SUSTAINABLE CHARCOAL AND BEYOND

ENSURING SUSTAINABLE CHARCOAL PRODUCTION AND USE AS TANZANIA TRANSITIONS TO CLEANER FUELS

Recommended citation: TFCG 2020. Sustainable charcoal and beyond. Ensuring sustainable charcoal production and use as Tanzania transitions to cleaner fuels. TFCG Technical Report 47.

This report was prepared by the Tanzania Forest Conservation Group and submitted to the World Bank Group in 2020.

TABLE OF CONTENTS

TABLE OF BOXES

TABLE OF FIGURES

TABLE OF TABLES

Abbreviations and Acronyms

BAU	Business as usual
CBFM	Community-Based Forest Management
CCFAT	Clean Cookstoves and Fuels Alliance of Tanzania
CHAPOSA	Charcoal Potential in Southern Africa
DoE	Division of Environment
ESD	Energy for Sustainable Development
FAO	Food and Agriculture Organization
FBD	Forest and Beekeeping Division
FS	Fuel switch
GAI	Green Advocates International
GDP	Gross Domestic Product
GoT	Government of Tanzania
HH	Household
ICS	Improved cook stove
IK	Improved kiln
IS	Improved stove
JFM	Joint Forest Management
LPG	Liquefied Petroleum Gas
ME	Ministry of Energy
MEM	Ministry of Energy and Minerals
MJ	Megajoule
MJUMITA	Community Forestry Network of Tanzania (Mtandao wa Jamii wa Usimamizi wa Misitu Tanzania)
MNRT	Ministry of Natural Resources and Tourism
NCTF	National Charcoal Task Force
NGO	Nongovernmental organization
NRM	Natural Resources Management
PFM	Participatory Forest Management
PJ	Petajoule
PO-RALG	President's Office – Regional Administration and Local Government

PSMP	Power Sector Master Plan
REDD	Reducing Emissions from Deforestation and Forest Degradation
RPTES	Regional Program for the Traditional Energy Sector
RWEDP	Regional Wood Energy Development Programme
SIDO	Small Industries Development Organisation
SNV	Netherlands Development Organisation
TANESCO	Tanzania Electric Supply Company
TANROADS	Tanzania National Roads Agency
TAREA	Tanzania Renewable Energy Association
TaTEDO	Tanzania Traditional Energy Development and Environment Organization
TEITI	Tanzania Extractive Industries Transparency Initiative
TFBA	Tanzania Forestry and Beekeeping Authority
TFCG	Tanzania Forest Conservation Group
TFS	Tanzania Forest Services Agency
TIRDO	Tanzania Industrial Research and Development Organization
TOF	Trees outside forests
UDSM	University of Dar es Salaam
URT	United Republic of Tanzania
US	United States of America
USAID	United States Agency for International Development
VAT	Value Added Tax
VLFR	Village Land Forest Reserve
VPO	Vice President's Office
WB	World Bank

Unless otherwise stated, all dollars are US Dollars and all tons are metric tons. 1 US Dollar = TZS 2,280 (September, 2018)

Executive Summary

Charcoal is the most popular urban household cooking fuel, in Tanzania. Charcoal is cheap, reliable and widely available. The charcoal trade is worth more than US$ 680 million and provides employment to ~380,000 people in rural and urban areas.

Charcoal is also a driver of forest degradation and contributes to climate change. Indoor air pollution from charcoal use contributes to diseases that cause tens of thousands of people to die prematurely. The trade is difficult to govern, with approximately 90% leakage of government revenues.

Various future scenarios indicate that, even strong fuel-switching policies are unlikely to result in a significant decline in the volume of charcoal being consumed, in Tanzania, although the proportion of urban households using charcoal could decline.

Recognizing that wood fuel will remain an important part of the livelihoods of millions of people for the foreseeable future, the main objective of this paper is to support the government of Tanzania in identifying opportunities that will make charcoal production and use more sustainable, as the country advances its transition to alternative, modern cooking fuels.

Alternative cooking solutions including LPG, electricity and improved cookstoves, bioethanol, and natural gas have been promoted in Tanzania, but households aiming to switch to these alternative options, are confronted with economic and non-economic barriers. These barriers contribute to charcoal remaining a popular choice, often alongside one or more other cooking fuel. Fuel stacking, the use of more than one cooking fuel, is a common practice in Tanzania. In Dar es Salaam, about 80 percent of households use more than one fuel type for cooking.

In the context of achieving sustainable development, Tanzania's goal of increasing access to clean and affordable energy remains a priority. At the same time, the continued role charcoal will play as part of Tanzania's cooking energy mix, needs to be recognized. Opportunities that will make charcoal production and use more sustainable will need to be identified as the country transitions to alternative fuels to ensure a balanced approach. Opportunities exist at each step along the charcoal value chain – wood production, charcoal production, transport, wholesale, retail, and consumption. The greatest opportunities for positive change are at the wood production stage in the form of measures to improve natural woodland management.

Tanzania's natural woodlands could produce enough biomass to meet most of Tanzania's charcoal demand, if well managed. Considering villages are the main owners of woodland in Tanzania with a share of 45.7 percent or approximately 21.9 million ha of woodland, community-based approaches toward improving the management of forest resources need to be strengthened. One option in Tanzania could be to scale-up the community-based forest management (CBFM) approach toward increasing the number and extent of village land forest reserves to provide a sustainable supply of charcoal. At the same time, options should be explored of how the charcoal sector can contribute more effectively to the broader Tanzanian economy.

1. INTRODUCTION

1.1 Objectives and scope of this analysis

Recognizing wood fuel will remain an important part of the livelihoods of millions of people for the foreseeable future, the main objective of this paper is to support the government of Tanzania in identifying opportunities that will make charcoal production and use more sustainable, as the country advances its transition to alternative, modern cooking fuels.

