply, resulting in an actionable list of grid expansion, mini-grid and solar standalone projects – not just indicative estimates of access. The list of projects, taken together with technology cost analysis, is used to evaluate financing requirements by technology and by geographic area within Madagascar. This is an important advancement in electrification planning that has yet to be applied in Madagascar.

- Prepare a scenario-based geospatial clean cooking model to promote the adoption of improved modern energy cooking services throughout Madagascar. This analysis includes the introduction of improved cooking devices, alternative biomass fuels and/or electricity for traditional cooking fuels. The integrated electrification and clean cooking analysis was prepared on a common geospatial information system sharing attribute layers to evaluate technology options and total ownership costs of alternative technologies.This analysis covers both household and institutional cooking as part of the project scope.

- Develop geospatial models to evaluate logistical costs, constraints and challenges for both medical and agricultural cold chains. The models incorporated medical cold chains for routine vaccinations, COVID-19 vaccinations and future vaccination needs as well as analysis of agricultural cold chains to assess the magnitude, energy demand and total cooling cost of selected agricultural products such as fish, dairy and other temperature-sensitive produce or agricultural products. The cold chain analyses were incorporated into the electrification and cooking models to identify areas where additional energy access priorities may arise for equitable access to cooling and refrigeration.

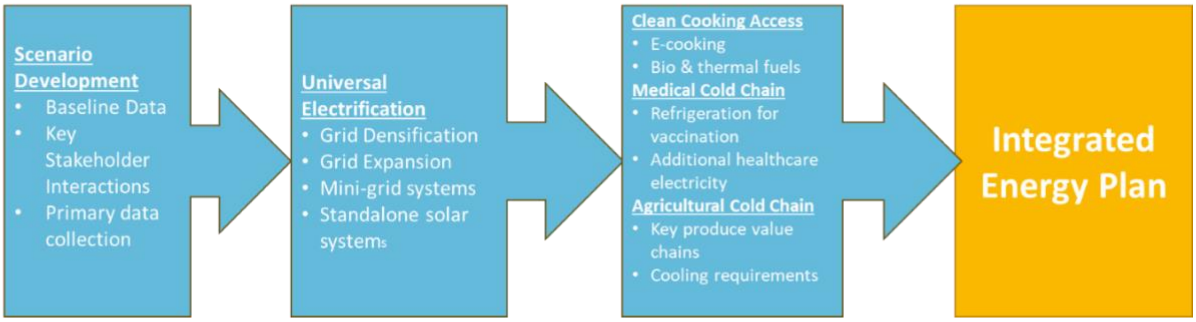
- Ensure that all public and private stakeholders can readily access and use IEP models and results including primary and secondary data. To achieve this goal, this project includes capacity building provided at multiple intervals during project implementation, including capacity building targetting women to ensure their equitable access and use of the data,

[7] Assistance Technique a la Préparation d'une analyse des options d'électrification géospatiale au moindre cout pour un déploiement sur réseau et hors réseau Madagascar, Rapport Finale. World Bank, August 2021.

as well as data management coordination particularly leading up to transfer of the database and models to the GoM.

- Develop a visualization platform designed to provide open access to all data layers, results and scenario analysis to public and private stakeholders for which these analyses were intended. The visualization platform design focuses on ease of use to allow stakeholders to access, interact, download and analyze the data and IEP results in a user-friendly manner. The platform is available to the public.

Figure 1. IEP development flow chart



Purpose of this report

This report presents the clean cooking component of the IEP. It includes an overview of the IEP and the clean cooking analysis, outputs and the clean cooking challenge in Madagascar, and is followed by a section summarizing the field data collection and validation completed during the project. From there, the methodological approach to the geospatial clean cooking analysis is presented, followed by the results of the modelling, scenarios analyses, cooking stove and fuel needs, final energy use, deforestation impacts, gender and youth impacts, health impacts and financing requirements. A final section on key conclusions is presented at the end of the document.

IEP objectives within the Clean Cooking Component

The clean cooking component of the IEP integrates with the electrification component to assess how different approaches to electrification, target electrification rates and the speed of electrification influence clean cooking opportunities. The clean cooking component contributes to supporting increased access to improved cooking technologies and fuels by:

- Quantifying production potentials and access for seven different fuel types (fuelwood, charcoal, electricity, LPG, biogas, bioethanol, biomass pellets/briquettes) for each of the 1,579 communes and municipalities in Madagascar.
- Describing customer preferences, quantifying stove ownership rates, quantifying usage rates of seven fuels across 15 different cookstoves, with differences identified and disaggregated by region, by urban or rural location and by type of customer (household or institution).
- Synthesizing primary data from a clean cooking survey with secondary data from public reports to create a comprehensive picture of clean cooking in Madagascar for the current situation.

- Developing two goal scenarios through 2030 based on cooking, bioenergy development, and electrification targets set out in Madagascar's New Energy Policy (2015–2030) and its National Energy Compact (2022), among others.
- Completing scenario analysis of clean cooking transition pathways using information on energy potential, consumer preferences, barriers to adopting clean cooking solutions, costs of cookstoves, fuel collection practices, costs of fuel and cookstove production.
- Quantifying clean cooking costs associated with stoves and fuels for each scenario and the affordability gap that must be bridged between what customers can pay and the price of clean cooking technologies.
- Emphasizing benefits of clean cooking to women and youth by quantifying impacts to health, time spent cooking and time spent collecting fuel
- Identifying benefits of clean cooking to reduce deforestation and greenhouse gas (GHG) emissions from cooking and improve energy security for households and institutions in Madagascar.
- Providing a geospatially explicit analysis of the opportunity space and challenges to transitioning to 100 percent access to clean cooking technologies and fuels.

Clean Cooking Challenge in Madagascar

The national importance of the clean cooking sector can be readily seen when noting that 71 percent of total final energy use in Madagascar occurs in households. This is driven primarily by fuelwood use for rural households (>80 percent of households) and charcoal use by urban households (>60 percent of households). Less than one percent of the population (27 million people) in Madagascar use clean fuels and technologies as of 2020, and without action, it is expected that 36 million people will lack access to clean cooking solutions by 2030, with a major impact on health, environmental and gender outcomes, among others.

Solid fuel combustion and poor ventilation lead to elevated levels of PM2.5 and other emissions create an estimated 21,000 deaths every year due to indoor air pollution in Madagascar. Deforestation is also a major threat to Madagascar ecosystems and livelihoods. By 2030, an estimated 25 percent of forest is expected to be removed, and while most of this loss is from agriculture (80–90 percent), the remainder is from wood and charcoal use by households and institutions for cooking, heating water and productive uses of energy such as agro-processing and meal preparation. As common globally, cooking roles in Madagascar also disproportionately affect women in significant and systematic ways. The burden of cooking commonly falls to women in the household and in the workplace – including collecting or purchasing fuels – and such activities have negative health effects and a large time cost sometimes consuming one-third to one-half of the day for fuel collection, food preparation, cooking, serving food and cleaning.

The benefits of clean cooking technologies include improved health, improved gender equity, reduced deforestation, reduced greenhouse gases (GHG) and other emissions, and, in some cases, a reduction in the energy cost to cook. Improved cookstoves can have a direct and measurable effect on increasing the efficiency of fuelwood and charcoal use and reducing the rate of deforestation. Cooking solutions that are locally available, with sustainable sources of fuel, can transition users completely away from wood and charcoal and improve energy security for families, business owners and communities that may have otherwise lost access to wood and charcoal cooking fuels over the next 5–20 years, particularly in areas of high land-use change where deforestation is accelerating. Similarly, clean cooking technologies that reduce time spent obtaining fuel and cleaning can enable women to utilize their time differently, and potentially direct additional time to income generation or education that creates even further benefits for gender equity and opportunity.

Alternatives to wood and charcoal include electricity (e-cooking), liquified petroleum gas (LPG), bioethanol, biogas, biomass pellets or briquettes and solar. As of 2023, there was very limited market penetration of any of these fuels, with estimates showing that, in aggregate, alternative fuels are used by 1 percent of households and less than 4 percent of institutions. These numbers are low despite the vast body of knowledge on clean cooking benefits, customer demand for cleaner cooking technologies and fuels, advocacy, and policy support from government actors and interested financing organizations and private sector actors to fund and deliver clean cooking technologies to customers present globally, albeit less common in Madagascar.

Entrepreneurs and development organizations have been piloting and advancing clean cooking programmes in Madagascar using a range of stoves, fuel types, stove and fuel access points and financing models. EnDev and ADES have implemented a programme to support the local production and distribution capacity for improved cookstoves benefitting over 370,000 households and 2,000 businesses and institutions as of end 2022. These early-stage efforts have laid the foundational awareness and progress for clean cooking to date, and furthermore, have provided both local and global understanding of the systematic challenges for clean cooking in Madagascar. Even while clean cooking adoption numbers are low, efforts to date in Madagascar have created insights on how to structure improved cookstove policies, enhance access to cleaner fuels, pilot stove programmes, provide entrepreneur support and coaching, deliver customer education, and enable financing needed to accelerate the transition to a cleaner cooking future.

The Government of Madagascar (GoM) has identified the importance of clean cooking and the transition from traditional biomass fuels and undertaken several initiatives to generate an enabling regulatory and policy environment for the development of alternative fuels and technologies with support from various development partners including the European Union, USAID, GIZ and others. These include the preparation of a draft law on bio-energies that provides a clear and incentivizing framework for the development of bio-energy fuels and technologies in Madagascar, standards for improved cookstoves and bioethanol stoves. The government has also developed a National Bioethanol Roadmap, regional bio-energy development plans and a National Strategy for Wood fuel Alternatives.

A recent major effort supported by the OPEC Fund for International Development has provided grant funding for a number of studies and pilot programmes aimed at mapping and quantifying clean cooking opportunities in Madagascar (through support to SEforALL for the completion of the Madagascar IEP), identifying and structuring priority value chains through a series of studies and pilots to be undertaken by UNIDO, as well as support through the UN Capital Development Fund (UNCDF) on funding mechanisms for clean cooking investments. The OPEC Fund's support could be extended through a USD 35 million clean cooking transition programme loan, currently under discussion with the GoM.

Complementary to the data and planning contributions of the Madagascar IEP, the Ministry of Energy and Hydrocarbons (MEH) is also working with the World Wide Fund for Nature (WWF) on developing regional monitoring and statistics for bioenergy and wood fuel production and use that will be available through a public national dashboard.

Work in this IEP clean cooking component supports such efforts by providing a generalized geospatial and analytical module to allow stakeholders to collaboratively visualize, plan and make decisions to reach clean cooking targets that account for locational differences across the country. Such work can provide more targeted guidance and prioritization of the development of energy and clean cooking policy, pilot projects, entrepreneurship and business growth opportunities, insights into technology or fuel innovations needed to realize goals, alternative fuel supply-chain needs, pricing and financing strategies, and consumer preferences and practices that influence cooking technologies and fuels, marketing and training.

METHODOLOGY FOR CLEAN COOKING ACCESS ANALYSIS

The clean cooking analysis includes geospatial and non-geospatial data, and a mix of both quantitative and qualitative data to create a representative picture of the clean cooking status in Madagascar in 2023 and projections out to 2030 under various scenarios.

Analyses consider targets for household and institutional cooking markets based on national targets, and account for urbanization forecasts by the government that affect the percentage of the total population with access to certain technologies, fuels and prices. The seven types of fuels included in the analysis are fuelwood, charcoal, biomass pellet and briquette fuels, bioethanol, biogas, liquified petroleum gas (LPG), and electricity, and these fuels pair with 15 different stove varieties for household and institutional cooking markets.

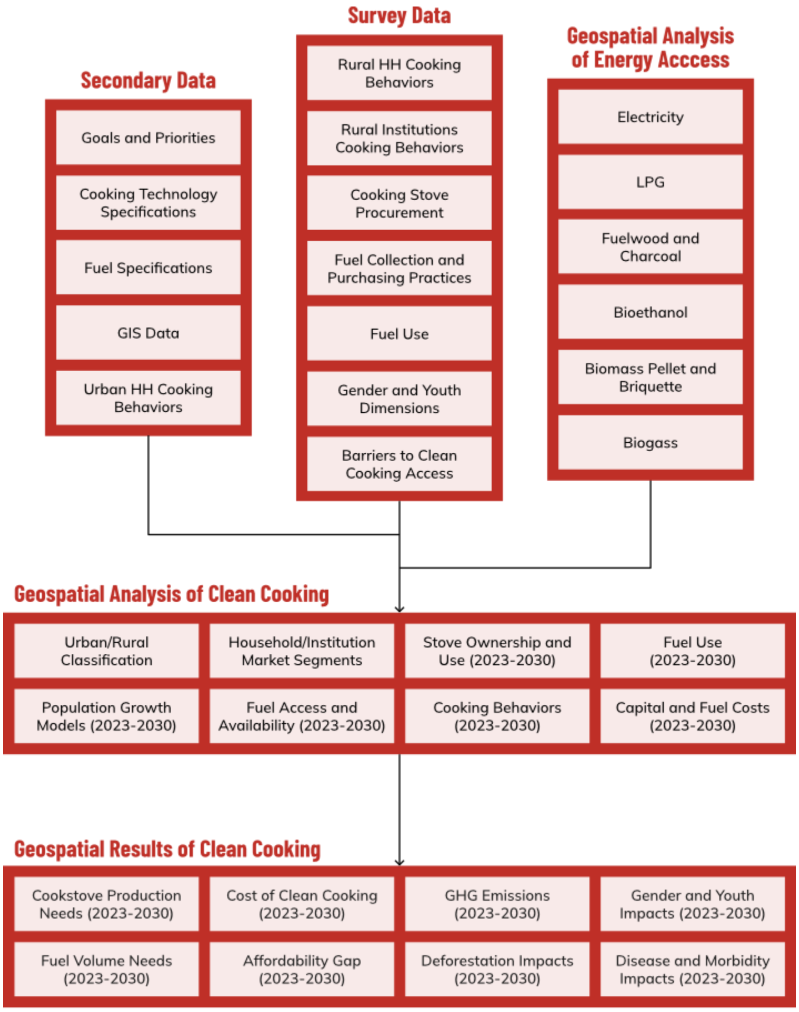
Methods account for user behaviour and preferences when estimating cooking technology use and fuel use. This is important when noting that many studies undertaken for cookstove programmes have historically overestimated impact by assuming full displacement of traditional cooking practices, and often resort to aggregate country-level characteristics that obviate the behaviours of actual market segments. While such studies provide valuable direction to policy development, the absence of geospatial data limits how to strategize and operationalize cookstove programmes with respect to the local circumstances that are not homogeneous across any nation or region. As a result, many such studies may miss essential local factors including user behaviour, stove stacking and fuel production potential. This work uses primary and secondary data to describe market segments and their stove ownership and use patterns to generate representative scenarios for the clean cooking transition conceptually and quantitatively. Computations and data analysis were completed in Excel.

The data used to evaluate clean cooking alternatives are quite broad in scope and diverse, heterogenous and sometimes conflicting. Much of the data needed are geospatial in nature – with values varying by geographic location or affected by population patterns in relation to fuel/resource accessibility including access to electricity, biomass resource accessibility, logistics and transportation costs associated with each fuel type, local meal and non-meal uses and general socio-demographic or occupational data for the locality. The challenge for this project was to formulate relationships between fuel types, stove and fuel costs, affordability, cookstove technologies, fuel accessibility, consumer preferences and distribution networks for specific fuels to facilitate analysis of clean cooking potential across Madagascar. It is also important in this early stage to characterize the scenarios and targets in a way that the forthcoming analyses lead to actionable recommendations for stakeholders such as government agencies, financing institutions, developers and regulatory bodies.

Methodology overview

Figure 2 summarizes the workflow for the clean cooking analysis, including process blocks for data inputs, analysis tasks and data outputs. Subsequent descriptions provide detail on each data or process of the workflow, and the following sections of the report go into details about the modelling assumptions, methods and outputs.

Figure 2. Workflow for clean cooking methodology



- **Secondary Data** – Secondary data collection included technical reports and papers, energy plans and targets, policies and standards, stakeholder interviews, technology and fuels specifications, urban cooking behaviours and GIS data.
- **Survey Study** – Primary data collection included surveys of households and institutions (e.g., schools, businesses) to obtain data on rural cooking behaviours, stove procurement, fuel collection and purchasing practices, gender and youth dimensions and barriers to clean cooking access.
- **Geospatial Analysis of Energy Access** – Geospatial data on energy access were taken from the IEP for electricity, secondary reporting sources for LPG, and generated for bioethanol, biogas, biomass pellets and briquettes, wood and charcoal based on GIS maps of land use.
- **Geospatial Cooking Analysis of Clean Cooking** – Geospatial analysis shows how to reach clean cooking scenario targets with respect to the market segment (household or institution), location in country (rural or urban, regional differences), population growth and the associated stove ownership and fuel consumption.
- **Geospatial Results of Clean Cooking** – Results include the total stove production volume and associated costs, fuel volume and associated costs, affordability gap, emissions, deforestation and impacts to health principally for women and youths.

Secondary Data

Data collection included technical reports and papers, energy plans and targets, policies and standards, stakeholder interviews and clean cooking surveys. Data were collected in various formats (GIS data, Excels, documents) and from interviews with various stakeholders, and then validated, aggregated and synthesized. UNIDO and MEH were very generous with sharing data and output of complementary efforts to improve accuracy and robustness of the clean cooking analysis, and further, this permitted development of synergies to augment clean cooking methods and generate output for direct inclusion in other clean cooking efforts, such as bioethanol refinery placement.

Studies and Documents

Major documents with secondary data include:

1. SEforAll (2023, January). Clean Cooking Country Brief: Madagascar.
2. SEforAll (2019). Energizing Finance: Taking the Pulse of Energy Access in Madagascar.
3. SDG7 Energy Compact for the Ministry of Energy and Hydrocarbons (MEH) - Madagascar, August 2022.
4. Dalberg and World Bank (2020, May). Madagascar Ethanol Clean Cooking – Impact & Policy Analysis
5. Dalberg and USAID (2020, March). ISP Madagascar, Ethanol Cooking Strategy and Roadmap, Recommendations Report.
6. Garcia, F. P., & Raji, A. K. (2020, August). Access to efficient and sustainable energy: case of Madagascar. In *2020 IEEE PES/IAS PowerAfrica* (pp. 1-5). IEEE.
7. Klug, T. (2018). Understanding the Impacts of Traditional Cooking Practices in Rural Madagascar and a Way Forward with Improved Cookstoves.
8. Reed, Erik. (2021, June 10). Disclosable Restructuring Paper - MG ethanol clean cooking climate finance program - P154440. World Bank.
9. Energy, A. R. (2014). Clean and improved cooking in Sub-Saharan Africa. *The World Bank Group: Washington, DC, USA*.
10. UNDP. (2020). Energy and the poor Unpacking the investment case for off-grid cleaner energy Madagascar.
11. Blanco, M., Greene, L. K., Davis, L. J., & Welch, C. (2019). Fuel use and cookstove preferences in the SAVA region. *Madagascar Conservation & Development*, *1*(4), 1.
12. Yu, S., Lew, V., Ma, W., Bao, Z., & Hao, J. L. (2022). Unlocking key factors affecting utilization of biomass briquettes in Africa through SWOT and analytic hierarchy process: a case of Madagascar. *Fuel*, *323*, 124298.
13. Food and Agriculture Organization of the United Nations (2023). FAOSTAT for Madagascar.

14. United States Department of Agriculture (2023). Foreign Agricultural Service for Madagascar.

15. Baraneedharan, V. (2023). MARKET ASSESSMENT ON COMPETITIVENESS AND DECARBONIZATION POTENTIAL OF THE SUGAR INDUSTRY IN THE REPUBLIC OF MADAGASCAR. www.unido.org

A second group of over 120 published articles was reviewed to facilitate data validation and fusion between secondary data and primary data and assist in assumption setting for scenario analysis. A bibliography can be found in Annex 1.

Stakeholders and Interviews

Annex 2 includes a comprehensive list of clean cooking stakeholders including government, NGOs, cookstove and fuel vendors, consulting organizations, funding organizations, developers, and universities and research institutions. Interviews were completed with many of these organizations to understand work that is in progress or planned but not yet published. These organizations were an invaluable source of secondary data introduced later in the report.

Scenario and Geospatial Data Sources

Major datasets obtained and curated from secondary data collection and interviews included:

- **Scenario targets** – Established targets for SDG7 were taken from the Energy Compact for Madagascar as the "clean cooking baseline scenario" and more aggressive clean cooking targets enabled through universal electrification and complete displacement of wood/charcoal fuels in the "clean cooking IEP scenario". Other major policy and energy transition targets were obtained through reports and data from organizations such as SEforALL's Energizing Finance and Country Brief for Madagascar, UNDP, MECS, USAID, World Bank, Clean Cooking Madagascar, Project Gaia, Montclair State University, the University of Liverpool and Duke University, to name a few. Of particular interest and focus are the 2019 SEforALL study on the energy situation in Madagascar that outlined the current state and pathways and investments needed to meet 2030 goals, and studies from Dalberg Consulting on ethanol opportunities. These studies and others cover historical and existing data, and some forecast to 2030 to suggest possible transition pathways.
- **World Bank Small Hydro Atlas** – Geospatial data on land use data were obtained to give commune-level data for cropland and forest land from World Bank, Madagascar Small Hydro GIS Atlas, 2017.[8]
- **Administrative layers and population** – The IEP uses the Humanitarian Data Exchange (HDX) portal to spatially represent Madagascar's administrative levels for: administrative level 0 (country), level 2 (district), level 3 (commune), and level 4 (fokontany). Meanwhile, for level 1 (region), an adapted UNIDO shapefile was used to spatially depict the 23 regions in Madagascar. Unfortunately, these layers were not available from INSTAT or FTM as

[8] World Bank via ENERGYDATA.info, under a project funded by the Energy Sector Management Assistance Program (ESMAP). For more information: Madagascar - Small Hydro GIS Atlas, 2017, https://energydata.info/dataset/madagscar-small-hydro-gis-atlas-2017"

official layers that could be publicly shared. INSTAT data were valuable as a geospatial resource for urbanization, showing urban homes in 76 communes of the 1,579 communes total in the HDX dataset. Clean cooking analysis is completed and analyzed at the commune level, and the population in each commune is attributed a percentage split between rural and urban.

Data Limitations

The following data limitations occurred during the analysis, and mitigation methods are discussed adjacent to the data limitations:

- **Commune name mismatch** – INSTAT commune names did not always match HDX commune names, and in such cases, urban homes from INSTAT were assigned to the closest commune name match in the HDX dataset or split between communes with related names (e.g., INSTAT lists commune Tsiroanomandidy and HDX lists communes Tsiroanomandidy Ville and Tsiroanomandidy Fihaonana).

- **Urbanization rate inconsistencies** – INSTAT data show approximately a 20 percent urbanization rate whereas UN data sources show a 40 percent urbanization rate. INSTAT data are the only resource at the commune level and these were selected and utilized. However, the INSTAT dataset includes commune names that do not match the commune names in the HDX dataset, requiring a line-by-line investigation of similar commune names in the HDX dataset that are likely analogous to the INSTAT dataset. There are a few instances in which the amount of urban population in a commune (from INSTAT) is more than the total population in a commune (from HDX), and in these cases, the excess urban households were shifted to reside in adjacent communes to ensure overall urbanization numbers match in the district, region and country.

- **Crop production generalized at the commune level** – There is no data resource for crop production at the commune level. A proxy is needed to estimate crop production, such as the land used for farming, as utilized in this study. Only land use for rice was disaggregated from other cropland in the Small Hydro Atlas dataset, therefore the geospatial production volumes of other crops such as maize, potatoes and cassava are proportional to the general farmland area in a commune. In other words, each commune cultivates each crop according to the relative amounts of each crop using country-wide production data.

- **Crop production levels uncertain in future years** – There are insufficient data to accurately forecast future crop production levels, particularly given the high uncertainty of factors such as cyclones and potentially significant implications of continued severe drought. Crop production numbers for the most recent year recorded were assumed constant.

- **Livestock numbers uncertain in future years** – There are insufficient data to accurately forecast future livestock volumes. Livestock volumes for the most recent year recorded were assumed constant.

Survey Data

A clean cooking survey was completed alongside an energy expenditure survey. The survey instrument was developed to collect primary data on stove ownership, stove acquisition, fuel sources, fuel collection/purchase practices, meal and non-meal stove uses, stove stacking, stove use preferences, stove use location, total expenditure, cooking expenditures gender of person cooking and making purchasing decisions, barriers to preferred stove and fuel use and time spent obtaining fuel. These data were obtained for residential and non-residential respondents. A single survey form was used for all respondent types, with nested questions to guide enumerators based upon responses from the survey respondents. An English version of the survey instrument, in PDF format, is presented in Annex 3, and full results of the survey are presented in Annex 4.

Surveys were conducted in French, while enumerators communicated in Malagasy as required. The sampling methodology used was a two-stage purposeful sample. In the first stage, a purposeful selection of up to two active mini-grid service areas were identified with SEforALL and the Agency for the Development of Rural Electrification (ADER) in the southern, central and northern zones of Madagascar. The selection of the mini-grid service areas included those operating mini-grids supported by ADER through their Appel a Project (AP) and open project solicitation process. The final selection of these sites included mini-grids operated by private operators such as ANKA in the southern region (solar PV mini-grid), WeLight in the northern region (solar PV mini-grids), HIER in the central region (hydropower mini-grid, and a community association in Manombo Sud in the southern region. The final selection of mini-grid service areas was conducted in coordination with SEforALL and ADER. For each selected mini-grid service area, a second stage of sampling was used to sample from four respondent types – electrified and unelectrified residential respondents and electrified and unelectrified commercial and institutional respondents. NRECA proposed that each sample contain between up to 350 households and 100 non-households per sampling frame. This sample size was split evenly between the electrified mini-grid area and non-electrified area to proportionally sample respondents. That is, the survey sample included 175 electrified area and 175 non-electrified area residential survey respondents for each sampling frame, as well as 50 electrified area and 50 non-electrified area non-residential survey respondents. A sample size calculator[9] was used to define the sample size target of up to 350 household surveys for each sampling frame. This was an estimate based on a maximum household population of 4,000 per site, with a 5 percent margin of error and 95 percent confidence level.

Two categories of respondents included:

- **Household (HH)** – a group of individuals who comprise a family unit, sometimes encompassing domestic help, and who live together under the same roof.

- **Institution** – small business or public facility (PF) defined as a structure whose primary purpose is to conduct income generating activities or to provide a public service such as a health clinic, school or public administration office. Further details on the characteristics of institutions surveys can be found in the Madagascar IEP Survey Report.