Specifically, this paper will focus on identifying and assessing opportunities that exist within the charcoal value chain toward strengthening its sustainability. How participatory forest management can function as a tool toward ensuring sustainable charcoal harvesting is being discussed. Addressing revenue leakages from charcoal production to increase income for the central, local, and village governments, as well as increasing employment opportunities in the sector are highlighted as an opportunity. Finally, the available alternative fuels are being reviewed against their prospects to become a viable alternative to charcoal in the long-term.

This paper has been developed in close collaboration with the Government of Tanzania, specifically, the Vice-President's Office Department of Environment (VPO-DoE), and with inputs from various stakeholders including representatives from different government ministries and agencies, local government authorities (LGAs), nongovernment organizations (NGOs) and development partners (DPs).

The paper is informed by i) a charcoal value chain survey that was carried out in 2018 by the Tanzania Forest Conservation Group; ii) a household and enterprise survey carried out in 2020 and focused on energy use in Dar es Salaam – the Environment for Development (EfD) Dar es Salaam Energy Survey (EfD-DES, 2020); iii) various interviews with relevant stakeholders and policy-makers; and iv) secondary research. In addition, the paper builds on previous work by the World Bank on charcoal in Tanzania.[1]

This paper is structured as follows:

- ✓ **Section 1: Introduction.** This section highlights how Tanzania's rapid population growth and expanding urbanization will drive a continued demand for charcoal, and the importance to promote sustainable charcoal practices.
- ✓ **Section 2: Charcoal as continued part of the cooking energy mix.** This section gives an overview of the environmental and health impact wood fuel production has, and that transitioning to alternative fuels is consequently a country's long-term goal. However, the section also highlights that while Asia and Latin America are successful in gradually switching to alternative fuels, Sub-Saharan Africa is not. On the contrary, it explains why charcoal will need to be recognized as part of the fuel mix going forward.
- ✓ **Section 3: Making charcoal production more sustainable.** The section elaborates on how charcoal can be produced more sustainably, and what the associated opportunities are. The section discusses how the governance of the charcoal sector can be strengthened, specifically, how wood-harvesting for charcoal can be carried out more sustainably; how revenues and

[1] World Bank (2009); World Bank (2010)

benefits from the value chain can be increased; and how cooking practices can be made more efficient.

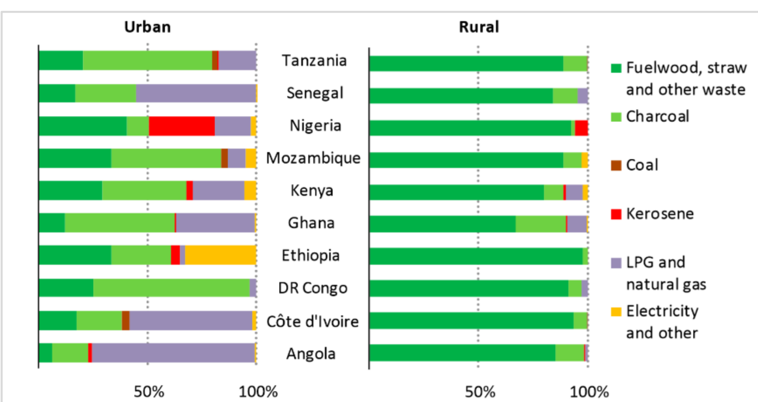
- ✓ **Section 4: Advancing the transition to alternative fuels.** This section discusses Tanzania's efforts toward transitioning to clean, alternative cooking fuel options, and how this process can be further advanced.
- ✓ **Section 5: A balanced approach toward clean cooking fuels.** This section summarizes the proposed actions that can help pave the way toward a more sustainable charcoal production, as the country transitions to alternative fuels.

1.2 Rapid population growth, expanding urbanization, and the impact on charcoal demand

According to the IEA (2019), which modelled energy futures for Africa based on detailed sectoral, country-specific analyses, charcoal will remain an important source of cooking energy in Sub-Saharan Africa through to 2040, with increasing demand coming from urban areas. Key drivers are (i) a growing population; and (ii) intensifying urbanisation.

As Tanzania's population is rapidly growing and urbanising, the demand for charcoal is growing apace. Tanzania's total population is projected to reach 84 million by 2030, and 138 million by 2050, with the growth most noticeable in its expanding cities (World Bank, 2018). The country's urban population is expected to increase from about 22 million in 2020 to over 35 million and 70 million, or 42 and 53 percent of the total, by 2030 and 2050, respectively (World Bank, 2018). Charcoal plays a key role in urban areas (see figure 1) (IEA, 2019). In 2012, about 3.9 million people were using charcoal as cooking fuel in Dar es Salaam, representing 91 percent of the city's population of 4.3 million. By 2030, Dar es Salaam is expected to have a population of 11 million;[2] with a population exceeding 10 million, the city will be considered as a megacity (United Nations, 2014). In order to keep the 2012 charcoal demand levels, approximately 7.5 million people would need to use alternative fuels by 2030 (i.e., 66 percent of the population). Considering Tanzania's national energy policy (URT, 2015b) predicts charcoal consumption to double from 2.3 million tonnes in 2012 to 4.6 million tonnes in 2030, significant market changes will be needed to maintain the 2012 charcoal demand levels. Unless the transition to alternative cooking fuels can be accelerated, charcoal demand will grow between now and 2030 and remain a significant source of household cooking energy. In rural areas, on the other hand, reliance on fuelwood, straw and waste, is expected to remain high, with changes observed in more improved and efficient cooking stoves.

Figure 1. Main fuels used by households for cooking in 2018



Source: IEA, 2019b p. 38

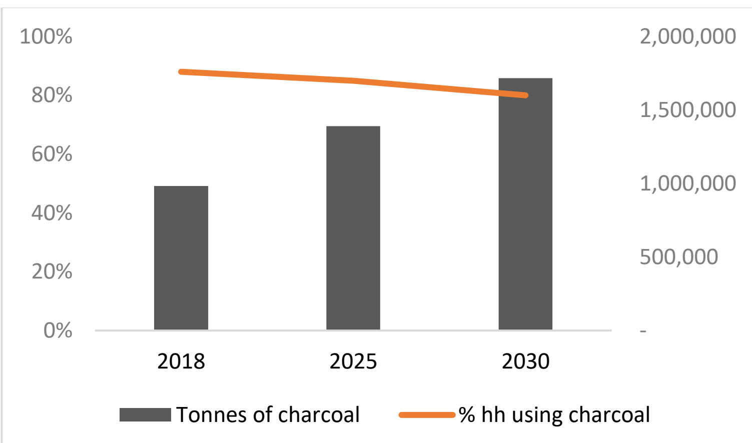
[2] The Dar es Salaam region had a population of 4.3 million in 2012. Population of Dar es Salaam is growing at a rate of 5.6 percent annually, representing an increase of about 75 percent over the 10-year period since 2002. At the current growth, the population of Dar es Salaam region will double in the next 12 years (NBS, 2016).