[9] See - (https://www.calculator.net/sample-size-calculator.html)

A summary of major sections and findings from the survey are given below.

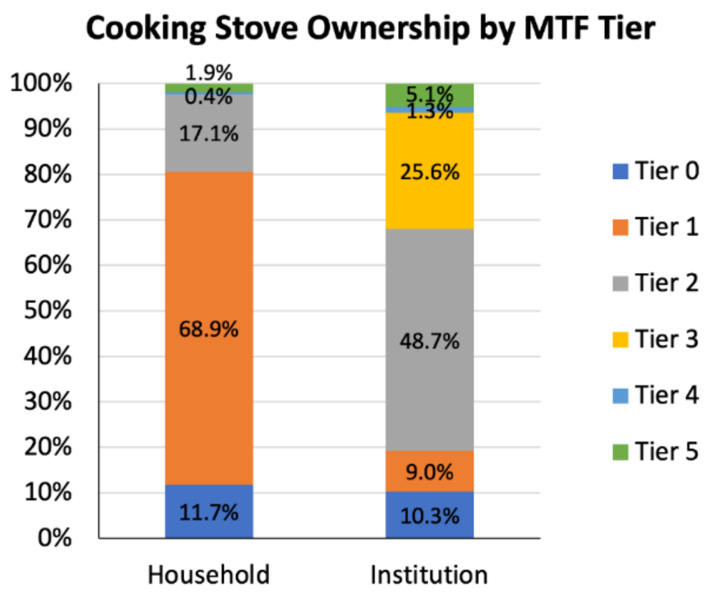
- **Cookstove and Fuels Summary** – Table 1 shows the stoves observed in the study, noting if they were used by households only, institutions only, or both. Fuel types included fuelwood, charcoal, electricity, LPG and biogas. Surveys for households identified a total of 12 cookstove types in use, and surveys for institutions identified a total of nine cooking stove types in use. Two types of fuelwood stoves (three-stone and basic), the electric kettle, the electric oven and LPG cylinders were observed in both households and institutions.

Table 1. Fuel and stove type used by households and institutions.

Fuel and Stove Type	MTF Tier	Household Use	Institution Use
Fuelwood stove – 3-stone	0	x	x
Fuelwood stove – basic	1	x	x
Fuelwood stove – improved	2	x	
Fuelwood stove – basic institutional	2		x
Fuelwood stove – improved institutional	3		x
Charcoal – basic	1	x	
Charcoal – improved	2	x	
Charcoal – basic institutional	2		x
Charcoal – improved institutional	3		x
Electric – rice cooker	5	x	
Electric – kettle	5	x	x
Electric – fryer	5	x	
Electric – oven	5	x	x
Electric – microwave	5	x	
LPG – cylinder	4	x	x
Biogas	4	x	
Total stoves observed	N/A	12	9

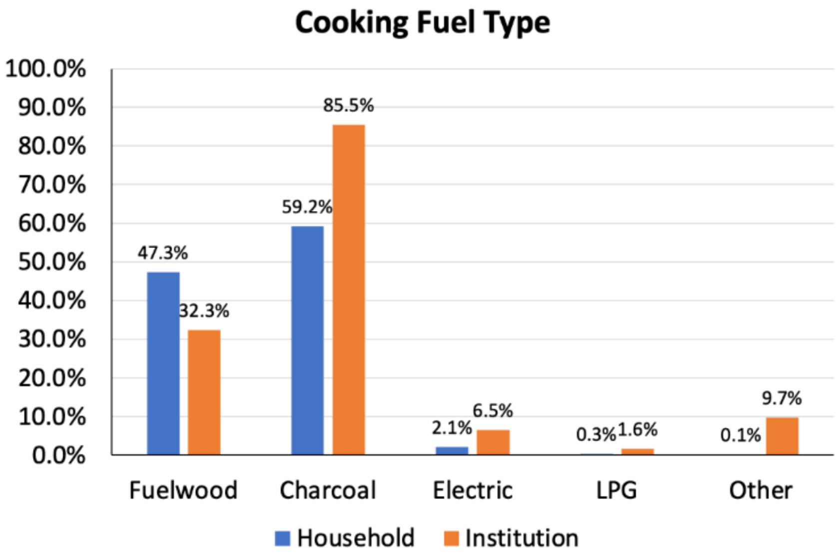
- **Cookstove Ownership** – Cookstove ownership varies by region. Charcoal use is common in the northern region where 67.9% percent of households use charcoal and 31.9 percent use fuelwood. Fuelwood and charcoal use are not equal but are more similar in the central and southern regions; 54.3 percent of households in the central region use fuelwood and 42.5 percent use charcoal and 43.3 percent of households in the southern region use fuelwood and 53.6 percent use charcoal. Electricity use is minimal; there is no usage in the northern region, 3.5 percent usage in the central region and 2.1 percent usage in the southern region. LPG use is minimal and only present in the southern region, and biogas was only found in one home. For institutional respondents across all regions, cookstove ownership included 25.6 percent fuelwood, 67.9 percent charcoal, 5.1 percent electricity and 1.3 percent LPG. Figure 3 categorizes these household and institution stove ownership patterns by MTF tier. Cookstoves owned by households were mostly tier 1, followed by tier 2 and tier 0, with a small number in the other tiers. No tier 3 stoves were reported by households in the survey.

Figure 3. Cookstove and fuel type by MTF tie



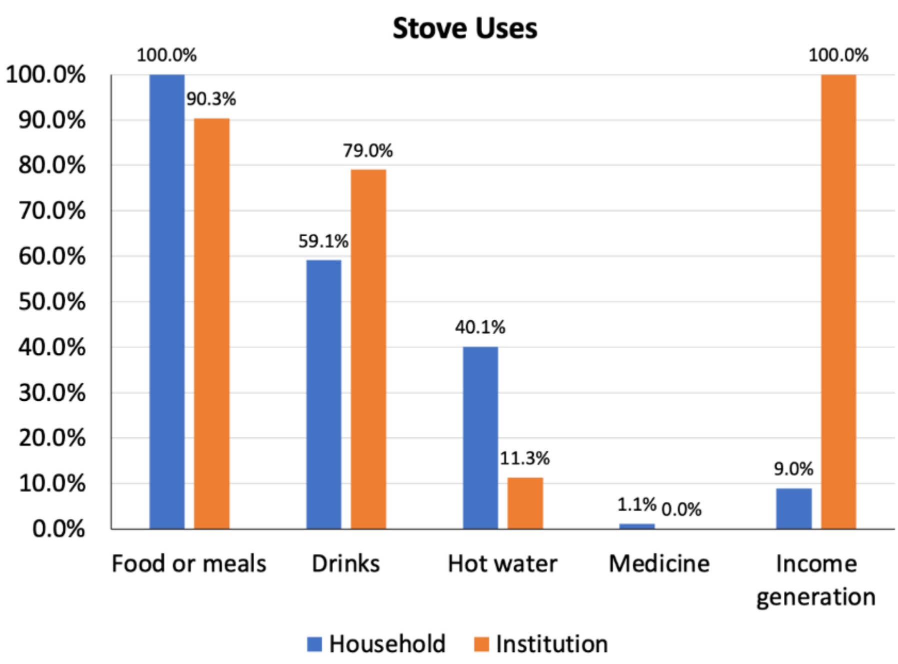
- **Cookstove Use** – Figure 4 provides a summary of ownership patterns for stove types based on fuel (fuelwood, charcoal, electric, other). Solid fuel stoves are clearly more prevalent than any other fuel type, with charcoal being the most common stove observed in both households and non-households. Most household respondents owned only one stove, with 91.5 percent of respondents reporting use of only one stove and the remaining 8.5 percent of households participating in cookstove stacking and using multiple stoves. Of note is that stove stacking was far more common among institutions than households, with 27.4 percent of institution respondents indicating they participated in stove stacking.

Figure 4. Cooking fuel types for household and institution respondents.



- **Uses of Cookstoves** – Cookstove uses are organized into five major groups – food or meals, drinks, hot water (for washing or bathing), medicine and income generation. Medicine was the only response given in the "other" category the question: "What else do you use the cookstove for?" Figure 5 shows the responses by percentage of respondents.

Figure 5. Stove uses for households and institutions.



- **Cookstove Procurement** – Among household respondents, 78.4 percent purchased their stoves outright, 14.4 percent made them at no cost, 5.9 percent received them for free and 1.3% made them themselves. Among institution respondents, 78.4 percent purchased their stoves outright, 14.4% made them at no cost, 5.9 percent received them for free and 1.3 percent purchased them using a payment plan. Of institution respondents, 79.8 percent purchased their stoves outright, 17.9 percent made them at no cost, 2.4 percent received them for free and none used a payment plan.

- **Fuel Collection and Purchasing Practices** – Cooking fuel collection and purchasing practices show that 73.5 percent of household respondents purchase fuel and 21.7 percent freely collect fuel, with a minor amount of 0.8 percent producing fuel and 4.0 percent having another method of obtaining fuel. Fuel was always available for most households and most institutions, across all fuel types. Fuelwood and charcoal were occasionally not available, whereas other fuels were always available or had minimal disruption.

- **Fuel Use** – Fuel use was self-reported by households and institutions. Values reported by respondents had a wide range, and hence, a large standard deviation compared to the average value. Notably households using a basic fuelwood stove had a slightly higher reported fuelwood use than the three-stone fire; this could be because of a number of factors such as smaller family size, the families had more uses for that cooking stove (potentially due to higher income), the basic stove designs were not as efficient as perceived, or other factors.

- **Barriers to Access** – Approximately nine in ten households said that some barrier existed to them owning an improved cookstove. Inability to afford the payment was the main reason given by three out of four households, regardless of the region surveyed. Notable regional differences in answers were found for respondents indicating a lack of access to the market as a reason for not owning an improved cookstove; this was said to be a barrier by 32.5 percent of households in the northern region, 20.5 percent of households in the southern region, and 13.1 percent of households in the central region. Far fewer institutions reported having a barrier to improved cookstove ownership, only about one in ten institutions. Again, inability to afford payments was the most cited response of any barrier listed regardless of region surveyed.

- **Gender and Considerations** – Women are predominately responsible for obtaining fuels. Women collect fuels in a total of 73 percent of households surveyed, with 64 percent of households indicating women were solely responsible for obtaining fuel. This figure decreases when it comes to the free collection of fuel from the forest, bush and mountainside, with men more likely to be the sole person responsible for collecting fuel. In institutions, women have a more common role in fuel procurement than in households, largely driven by the high amount of charcoal purchases led by women. Women also maintain a larger proportion of decision-making in stove and fuel selection, with over 80 percent of respondents indicating women manage the budget and are responsible for selecting cookstoves and fuels.

- **Youth Considerations** – Adults are predominantly responsible for obtaining fuel for both households and institutions. Children take on a small fraction of this responsibility for institutions, and this number is only marginally higher for households. Household data were obtained using the demographics question with many categories, and this was categorized into adult, child and elder by assuming that child, grandchild and niece/nephew fall into a "children" category and that grandfather/grandmother falls into the "elder" category. Adults are the only group responsible for cooking in 73.2 percent of households surveyed and share that role with another group in 21.6 percent of households surveyed. A small but notable number of 4.7 percent of households included children as the sole group responsible for cooking, and a minimal number of households (0.5 percent) had elders leading cooking tasks. A similar question for institutions only gave the relationship of the individual and did not include information on their age.

Cooking Technologies and Fuels

Descriptions and data on cooking technologies and fuels were curated from the initial data collection (secondary data) and clean cooking survey (primary data). The primary data emphasized information for rural areas that was not prevalent in available reports.

Data on final energy use – energy in the fuel – and the associated stove efficiency are used to calculate total useful energy – energy "into the pot". This value for the total useful energy required to cook a meal can then be used to calculate final energy needed from any fuel-stove combination based on well-documented functional relationships between fuel energy characteristics and fuel conversion characteristics (efficiency). Images of stoves and fuels can be found in Annex 5 and Annex 6, respectively.

Cooking Technologies

Cooking technologies are shown in Table 2, organized by fuel type. Analysis inputs described below are the synthesis of more than 40 references, survey data and interviews with stakeholders. No intra-country variation is modelled for cooking technologies to match assumptions across the entire IEP that equipment costs do not vary across Madagascar. There are hundreds of stove design types and thousands of stove vendors with variations on those designs, and Table 2 provides a simplified yet representative picture to complete the scenario modelling from 2023 out to 2030.

Table 2. Cooking technologies observed in Madagascar and corresponding data

Fuel (stove)	Price ($)	Lifetime (y)	Efficiency (%)	MTF Rating
Fuelwood (3-stone)	0.10	1	14%	0
Fuelwood (basic)	1.19	2	25%	1
Fuelwood (improved)	1.73	5	27%	2
Fuelwood (basic institutional)	6.68	10	30%	2
Fuelwood (improved institutional)	9.71	10	35%	3
Charcoal (basic)	3.29	1	10%	1
Charcoal (improved)	4.77	2	24%	2
Charcoal (basic institutional)	12.88	5	25%	2
Charcoal (improved institutional)	18.72	5	30%	3
Briquette/pellet (single burner)	20.00	4	35%	3
Biogas (stove top and oven)	84.00	3	44%	4
Bioethanol (dual burner)	24.50	3	52%	4
LPG (stove top and oven)	92.00	6	56%	4
E-cooking (rice cooker)	15.00	6	45%	5
E-cooking (hot plate)	18.20	2	62%	5
E-cooking (induction)	40.00	6	90%	5

Cooking Fuels

Primary cooking fuels in Madagascar are given in Table 3 and corresponding prices in Table 4. The emissions factor noted is for combustion for final energy use only and does not include life-cycle emissions that may result from the production or transportation of fuels like charcoal. Table 4 includes rural and urban pricing when such data are available. CO_2e emissions factor data are taken from United Nations Framework Convention on Climate Change (UNFCCC).

Table 3. Cooking fuels observed in Madagascar and corresponding data

Fuel	Energy value (MJ / kg)	CO_2e Emissions Factor (kg / kg_fuel)	Reference
Fuelwood	18.41	1.775	Clean Cooking Alliance (2019)
Charcoal	31.98	3.662	Jetter and Kariher (2009)
Briquette/pellet	16.75	2.409	Mlotha (2019)
Biogas	22.65	1.476	Decker et al. (2018) with 60% methane
Bioethanol	22.80	1.943	Energypedia (2023)
LPG	45.00	3.242	Benka-Coker et al. (2018)
Electric	N/A	0.520 (per kWh)	Randrianarison et al. (2022) for Antananarivo region

Table 4. Cooking fuels observed in Madagascar and corresponding price[10]

Fuel	Price rural ($ / unit)	Price urban ($ / unit)	Unit	Reference
Fuelwood	0.03	0.06	kg	IEP cooking survey, SEforALL (2023), urban scaling twice rural price
Charcoal	0.08	0.16	kg	IEP cooking survey, SEforALL (2023)
Briquette/pellet	0.42	0.84	kg	Matek et al. (2020), urban scaling twice rural price
Biogas	0.74	Not used	kg	Matek et al. (2020)
Bioethanol	1.04	1.04	liter	SEforALL (2023)
LPG	1.65	1.65	kg	SEforALL (2023)
Electric	0.13 (grid connected) 0.50 (mini-grid)		kWh	Madagascar IEP electrification component

[10] While fuels are, in many contexts, more expensive in rural settings, 1:1 scaling was used for LPG and Bioethanol in the IEP in the absence of appropriate data to determine an urban/rural differential for fuel prices.

Geospatial Analysis of Energy Access

Total fuel production potential is analyzed and presented at the commune level as the common geospatial level used in all IEP analyses. Proximity to roadways or waterways is not considered in assessing if those fuels can get to end users. This study only focuses on the production potential as part of a descriptive analysis of "what is possible for consumer access" to guide dialogue on cookstove planning conversations that must also account for factors outside the scope of this study.

Total production volumes of each fuel are presented at the commune level calculated as the *unconstrained* amount of production, meaning the analysis did not impose any hypothetical site-specific constraints or alternative uses of the fuel(e.g., biomass for food stuffs). Production volumes at the commune level can then be summed across communes to estimate the total biomass volume, and hence total energy of each fuel, within any administrative boundary of Madagascar be it commune, district, region, or country. At each administrative level, the total amount of energy available is then compared against the total cooking energy requirements of all households and institutions, which addresses questions of fuel sufficiency such as: "Are there sufficient bioethanol resources available in this commune to meet all cooking needs?" Answering that question does not presume a fuel will stay just within a commune boundary, but it does indicate which fuels may be produced and consumed locally, thereby reducing supply chain costs and emissions. This process identifies locations in the country that developers can prioritize for certain fuels and stoves that meet local needs and offer enough excess production to ship to urban centres (such as bioethanol).

Electricity access is taken from the Madagascar IEP study on electrification. LPG access is minimal and available only in some urban areas. Fuelwood access and charcoal production are higher in areas with more forest as identified by land-use categories. Fuel production potential from other biofuels is evaluated using data such as agricultural waste, sugarcane and other bioethanol feedstocks, and livestock ownership, and this total production potential can then be used to prioritize districts and communes for detailed local and logistical analyses of collecting raw materials and producing biofuels.

Electricity

Electricity-access data provided by the electrification component to the IEP categorizes customers as grid-connected, mini-grid, standalone solar sytem (SSS) and no access aggregated to the commune level. The segment for "no access" is pertinent to the business-as-usual baseline scenario that assumes a less aggressive electrification rate, and this segment is removed when all customers receive access to electricity in the more aggressive universal access scenario. Emissions rates from electricity can be found in the IEP Electrification Component.

E-cooking is considered viable for JIRAMA grid-connected, JIRAMA isolated systems and larger grid-edge mini-grids, and not viable for small or isolated mini-grids or SSS. Table 5 provides the breakdown of electrification modality and how this influences e--cooking potential. Isolated mini-grid and SSS are tier 4 and do not have sufficient power capacity for cooking. In addition, they have high end-user tariffs that are cost prohibitive for cooking outside a very small amount of customers compared to other fuel and stove types as identified in the clean cooking survey, and that minor use of e-cooking in rural areas is reflected in this study. Figure 6 and Figure 7 visualize communes in Madagascar where e--cooking is possible.

Table 5. Electrification modalities and implications to e-cooking considerations in modelling approach

E-cooking Possible (grid connection)	E-cooking Not Possible (isolated connection)
JIRAMA existing	MV mini-grid (Isolated)
JIRAMA densification	LV mini-grid
JIRAMA grid expansion (Interconnected)	Standalone solar solutions
JIRAMA grid expansion (Isolated)	No access
MV Mini-grid (grid-edge)	

Figure 6. E-cooking potential measured as percentage of grid-connected structures in 2023

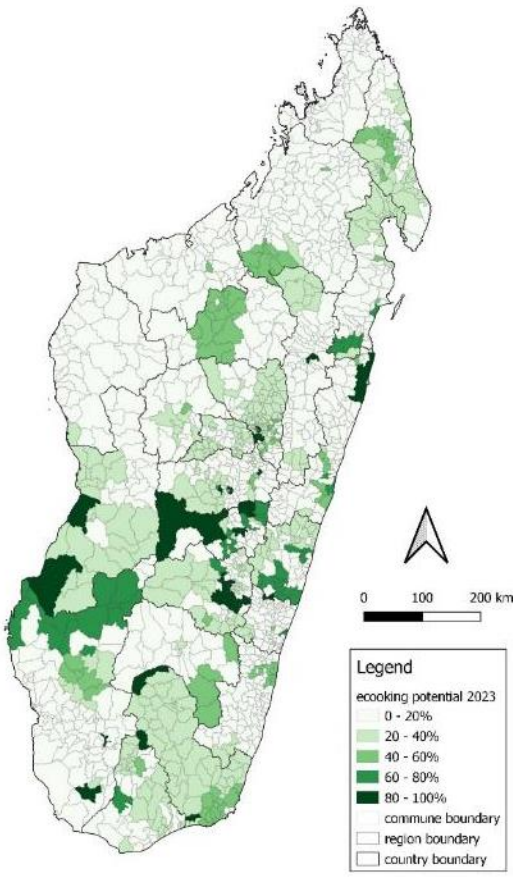
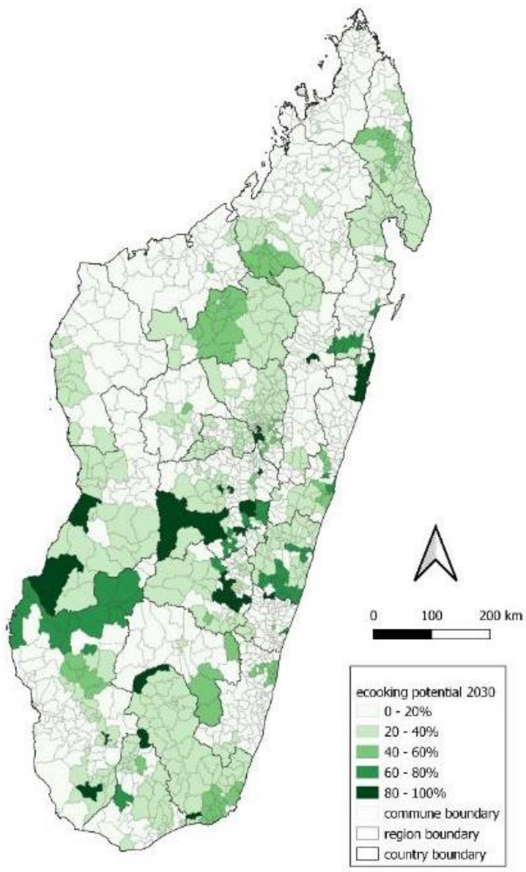


Figure 7. E-cooking potential measured as percentage of grid-connected structures in 2030



Liquified Petroleum Gas (LPG)

The LPG market in Madagascar is currently underdeveloped. Madagascar does not have an oil refinery, and thus LPG must be imported from abroad. Furthermore, there has thus far been little intervention by the government to regulate or promote the market. Major companies in the market are the French multinational companies Total Energiesand Rubis Group and a local company Jovena.

Rubis Group owns two subsidiaries in the country: Vitogaz Madagascar and Galana, both of which distribute LPG. Figure 8 shows terminals, depots and filling plants in Madagascar. Vitogaz has 14 accredited distributors and 640 individual retailers throughout the island. The company's main cannister sizes include 9 kg, 12.5 kg, 25 kg and 39 kg. Total domestic consumption of LPG is reported at 9,500 tonnes per annum with an estimated 250,000 cylinders of 6kg equivalent in circulation at any time (values taken from Vakana 2023).

Based on existing reports less than 1 percent of households use LPG and nearly all uses are in urban areas. Vitogaz's current customers also include a substantial share of commercial and industrial clients, including bakeries, roasteries, restaurants, hotels and a range of others. Thus, household consumption represents only a fraction of total sales. Household consumption has remained steady over the last 10 years at around 0.2 to 0.3 kg per person.

Figure 8. LPG infrastructure in Madagascar (taken from Vakana 2023)

Fuelwood

Land-use data on forest cover were obtained from World Bank, Madagascar Small Hydro GIS Atlas, 2017. Tropical forests can offer approximately between 600 and 3,000 kg/ha of fuelwood. Most often, the range lies between 600 and 1,200 kg/ha. If branches are included, the range lies between 1,000 and 2,000 kg/ha.

Table 6 shows the various classifications of forests present in Madagascar. Each classification has an area, fuelwood potential per hectare and total fuelwood potential. Figure 9 visualizes the fuelwood potential of each forest type. Forests classified as dense outnumber all other forests combined. Furthermore, dense forest has the highest fuelwood potential per area. Therefore, most of the fuelwood potential in Madagascar is projected from dense forests. Fuelwood potential was also calculated for savannah areas noting literature stating that 29 percent of fuelwood can be found outside of forests[11]. That total amount of fuelwood was calculated and then spread evenly across the wide expanse of available savannah, which equated to a small amount of fuelwood potential per hectare.

Table 6. Fuelwood potential per unit area and total fuelwood potential across forest types in Madagascar

		Sum of area (ha)	Fuelwood density (kg per hc)	Fuelwood potential (kg)
Forest Type	Coastal forest	72,729	1,000	72,728,713
	Degraded forest	2,414,599	1,000	2,414,598,926
	Dense forest	9,116,015	2,000	18,232,030,149
	Reforested area	311,902	1,000	311,901,888
	Riprarian Forest	120,359	1,000	120,358,796
	Tree savannah	17,707,977	47	839,144,604
	Grassy savannah	19,119,165	47	906,017,889
Total	**Madagascar**	**48,862,746**	**N/A**	**22,896,780,965**

[11] Reiner, F., Brandt, M., Tong, X., Skole, D., Kariryaa, A., Ciais, P., Davies, A., Hiernaux, P., Chave, J., Mugabowindekwe, M., Igel, C., Oehmcke, S., Gieseke, F., Li, S., Liu, S., Saatchi, S., Boucher, P., Singh, J., Taugourdeau, S., … Fensholt, R. (2023). More than one quarter of Africa's tree cover is found outside areas previously classified as forest. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-37880-4

Figure 9. Fuelwood potential by forest type

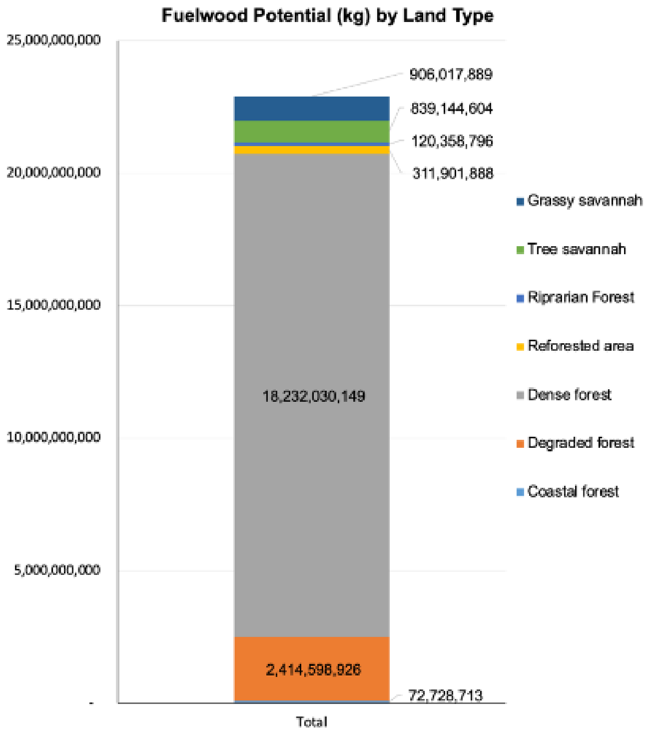
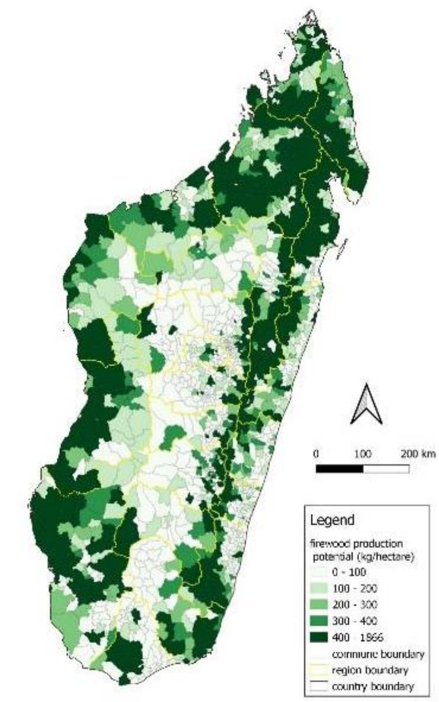


Figure 10 displays the total fuelwood potential in each commune in Madagascar when considering the various forest types present and the associated fuelwood potential for each type. Communes with the highest fuelwood potential are generally found along the coast, and the highest potential communes are along the midwestern and northeastern coasts.

Figure 10. Geospatial fuelwood potential in Madagascar



Charcoal

Charcoal production is expected to be denser in areas with greater fuelwood potential as shown in Figure 10. Kiln technology can significantly influence wood consumption needed to produce charcoal, and also affects the end quality and energy density of the product. Table 7 provides a summary of kiln technologies and charcoal production efficiencies. Charcoal production can be lawfully produced or produced illicitly. Sustainable and regulated charcoal production is a priority, and such efforts are examining the potential for dedicated plantations that reduce deforestation.

Table 7. Charcoal kiln type and corresponding conversion from wood to charcoal

Kiln type	Efficiency (kg_c/kg_w)
Earth mount kiln	19.5%
Brick kiln	31.0%
Kon-Tiki kiln	22.0%
Steel drum kiln	29.0%

Bioethanol

Bioethanol can be made from a variety of crops, specifically the grain of the crop (e.g., maize kernel and not the maize stalk). The geospatial component of bioethanol potential is calculated using national crop production volumes, commune data on cropland sizes and crop conversion factors for grain to ethanol. This analysis calculates the total bioethanol production potential by assuming all crop production is available for biofuel conversion (assuming no crops are used for human or animal consumption). Estimates should therefore be considered an upper limit on what is possible to inform discussions of food vs. biofuel. These data can then be used in planning conversations regarding an absolute amount or a percentage deviation of crop production for bioethanol, which could also vary by region or district. Establishing such limits is not within the scope of this analysis as it focuses only on estimating the total potential.

Crop production volumes were obtained from FAOSTAT and USDA and are summarized in Table 8. There were insufficient data to accurately forecast potential crop volumes to 2030, particularly given extended periods of drought, and thus a constant annual production volume was assumed for 2023 to 2030. For example, the production volumes for maize have been stable for the past five years but are half the production levels of 10 years ago (USDA 2023).

Table 8. Annual grain production volumes for selected crops.

Crop	Annual grain production volume (ton)
Sugarcane	3,122,686
Maize	225,000
Rice	4,391,386
Cassava	2,439,642
Sweet potato	1,143,320
Potato	251,258

Land-use data on cropland per commune were obtained from World Bank, Madagascar Small Hydro GIS Atlas, 2017. There are three designations for cropland with total land use listed in Table 9. Rice fields were explicitly separated from other croplands, allowing rice production to be geospatially located according to rice field location. The other two crop land types (field crops, mix of crops) were aggregated as "other crop land", or non-rice land, with crop production geospatially distributed across these remaining crop lands according to the relative amount of "other crop land" per commune.

Table 9. Land-use data for farmland. (World Bank 2017)

Land use category	Land area (hectares)
Rice field	1,260,024
Field crops	429,565
Mix of crops	5,438,911
Total	**7,128,500**

Ethanol conversion rates for the principal crops in Madagascar are shown in Table 10. The energetic value of cooking ethanol is 22.8 MJ per kg (energypedia 2023) with density of 0.783 kg per liter (Cool Conversion 2023) to equate volumetric energetic value of 17.85 MJ per liter.

Table 10. Ethanol conversion factors for the grain component of selected crops

Crop	Ethanol conversion rate (L per ton of grain)
Sugarcane	700
Maize	390
Rice	525
Cassava	500
Sweet potato	219
Potato	208

Total bioethanol fuel production potential is given in Table 11, which represents the maximum amount of ethanol that could be produced if all available grain was sourced from each crop and converted into ethanol. Figure 11 displays the total potential production volume of bioethanol from sources within each commune. This amount is compared against the total energetic requirements for cooking in 2023 and 2030 and displayed in Figures 12 and 13, respectively. These figures include energetic needs for both households and institutions. In looking at the nation as a whole, the total potential bioethanol energy supply could meet 416percent or 5,863 percent of cooking requirements for households and institutions, respectively, in 2030, assuming that all crops are used for bioethanol production. These findings identify the upper limit for unconstrained bioethanol production and should not be taken as a prescriptive action plan for cookstove production and use, which considers more factors as introduced in the Clean Cooking Scenarios and geospatial analysis.

Table 11. Ethanol production potential for selected crops if all grain is converted into ethanol.

Crop	Grain (ton)	Ethanol volume (liters)	Ethanol energetic value (MJ)
Sugarcane	3,122,685	2,185,879,948	39,023,203,184
Maize	225,000	87,750,000	1,566,548,100
Rice	4,391,386	2,305,477,650	41,158,309,199
Cassava	2,439,642	1,219,821,000	21,776,732,420
Sweet potato	1,143,320	250,249,903	4,467,561,377
Potato	251,257	52,350,419	934,580,624
Total	**11,573,291**	**6,101,528,921**	**108,926,934,904**

Figure 11. Potential for bioethanol production from all sources.

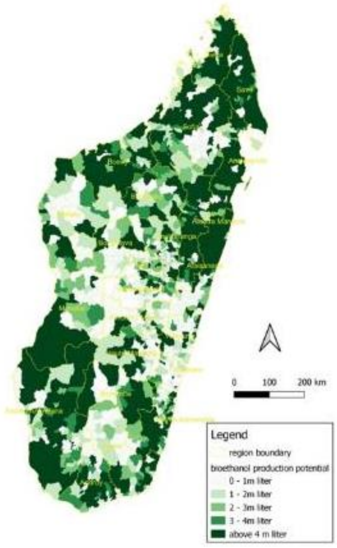


Figure 12. Potential for total cooking energy needs that can be met by ethanol production potential from all sources within each commune in 2023.

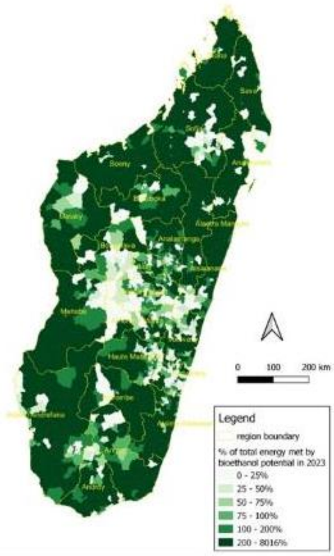
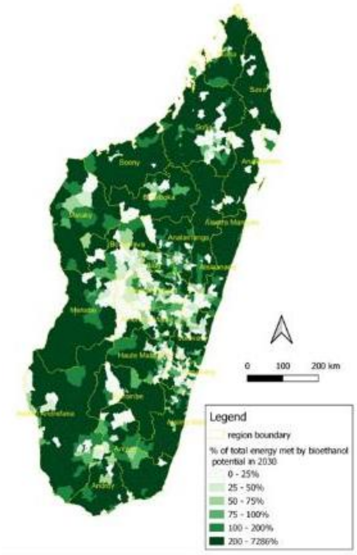


Figure 13. Potential for total cooking energy needs that can be met by ethanol production potential from all sources within each commune in 2030.



Biomass Pellets and Briquettes

Agriculture waste can be collected and used to make compressed pellet and briquette fuel (e.g., using the maize stalk, not the maize kernel). Data on sawdust waste from mills are not available and not considered here. The geospatial component of biomass pellet and briquette potential is calculated using national crop production volumes, commune data on cropland sizes, conversion factors between grain to agriculture waste and the energy content in each type of agriculture waste.

Crop production volumes and cropland sizes used in bioethanol calculations are used again here. Table 12 gives conversion factors between grain to agriculture waste, and the energy content in each type of agriculture waste. The waste to grain ratio for certain crops can be greater than one if the waste (e.g., maize stalk and straw) weighs more than the grain (e.g., maize kernel). The energetic value for each agricultural waste type is given on a dry basis, and then a moisture content of 10 percent is assumed for the pellet/briquette fuel.

Table 12. Conversion factors for agriculture waste and associated energy content.

Crop	Waste type	Waste to grain ratio (kg waste per kg grain)	Energetic value* (MJ per kg)
Sugarcane	Sugarcane bagasse	0.25	18
	Sugarcane waste	0.6	16
Maize	Maize cob	0.3	15
	Maize stalk and straw	1.56	16
Rice	Rice husk	0.33	13
Rice	Rice straw	1.53	16
Cassava	Cassava stalks	0.5	17
Sweet potato	Sweet potato	0.25	18
Potato	Potato	0.25	18

* Energetic value is given on a dry basis

Total biomass pellet/briquette fuel production potential is given in Table 13, which represents the maximum amount of biomass pellet/briquette that could be produced if all available agriculture waste was sourced from each crop and converted into pellets. Agriculture waste can be collected at farms or agro-processing facilities, and the cost and complexity of collection from many distributed sites could reduce potential for biomass pellet/briquette fuel. Figure 14 displays the total potential production volume of biomass pellet/briquettes from sources within each commune. This amount is compared against the total energetic requirements for cooking in 2023 and 2030 and displayed in Figures 15 and 16, respectively. These figures include energetic needs for both households and institutions. In looking at the nation as a whole, the total potential biomass pellet/briquette energy supply could meet 556 percent and 7,826 percent of cooking requirements for households and institutions, respectively, in 2030, assuming that all crop waste is used for pellet/briquette production. These findings identify the upper limit for unconstrained biomass pellet/briquette production and should not be taken as a prescriptive action plan for cookstove production and use, which considers more factors as introduced in the Clean Cooking Scenarios and geospatial analysis.

Table 13. Agriculture waste production potential for selected crops if all waste is converted into pellet and briquette fuel.

Crop	Waste (ton)	Energy (MJ)
Sugarcane	2,654,282	39,234,852,321
Maize	418,500	2,827,003,032
Rice	8,167,977	55,175,384,607
Cassava	1,219,821	30,652,779,249
Sweet potato	285,830	14,365,197,286
Potato	62,814	3,156,915,165
Total	**12,809,226**	**145,412,131,660**

Figure 14. Potential for biomass pellet/briquette production.

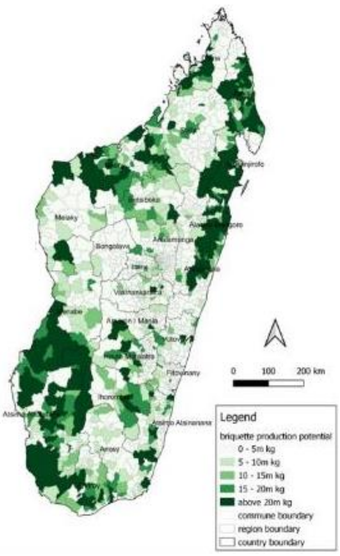


Figure 15. Potential for total cooking energy needs that can be met by biomass pellet/briquette production potential within each commune in 2023.

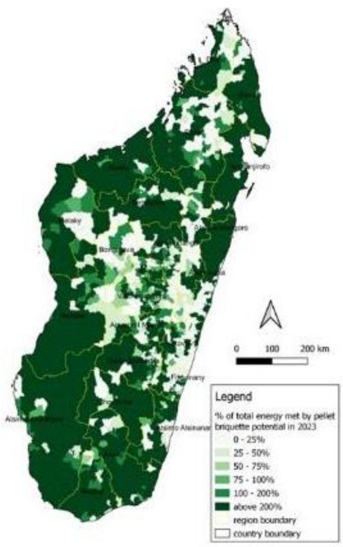
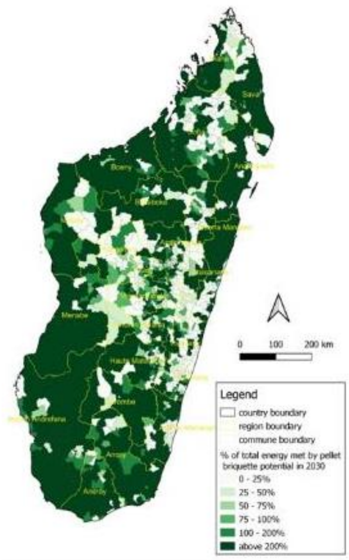


Figure 16. Potential for total cooking energy needs that can be met by biomass pellet/briquette production potential within each commune in 2030.



Biogas

Biogas can be generated from the anerobic digestion of animal waste, and while some types of food or crop waste could also be used for anerobic digestion, this study does not include food waste due to lack of data and assumes crop waste is diverted to biomass pellet/briquettes and not biogas. Biogas potential for Madagascar is calculated using livestock counts, geospatial location on farmland and conversion factors from livestock counts to biogas generation. Other needs such as water and equipment availability are not considered; only the fuel source is reflected here.

Livestock counts (head) were obtained from FAOSTAT and are summarized in Table 14. There were insufficient data to accurately forecast potential changes in livestock counts to 2030, and thus a constant number of livestock was assumed for 2023 to 2030. The geospatial locations for farmland are used as proxies for the geospatial locations of livestock because there is no commune-level database on livestock locations.

Table 14. Livestock counts (FAOSTAT, 2021)

Livestock	Count (head)
Cattle	8,800,000
Goats	1,498,079
Sheep	852,075
Pigs	1,249,339
Chickens	42,700,000

Biogas production volumes per livestock head are calculated using conversion factors that indicate differences in solid waste production, volatile solid fraction of the solid waste (what percentage of the wet mass generates biogas) and the methane production fraction (the methane productivity for the solid waste of a particular animal) to calculate the total methane production for a single head of livestock per annum. These volumes are shown in Table 15. The total amount of methane with an energetic value of 55.5 MJ per kg and density of 0.716 kg per sq meter (Engineering Toolbox 2023) is used to calculate cooking potential because methane is a far more common metric available for comparison across all livestock types than biogas generated (biogas by volume has a wider range in energetic values due to the methane fraction of 0.4 to 0.6 by volume, making it a less accurate benchmark to source across studies that may only cite biogas production by volume but not by energetic value). The equivalent biogas amount can be easily calculated using a methane volume fraction of 0.4–0.6 with the remaining volume considered to be inert (not combustible). As an example, a volume fraction of 0.4 yields 22.25 MJ per kg (55.5 * 0.4), which is near to a common energetic value of 22.65 for biogas used in cookstoves (energypedia 2023).

Table 15. Biogas production volumes for selected livestock.

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

Total biogas production potential is given in Table 16, which represents the maximum amount of biogas that could be produced if all available animal waste was sourced. Figure 17 displays the total potential production volume of biogas from sources within each commune. This amount is compared against the total energetic requirements for cooking in 2023 and 2030 and displayed in Figures 18 and 19, respectively. These figures include energetic needs for both households and institutions. In looking at the nation as a whole, the total biogas energy supply could meet 608 percent and 8,569 percent of cooking requirements for households and institutions, respectively, in 2030, assuming that all animal waste is used for biogas. This total production potential can then be used to prioritize districts and communes for detailed local and logistical analyses of collecting and turning animal waste into biogas, including consideration for competition with fertilizer and total collectable waste amounts from small shareholder farms and larger commercial farms.

Table 16. Biogas production potential for selected livestock if all waste is converted into biogas.

Crop	Waste (ton)	Energy (MJ)
Cattle	3,626,648,256	144,115,748,397
Goats	45,905,934	1,824,210,022
Sheep	10,824,897	430,159,762
Pigs	184,388,144	7,327,216,065
Chickens	138,829,656	5,516,812,870
Total	**4,006,596,888**	**159,214,147,116**

Figure 17. Potential for biogas production.

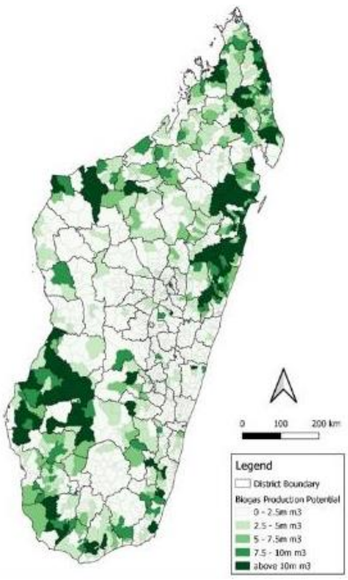


Figure 18. Potential for total cooking energy needs that can be met by biogas production potential within each commune in 2023.

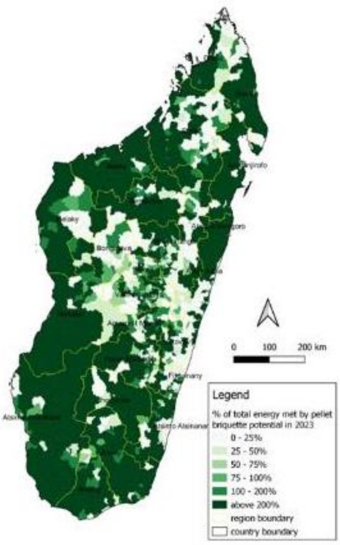
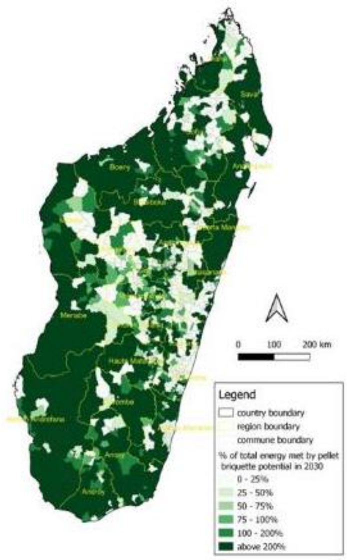


Figure 19. Potential for total cooking energy needs that can be met by biogas production potential within each commune in 2030.



Other Cooking Technologies and Fuels

Other cooking technologies and fuels such as solar cookers, saw dust, dung and kerosene[12] have minimal to no penetration in the overall Madagascar market and thus have negligible impact on overall quantitative results and recommendations. They are therefore not represented in modelling or geospatial analyses.

Geospatial Analysis of Clean Cooking

Two clean cooking scenarios are prepared, each with target stove adoption numbers in 2030. Established targets for Sustainable Development Goal 7 (SDG7) were taken from the Energy Compact to yield the baseline scenario and more aggressive universal access to clean cooking targets are evaluated in the IEP universal access scenario. Other major policy and energy transition targets were obtained through reports and data from organizations such as SEforALL's Energizing Finance and Country Brief for Madagascar, UNDP, MECS, USAID, World Bank, Clean Cooking Madagascar, Dalberg Consulting, Project Gaia, Montclair State University, the University of Liverpool and Duke University, to name a few. These studies and others cover historical and existing data, and some forecast to 2030, to suggest possible transition pathways.

The analysis provides a scenario-based prospective model to reach quantitative goals for the baseline and universal energy access scenarios. This is not a least-cost optimization problem because such an analysis does not convey circumstances such as limitations of fuel potential, consumer preferences for cookstoves or policy effects. This geospatial study: (1) forecasts fuel potential including alternative biofuels and expanded access to electricity; and (2) utilizes the improved fuel potential to guide scenario analyses that describe pathways to reach established national clean cooking goals and universal access goals.

The two scenarios are introduced and described. Descriptions of market segments (e.g., household and institutions, rural vs. urban) then follow and include greater details for stove ownership projections and user behaviours of each market segment. No public targets have been set for institutional cooking solutions, and those values are assumed to mimic the fuel adoption goals for households in the absence of other data to describe possible trends for institutional stove adoption. These data describing average stove adoption for a specific geographic area (urban, rural north, rural central, rural south) were then projected evenly across all communes within that geographic area. Rural household trends utilize information from the survey, whereas urban household trends are taken from the Multi-Tier Framework (MTF) because urban locations were not included in the IEP survey.

SDG7 Energy Compact Scenario (baseline scenario)

The baseline scenario assumes that Madagascar reaches existing 2030 targets set forth in SDG7 Energy Compact of the Ministry of Energy and Hydrocarbons (MEH) as follows (with notes in parentheses):

[12] Kerosene is sometimes used for lighting but not cooking.

- Equipment with improved cookstoves for 50 percent of households (assumed to be improved fuelwood and improved charcoal and maintain household preferences for fuelwood or charcoal observed in 2023).
- Using fuels of biological origin for 20 percent of households (assumed to be 80 percent ethanol, 10 percent biogas, 10 percent biomass pellet/briquette to prioritize bioethanol deployment ongoing in Madagascar).
- 2,500,000 households will be using clean cooking solutions (assumed to be 90 percent e-cooking and 10 percent LPG, with e-cooking solutions for households with one stove and stove stacking and split evenly between hot plate and induction plate, this amount prioritizes e-cooking as part of the overall focus of the IEP effort).

The remaining, unallocated 0.64M households in the Compact are assumed to continue using tier 0 and tier 1 stoves. Urban households include all households estimated with LPG (10.4 percent), and the remaining urban households prioritize e-cooking solutions (71.7 percent) that are split evenly between a hot plate and an induction plate, and then bioethanol (10 percent) and improved charcoal (7.4 percent). Rural household cookstove ownership can then be calculated as the difference between national goals and urban stove use.

Institution stove ownership in 2030 followed similar trends for fuel switching as households, though for improved institutional stoves and away from single-burner stoves with lower size and lower efficiency. Stove stacking is maintained for fuelwood and charcoal stoves and assumes customers transition to an improved institutional stove of either fuel type. This leads to urban institutions' behaviour for fuel switching following similar trends to households to prioritize e-cooking (71.7 percent), LPG (10.4 percent), bioethanol (10 percent) and charcoal improved institutional stoves (7.9 percent). This leaves a small amount of LPG use estimated for rural institutions (0.6 percent of all rural institutions), and the remaining stove types for rural households can be calculated as the difference between national goals and urban stove use.

Universal Access Scenario (IEP scenario)

The universal access scenario emphasizes e-cooking followed by bioethanol and then other fuels. This scenario reaches more aggressive targets for cleaner cooking technologies and fuels as motivated by the electrification study of the IEP and stakeholder input from SEforALL, government stakeholders and development partners to fully displace solid fuel use by 2030, representing 2.1 million people per year gaining access to clean cooking. The section on Geospatial Analysis of Energy Access discusses the geospatial nature of this approach.

IEP analysis calculates there are 3,013,000 JIRAMA grid-connected households in 2023 and 3,557,000 JIRAMA grid-connected households in 2030. These households are assumed to use e-cooking with induction plates and not hot plates and maintain similar cookstove stacking behaviours as observed in 2023 for an electric stove plus a biomass stove. LPG usage is maintained from the baseline scenario. Fuels from biological origin are used to meet the remaining cooking needs with 60 percent bioethanol, 20 percent briquette/pellet and 20 percent biogas. Urban households are assumed to be the only household users of LPG (10.4 percent), a similar number of e-cooking users are expected as those in the baseline scenario (71.7 percent) but all use an induction plate rather than hot plates, and the remaining number of households use bioethanol (17.9 percent). Rural household cookstove ownership can then be calculated as the difference between national goals and urban stove use. A minor amount of cooking using wood and charcoal remains to reflect that some consumers may continue to prefer cookstove stacking and complement induction plates with improved wood and charcoal stoves.

Institution stove ownership in 2030 followed similar trends for fuel switching as households, with e-cooking solution occurrences estimated for users with only one stove (27.1 percent) and those with multiple stoves (28.2 percent) to give a total of 55.3 percent of institutions with access to e-cooking. Stove stacking includes an induction plate and either a fuelwood improved institutional stove or a charcoal improved institutional stove. The remaining institutions are assumed to prioritize bioethanol (42.3 percent) and a small amount use LPG (2.4 percent). The behaviour of urban institutions for fuel switching followed similar trends to that of households to prioritize e-cooking (71.7 percent), LPG (10.4 percent) and bioethanol (17.9 percent). This leaves a small amount of LPG use estimated for rural institutions (0.6 percent of all rural instirutions), and the remaining stove types for rural households can be calculated as the difference between national goals and urban stove use. Single stove types include bioethanol and electric induction plates, whereas any use of improved institutional stoves is assumed to be complemented by an electric induction plate.

Market Segments

No single work has completed a comprehensive study across rural and urban customers, different regions of Madagascar, different types of customers (households, non-households), energy access limitations (wood, electrical, LPG, etc), and cooking meal preferences and behaviours. Further, studies of cooking energy often use different methods, are completed in different locations and times of year, and are often not of a sufficient sample size across a region or country to permit generalized use of findings as representative of market segments for Madagascar. Primary data for rural areas and secondary data for urban areas create a representative image of cooking in Madagascar for households and non-household consumers. These data were contrasted to 40+ secondary data sources to reach consensus on high-level generalizable inputs organized as follows with major classifications for: (a) households or institutions;and (b) rural or urban location:

- **Customer geospatial placement** – GIS mapping was used to digitize structures (buildings). Structure types were then assumed as households or institutions, using proximity to the JIRAMA grid as a proxy to differentiate between rural and urban. Table 17 provides the percentages of households to structures and institutions to structures taken from the electrification part of the IEP, and the percentages of those customers who own cookstoves is derived from primary data. Table 18 provides the resulting number of structures for rural and urban, and household and institution cookstove users. Population and structure data from 2023 were extrapolated to 2030 using an assumed population growth rate of 2.4 percent. Additional detail is given for rural segments that includes the region of analysis as that influences stove preferences, fuel potential and fuel procurement (freely collect, cost of fuel, etc.).