1.3 Future charcoal demand scenarios

To better understand how total demand for the different cooking fuels in an urban area such as Dar es Salaam could change between now and 2030, three simple scenarios have been explored: a scenario of business as usual, a scenario based on more energy efficiency, and a scenario of accelerated fuel switching.[3] As can be seen, charcoal demand will increase unless a transition to alternative fuels be accelerated. Scenarios 1 and 2 show that even if Tanzania's national energy policy is successful in reducing the proportion of households using charcoal from 88 to 80 percent, demand for charcoal would still double between now and 2030. While charcoal demand is expected to decline under scenario 3, it would remain above 0.5 million tonnes per year. Assuming fuel-switching takes place at the same rate in urban areas and considering that Dar es Salaam accounts for about one third of the total urban population, there would still be demand for approximately 1.5 million tonnes of charcoal per year.

Scenario 1 – Business as usual: With regards to policy, this scenario assumes that national energy policy maintains its focus on a gradual transition of households away from biomass energy to modern, alternative cooking fuels, with no change to household use efficiency. Under this scenario, the percentage of households using charcoal is projected to decline from 88 to 80 percent between 2018 and 2030 as a result of gradual implementation of current fuel-switching policies. The number of households not using charcoal would increase by approx. 405,000, from 183,471 in 2018 to 588,010 by 2030. Use efficiency would not change considering (i) clear evidence is lacking that per household charcoal consumption has changed over the last decade (Malimbwi & Zahabu, 2008; TFCG-DES, 2018); and (ii) campaigns to improve the efficiency of charcoal have not been as successful as planned (TFCG-ESS, 2020). Households would continue using 2kg of charcoal per day on average. Under this scenario, total demand for charcoal would increase from 0.98 million tonnes in 2018 to 1.7 million tonnes in 2030 (figure 2).

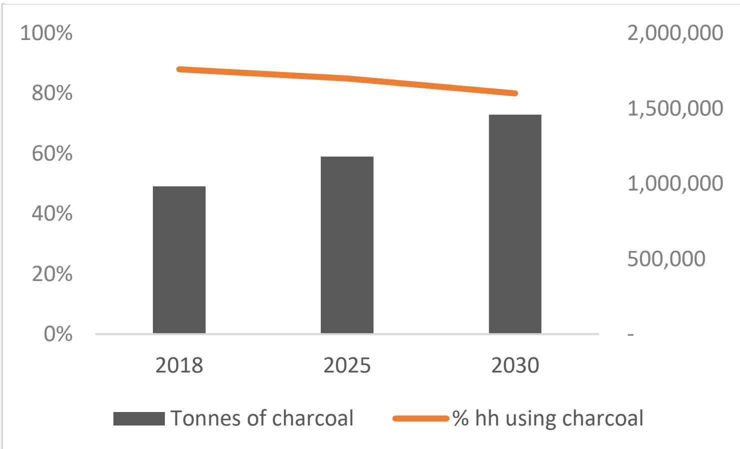
Figure 2. Demand Scenario 1 – Business as Usual



[3] Demographic assumptions of the scenarios: all of the scenarios assume that the population for Dar es Salaam will increase at approximately 5.6 percent per year and that household size will remain at approximately 3.9 persons per household (NBS, 2017). In addition, households' daily charcoal use: the scenarios assume that, on average, households use 2 kg of charcoal per day. This is an average across all households using charcoal in their fuel mix. This is based on data from Malimbwi and Zahabu (2008). There is a wide range of values in households' daily charcoal use, depending on household size and the relative contribution of charcoal to the households' overall energy mix. In 2018, daily average use was 2.45 kg / household (n = 50, median = 2 kg) based on weighed samples (TFCG-DES, 2018). In 2020, household surveys found a median expenditure of TZS 30,000 / month. At an assumed price of TZS 1,300 / kg the 2020 data suggests that household charcoal consumption is closer to 0.8 kg / day (EFD-DES, 2020). The scenarios are based on the 2 kg figure based on the median value for the 2018 surveys (TFCG-DES, 2018), and the data from Malimbwi and Zahabu (2008). The rate could be lower as suggested by the 2020 surveys, or higher as suggested by the mean value for the 2018 surveys. This is an area requiring further research.

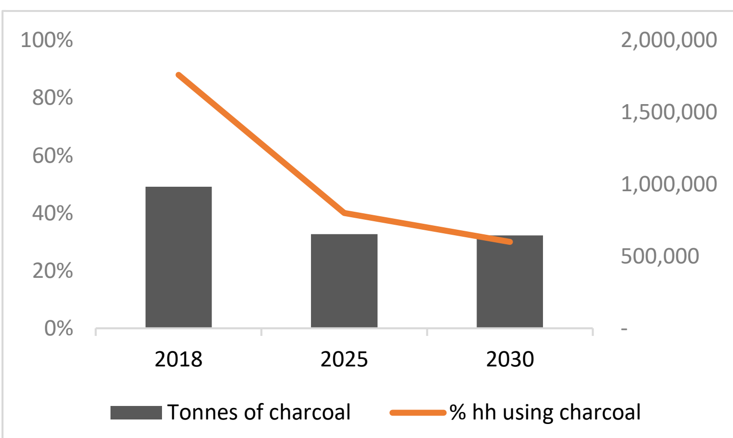
Scenario 2 – Energy efficiency scenario. With regards to policy, this scenario assumes that national energy policy maintains its focus on a gradual transition of households away from biomass energy to modern energy sources, as in the business as usual scenario. In addition, there is an active campaign to promote more efficient charcoal use including more efficient stoves, widespread use of pressure cookers and changes in cooking behaviour. Similar to scenario 1, the percentage of households using charcoal is projected to decline from 88 to 80 percent between 2018 and 2030 as a result of gradual implementation of current fuel-switching policies, and the number of households not using charcoal would increase by approx. 405,000, from 183,471 in 2018 to 588,010 by 2030. However, as a result of widespread adoption of more efficient charcoal use, behaviours and technologies, a 15 percent reduction in daily charcoal household use would be estimated, from 2kg to 1.7kg. Under this scenario, total demand for charcoal would only increase from 0.98 million tonnes in 2018 to 1.2 million tonnes in 2030, reflecting a reduction of 0.2 million tonnes compared to scenario 1 (figure 3).