Table 17. Customer geospatial placement for cookstoves

Parameter	Rural (> 15 km from JIRAMA)	Urban (< 15 km from JIRAMA)
Households to structures (buildings)	95.0%	99.0%
Households that cook	99.3%	99.3%
Institutions to structures	5.0%	1.0%
Institutions that cook	18.7%	18.7%

Table 18. Structure counts for households and institutions by rural and urban segments

Structure Counts	Households		Institutions		Total	
Location	**2023**	**2030**	**2023**	**2030**	**2023**	**2030**
Rural - Northern	2,438,384	2,505,230	20,442	20,597	2,458,825	2,525,827
Rural - Central	3,645,206	3,735,257	26,963	26,602	3,672,169	3,761,859
Rural - Southern	1,748,205	1,816,711	14,581	14,840	1,762,786	1,831,552
Rural	7,831,795	8,057,198	61,985	62,040	7,893,780	8,119,238
Urban	1,980,281	2,412,383	11,620	13,799	1,991,901	2,426,182
Total	**9,812,075**	**10,469,580**	**73,605**	**75,839**	**9,885,681**	**10,545,419**

- **Energy use** – The useful energy or “energy into the pot” for household meal preparation is assumed to be 2,500 MJ / HH / yr to coincide with the MTF study. Primary data collection for households showed a wide variance and inconsistencies in the useful energy reported by respondents for wood and charcoal use. Use of the MTF value, or any consistent average value, assumed that households across Madagascar could be represented by a common diet and energy requirements. Other studies reporting in MJ for dietary needs or in fuel consumption (fuelwood or charcoal) across Sub-Saharan Africa resulted in a range of 2,000 to 10,000 MJ / HH / yr useful energy.[13] The useful energy for institutions was recorded as 24,497 MJ / institution / year from survey data collected from 62 institutions. There are insufficient secondary data to contrast against this value for institution energy requirements. A summary of these values is given below.
  - Household: 2,500 MJ / HH / yr
  - Institution: 24,497 MJ / institution / yrF
- **Stove ownership and use** – Rural household trends utilize information from the survey, whereas urban household trends are taken from the MTF because urban locations were not included in the IEP survey. Institution cookstove ownership was also part of the IEP survey for rural customers. There is no urban counterpart for institutions, and as such, assumptions are introduced to describe cookstove ownership and cooking behaviours for urban institutions. The following sections describe these inputs and assumptions.

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

- **Stove stacking** – There are limited data from past reports on the behaviour and energy use associated with stove stacking. The IEP survey worked to close this knowledge gap by identifying respondents who owned multiple stoves, how often they used each stove, and how much fuel they used in each stove during a typical week. Some additional information was also obtained for what activities (e.g., meals, heating water for bathing) each stove was used for, but that behaviour was not modelled explicitly here because the study uses aggregate energy use for the day and does not consider intra-day variations. Therefore, this study assumes customers with wood and biomass stoves use a wood stove for 50 percent of their cooking and a charcoal stove for the remaining 50 percent, and customers with biomass (fuelwood or charcoal) and an electric stove are assumed to use a biomass stove for 75 percent of their cooking and an electric stove for the remaining 25 percent. This assumption is not considered to significantly affect results and quantitative-driven recommendations because stacking occurs in less than 8 percent of all entities (household or institution) and any percentage split will have a minor effect on overall calculations.

Household market segments are differentiated by primary cooking technology, rural or urban, and rural region. Table 19 shows the distribution of household stove ownership by cooking technology for the entire country for 2023, the baseline scenario in 2030 and the universal access scenario in 2030 following the above descriptions of scenarios. Detailed breakdowns of stove ownership by rural and urban, and by rural region are given in Annex 7. Commune-level stove ownership percentages are assumed to be consistent within each region.

Table 19. National household fuel and stove type for modelling scenarios.

Total	Households (%)			Households (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	13.8%	1.1%	0.0%	1,349,813	114,055	-
Fuelwood stove - basic	20.8%	1.6%	0.0%	2,041,094	172,465	-
Fuelwood stove - improved	7.0%	20.9%	0.0%	691,203	2,186,432	-
Fuelwood stove - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic	31.4%	2.5%	0.0%	3,078,563	260,128	-
Charcoal - improved	19.5%	25.5%	0.0%	1,909,092	2,671,453	-
Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Briquette/pellet	0.0%	2.0%	12.7%	-	209,392	1,332,516
Biogas	0.1%	2.0%	12.7%	5,245	209,392	1,332,516
Bioethanol	0.0%	16.0%	38.2%	-	1,675,133	3,997,548
LPG	0.3%	2.4%	2.4%	32,363	250,000	250,000
Electric - hot plate	0.2%	9.6%	0.0%	23,067	1,000,000	-
Electric - induction plate	0.0%	9.6%	27.1%	-	1,000,000	2,835,869
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	2.1%	0.9%	0.0%	207,631	94,226	-
Fuelwood - improved + Charcoal - improved	2.8%	3.6%	0.0%	271,360	376,905	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.5%	0.0%	0.0%	53,934	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.5%	1.2%	3.4%	47,388	125,000	360,566
Charcoal - basic + Electric - hot plate / rice cooker	0.5%	0.0%	0.0%	53,934	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.5%	1.2%	3.4%	47,388	125,000	360,566
Fuelwood - basic institutional + Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-

Institution market segments are differentiated by primary cooking technology, rural or urban, and rural region. Table 20 shows the distribution of institution stove ownership by cooking technology for the entire country for 2023, the baseline scenario in 2030 and the universal access scenario in 2030 following the above descriptions of scenarios. Detailed breakdowns of stove ownership by rural and urban, and by rural region are given in Annex 8. Commune-level stove ownership percentages are assumed to be consistent within each region.

Table 20. National institution fuel and stove type for modelling scenarios.

Total	Institutions (%)			Institutions (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	2.1%	0.0%	0.0%	1,517	-	-
Fuelwood stove - basic	6.2%	0.0%	0.0%	4,528	-	-
Fuelwood stove - improved	1.6%	0.0%	0.0%	1,162	-	-
Fuelwood stove - basic institutional	2.9%	0.0%	0.0%	2,098	-	-
Fuelwood stove - improved institutional	2.5%	4.0%	0.0%	1,807	3,003	-
Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved	1.6%	0.0%	0.0%	1,162	-	-
Charcoal - basic institutional	34.2%	0.0%	0.0%	25,187	-	-
Charcoal - improved institutional	16.5%	26.3%	0.0%	12,144	19,946	-
Briquette/pellet	0.0%	0.0%	0.0%	-	-	-
Biogas	0.0%	0.0%	0.0%	-	-	-
Bioethanol	0.0%	20.0%	42.3%	-	15,168	32,061
LPG	1.5%	2.4%	2.4%	1,106	1,811	1,811
Electric - hot plate	2.0%	9.6%	0.0%	1,471	7,244	-
Electric - induction plate	0.0%	9.6%	27.1%	-	7,244	20,542
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	1.5%	0.0%	0.0%	1,079	-	-
Fuelwood - improved + Charcoal - improved	6.0%	7.3%	0.0%	4,426	5,505	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Charcoal - basic institutional	11.6%	0.0%	0.0%	8,547	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	8.0%	19.1%	0.0%	5,906	14,453	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	7.1%	-	-	5,356
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.8%	0.8%	0.0%	598	598	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	1.2%	1.1%	21.2%	869	869	16,068

GEOSPATIAL RESULTS OF CLEAN COOKING

Cookstove Ownership

Cookstove ownership preferences are tracked for 15 cookstove types and fuel combinations, plus 12 combinations of cookstove stacking. These user groups – with one or multiple stoves – are used to calculate the total number of cookstoves owned by households and by institutions. Summary national-level graphics are provided to visualize annual stove adoption trends between 2023 and 2030, which are then followed with GIS representations of cookstove ownership by commune.

The universal scenario greatly reduces solid fuel (fuelwood and charcoal) stove ownership from 97.5 percent in 2023 to 6.4 percent in 2030 for households as shown in Figure 22, with minor utilization of fuelwood and charcoal due to users who continue to prefer multiple stoves (stove stacking). This is a significant improvement over the baseline scenario shown in Figure 20 that reduces solid fuel stove ownership to only 58.9 percent in 2030. Similarly, for institutions, the 2023 penetration rate of solid fuel stoves is 95.8 percent in 2023 and decreases to 66.4 percent and 22.1 percent in 2030 for the baseline and universal scenarios, respectively. Access to higher-level tiers is enabled in both scenarios as shown in Figures 21 and 23, with the greatest improvements in the universal scenario.

Figure 20. Projected ownership of cooking technologies for households in baseline scenario

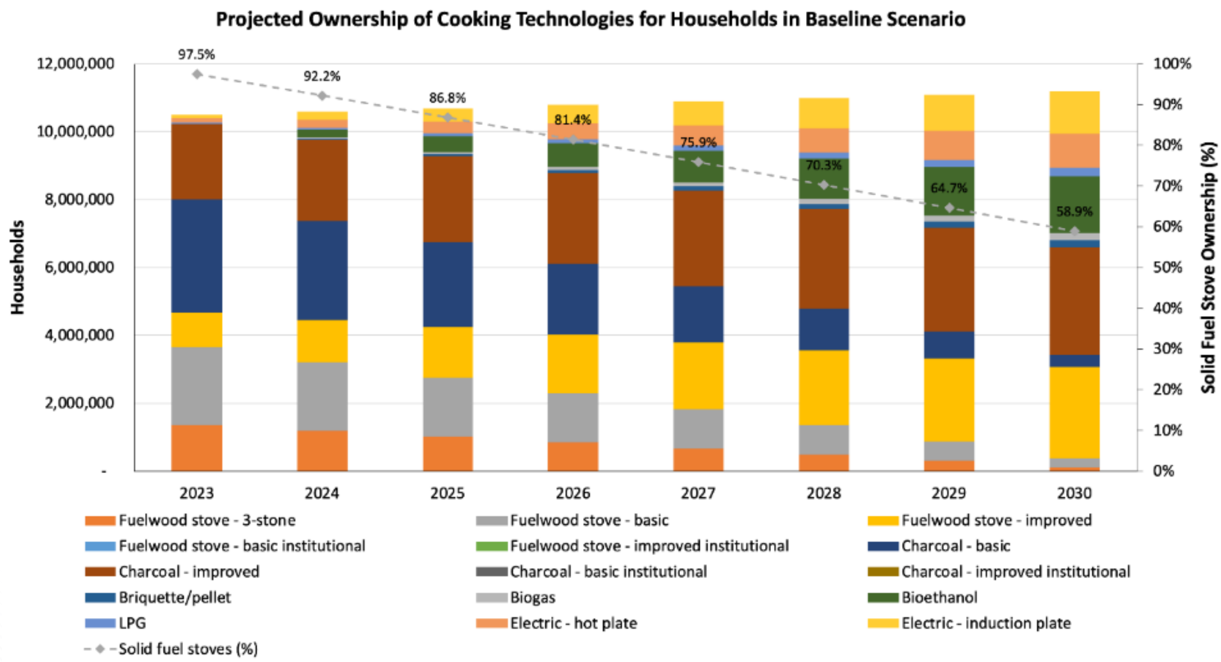


Figure 21. Projected tier rating of cooking technologies for households in baseline scenario

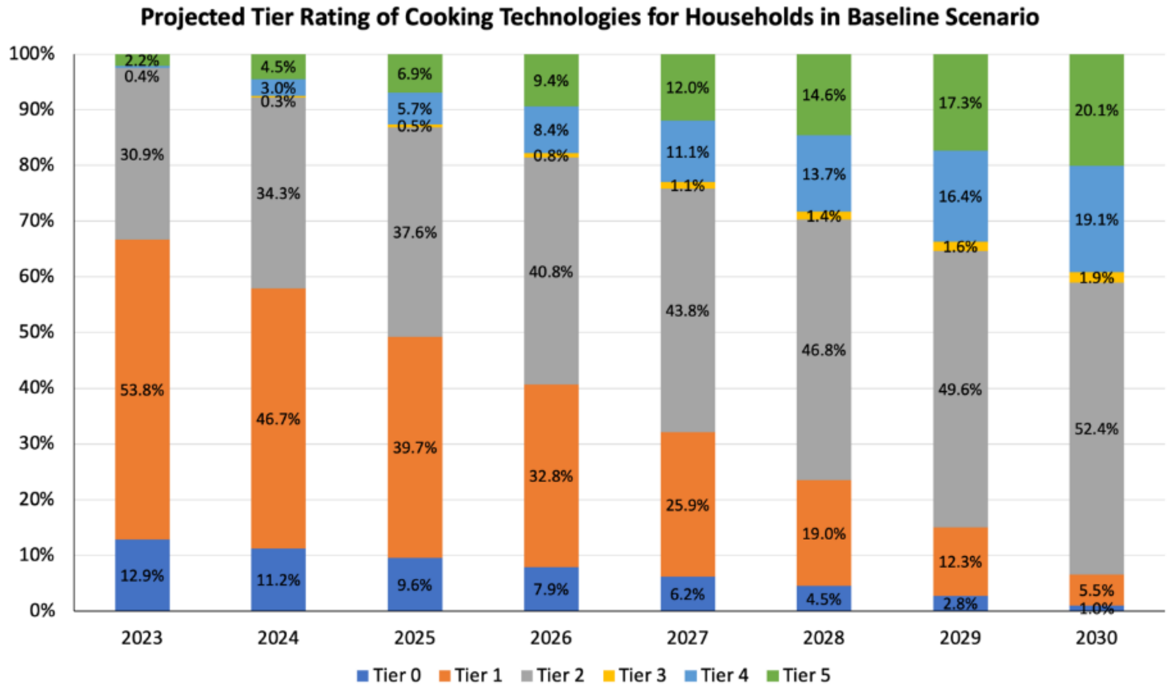


Figure 22. Projected ownership of cooking technologies for households in universal scenario

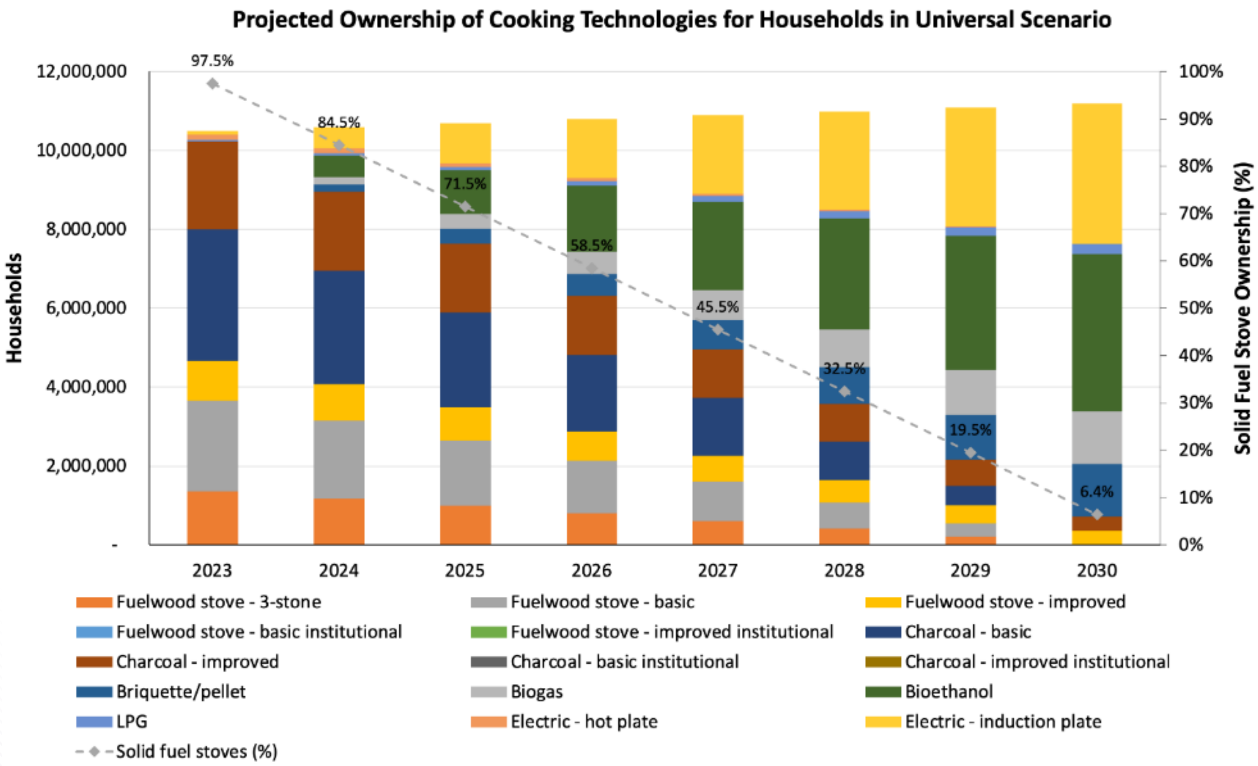
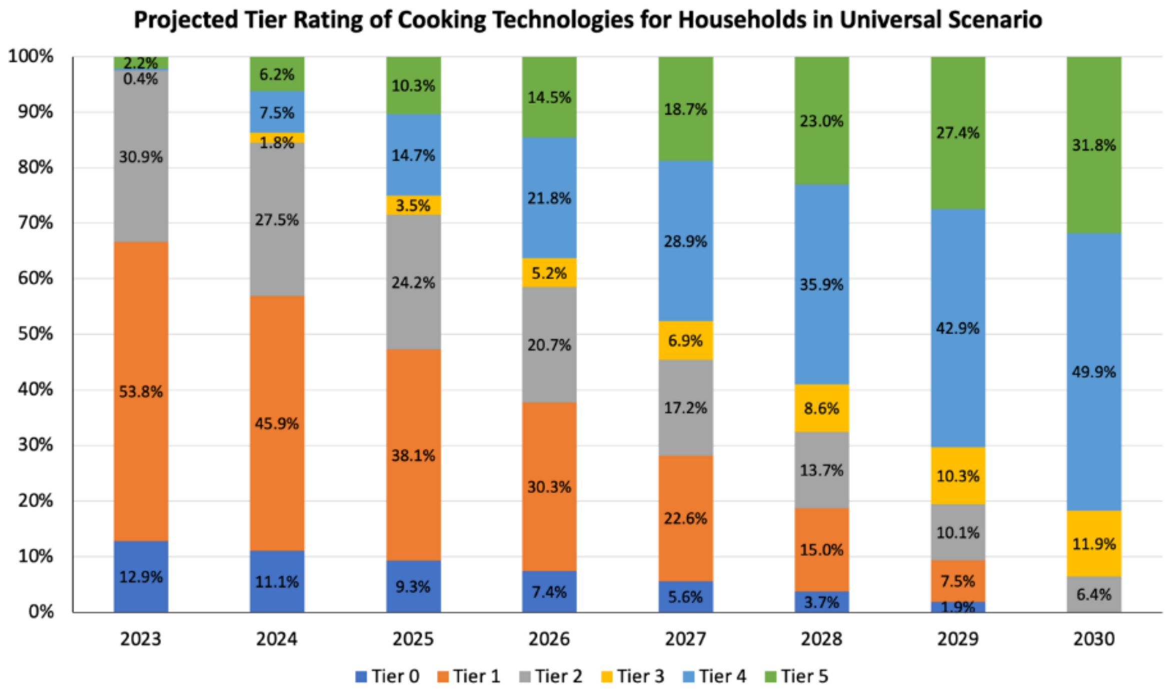


Figure 23. Projected tier rating of cooking technologies for households in universal scenario



A higher percentage of institutions than households utilize solid fuel stoves. For the baseline scenario shown in Figure 21, solid fuel ownership decreases from 95.8 percent to 66.4 percent between 2023 and 2030, whereas the more aggressive universal scenario reduces solid fuel ownership down to 22.1 percent in 2023, as shown in Figure 22. Institutions benefit from improved stove tier ratings under both scenarios as shown in Figures 21 and 23..

Figure 24. Projected ownership of cooking technologies for institutions in baseline scenario

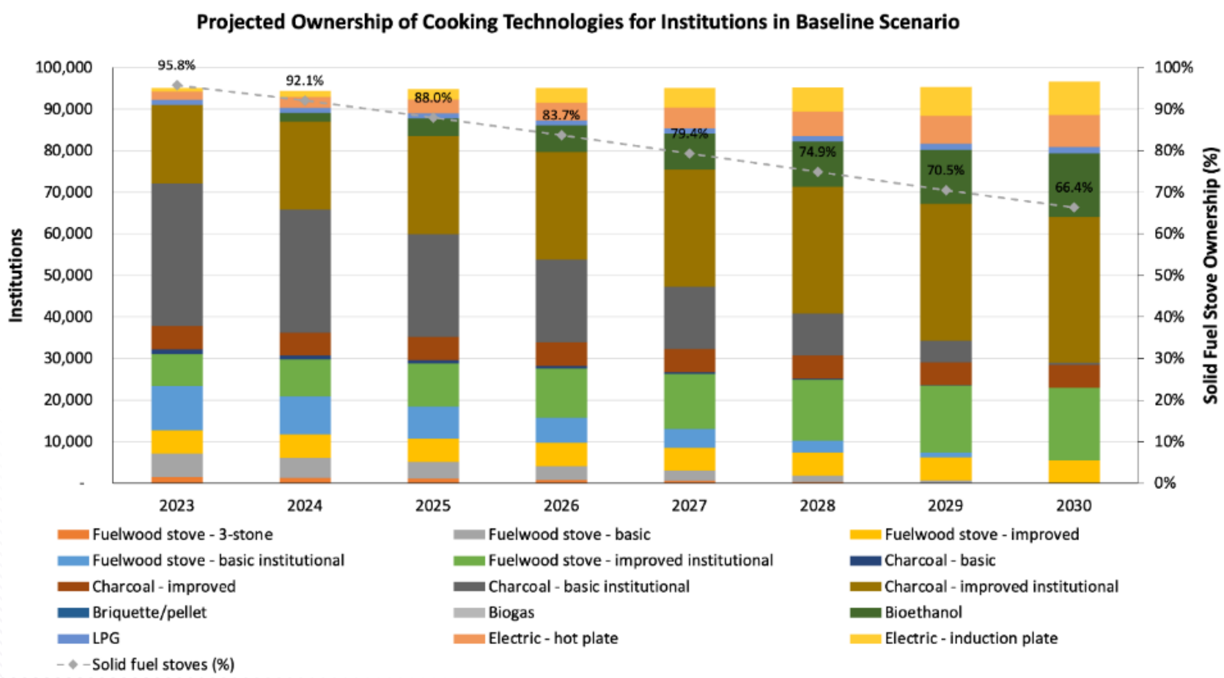


Figure 25. Projected tier rating of cooking technologies for institutions in baseline scenario

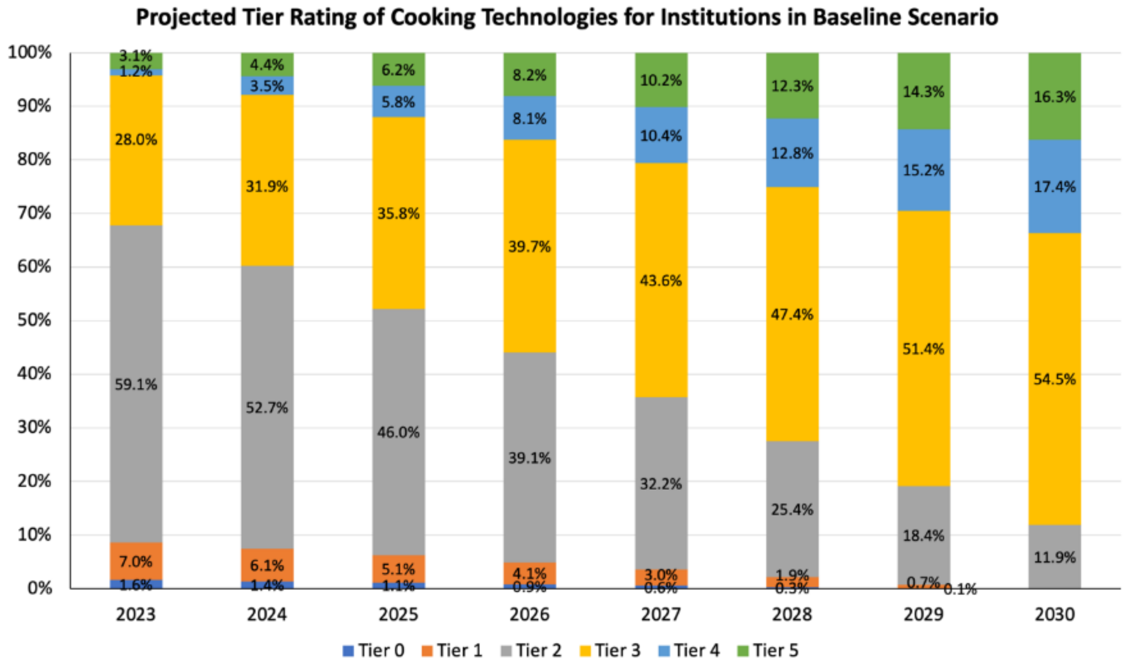


Figure 26. Projected ownership of cooking technologies for institutions in universal scenario

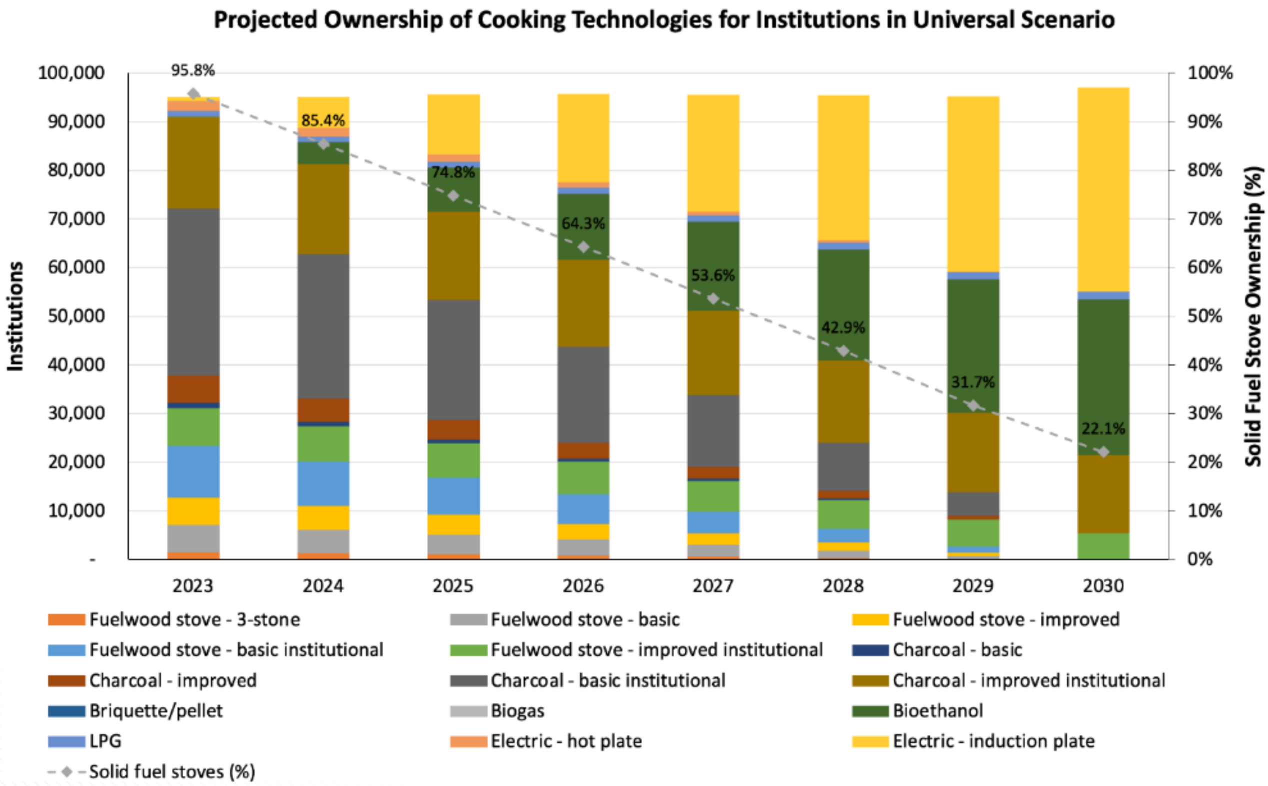
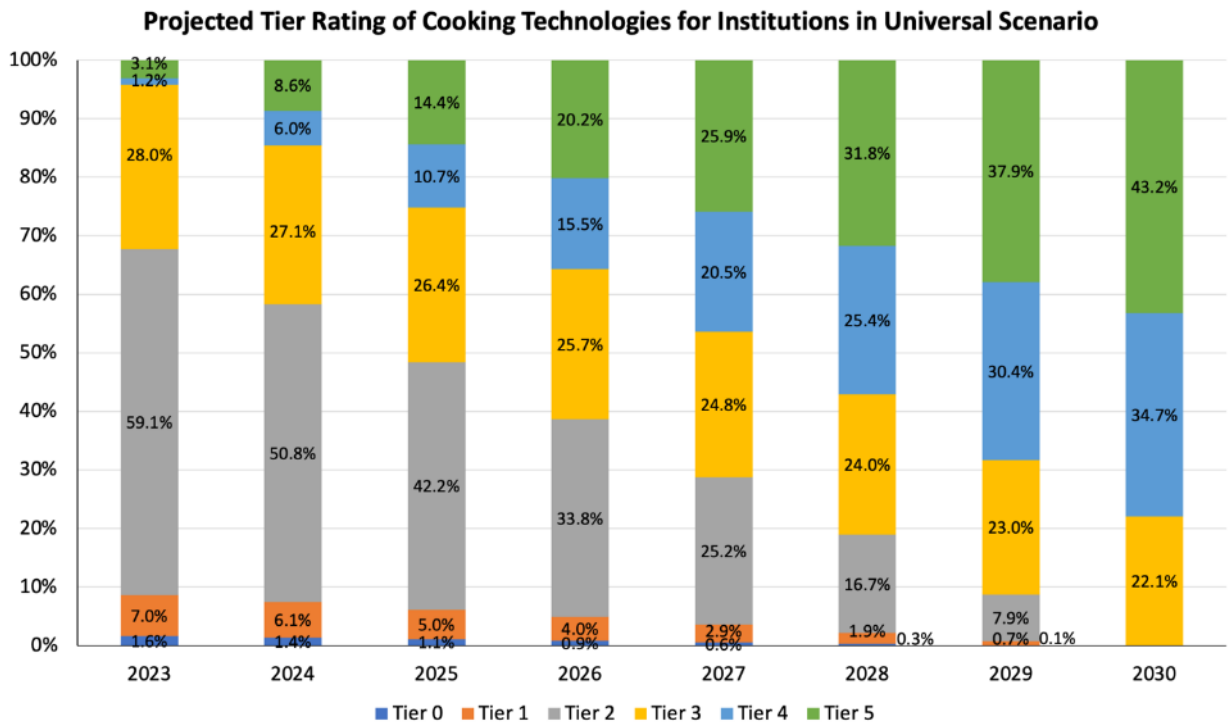


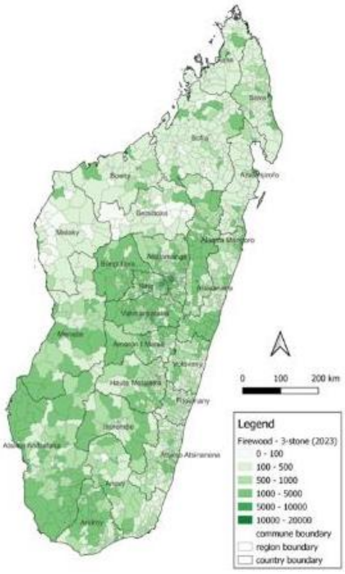
Figure 27. Projected tier rating of cooking technologies for institutions in universal scenario



A GIS map is provided for each stove-fuel combination in 2023 (present day), 2030 (baseline scenario) and 2030 (universal scenario). Maps are generated using the same legend colour gradations to permit easy comparison across all maps, noting that an artefact of this choice is that some maps will look simplistic or lacking colour (which shows that stove type is not present or not common compared to other stove types).

Figure 28. Estimated stove ownership rates for 2023, the 2030 baseline scenario and the 2030 universal scenario

Fuelwood - 3-stone (2023)

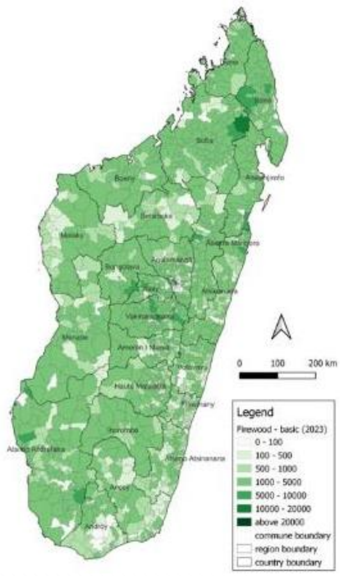


Fuelwood - 3-stone (2030 Baseline)

Fuelwood - 3-stone (2030 Universal)

None to map

Fuelwood - basic (2023)

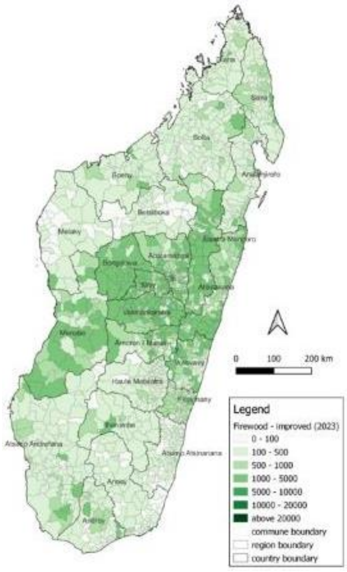


Fuelwood - basic (2030 Baseline)

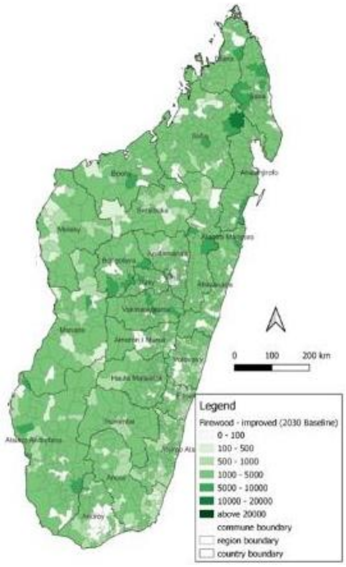
Fuelwood - basic (2030 Universal)

None to map

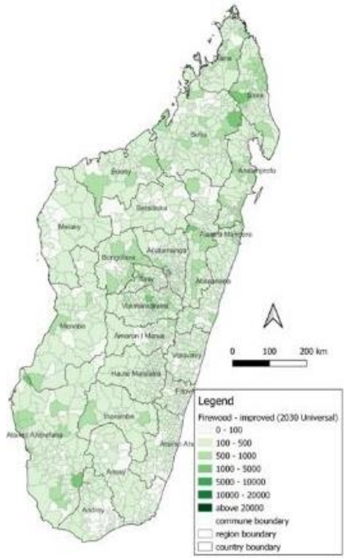
Fuelwood - improved (2023)



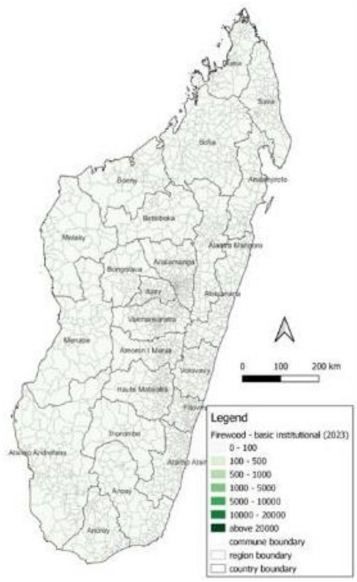
Fuelwood - improved (2030 Baseline)



Fuelwood - improved (2030 Universal)



Fuelwood - basic institutional (2023)



Fuelwood - basic institutional (2030 Baseline)

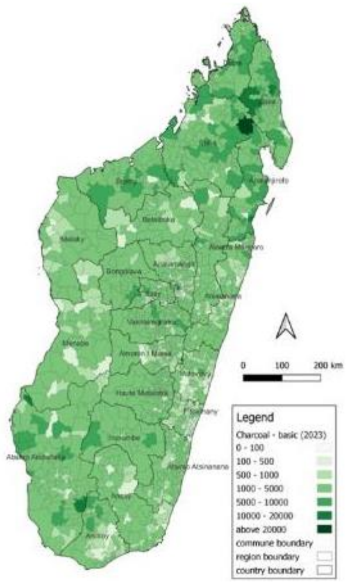
Fuelwood - basic institutional (2030 Universal)

Fuelwood - improved institutional (2023)

Fuelwood - improved institutional (2030 Baseline)

Fuelwood - improved institutional (2030 Universal)

Charcoal - basic (2023)

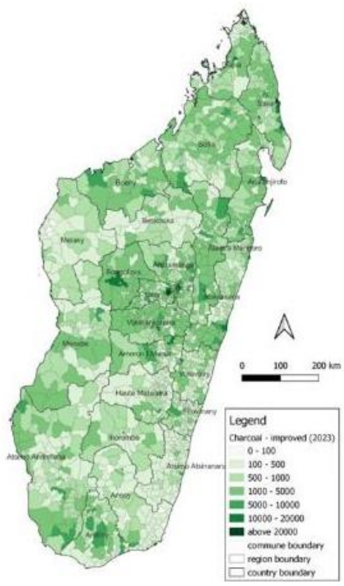


Charcoal - basic (2030 Baseline)

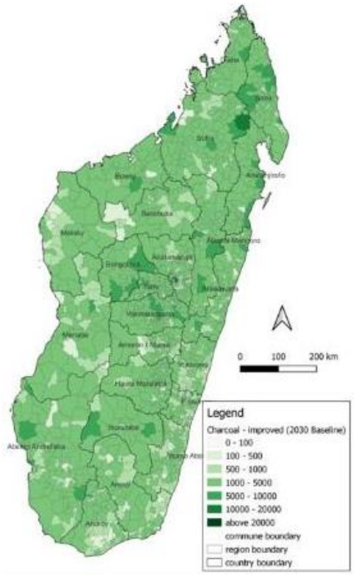
Charcoal - basic (2030 Universal)

None to map

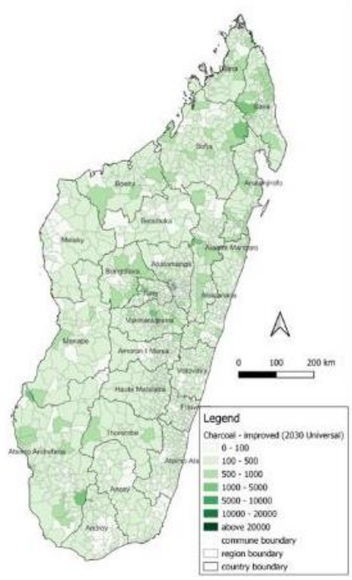
Charcoal - improved (2023)



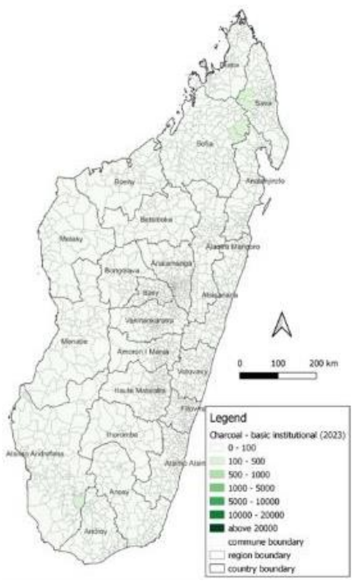
Charcoal - improved (2030 Baseline)



Charcoal - improved (2030 Universal)



Charcoal - basic institutional (2023)

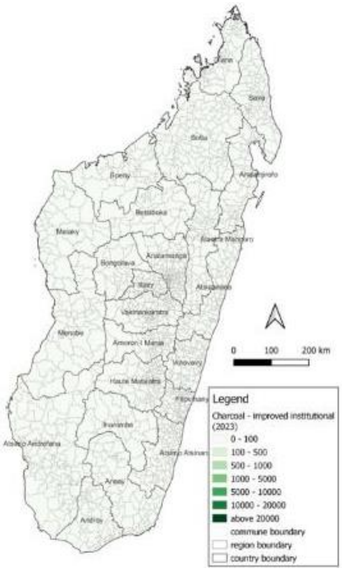


Charcoal - basic institutional (2030 Baseline)

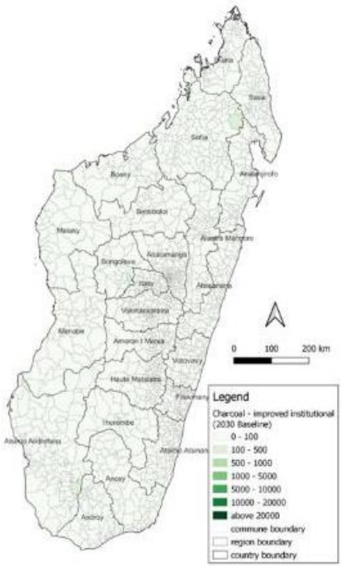
Charcoal - basic institutional (2030 Universal)

None to map

Charcoal - improved institutional (2023)



Charcoal - improved institutional (2030 Baseline)



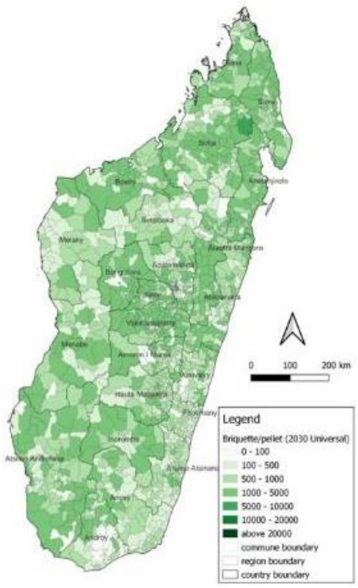
Charcoal - improved institutional (2030 Universal)

Briquette/pellet (2023)

None to map

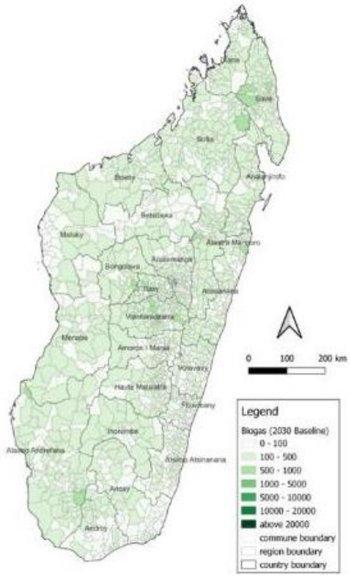
Briquette/pellet (2030 Baseline)

Briquette/pellet (2030 Universal)

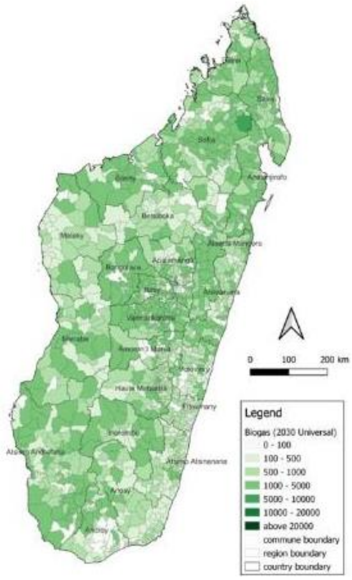


Biogas (2023)

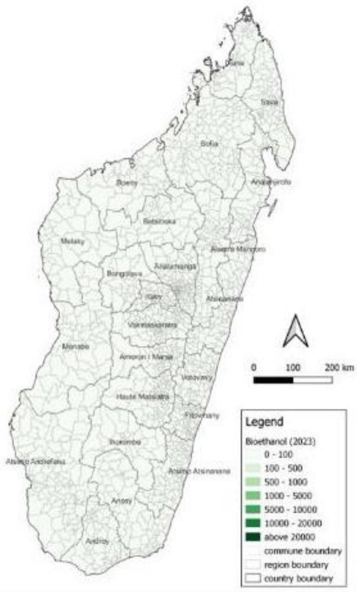
Biogas (2030 Baseline)



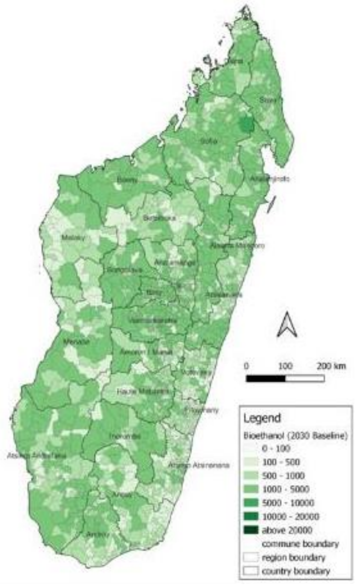
Biogas (2030 Universal)



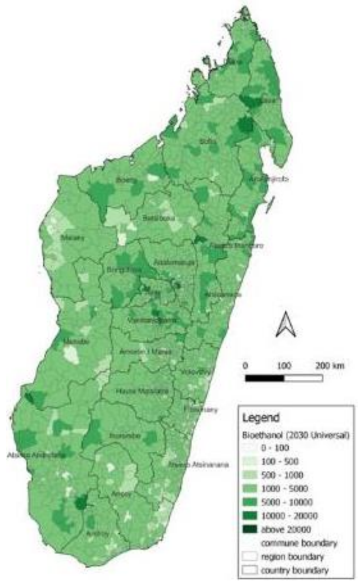
Bioethanol (2023)



Bioethanol (2030 Baseline)

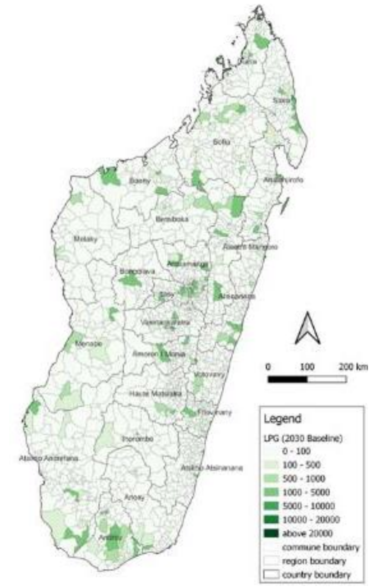


Bioethanol (2030 Universal)

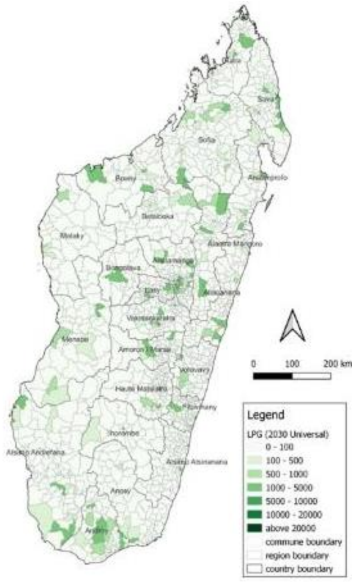


LPG (2023)

LPG (2030 Baseline)

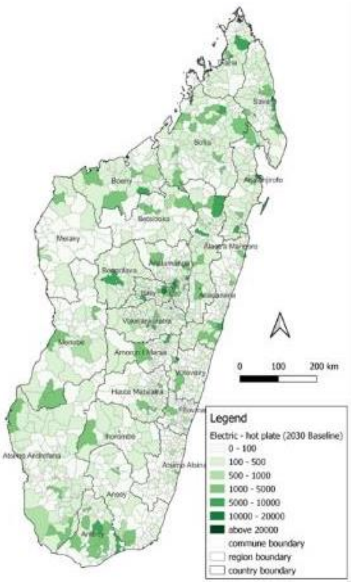


LPG (2030 Universal)



Electric - hot plate (2023)

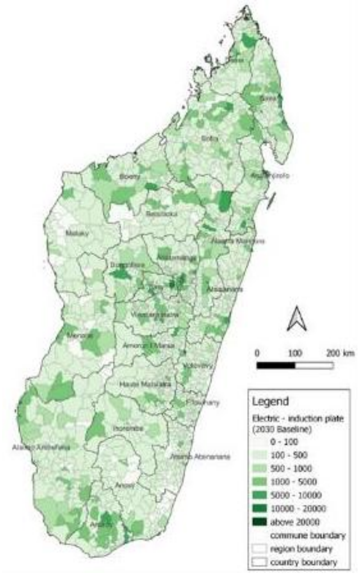
Electric - hot plate (2030 Baseline)



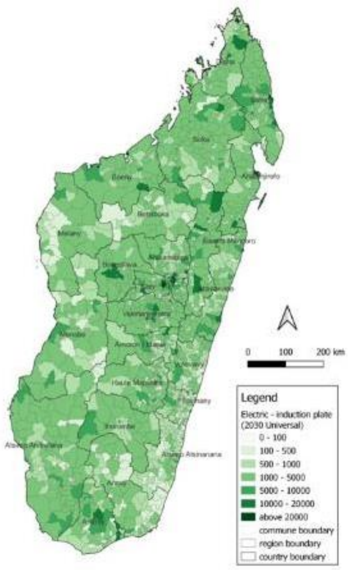
Electric - hot plate (2030 Universal)

Electric - induction plate (2023)

Electric - induction plate (2030 Baseline)



Electric - induction plate (2030 Universal)



Final Energy Use

Final energy use is the energy in the fuel, which after accounting for stove efficiency, is converted into useful energy for cooking. Geospatial data for final energy use by commune are calculated based on stove and fuel ownership by commune (see section Cookstove Ownership and Use), stove and fuel efficiency (see section Cooking Technologies) and the amount of useful energy for cooking that each customer requires (see section Scenario Market Segments). This information is used to calculate the final energy needs to cook on each stove for each type of consumer in Table 21, recalling that the useful energy for cooking in households is 2,500 MJ / HH / y and for institutions is 24,497 MJ / institution / y.

Table 21. Final energy needs to cook on various stoves for households and institutions

	Final Energy Needs to Cook (MJ / y)	
Stove type	**Household**	**Stove type**
Fuelwood stove - 3-stone	17,921	Fuelwood stove - 3-stone
Fuelwood stove - basic	10,000	Fuelwood stove - basic
Fuelwood stove - improved	8,333	Fuelwood stove - improved
Fuelwood stove - basic institutional	9,259	Fuelwood stove - basic institutional
Fuelwood stove - improved institutional	7,143	Fuelwood stove - improved institutional
Charcoal - basic	25,000	Charcoal - basic
Charcoal - improved	10,417	Charcoal - improved
Charcoal - basic institutional	10,000	Charcoal - basic institutional
Charcoal - improved institutional	8,333	Charcoal - improved institutional
Briquette/pellet	7,143	Briquette/pellet
Biogas	5,747	Biogas
Bioethanol	4,854	Bioethanol
LPG	4,464	LPG
Electric - hot plate	4,003	Electric - hot plate
Electric - induction plate	2,778	Electric - induction plate

Final energy use per consumer improves over time from 2023 to 2030 as households and institutions use higher-tier stoves with better thermal efficiencies. Final energy use per household reduces by 49.5 percent under the baseline scenario (Figure 29) and by 69.3 percent under the universal scenario (Figure 31). In institutions, the final energy use reduces by 28.5 percent under the baseline scenario (Figure 30 and by 45.9 percent under the universal scenario (Figure 32). Each of these scenarios has a significant impact on reducing deforestation, as quantified and discussed later.