Figure 3. Demand Scenario 2 – Energy Efficiency Scenario



Scenario 3 – Accelerated fuel-switching scenario. With regards to policy, this scenario assumes radical fuel-switching driven by a combination of sudden economic growth resulting in more households being able to afford modern fuels, combined with charcoal price increases and a 10-fold increase in the supply of alternative fuels. Under this scenario, the percentage of households using charcoal is projected to decline from 88 percent in 2018 to 30 percent in 2030. The number of households not using charcoal would be expected to increase from 183,471 households in 2018 to 2 million households by 2030. This is equivalent to an average annual increase of 22 percent in the number of households not using charcoal. Households would continue using 2kg of charcoal per day on average. Under this scenario, total demand for charcoal would decrease from 0.98 million tonnes in 2018 to 0.64 in 2030 (figure 4).

Figure 4. Demand Scenario 3 – Accelerated Fuel-Switching



1.4 The importance of making charcoal sustainable

Based on the projected trends presented above, there is a clear need to recognize that charcoal will be part of the cooking fuel mix going forward in Tanzania. As the country continues to advance its transition to alternative, modern fuels, the Government of Tanzania should place emphasis on ensuring the policy and regulatory framework is conducive to leveraging opportunities that allow for making the production of charcoal more sustainable. Opportunities exist at each step along the charcoal value chain – wood production, charcoal production, transport, wholesale, retail, and consumption. The greatest opportunities are at the wood production stage in the form of measures to improve natural woodland management. A diverse set of options toward promoting sustainable forest management is available to be applied and/or strengthened in Tanzania including expanding community-based forest management (CBFM), establishing woodlots or plantations, strengthening agro-forestry, and building capacity.

2. CHARCOAL AS A CONTINUED PART OF THE COOKING ENERGY MIX

2.1 Impact of charcoal on the environment, climate change, and human health

Unsustainable wood harvesting and charcoal production is commonly attributed to forest and land degradation, greenhouse gas (GHG) emissions, and negative human health effects. This applies especially to areas where demand for charcoal is high, as is the case in Sub-Saharan Africa. The production and use of solid fuels for cooking purposes has resulted in approx. 300 million tonnes of wood being consumed annually across Sub-Saharan Africa (World Bank, 2014), of which 130-180 million tonnes of wood are being harvested annually for charcoal production. The global production of charcoal stood at 53.2 million tonnes in 2018, with 34.2 million tonnes produced in Sub-Saharan Africa (FAOSTAT, 2020).

Tanzania has one of the highest deforestation rates in the world. The country had an average annual change rate of -0.8 percent over the period 2010-2015 (FAO, 2015), and an estimated annual loss of forest area of 372,000 ha, from nearly 56 million ha of forests in 1990 to 46 million ha in 2015 (FAO, 2015). Other, more recent estimates suggest even higher rates.[4] While charcoal production is often associated with deforestation, the key driver is agricultural activity. The cultivation of major agricultural cash crops for export—primarily maize but also cassava, cotton, and tobacco—has led to vast clearances of the miombo woodland over the past decades.[5] Most forms of agriculture require a permanent shift in land

Box 1. Defining deforestation, forest degradation, and land degradation

Deforestation is the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10 percent threshold. Deforestation

Forest degradation is a process leading to a 'temporary or permanent deterioration in the density or structure of vegetation cover or its species composition'. It is a change in forest attributes that leads to a lower productive capacity caused by an increase in disturbances. The timescale of processes of forest degradation is in the order of a few years to a few decades. forest degradation is assumed to be indicated by the reduction of canopy cover and/or stocking of the forest.

Land degradation acts synergistically with forest degradation. Land degradation often follows deforestation and forest degradation. It is most commonly associated with soil erosion, nutrient depletion, water scarcity and disturbances in biological cycles, but can also be the result of chemical contamination and salinity.

Source: FAO (2007), FAO (2009)