Figure 29. Final energy use for cooking for households in baseline scenario

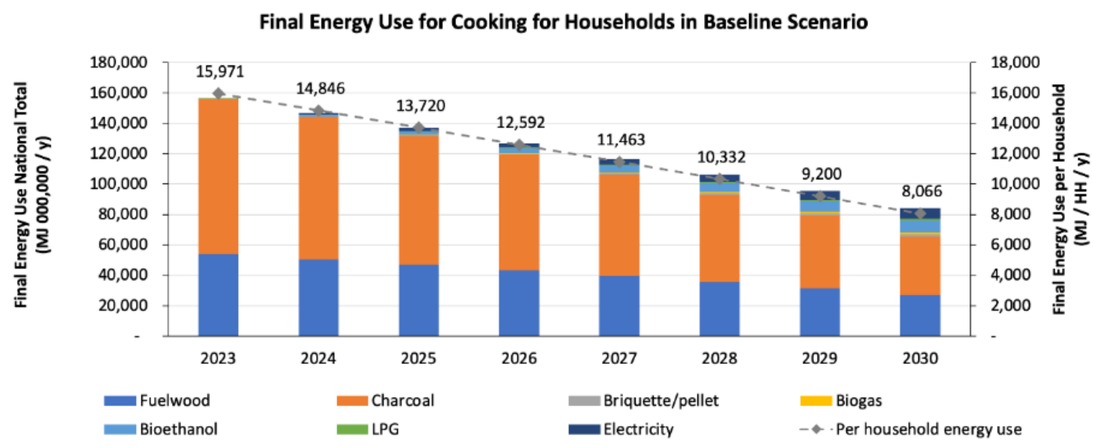


Figure 30. Final energy use for cooking for institutions in baseline scenario

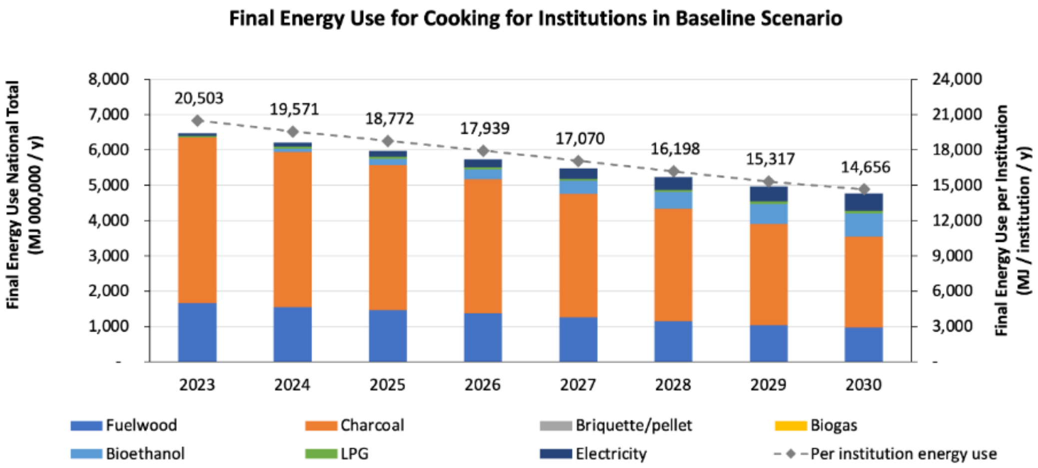


Figure 31. Final energy use for cooking for households in universal scenario

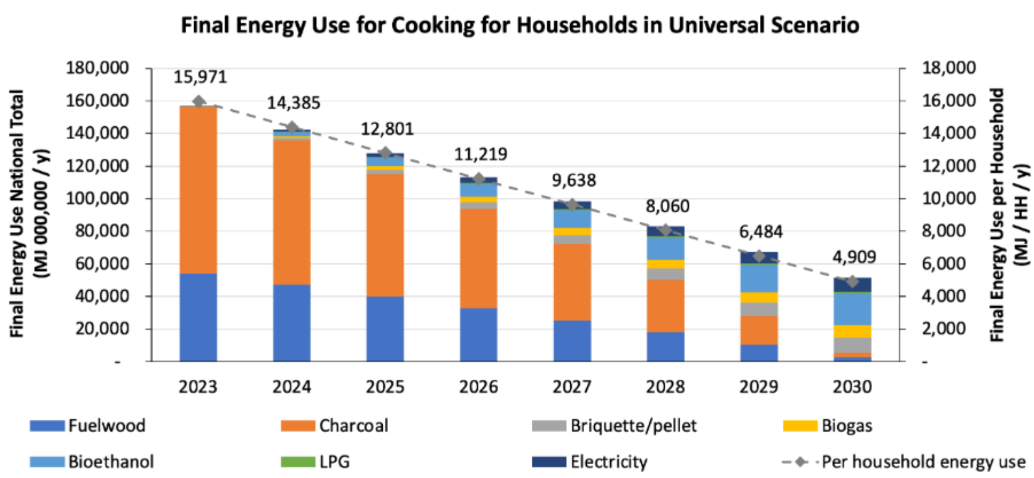
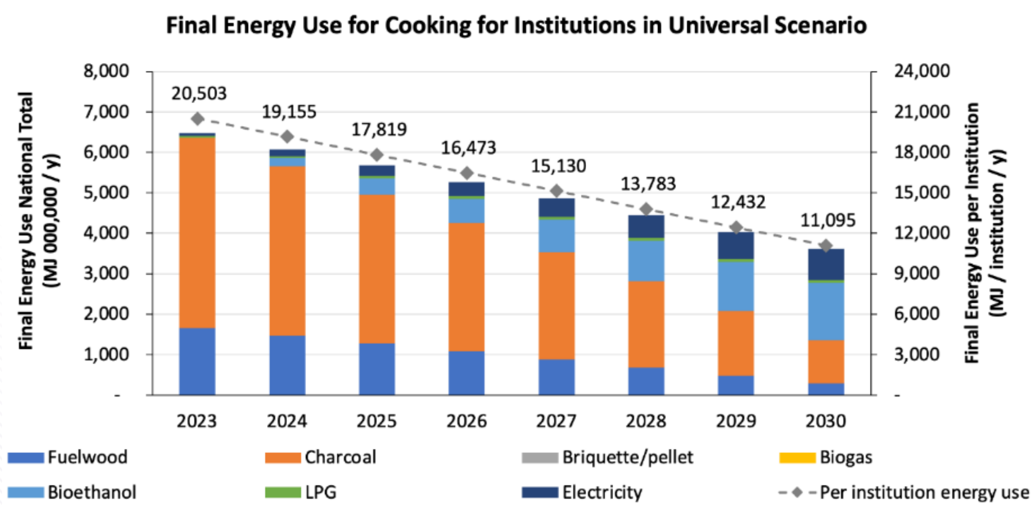


Figure 32. Final energy use for cooking for institutions in universal scenario



In looking at biomass fuels including bioethanol, biogas, and pellets/briquettes, there is more than enough available raw biomass to generate the fuel requirements needed for each scenario as summarized in Table 22. This quantification can also be used to guide policy on establishing allowable crops or percentage diversion rates from foodstuffs to make fuel, including any grains to avoid completely and instead looking to biogas or agricultural waste (pellet/briquette fuel) as alternatives. While biogas is almost always used at the location of production, bioethanol and pellet/briquette fuels can be packaged and shipped to urban centres, creating a valuable potential industry for clean cooking that displaces charcoal use in urban areas. Each fuel type has a similar potential for final energy in Madagascar, and this insight when coupled with the geospatial maps of fuel access can be used to plan district-level or commune-level strategies for fuel supply chains.

Table 22. Biomass fuel type and utilization rate to meet demand in 2030 for each scenario

Fuel type	2030 Baseline Demand	2030 Universal Demand	2030 Fuel Potential* as Energy MJ 000,000
		MJ 000,000 (% of Fuel Potential)	
Pellet/Briquette	1,496 (1.03%)	9,518 (6.55%)	145,412
Biogas	1,203 (0.76%)	7,658 (4.81%)	159,214
Bioethanol	8,792 (8.07%)	20,816 (19.11%)	108,926

* Maximum potential fuel available assuming no constraints (such as the use of grain for food) to show the upper limit of what is possible

Cookstove Costs

The total number of cookstove requirements per annum are calculated using the aggregate stove ownership estimates (see section Cookstove Ownership) and associated cost and lifetime of cookstoves (see section Cooking Technologies). Stove numbers per annum are classified as either: (a) stove additions – stoves that are newly acquired that users did not previously own or use; or (b) stove replacements – stoves that are a replacement for the same stove type and are replaced at the end of the original stove's useful lifetime. Stove additions increase the total stove count for a user and country whereas stove replacements do not because they are direct replacements for a stove at the end of its useful lifetime. Cookstove and fuel costs account for population growth, stove stacking and fuel switching as described in the section Geospatial Analysis of Clean Cooking. Results are provided by technology type and by aggregate amount across all technologies.

Figures 33 and 34 provide total cookstove volumes and costs by year for the baseline case and universal case, respectively. Graphs are plotted on the same y-axis range to permit easier comparison between the two scenarios. The total capital cost of cookstoves over the period 2023–2030 is estimated to be USD 362,143,967 for the baseline scenario and USD 672,020,070 for the universal scenario, an increase of 85.6 percent for the universal scenario driven by the higher price of alternative biomass-derived stoves (bioethanol, pellet/briquette, biogas) and e-cooking stoves. The jagged nature of the graph reflects different adoption rates as different stove types reach the end of their useful lifespans.

Figure 33. Stove procurement amounts and costs for the baseline scenario

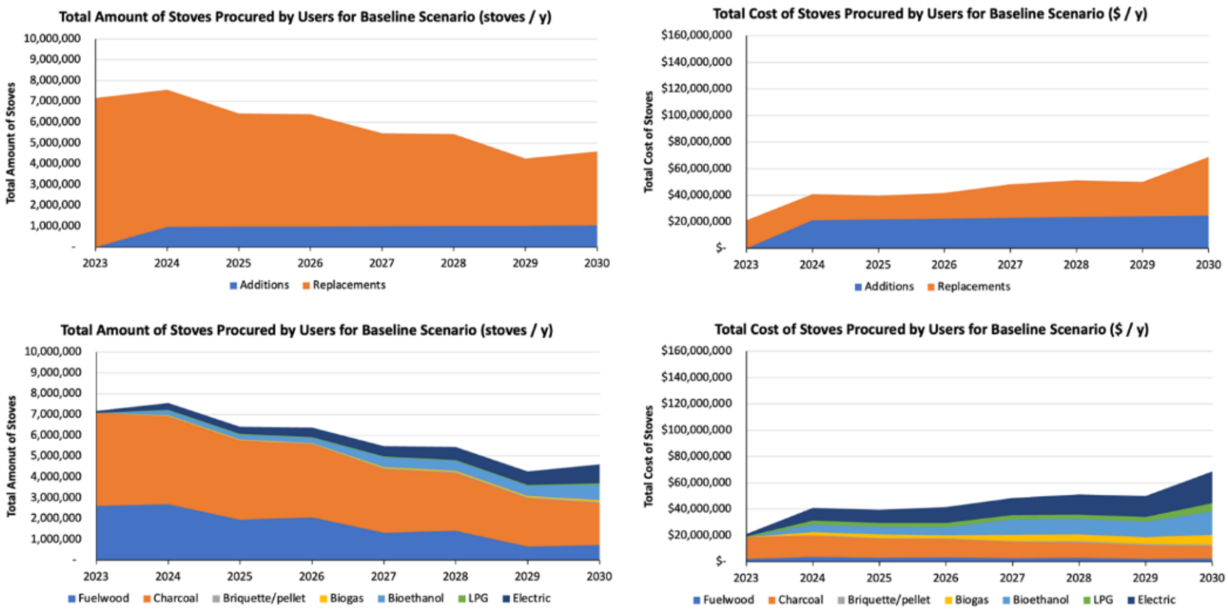
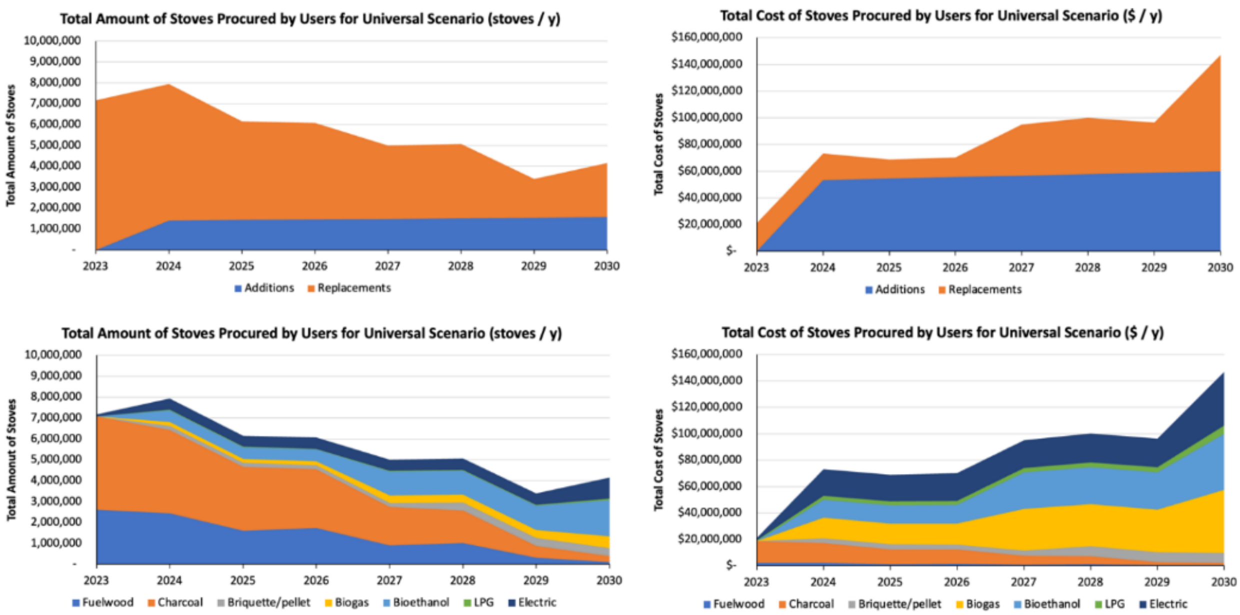


Figure 34. Stove procurement amounts and costs for the universal scenario



Cooking Fuel Costs

Tables 23 and 24 provide the annual cost of cooking (fuel only) for households and institutions, respectively, with results shown for each fuel and stove combination and differentiated by location to illustrate effects of fuel price for rural and urban locations. These annual costs are calculated from the cooking fuel costs and stove efficiencies introduced earlier in the Cooking Technologies and Fuels section. The low cost of wood and charcoal makes up for the lower efficiency compared to improved stoves and the total cost of cooking is less for solid fuel stoves. However, one notable case is that electric induction plates can provide lower cost cooking than basic charcoal stoves in urban areas if electricity is purchased at the JIRAMA tariff (a related reason is that basic charcoal stoves have only 10 percent efficiency vs. electric induction at 90 percent).

Table 23. Cooking costs for households using each stove type and reflecting fuel price differential for rural and urban locations

	Household Cooking Cost for Fuel ($ / y)	
Stove type	**Rural**	**Urban**
Fuelwood stove - 3-stone	29	58
Fuelwood stove - basic	16	33
Fuelwood stove - improved	15	30
Fuelwood stove - basic institutional	14	27
Fuelwood stove - improved institutional	12	23
Charcoal - basic	63	125
Charcoal - improved	26	52
Charcoal - basic institutional	25	50
Charcoal - improved institutional	21	42
Briquette/pellet	179	358
Biogas	188	188
Bioethanol	283	283
LPG	164	164
Electric - hot plate	556	145
Electric - induction plate	386	100

Table 24. Cooking costs for institutions using each stove type and reflecting fuel price differential for rural and urban locations

	Institution Cooking Cost ($ / y)	
Stove type	**Rural**	**Urban**
Fuelwood stove - 3-stone	286	572
Fuelwood stove - basic	160	319
Fuelwood stove - improved	148	296
Fuelwood stove - basic institutional	133	266
Fuelwood stove - improved institutional	114	228
Charcoal - basic	613	1,226
Charcoal - improved	255	511
Charcoal - basic institutional	245	490
Charcoal - improved institutional	204	409
Briquettes/pellets	1,755	3,510
Biogas	1,840	1,840
Bioethanol	2,771	2,771
LPG	1,604	1,604
Electric - hot plate	5,448	1,417
Electric - induction plate	3,780	983

In terms of the nation as a whole, the cost of cooking for all households and institutions is calculated using rural and urban values for the cost of fuel and behaviours for purchasing or freely collecting fuel, specifically given that an assumed 49.7 percent of fuelwood users purchase fuelwood and 98.6 percent of charcoal users purchase charcoal. No monetary cost was assigned for freely collecting fuel, and the cost of fuel in each year is calculated from stove ownership numbers and accounts for the effects of stove stacking. Between 2023 and 2030, nationwide expenditure for cooking fuel by households increase by 185 percent for the baseline scenario and by 519 percent for the universal scenario as shown in Figure 35 and Figure 37, respectively. Over that same period, nationwide expenditure for cooking fuel by institutions increased by 226 percent for the baseline scenario and by 526 percent for the universal scenario as shown in Figure 36 and Figure 38, respectively. The significant increase in fuel costs under the universal scenario is attributed to the increased use of bioethanol and electricity.

Figure 35. National total fuel costs for cooking for households in baseline scenario

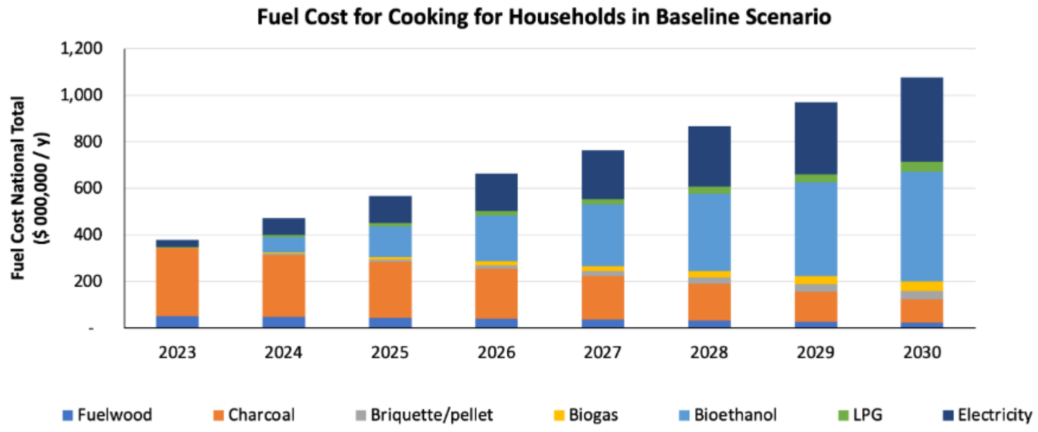


Figure 36. National total fuel costs for cooking for institutions in baseline scenario

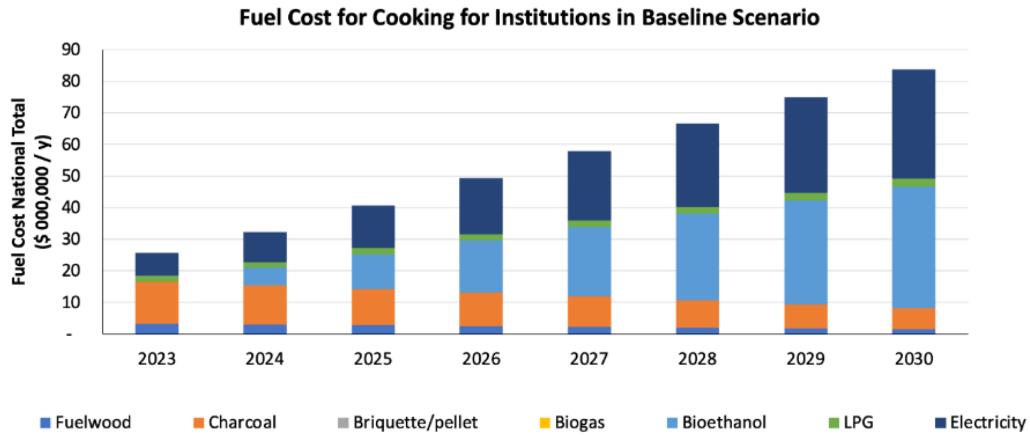


Figure 37. National total fuel costs for cooking for households in universal scenario

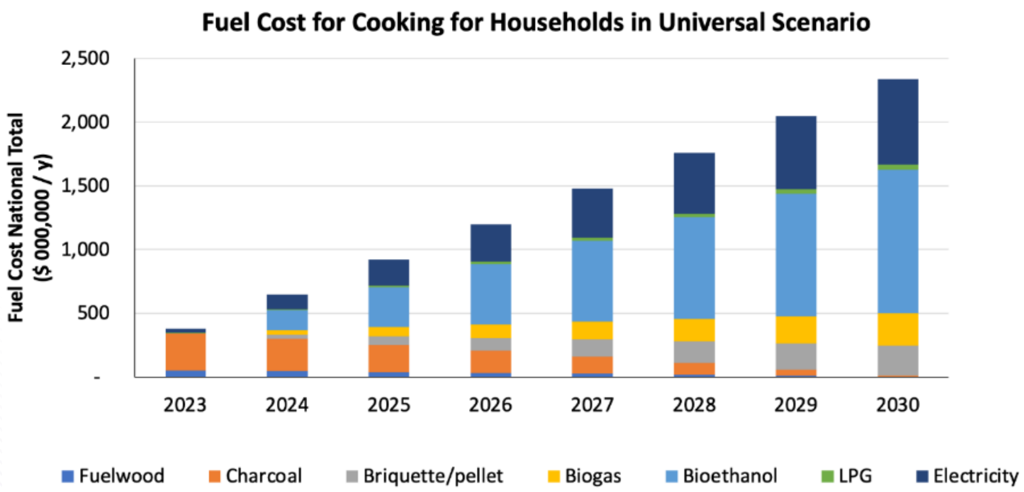
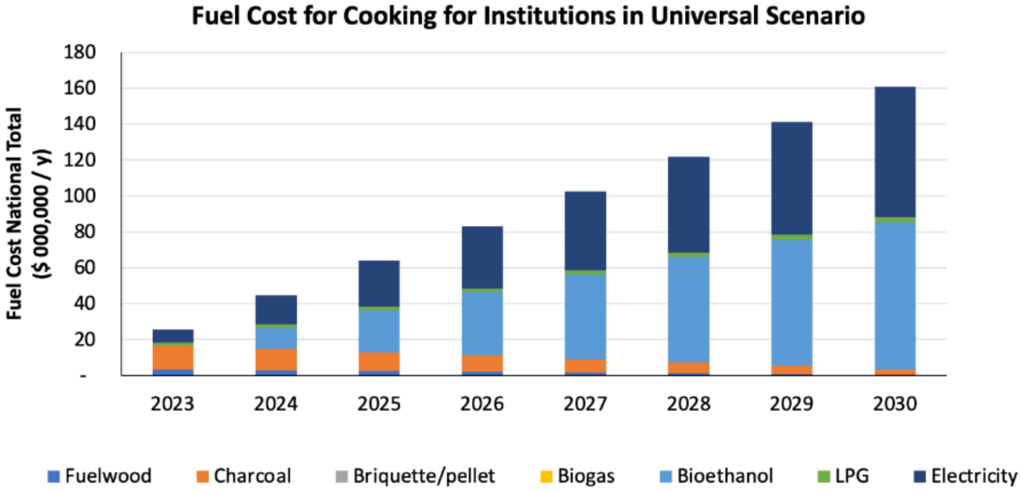


Figure 38. National total fuel costs for cooking for institutions in universal scenario



Clean Cooking Costs

The overall cost of stoves and fuels in the clean cooking transition from 2023 to 2030 is summarized in Tables 28 and 29 for the baseline scenario and universal scenario, respectively, organized by fuel type to assist with planning away from wood and charcoal stoves and to alternative fuels that reduce and halt deforestation for cooking. Additional costs for infrastructure to produce stoves and fuels, and associated supply chain costs, are not reflected here. Neither are potential cost reductions with increased volume of production reflected.

In each scenario, some fuelwood and charcoal are used because it is not possible to shift away from those fuels overnight, it will take years of targetted and sustained reductions. Stove costs include the capital cost of the stove upon initial purchase and any re-purchase of the stove at the end of its lifetime, and fuel costs are aggregated over the full timeframe from 2023 to 2030. Over that timeframe, fuel costs are the primary driver of the energy transition, equating to 97.1 percent of the cost of the transition; efforts to subsidize the cost of procuring stoves are helpful but fuel costs need to be addressed through reductions in production cost and/or subsidies.

Table 25. Total fuel and stove costs of baseline scenario

Stove and Fuel Type	Stove	Fuel	Total
Fuelwood	$ 23,227,227	$ 318,800,956	**$ 342,028,183**
Charcoal	$ 103,849,793	$ 1,661,858,534	**$ 1,765,708,327**
Briquettes/pellets	$ 5,955,140	$ 148,859,104	**$ 154,814,244**
Biogas	$ 30,403,744	$ 160,037,979	**$ 190,441,723**
Bioethanol	$ 70,247,062	$ 2,021,745,095	**$ 2,091,992,156**
LPG	$ 26,581,775	$ 194,055,551	**$ 220,637,326**
Electric	$ 101,879,227	$ 1,684,739,530	**$ 1,786,618,757**
Total	**$ 362,143,968**	**$ 6,190,096,749**	**$ 6,552,240,717**

Table 26. Total fuel and stove costs of universal scenario

Stove and Fuel Type	Stove	Fuel	Total
Fuelwood	$ 11,200,040	$ 235,436,905	$ 246,636,945
Charcoal	$ 69,455,821	$ 1,280,430,187	$ 1,349,886,007
Briquettes/pellets	$ 37,895,240	$ 947,276,658	$ 985,171,898
Biogas	$ 191,194,024	$ 997,064,244	$ 1,188,258,268
Bioethanol	$ 167,660,997	$ 4,793,947,921	$ 4,961,608,918
LPG	$ 26,581,867	$ 195,739,067	$ 222,320,934
Electric	$ 168,032,082	$ 3,064,264,520	$ 3,232,296,602
Total	**$ 672,020,070**	**$ 11,514,159,502**	**$ 12,186,179,573**

Deforestation Impacts

Cooking-related deforestation accounts for 5–20 percent of all deforestation with land-use change for agriculture attributing to 80 percent or more of the deforestation. Within cooking-related deforestation, charcoal use is the primary driver with an average of 83.2 percent forest loss attributed to charcoal production over the period from 2023 to 2030 in the baseline scenario. Figure 39 provides a visualization of these amounts by year, and while the total amount of fuelwood and charcoal consumption is similar, after accounting for a nominal kiln efficiency of 20 percent, the accumulated fuelwood loss is dominated by charcoal production. A total of 95.3 percent of deforestation over that time period is attributed to households in the baseline scenario, though through cookstove advancements, annual deforestation rates reduce by 59.8 percent between 2023 and 2030. In looking to the universal scenario in Figure 40, more aggressive cookstove improvements and adoption targets yield a reduction of 96.2 percent in annual deforestation rates between 2023 and 2030. Charcoal usage continues to be the strongest driver of deforestation, accounting for 83.9 percent of cooking related forest loss. Figures 41 and Figure 42 show geospatial representations of deforestation by commune for the baseline scenario and the universal scenario, respectively.

Figure 39. Total biomass utilization and deforestation from cookstoves for baseline scenario

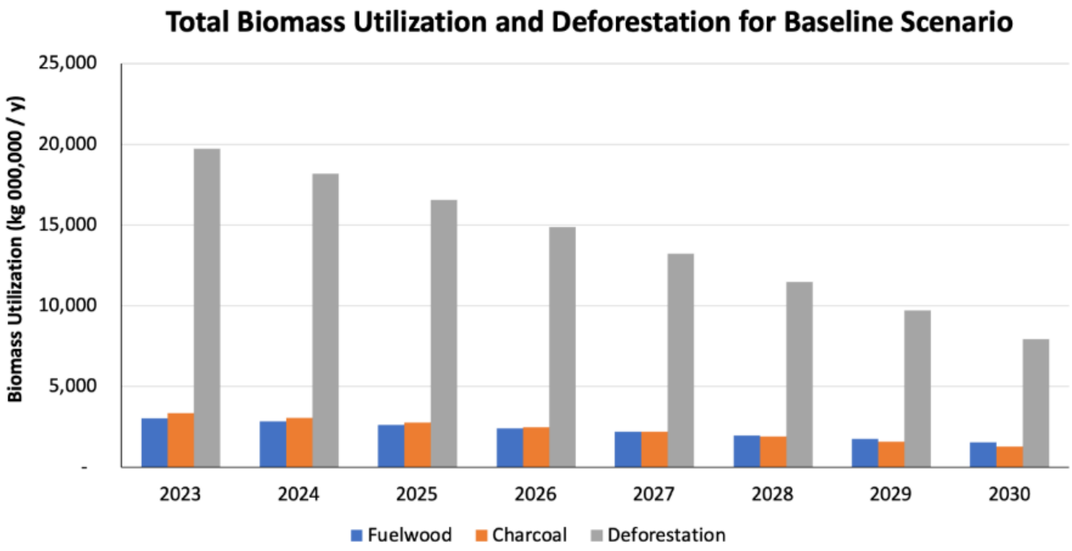


Figure 40. Total biomass utilization and deforestation from cookstoves for universal scenario

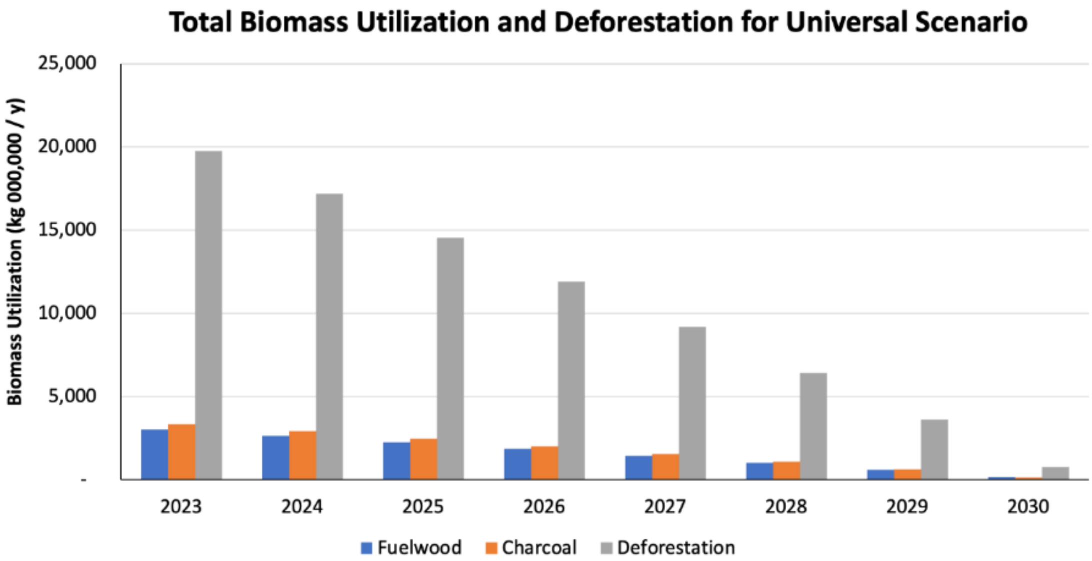


Figure 41. Total causes of cooking related deforestation from 2023–2030 for baseline scenario

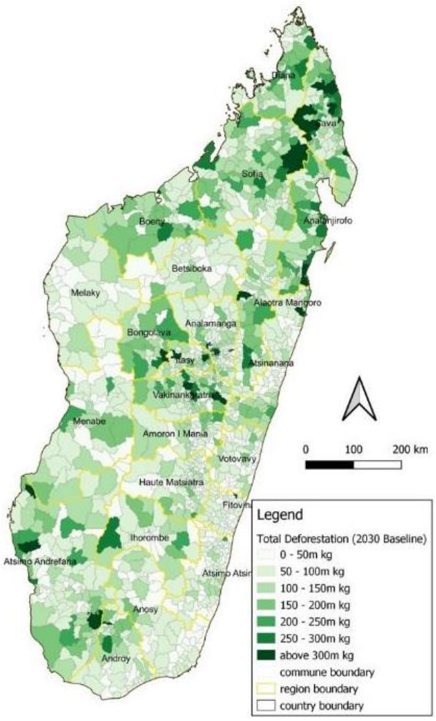
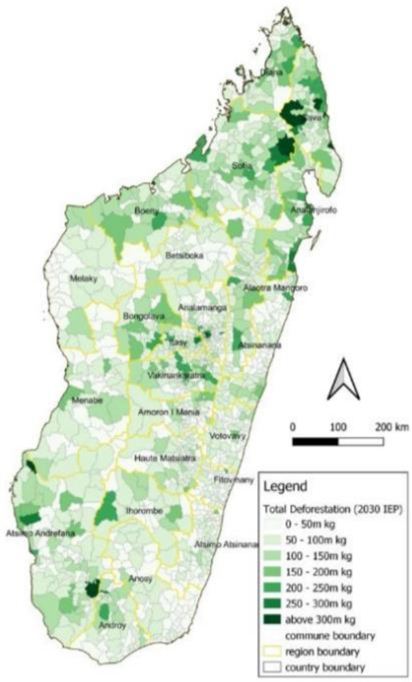


Figure 42. Total causes of cooking related deforestation from 2023–2030 for universal scenario



Co-factors

There are several pertinent data inputs to equate co-factors in the analysis with implications for environmental health, personal health and women. Outputs of the baseline scenario are compared with outputs of the IEP scenario.

Emissions and global warming potential – Cooking emissions are calculated from emissions factors associated with fuel combustion and CO_2 production at the site of combustion. Total annual CO_2 emissions of households and institutions for the baseline scenario reduce by 49.8 percent and 28.2 percent, respectively, from 2023 to 2030, and these reductions improve to 70.3 percent and 46.2 percent, respectively, for the universal scenario. Figures 43,44,45 and 46 visualize this reduction over time for the baseline and universal scenarios.

Figure 43. Climate impact of households in baseline scenario

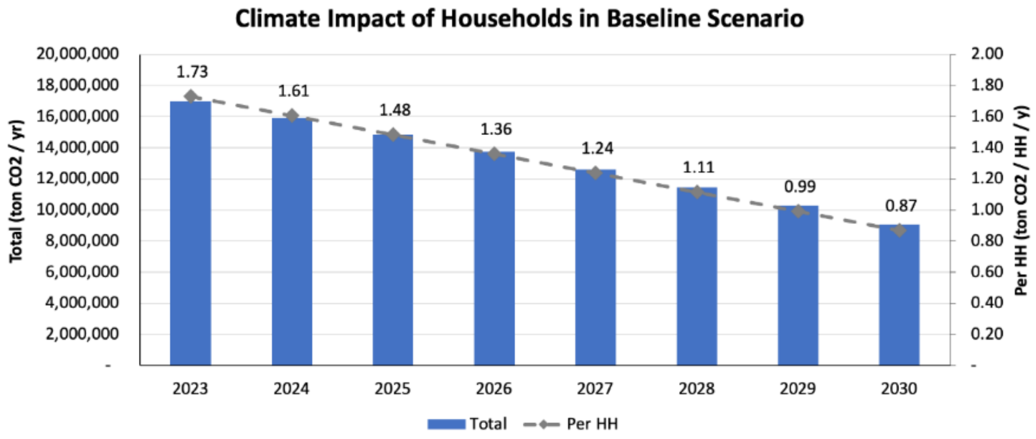


Figure 44. Climate impact of institutions in baseline scenario

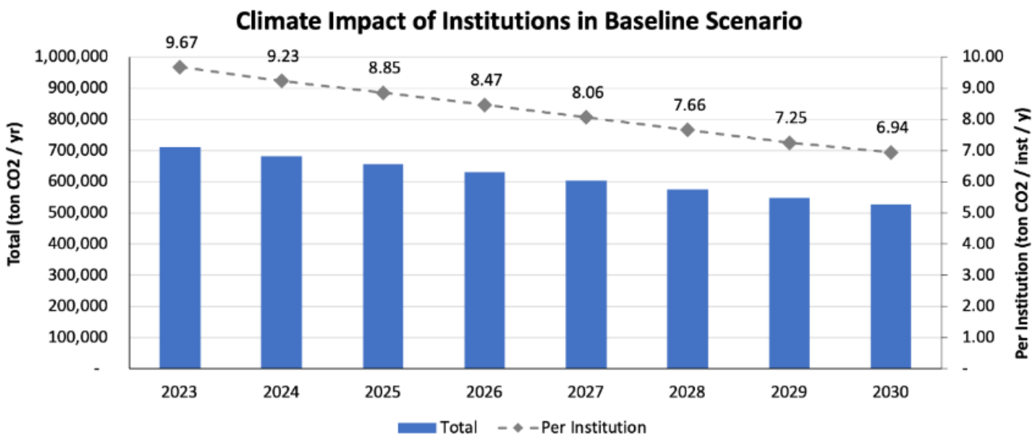


Figure 45. Climate impact of households in universal scenario

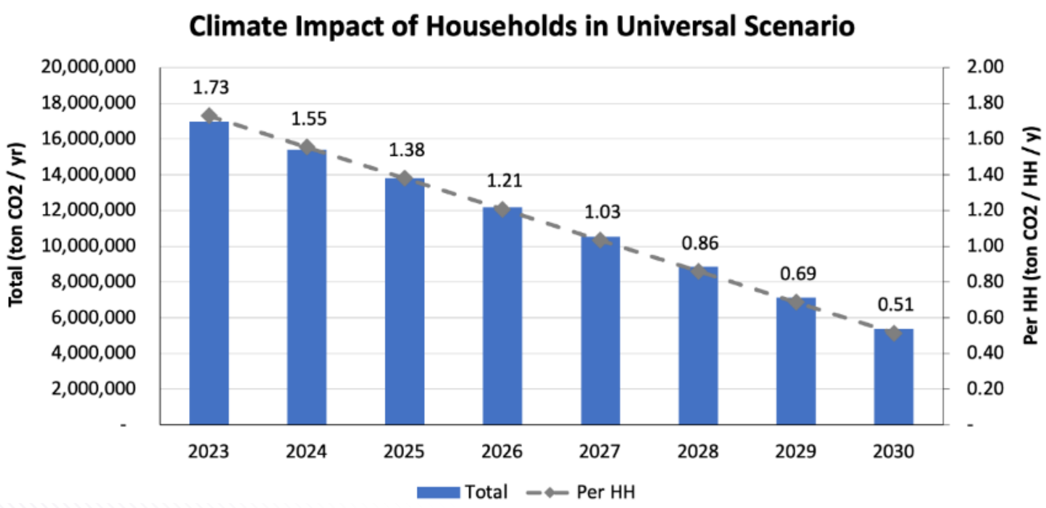
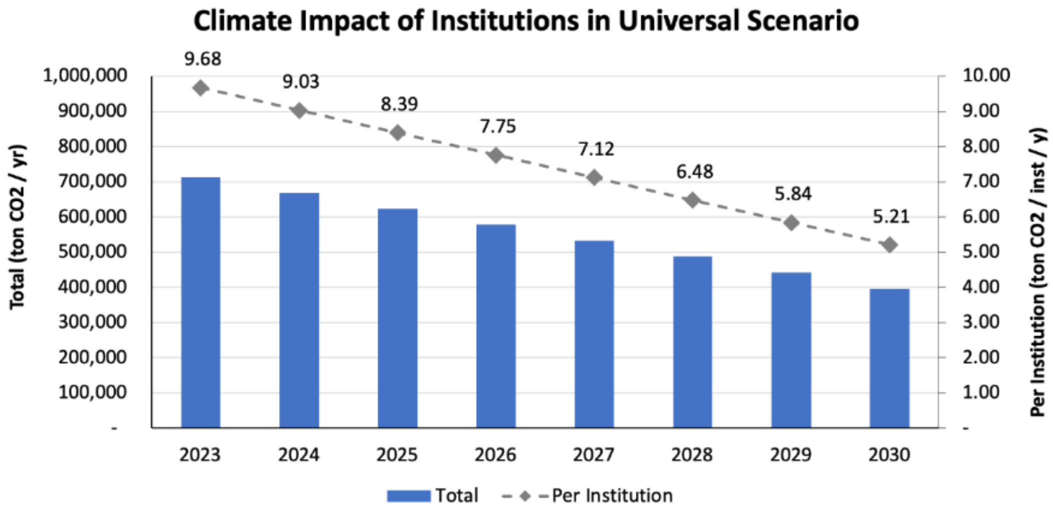


Figure 46. Climate impact of institutions in universal scenario



Exposure and health – Cooking emissions data and cooking practices help calculate personal exposure to harmful pollutants such as CO, CO_2, PM10 and PM2.5, and this is used to equate health impacts to people using cookstoves, particularly harmful effects on women and children. Health impacts are calculated using the HAPIT tool. The HAPIT tool can be used to estimate aggregate health impacts of cookstove interventions using a variety of assumptions as summarized below with results provided in Table 25 for disability-adjusted life years (DALYs). Positive health impacts are far greater in the universal scenario, as measured by DALYs averted and deaths averted, because of the greater adoption and use of improved cooking technologies.

- Baseline scenario (2030): pre-intervention PM2.5 for a basic fuelwood stove (77.6 PM2.5 / day / person), post-intervention PM2.5 for an improved fuelwood stove (64.7 PM2.5 / day / person), all population, useful intervention lifetime of five years.

- Universal scenario (2030): pre-intervention PM2.5 for a basic fuelwood stove (77.6 PM2.5 / day / person), post-intervention PM2.5 for lowest possible PM rating that can be selected (7 PM2.5 / day / person), all population, useful intervention lifetime of five years.

Table 27. Health impacts under each intervention scenario

Health Impact	Baseline Scenario	Universal Scenario
DALYs averted (child)	64,934	689,349
Deaths averted (child)	756	8,022
DALYs averted (adult)	97,164	1,225,051
Deaths averted (adult)	3,653	49,183

Gender – Fuel collection and cooking require a significant investment of time, and this responsibility falls primarily on women. Assuming no changes in gender roles, the following time savings are expected with the transition to cleaner cooking technologies and fuels based on the self-reported time spent on fuel collection and cooking in the household survey data. The self-reported time allocations from survey data in Table 26 can be combined with the stove ownership percentages in Table 27 to estimate time saved cooking for households and institutions, respectively, noting, however, that some respondents with electric and LPG may also prepare different types of meals or beverages than those prepared on fuelwood and charcoal stoves. Stove and fuel switching in the baseline scenario saves 19.4 percent and 14.5 percent of cooking time for households and institutions, respectively, and this is improved under the universal scenario saving 46.5 percent and 39.6 percent of cooking time for households and institutions, respectively. This is primarily attributed to e-cooking, and also to household LPG use. Fuel collection time also changes, which is good for both women and men; the gender differences are not estimated here due to the complexity that gender representations vary by each fuel type, collection process and urban or rural classification.

Table 28. Hours allocated to cooking each day by fuel type

	Hours cooking (h / day)	
Stove fuel type	Household	Institution
Fuelwood	3.22	6.15
Charcoal	3.44	5.62
Electric	1.77	1.75
LPG / other	1.60	4.00

Table 29. Household stove ownership (%)

	Household stove ownership (%)		
Stove fuel type	**Present day (2023)**	**Baseline (2030)**	**Universal (2030)**
Fuelwood	44.4%	27.4%	3.2%
Charcoal	53.1%	31.5%	3.2%
Electric	2.2%	20.1%	31.8%
LPG / other	0.4%	20.9%	61.8%
Avg (h / day)	3.30	2.66	1.77

CLEAN COOKING COSTS AND AFFORDABILITY GAP

The total costs of the baseline scenario and the universal scenario are first shown, and then the affordability gap is shown as the difference between the two scenarios.

Affordability Gap

The affordability gap is calculated as the difference between a reference case and each scenario. Table 28 provides the reference case that assumes households and institutions maintain the same stove-ownership and fuel-use practices from 2023 to 2030 with no stove or fuel switching, with annual increases in costs only attributed to population growth. Table 29 and Table 30 equate the affordability gap between the reference case in Table 28 and the total programme costs for the baseline and universal scenarios in Tables 29 and 30, respectively. Negative numbers shown in Table 29 and 30 show the potential financial savings of switching users away from those stoves and fuels. Between 2023 and 2030, financing the affordability gap for the baseline scenario would require 85 percent additional funds compared to present day costs, and the universal scenario would require 244 percent additional funds to finance the affordability gap compared to the reference case. Below is a summary of the cooking technologies and fuels included in calculating the affordability gap.

- Cooking Technologies: improved wood, improved charcoal, briquettes/pellets, biogas, bioethanol, LPG, electric
- Fuels: briquettes/pellets, biogas, bioethanol, LPG, electric induction

Costs are only reflected for stoves and fuels, and do not account for any infrastructure needs for increased stove production or supply. The per-unit stove and fuel cost from 2023 to 2030 is assumed static and does not attempt to explain the effects of price escalation, international currency exchange rates, or production volume price reductions.

Table 30. Reference case for calculating the affordability gap

Stove and Fuel Type	Stove	Fuel	Total
Fuelwood	$ 18,641,371	$ 466,923,504	$ 485,564,876
Charcoal	$ 136,850,267	$ 2,521,647,781	$ 2,658,498,048
Briquette/pellet	$ -	$ -	$ -
Biogas	$ 1,222,772	$ 8,199,773	$ 9,422,545
Bioethanol	$ -	$ -	$ -
LPG	$ 4,338,952	$ 59,917,544	$ 64,256,495
Electric	$ 15,433,507	$ 308,361,980	$ 323,795,488
Total	**$ 176,486,870**	**$ 11,514,159,502**	**$ 3,541,537,452**

Table 31. Affordability gap for baseline scenario

Stove and Fuel Type	Stove	Fuel	Total
Fuelwood	$ 4,585,856	$ (148,122,549)	$ (143,536,693)
Charcoal	$ (33,000,474)	$ (859,789,247)	$ (892,789,721)
Briquette/pellet	$ 5,955,140	$ 148,859,104	$ 154,814,244
Biogas	$ 29,180,972	$ 151,838,207	$ 181,019,179
Bioethanol	$ 70,247,062	$ 2,021,745,095	$ 2,091,992,156
LPG	$ 22,242,823	$ 134,138,008	$ 156,380,830
Electric	$ 86,445,719	$ 1,376,377,550	$ 1,462,823,269
Total	**$ 185,657,098**	**$ 2,825,046,168**	**$ 3,010,703,265**

Table 32. Affordability gap for universal scenario

Stove and Fuel Type	Stove	Fuel	Total
Fuelwood	$ (7,441,332)	$ (231,486,599)	$ (238,927,931)
Charcoal	$ (67,394,446)	$ (1,241,217,594)	$ (1,308,612,040)
Briquette/pellet	$ 37,895,240	$ 947,276,658	$ 985,171,898
Biogas	$ 189,971,252	$ 988,864,472	$ 1,178,835,724
Bioethanol	$ 167,660,997	$ 4,793,947,921	$ 4,961,608,918
LPG	$ 22,242,915	$ 135,821,524	$ 158,064,438
Electric	$ 152,598,575	$ 2,755,902,539	$ 2,908,501,115
Total	**$ 495,533,201**	**$ 8,149,108,920**	**$ 8,644,642,121**

RECOMMENDATIONS

Universal access to clean cooking solutions in Madagascar can be accelerated through policy interventions, investment, private sector engagement and gender-responsive strategies that account for local variability in available fuels and consumer interests across Madagascar as identified through the geospatial analysis presented. These national-scale priorities developed with an understanding of local contexts highlight options to make broad policies that are inclusive and faciliatory of local needs. Primary recommendations are given below:

- **Biomass derived fuels such as bioethanol, biogas and pellet/briquette fuels show significant potential to meet clean cooking needs and can meet both rural and urban requirements for household and institution energy needs.** Such fuels can complement e-cooking solutions utilized in areas with grid access and medium-voltage (MV) mini-grids. Even in the universal scenario with the most aggressive clean fuel adoption rates, the energy needed for cooking fuel would only utilize 19.11 percent, 4.81 percent and 6.55 percent of the biomass needed to create bioethanol, biogas and pellets/briquettes, respectively, suggesting that at a nationallevel the diversion of biomass for fuels may not have a substantial effect on food availability (e.g., maize) or natural fertilizer (e.g., manure). Targeted investments, supply chain planning and commercial pilots can demonstrate the opportunity space for e-cooking and improved biofuel stoves that increase customer awareness and attract private-sector participation. Associated policy innovations and government advocacy work is also needed to create the enabling environment that enables self-sustained growth of the clean cooking sector in Madagascar. Such efforts can inform and amplify other investments such as the OPEC Fund for International Development to the National Clean Cookery Transition Programme in Madagascar that could provide loans and grants totalling USD 35M to reach goals outlined in Madagascar's primary energy policy, La Nouvelle Politique de l'Energie 2015–2030.
- **Rural customers should prioritize alternative biomass fuels**. Approximately 80 percent of households are rural and utilize wood or charcoal as the primary or only fuel source. The amount of rural designated households and institutions will be consistent as Madagascar grows in population and with modest urbanization. Therefore, rural households and institutions must have alternative fuels opportunities. When considering fuel access and costs, the best opportunities are in bioethanol, biogas and agriculture waste converted into pellets and briquettes, with approximately 77 percent of rural households and 48 percent of rural institutions using alternative biomass fuels in the universal scenario.
- **Urban customers have opportunities to transition away from charcoal.** A nationwide effort to enhance utilization of biomass-derived fuels can reduce deforestation. Portability of fuels is essential, specifically bioethanol and biomass pellets/briquettes in rural areas, with e-cooking and LPG expected to have improved access and adoption (purchasing) in urban areas. Approximately 72 percent and 10 percent of urban households are expected to use electricity and LPG for cooking in the universal scenario, respectively, with urban institutions following a similar trend.
- **Options for energy equity are available and can be accelerated through broad stakeholder engagement across the value chain.** Two scenarios were compared including a baseline scenario as defined by the Clean Cooking Compact and the IEP scenario that provide universal access to electricity to enable greater utilization of e-cooking while also advancing higher adoption of tier-4 and tier-5 stoves using biomass-

derived fuels. Each scenario modelling a potential transition pathway from 2023 to 2030 with consideration for fuel potential, consumer preferences, costs of cookstoves, fuel collection practices and costs of fuel. Results showed production volumes required for clean cooking solutions and alternative fuels, associated effects to deforestation, implications to women and youth, customer-level and aggregated consumer costs of clean cooking, and the affordability gap that will need to be bridged to deliver a cleaner cooking future.

- **Cleaner cooking technologies and fuels create a significant and tangible benefit for women and youth.** As common globally, the cooking roles in Madagascar disproportionately affect women in significant and systematic ways. Clean cooking technologies not only benefit women during meal preparation, but also reduce time spent obtaining fuel and cleaning and can enable women to utilize their time differently and potentially direct that free time to income generation or education that creates benefits for gender equity and opportunity. Looking to household cooking tasks that are predominantly the responsibility of women, an estimated 3.30 hours per day were spent cooking in 2023, which is reduced to an average of 2.66 hours per day in the 2030 baseline scenario, and further reduced to an average of 1.77 hours per day in the 2030 universal scenario. Health benefits for adults and children are significant, with an estimated 756 and 8,022 childhood deaths averted in the baseline and universal scenarios, respectively, and an estimated 3,653 and 49,183 adult deaths averted in the baseline and universal scenarios, respectively.
- **Charcoal production improvements are a proven and immediate way to reduce deforestation.** Improved kiln usage can reduce fuelwood usage by 50 percent for charcoal production. Charcoal production improvements are necessary to reduce losses to forests even while Madagascar transitions away from fuelwood and charcoal use. Intermediate and transitionary solutions are necessary and practical to provide incremental opportunities for improvement by local actors.
- **Affordability of clean cooking is a significant barrier to reaching national goals**. Survey data indicated that approximately 75 percent of households identified the costs of cooking as the primary barrier to using clean cooking solutions, whereas a small percentage of institutions indicated challenges to using clean cooking solutions. When noting that the capital cost of procuring a stove is modest compared to the cost of fuel, the approach to subsidize stove cost is helpful but must be paired with reductions in the production cost of fuels and enable private investment to drive those cost efficiencies at scale. Fuel subsidies should also be considered to close the affordability gap. There is also potential in lowering the cost of producing a stove as production volumes increase and supply chains are further developed and become more efficient. Additional costs not included here must also be considered such as infrastructure investments.
- **Collaboration and partnerships will be key to addressing barriers to universal access.** The projected clean cooking future for Madagascar under the IEP scenario will require interministerial collaboration for energy, finance, agriculture, transportation, trade and other sectors of the Madagascar government. Further, greater collaboration between the government and stove developers and fuel producers will be essential to collaboratively planning and evaluating opportunities for clean cooking. Non-governmental organizations can play a facilitatory role in helping plan and support interventions by the private sector and public sector.

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ANNEX 2: CLEAN COOKING STAKEHOLDERS

The table below provides stakeholders with experience, knowledge, or decision-making authority for clean cooking in Madagascar. Gathered as of May 2023.