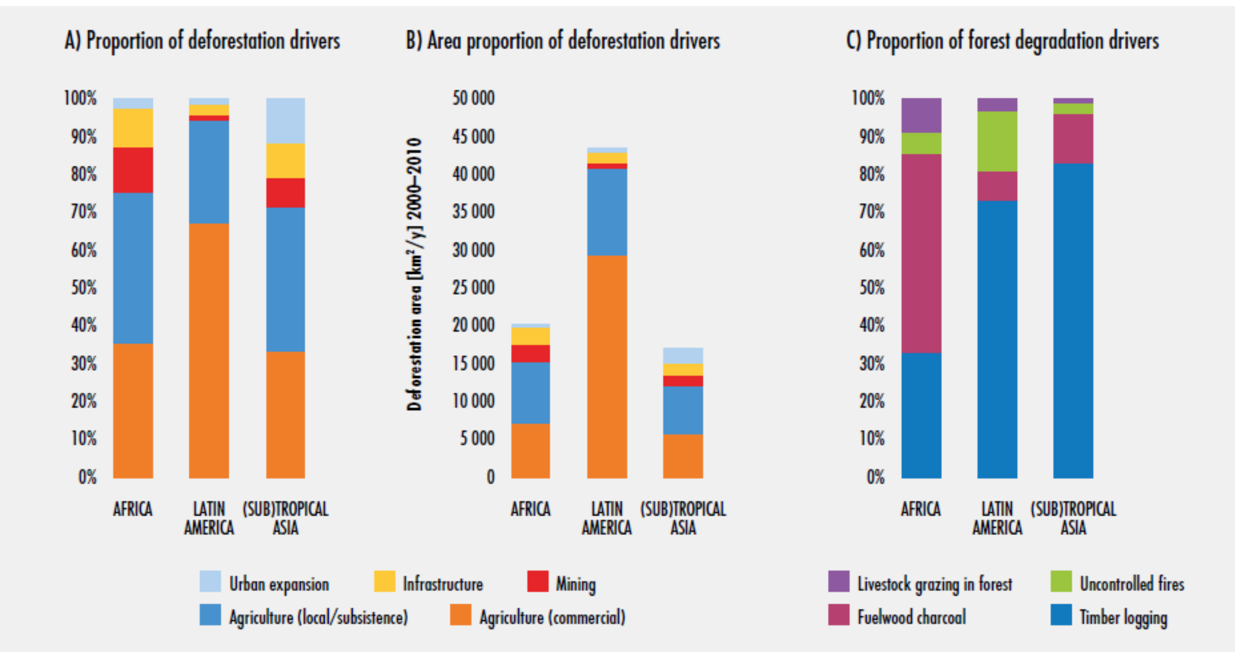
[4] Tanzania's Forest Reference Emission Level submission to the United Nations Framework Convention on Climate Change (URT, 2017) reported an estimated annual loss from deforestation of 483,859 ha over the period 2002-13. Doggart et al. (2020a) estimate that roughly 542,000 ha are deforested per year, and that if the current annual rate of forest loss in Tanzania is maintained, it would result in complete depletion in the next 50 years (URT 2015; USAID 2019).

[5] The Miombo woodlands are a vast region of tropical grasslands and savannas, stretching through central and southern Africa.

cover, from forest to non-forest. Land is also converted for raising livestock. See box 1 for definitions of deforestation, forest degradation and land degradation.

Unsustainable charcoal production is considered a driver of forest degradation, rather than deforestation, considering charcoal production only involves a temporary removal of tree cover, which can regenerate. While many studies have established linkages, the extent to which charcoal production drives forest degradation, and in some cases deforestation, is not fully quantified and differs across and within countries.[6] However, unsustainable charcoal production and fuel wood collection, mostly as a result of open access to forests and a lack of forest and tree tenure, is considered a key cause of forest degradation, especially in Sub Saharan Africa (figure 5). In Tanzania, charcoal production is often a by-product of the farm clearance. In about one third of deforestation events in Tanzania, clearance for agricultural purposes was preceded by charcoal production. However, in about 13 percent of cases, forest clearance is initiated specifically for charcoal production, which is then succeeded, opportunistically, by farmers or livestock herders (Doggart et al. 2020a). Another study found that charcoal production caused the degradation of 25 percent of closed woodland in Tanzania, and the deforestation of 20 percent of closed woodland, and 51 percent of open woodland around Dar es Salaam (SEI, 2002 in African Forestry and Wildlife Commission, 2020).

Figure 5. Drivers of deforestation and forest degradation by region, 2000-2010



Source: Hosonuma et al. (2012) in FAO (2020)

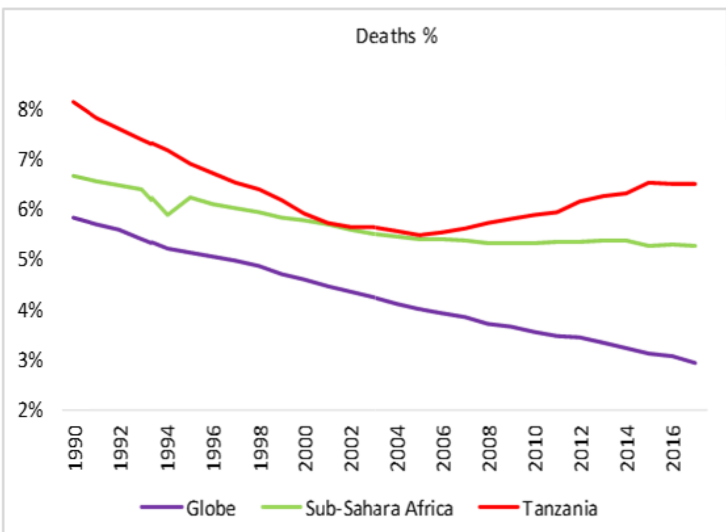
The value chain of charcoal production and its impact on forest degradation also has linkages to climate change, due to emissions of greenhouse gases (GHG). Charcoal production generates emissions of GHG

[6] It depends on the production method, the intensity of harvest and the regenerative capacity of the wood source, the availability of alternative wood sources, and most importantly the impacts of other deforestation drivers, especially agriculture (FAO, 2017).

including carbon dioxide, methane and carbon monoxide. GHG emissions are generated at various stages along the charcoal value chain – sustainable wood harvesting and efficiency of charcoal production technologies are the greatest determinants of overall GHG emissions (FAO, 2017). It is estimated that fuelwood and charcoal production and use contribute between two and seven percent to global greenhouse gas emissions. Sub-Saharan Africa is estimated to account for about a third of these emissions (FAO, 2017). Considering the above presented increasing demand for charcoal, continued unsustainable charcoal production and use can be expected to exacerbate climate change. Consequently, the health and productivity of forests and woodlands could be affected, reducing future wood energy supplies.

With respect to human health, there is broad international consensus that cooking with solid fuels including charcoal has negative effects, which, however, can vary across different populations, based on behavioural, fuel, genetic, income and other differences across regions. Close to 4 million people die prematurely every year from illness attributable to household air pollution (HAP) from inefficient cooking practices using solid fuels and kerosene paired with polluting stoves – more than HIV, malaria, and tuberculosis combined (WHO, 2018a). The release of particulate matter, carbon monoxide, and other products of incomplete combustion from solid-fuel cooking is linked with several diseases such as ischemic heart disease, pneumonia, lung cancer, lower respiratory infections, chronic obstructive pulmonary disease, and others (World Bank, 2014). In Sub-Saharan Africa, HAP from solid-fuel cooking emissions kills nearly 600,000 people annually and is recognized as the second-highest risk factor for DALYs and the third-highest driver of premature death in 2010 (World Bank, 2014).