Organization name	Organization role in Madagascar
Ministry of Energy and Hydrocarbons (MEH) - Madagascar	Government
Ministry of Agriculture (MAEP)	Government
Ministry of Environment and Sustainable Development (MEDD)	Government
Office Malgache des Hydrocarbures	Government
Modern Energy Cooking Services	NGO
Clean Cooking Alliance	NGO
UNIDO	UN Organization
Clean Cooking Madagascar	NGO
CIRAD (French Agricultural Research Centre for International Development)	Research
GIZ	Consulting
Ethnolab	Vendor
Nosy Maitso	Vendor
World Bank Ci-Dev	Funder
Project Gaia	NGO
Green Development (Norway)	NGO
OPEC Fund for Int Development	Funder
FAO	UN Organization
The World LPG Association (WLPGA)	NGO
REDD+ Country Rep Madagascar	UN
UNDP	UN Organization
WFP	NGO
Zahana	NGO
Madaprojects	Developer
Tozzi Green	Developer
BeLocal	NGO
Native	Consulting
SAFI	Vendor

World Wildlife Fund	NGO
Guangzhou Iceberg Environmental Consulting Services	Consulting
Indiana University	University
Berkeley Air Monitoring Group	University
Duke University Lemur Center	University
Liverpool Institute of Public Health	University
Aid4Mada	NGO
World Food Programme (WFP)	UN Organization
UN Framework Convention on Climate Change (UNFCCC)	UN Organization
ADES/ MyClimate	NGO
INBAR	NGO
Angovo Maharitra (Carbon Credits Consulting)	Consulting
SEED Madagascar	NGO
Ascension and Holy Trinity, Wyoming	Funder
Caring Response Madagascar Foundation	NGO
Lernen-Helfen-Leben e.V.	NGO
Sol Solidari	NGO
Sun24	NGO
Blazing Tube Solar	Vendor
Public Private Alliance Foundation	NGO
Centre Écologique Albert Schweitzer	NGO
University of Toliara	University
Catholic Relief Services	Funder
UK Aid	Funder
Sommer Holzwerkstatt	Vendor
Haute Ecole l'Ingénieurs d'Yverdon-les-Bains	University
Global LPG Partnership (GLPGP)	NGO

ANNEX 3: CLEAN COOKING SURVEY

Attached as separate PDF

ANNEX 4: CLEAN COOKING SURVEY RESULTS

Attached as separate PDF

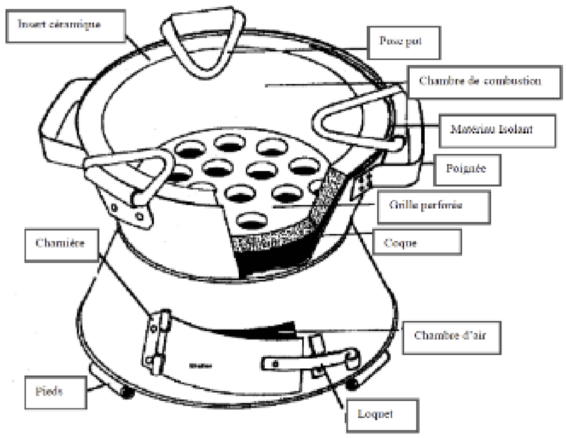
ANNEX 5: COOKING TECHNOLOGIES

Fuelwood (3-Stone) (Madagascar, Beyond Connections (World Bank Group 2022))

Fuelwood (Basic) (Madagascar, Beyond Connections (World Bank Group 2022))

Fuelwood (Improved) (SEforALL, Clean Cooking Country Brief: Madagascar (SEforALL 2023)

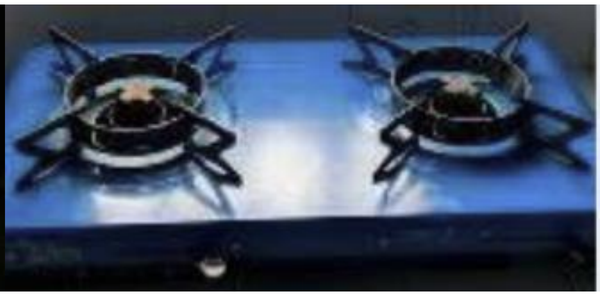
Charcoal (basic) (Alleviating Deforestation Pressures? Impacts of Improved Stove Dissemination on Charcoal) Consumption in Urban Senegal, Bensch and Peters 2013)



Charcoal (improved) (FOYER AMELIORE A CHARBON DE BOIS (NORME MALAGASY 2018))

Briquette (Ethanol briquettes as clean cooking alternative in Malawi, Chomanika et al 2022)

Biogas (Small-scale biogas plants in central Vietnam and biogas appliances with a focus on a flue gas analysis of biogas cookstoves (Roubik and Mazancova 2019))

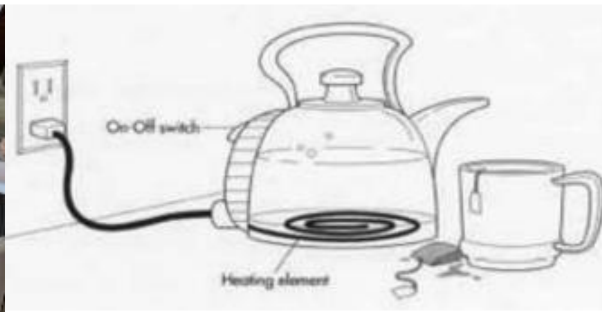


Bioethanol (SE4ALL, Clean Cooking Country Brief: Madagascar (SEforALL 2023))

LPG
Madagascar, Beyond Connections (World Bank Group 2022)

E-Cooking (Experimental evaluation of electric clean cooking options for rural areas of developing countries, (Aemro et. al 2020)

Electric – rice cooker (https://www.insider.com/guides/kitchen/best-rice-cooker#best-overall-yum-asia-panda-mini-rice-cooker-1)



Electric – kettle (PID-based temperature control device for electric kettle, Shah et al 2019)

Electric – fryer (https://thewell.northwell.edu/healthy-living-fitness/is-an-air-fryer-healthy)

Electric – oven (https://muse.union.edu/nguyenh/transforming-a-toaster-oven-into-a-solder-reflow-oven/)

Electric – microwave (http://careercenter.blog.hofstra.edu/2014/07/dont-cook-fish-in-microwave.html)

Fuelwood – basic institutional (https://cleancookingmarket.com/product/institutional-brick-fuelwood-stove-double-unit/)

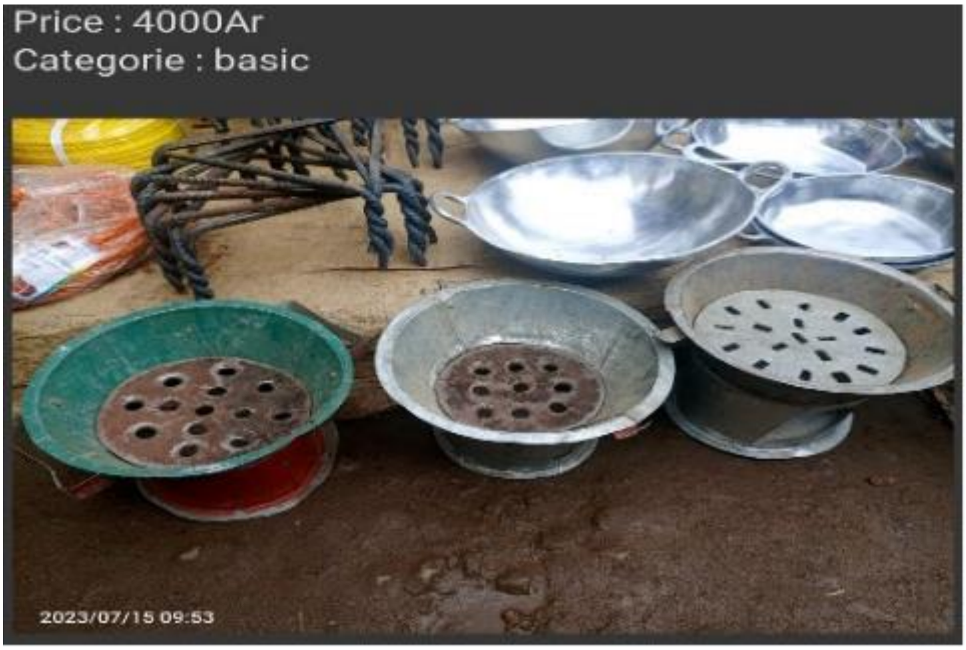
Fuelwood – improved institutional (https://sescom.co.tz/about-us/19-improved-and-modern-institutional-fuelwood-stoves-seta-is)

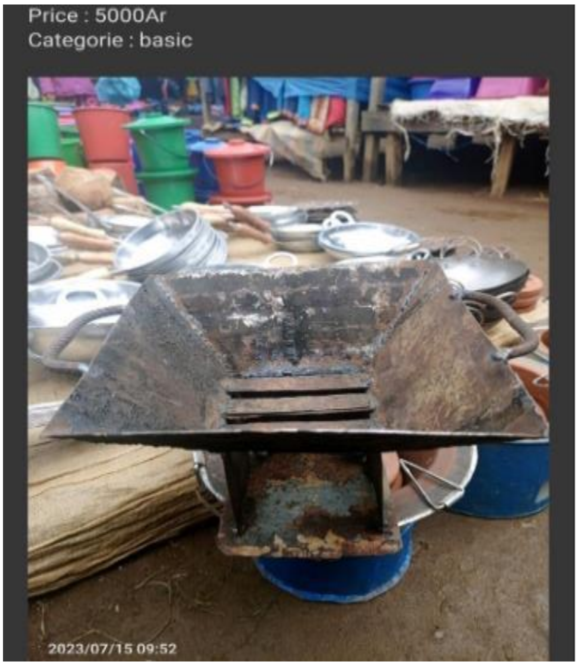
Charcoal – basic institutional (https://cleancookingmarket.com/product/cookmate-charcoal-stove-large-size/)

Charcoal – improved institutional (http://www.renewables-liberia.info/index.php/projects-new/biomass-cooking/82-the-role-of-endev-in-providing-renewable-and-efficient-energies-to-the-people-of-liberia)

Solar Stove
Madagascar, Beyond Connections (World Bank Group 2022)

Additional images of stove types

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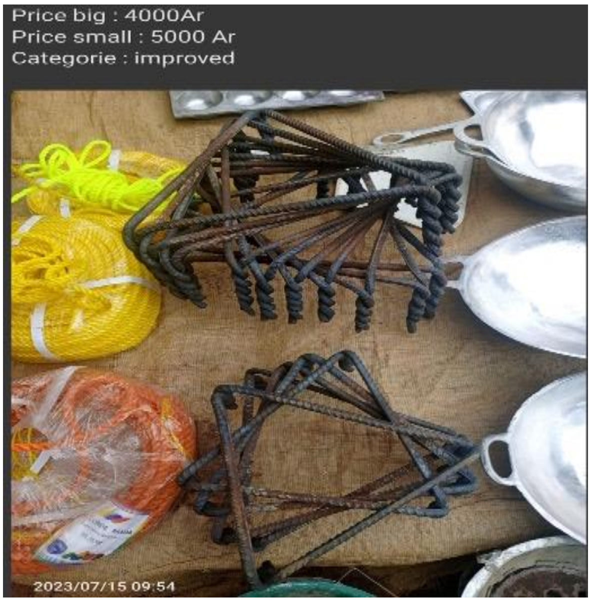
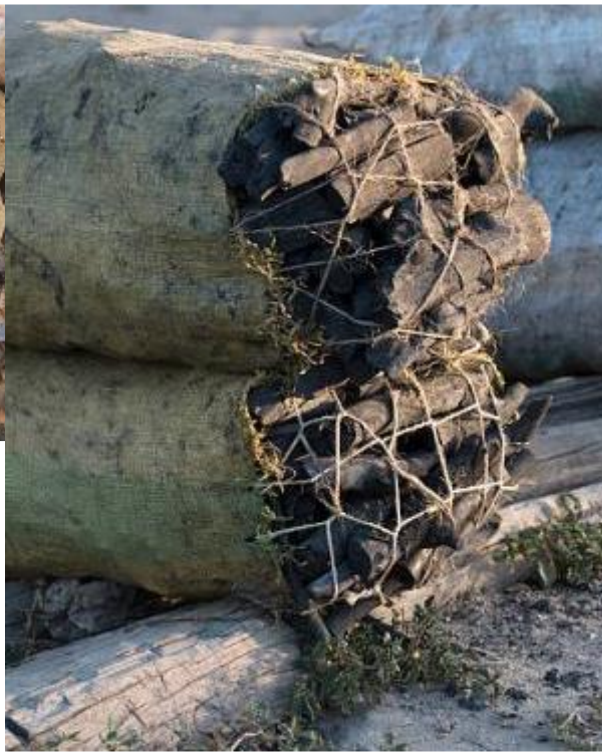
Categorie : basic
2023/07/15 09:52


Price big : 4000Ar
Price small : 5000 Ar
Categorie : improved
2023/07/15 09:54


ADES
ADES

ANNEX 6: COOKING FUELS

Wood bundles (https://www.themillstores.com/products/fuelwood)



Charcoal sack (https://www.istockphoto.com/photo/charcoal-filled-bags-along-madagascar-spiny-desert-roadside-gm475566182-66027733)

LPG cylinder (SEforALL, Clean Cooking Country Brief: Madagascar (SEforALL 2023))

Bioethanol (https://fireplaceuniverse.com/bioethanol-fireplace-fuel/)

Briquettes (https://gogetfunding.com/biomass-briquette-in-madagascar/)

Biogas (https://www.cooleffect.org/project/biogas-digesters-and-clean-cookstoves-aa)

Electric ()

ANNEX 7: HOUSEHOLD COOKING MARKET SEGMENTS

Urban	Households (%)			Households (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	24.0%	0.0%	0.0%	475,267	-	-
Fuelwood stove - basic	0.8%	0.0%	0.0%	15,842	-	-
Fuelwood stove - improved	7.0%	0.0%	0.0%	138,620	-	-
Fuelwood stove - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic	6.1%	0.0%	0.0%	120,797	-	-
Charcoal - improved	60.2%	7.9%	0.0%	1,192,129	191,238	-
Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Briquette/pellet	0.0%	0.0%	0.0%	-	-	-
Biogas	0.0%	0.0%	0.0%	-	-	-
Bioethanol	0.0%	10.0%	17.9%	-	241,238	432,477
LPG	1.0%	10.4%	10.4%	19,803	250,000	250,000
Electric - hot plate	0.9%	35.9%	0.0%	17,823	864,953	-
Electric - induction plate	0.0%	35.9%	71.7%	-	864,953	1,729,906
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Charcoal - improved	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-

Rural	Households (%)			Households (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	11.2%	1.4%	0.0%	874,546	114,055	-
Fuelwood stove - basic	25.9%	2.1%	0.0%	2,025,252	172,465	-
Fuelwood stove - improved	7.1%	27.1%	0.0%	552,583	2,186,432	-
Fuelwood stove - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic	37.8%	3.2%	0.0%	2,957,766	260,128	-
Charcoal - improved	9.2%	30.8%	0.0%	716,963	2,480,215	-
Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Briquette/pellet	0.0%	2.6%	16.5%	-	209,392	1,332,516
Biogas	0.1%	2.6%	16.5%	5,245	209,392	1,332,516
Bioethanol	0.0%	17.8%	44.2%	-	1,433,895	3,565,072
LPG	0.2%	0.0%	0.0%	12,560	-	-
Electric - hot plate	0.1%	1.7%	0.0%	5,245	135,047	-
Electric - induction plate	0.0%	1.7%	13.7%	-	135,047	1,105,963
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	2.7%	1.2%	0.0%	207,631	94,226	-
Fuelwood - improved + Charcoal - improved	3.5%	4.7%	0.0%	271,360	376,905	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.7%	0.0%	0.0%	53,934	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.6%	1.6%	4.5%	47,388	125,000	360,566
Charcoal - basic + Electric - hot plate / rice cooker	0.7%	0.0%	0.0%	53,934	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.6%	1.6%	4.5%	47,388	125,000	360,566
Fuelwood - basic institutional + Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-

Rural - Northern	Households (%)			Households (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	3.4%	1.4%	0.0%	82,905	35,463	-
Fuelwood stove - basic	28.5%	2.1%	0.0%	694,939	53,625	-
Fuelwood stove - improved	0.0%	27.1%	0.0%	-	679,829	-
Fuelwood stove - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic	53.6%	3.2%	0.0%	1,306,974	80,882	-
Charcoal - improved	8.7%	30.8%	0.0%	212,139	771,175	-
Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Briquette/pellet	0.0%	2.6%	16.5%	-	65,106	414,320
Biogas	0.0%	2.6%	16.5%	-	65,106	414,320
Bioethanol	0.0%	17.8%	44.2%	-	445,842	1,108,490
LPG	0.3%	0.0%	0.0%	7,315	-	-
Electric - hot plate	0.0%	1.7%	0.0%	-	41,990	-
Electric - induction plate	0.0%	1.7%	13.7%	-	41,990	343,878
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	2.0%	1.2%	0.0%	48,768	29,298	-
Fuelwood - improved + Charcoal - improved	3.5%	4.7%	0.0%	85,343	117,191	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	1.6%	4.5%	-	38,866	112,111
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	1.6%	4.5%	-	38,866	112,111
Fuelwood - basic institutional + Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-

Rural - Central	Households (%)			Households (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	13.9%	1.4%	0.0%	506,684	52,875	-
Fuelwood stove - basic	25.8%	2.1%	0.0%	940,463	79,954	-
Fuelwood stove - improved	14.2%	27.1%	0.0%	517,619	1,013,614	-
Fuelwood stove - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic	25.0%	3.2%	0.0%	911,301	120,593	-
Charcoal - improved	10.3%	30.8%	0.0%	375,456	1,149,809	-
Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Briquette/pellet	0.0%	2.6%	16.5%	-	97,072	617,745
Biogas	0.0%	2.6%	16.5%	-	97,072	617,745
Bioethanol	0.0%	17.8%	44.2%	-	664,743	1,652,741
LPG	0.0%	0.0%	0.0%	-	-	-
Electric - hot plate	0.0%	1.7%	0.0%	-	62,607	-
Electric - induction plate	0.0%	1.7%	13.7%	-	62,607	512,716
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	2.2%	1.2%	0.0%	80,195	43,683	-
Fuelwood - improved + Charcoal - improved	4.0%	4.7%	0.0%	145,808	174,730	-
Fuelwood - basic + Electric - hot plate / rice cooker	1.0%	0.0%	0.0%	36,452	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	1.3%	1.6%	4.5%	47,388	57,949	167,156
Charcoal - basic + Electric - hot plate / rice cooker	1.0%	0.0%	0.0%	36,452	-	-
Charcoal - improved + Electric - induction plate / rice cooker	1.3%	1.6%	4.5%	47,388	57,949	167,156
Fuelwood - basic institutional + Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-

Rural - Southern	Households (%)			Households (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	16.3%	1.4%	0.0%	284,957	25,717	-
Fuelwood stove - basic	22.3%	2.1%	0.0%	389,850	38,887	-
Fuelwood stove - improved	2.0%	27.1%	0.0%	34,964	492,990	-
Fuelwood stove - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic	42.3%	3.2%	0.0%	739,491	58,653	-
Charcoal - improved	7.4%	30.8%	0.0%	129,367	559,231	-
Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Briquette/pellet	0.0%	2.6%	16.5%	-	47,213	300,451
Biogas	0.3%	2.6%	16.5%	5,245	47,213	300,451
Bioethanol	0.0%	17.8%	44.2%	-	323,310	803,841
LPG	0.3%	0.0%	0.0%	5,245	-	-
Electric - hot plate	0.3%	1.7%	0.0%	5,245	30,450	-
Electric - induction plate	0.0%	1.7%	13.7%	-	30,450	249,369
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	4.5%	1.2%	0.0%	78,669	21,246	-
Fuelwood - improved + Charcoal - improved	2.3%	4.7%	0.0%	40,209	84,983	-
Fuelwood - basic + Electric - hot plate / rice cooker	1.0%	0.0%	0.0%	17,482	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	1.6%	4.5%	-	28,185	81,299
Charcoal - basic + Electric - hot plate / rice cooker	1.0%	0.0%	0.0%	17,482	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	1.6%	4.5%	-	28,185	81,299
Fuelwood - basic institutional + Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-

ANNEX 8: INSTITUTION COOKING MARKET SEGMENTS

Urban	Institutions (%)			Institutions (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - basic	15.0%	0.0%	0.0%	1,743	-	-
Fuelwood stove - improved	10.0%	0.0%	0.0%	1,162	-	-
Fuelwood stove - basic institutional	5.0%	0.0%	0.0%	581	-	-
Fuelwood stove - improved institutional	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved	10.0%	0.0%	0.0%	1,162	-	-
Charcoal - basic institutional	30.0%	0.0%	0.0%	3,486	-	-
Charcoal - improved institutional	20.0%	7.9%	0.0%	2,324	1,094	-
Briquette/pellet	0.0%	0.0%	0.0%	-	-	-
Biogas	0.0%	0.0%	0.0%	-	-	-
Bioethanol	0.0%	10.0%	17.9%	-	1,380	2,474
LPG	5.0%	10.4%	10.4%	581	1,430	1,430
Electric - hot plate	5.0%	35.9%	0.0%	581	4,948	-
Electric - induction plate	0.0%	35.9%	71.7%	-	4,948	9,895
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Charcoal - improved	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Charcoal - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-

Rural	Institutions (%)			Institutions (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	2.4%	0.0%	0.0%	1,517	-	-
Fuelwood stove - basic	4.5%	0.0%	0.0%	2,785	-	-
Fuelwood stove - improved	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - basic institutional	2.4%	0.0%	0.0%	1,517	-	-
Fuelwood stove - improved institutional	2.9%	4.8%	0.0%	1,807	3,003	-
Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional	35.0%	0.0%	0.0%	21,701	-	-
Charcoal - improved institutional	15.8%	30.4%	0.0%	9,820	18,852	-
Briquette/pellet	0.0%	0.0%	0.0%	-	-	-
Biogas	0.0%	0.0%	0.0%	-	-	-
Bioethanol	0.0%	22.2%	47.7%	-	13,788	29,588
LPG	0.8%	0.6%	0.6%	525	381	381
Electric - hot plate	1.4%	3.7%	0.0%	890	2,296	-
Electric - induction plate	0.0%	3.7%	17.2%	-	2,296	10,647
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	1.7%	0.0%	0.0%	1,079	-	-
Fuelwood - improved + Charcoal - improved	7.1%	8.9%	0.0%	4,426	5,505	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Charcoal - basic institutional	13.8%	0.0%	0.0%	8,547	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	9.5%	23.3%	0.0%	5,906	14,453	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	8.6%	-	-	5,356
Charcoal - basic institutional + Electric - hot plate / rice cooker	1.0%	1.0%	0.0%	598	598	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	1.4%	1.4%	25.9%	869	869	16,068

Rural - Northern	Institutions (%)			Institutions (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - basic	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - basic institutional	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - improved institutional	0.0%	4.8%	0.0%	-	997	-
Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional	44.4%	0.0%	0.0%	9,076	-	-
Charcoal - improved institutional	11.1%	30.4%	0.0%	2,269	6,259	-
Briquette/pellet	0.0%	0.0%	0.0%	-	-	-
Biogas	0.0%	0.0%	0.0%	-	-	-
Bioethanol	0.0%	22.2%	47.7%	-	4,578	9,823
LPG	0.0%	0.6%	0.6%	-	126	126
Electric - hot plate	0.0%	3.7%	0.0%	-	762	-
Electric - induction plate	0.0%	3.7%	17.2%	-	762	3,535
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Charcoal - improved	11.1%	8.9%	0.0%	2,269	1,828	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Charcoal - basic institutional	22.3%	0.0%	0.0%	4,558	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	11.1%	23.3%	0.0%	2,269	4,798	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	8.6%	-	-	1,778
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	1.0%	0.0%	-	198	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	0.0%	1.4%	25.9%	-	288	5,335

Rural - Central	Institutions (%)			Institutions (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	3.3%	0.0%	0.0%	890	-	-
Fuelwood stove - basic	3.3%	0.0%	0.0%	890	-	-
Fuelwood stove - improved	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - basic institutional	3.3%	0.0%	0.0%	890	-	-
Fuelwood stove - improved institutional	6.7%	4.8%	0.0%	1,807	1,288	-
Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional	23.3%	0.0%	0.0%	6,282	-	-
Charcoal - improved institutional	23.3%	30.4%	0.0%	6,282	8,083	-
Briquette/pellet	0.0%	0.0%	0.0%	-	-	-
Biogas	0.0%	0.0%	0.0%	-	-	-
Bioethanol	0.0%	22.2%	47.7%	-	5,912	12,687
LPG	0.0%	0.6%	0.6%	-	163	163
Electric - hot plate	3.3%	3.7%	0.0%	890	985	-
Electric - induction plate	0.0%	3.7%	17.2%	-	985	4,565
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	4.0%	0.0%	0.0%	1,079	-	-
Fuelwood - improved + Charcoal - improved	8.0%	8.9%	0.0%	2,157	2,360	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Charcoal - basic institutional	12.9%	0.0%	0.0%	3,478	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	7.0%	23.3%	0.0%	1,887	6,197	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	8.6%	-	-	2,297
Charcoal - basic institutional + Electric - hot plate / rice cooker	0.0%	1.0%	0.0%	-	256	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	1.6%	1.4%	25.9%	431	373	6,890

Rural - Southern	Institutions (%)			Institutions (count)		
Stove	2023 (present)	2030 (baseline)	2030 (universal)	2023 (present)	2030 (baseline)	2030 (universal)
Single stove ownership						
Fuelwood stove - 3-stone	4.3%	0.0%	0.0%	627	-	-
Fuelwood stove - basic	13.0%	0.0%	0.0%	1,896	-	-
Fuelwood stove - improved	0.0%	0.0%	0.0%	-	-	-
Fuelwood stove - basic institutional	4.3%	0.0%	0.0%	627	-	-
Fuelwood stove - improved institutional	0.0%	4.8%	0.0%	-	718	-
Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic institutional	43.5%	0.0%	0.0%	6,343	-	-
Charcoal - improved institutional	8.7%	30.4%	0.0%	1,269	4,509	-
Briquette/pellet	0.0%	0.0%	0.0%	-	-	-
Biogas	0.0%	0.0%	0.0%	-	-	-
Bioethanol	0.0%	22.2%	47.7%	-	3,298	7,078
LPG	3.6%	0.6%	0.6%	525	91	91
Electric - hot plate	0.0%	3.7%	0.0%	-	549	-
Electric - induction plate	0.0%	3.7%	17.2%	-	549	2,547
Multiple stove ownership (stove stacking)						
Fuelwood - basic + Charcoal - basic	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Charcoal - improved	0.0%	8.9%	0.0%	-	1,317	-
Fuelwood - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - basic + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Charcoal - improved + Electric - induction plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - basic institutional + Charcoal - basic institutional	3.5%	0.0%	0.0%	510	-	-
Fuelwood - improved institutional + Charcoal - improved institutional	12.0%	23.3%	0.0%	1,750	3,457	-
Fuelwood - basic institutional + Electric - hot plate / rice cooker	0.0%	0.0%	0.0%	-	-	-
Fuelwood - improved institutional + Electric - induction plate / rice cooker	0.0%	0.0%	8.6%	-	-	1,281
Charcoal - basic institutional + Electric - hot plate / rice cooker	4.1%	1.0%	0.0%	598	143	-
Charcoal - improved institutional + Electric - induction plate / rice cooker	3.0%	1.4%	25.9%	437	208	3,844