Figure 6. Death (%) due to HAP in Tanzania 1990-2017

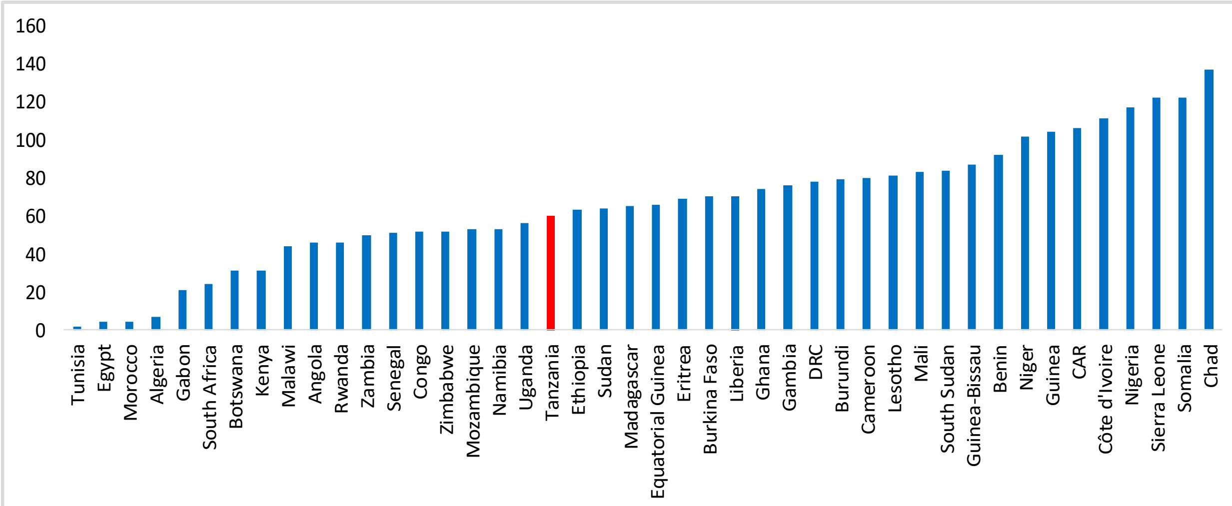


Source: IHME 2018

While worldwide deaths due to HAP from solid fuels have steadily declined over time, in Tanzania, deaths attributable to HAP show a gradual increase from the mid-2000's. Deaths recorded in Tanzania pertaining to HAP have been repeatedly higher than the Sub-Saharan Africa average from 1990-2017. In 1990, 26,718 (8 percent) of all deaths associated with risk factors in Tanzania were attributable to HAP. This figure declined to 5.6 percent in 2004, and finally gradually rose to 6.5 percent in 2017 (figure 6). Except for Burundi, Tanzania experienced more HAP-related deaths compared to its neighbouring East African countries (see figure 7).[7] Women and girls are particularly affected, as they often do the cooking and fuel gathering. Consequently, WHO (2018a) indicates that Tanzania's HAP attributable death rate for women (61 per 100,000 population) is slightly higher than the rate for men (59 per 100,000 population).

[7] Kenya experienced 15,140 deaths (31 deaths per 100,000 population); Uganda recorded 23,364 deaths (56 deaths per 100,000 population); and Rwanda 5,432 deaths (46 deaths per 100,000 population) attributable to HAP (WHO, 2018b). Burundi experienced 8,324 deaths (79 deaths per 100,000 population).

Figure 7. Africa - Death per 100,000 attributable to HAP 2016



Source: WHO, 2018b

2.2 Slow progress despite national strategies pertaining to transitioning to modern cooking fuels

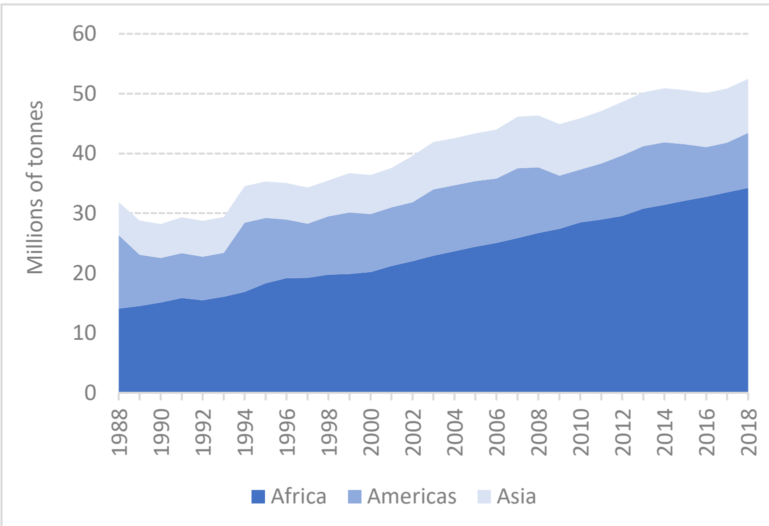
Accelerating efforts to increase access to modern cooking fuels as well as improved cook stoves is therefore integral to sustainable development, and a priority in national energy policies. The sustainable development goals (SDGs) aim for ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030 – to reduce the negative impacts wood harvesting and charcoal production have on the environment, human health, and climate change. It is broadly recognized that clean cooking must be a political, economic, and environmental priority supported by policies and relevant investments.

Tanzania's national development and policy plans have also increasingly recognized the need for better regulating the country's fuelwood use and promoting alternative fuels. Tanzania's Long-Term Perspective Plan 2011/12-2025/26 (URT, 2012a) emphasizes reducing reliance on biomass for energy supplies due to its adverse environmental impacts, and the National Five-Year Development Plan II 2015/16-2020/21 (URT, 2016a) promotes enhancing community-based natural resource management systems, sets a target for reducing charcoal use to 30 percent of urban households by 2025/26, and proposes to prepare and enact a "charcoal production and use regulation policy". Under the mandate of the Ministry of Natural Resources and Tourism (MNRT), a dedicated charcoal task force was formed in 2019 with the objective to provide advice to the minister on developing the envisaged policy. In addition, the Vice-President's Office – Department of Environment (VPO-DoE) is currently preparing a tree planting strategy and has tasked the Tanzania Industrial Research and Development Organization (TIRDO) and the Small Industries Development Organization (SIDO) with identifying charcoal production technologies. In 2018, the VPO-DoE led a high-level dialogue on charcoal alternatives and has since actively promoted tree planting and alternative cooking fuels.

Reducing charcoal consumption, promoting alternative energy sources, and facilitating participatory forest management programmes are key objectives in Tanzania's Nationally Determined Contribution

(NDC) 2019 (URT, 2019) and the country's national policies on energy, forest and environment. The NDC plans for Tanzania to reduce greenhouse gas emissions by up to 20 percent through priority mitigation actions in the energy, transport, forest and waste sectors including (i) reducing consumption of charcoal in urban and rural areas by promoting affordable alternative energy sources through a regulation policy for charcoal production and use; (ii) enhancing and up-scaling implementation of participatory forest management programmes and developing payment for environmental service schemes; and (iii) enhancing the contribution from the forest sector including through forest policies, national forest programmes, and REDD+ related activities. Furthermore, Tanzania's National Energy Policy 2015 (URT, 2015b) provides support for transitioning the economy from its current dependence on solid biomass fuels, to electricity and fossil fuels, and the country's National Forest Policy 1998 (URT, 1998), which has been under review for several years, encourages the establishment of private woodlots and plantations for wood fuel production, and promotes the use of alternative affordable sources of energy. Tanzania's National Environmental Policy 1997 includes similar objectives including the reduction of wood fuel consumption, and rational exploitation of forest resources.

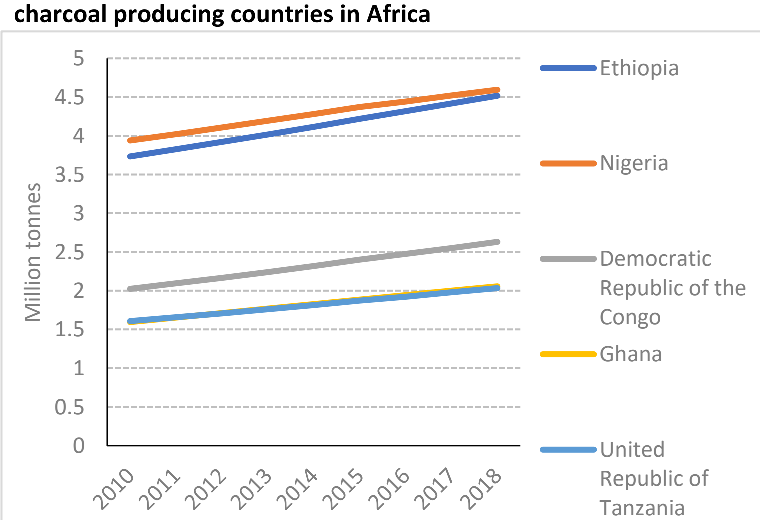
Figure 8. Charcoal production trends 1988 – 2018 in Africa, Asia and the Americas



Source: FAOSTAT 2020

Nevertheless, despite several decades of efforts to promote both modern fuels and improved cooking stoves, access to clean cooking fuel and related technologies continues to be a challenge. There are still 2.6 billion people worldwide, who do not have access to clean cooking fuels, relying on wood fuel, including firewood and charcoal, as their primary means of cooking (IEA et al. 2019). Over 450 million people in India and China have gained access to clean cooking fuels since 2010, particularly as a result of LPG programmes, however, in Sub-Saharan Africa, the challenge remains significant with only 17 percent of the population having access to clean cooking fuels. Since

Figure 9. Charcoal production trends 2010-2018 in the top five charcoal producing countries in Africa



Source: FAOSTAT, 2020

2015, only 25 million people in Sub-Saharan Africa have gained access to clean cooking fuel, while the total number of people without access increased to 900 million in 2018 (IEA, 2019). In Asia, charcoal consumption is about 9 million tonnes per year, while Africa accounts for 34 million tonnes, constituting more than 60 percent of the total global outputs of 53 million tonnes (see figure 8).

In some African countries, access to alternative fuels has improved, but often the consumption of charcoal continues. In Ethiopia, about 32 percent of the population has electricity access (IEA, 2019), yet charcoal production continues to increase (figure 9). The same applies to Cote d'Ivoire, where LPG is now used by almost 55 percent of urban households, yet at the same time about 95 percent of rural households still rely on charcoal and fuelwood. In Tanzania, only 6 percent of the population has access to clean cooking fuels; about 55 million people rely on traditional use of biomass. More than 3 million households in Tanzania, or 29 percent of all households, rely on charcoal as their primary cooking fuel (NBS, 2019). While the share of households with access to modern fuels increased slightly between 2000 and 2018 - the share of households with access to electricity and LPG increased from 9.8 and 0.3 percent to 29 and 3.2 percent, respectively - the share of households using charcoal as their main source of cooking fuel increased, from 14 to 29 percent over the same period (NBS, 2014; NBS, 2019).

2.3 Economic and non-economic barriers to transitioning to modern fuels

Alternative cooking solutions including LPG, electricity and improved cookstoves, bioethanol, and natural gas have been promoted in Tanzania, but households aiming to switch to these alternative options, are confronted with economic and non-economic barriers. Households consider the high price of alternative cooking fuels and technologies, relative to those associated with charcoal, as a barrier. Even when prices of alternative fuels are made more competitive, and financing options are more easily available, most households may not be able to afford the cost of switching to cleaner fuels (IEA, 2019).

Charcoal remains among the most affordable cooking fuels in Dar es Salaam. Charcoal together with traditional and improved charcoal stoves are sold at the lowest unit price per megajoule of energy produced, while electricity, bioethanol and LPG remain the highest-priced fuels (Doggart et al 2020b).

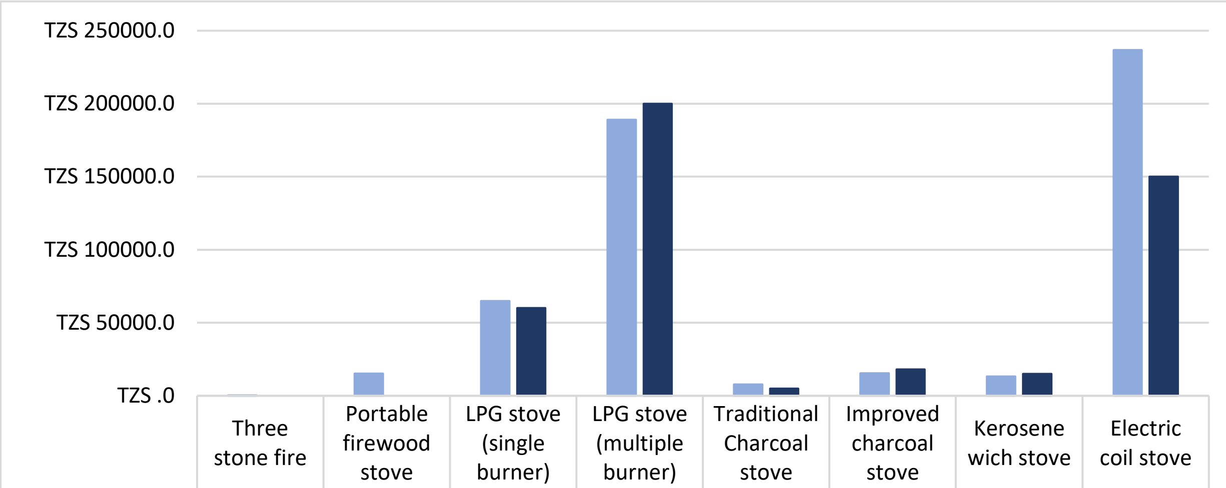
Table 1. Relative fuel prices of household cooking fuels

Type of Cooking Fuel	Unit	Price per unit	Conversion factor to megajoule	End use cooking efficiency	Price TZS per megajoule
Charcoal	Per kg	776	29.0	0.30	89.20
LPG	Per kg	3,333	45.0	0.60	123.43
Electricity	Per kWh	356	3.6	0.70	141.27
Kerosene	Per liter	2247	36.3	0.40	154.75

Source: Based on Doggart et al. 2020b

Charcoal costs approximately TZS89 per megajoule, compared with TZS123 megajoule for LPG and TZS141 per megajoule for electricity (table 1). Firewood could be considered the least costly option, but as most households collect firewood themselves rather than purchasing it, firewood is not included in this comparison. Similarly, traditional charcoal stoves cost about TZS5,000, while single and multiple burner LPG stoves cost about TZS60,000 and TZS200,000, respectively (figure 10).

Figure 10. Cost of commonly used stoves

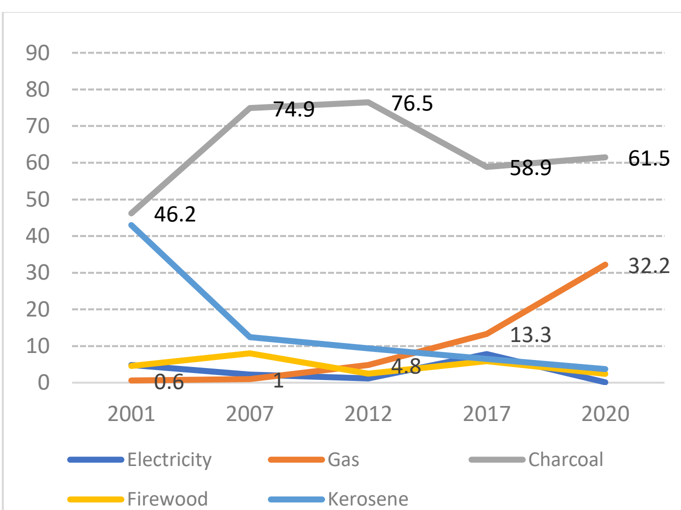


	Three stone fire	Portable firewood stove	LPG stove (single burner)	LPG stove (multiple burner)	Traditional Charcoal stove	Improved charcoal stove	Kerosene wich stove	Electric coil stove
Mean price	TZS 253.42	TZS 15200.	TZS 64895.	TZS 189143	TZS 7842.5	TZS 15428.	TZS 13160.	TZS 236666
Modal price	TZS .0	TZS .0	TZS 60000.	TZS 200000	TZS 5000.0	TZS 18000.	TZS 15000.	TZS 150000

LPG is a clean-burning and efficient cooking fuel which is normally considered as the first alternative fuel consumers can switch to when opting to move away from biomass. LPG emits negligible amounts of black carbon and other pollutants, rendering it even more advantageous when it comes to indoor air pollution and health implications. Households, particularly women, spend significant time collecting firewood. The transitioning to LPG frees up women's time for other work activities, child-care and leisure (Alem et al 2020).

Current consumption of household energy in the country already suggests an encouraging trend for LPG use in contrast to other sources, particularly in Dar es Salaam. There is a clear pattern that LPG is gradually replacing kerosene as a household cooking fuel in Dar es Salaam, though at a relatively low pace (figure 11). The trend shows an increase in LPG use after 2012, which coincides with the government's removal of the import duty and value added tax (VAT) on LPG fuel and cylinders, reducing its price, and providing a strong case as to how such fiscal policy-related interventions could alter the adoption dynamics. Specifically, LPG imports have increased from 28,286 tonnes in 2011/12 to 145,800 tonnes in 2018/19 (EWURA, 2019).

Figure 11. Share of households by main cooking fuel in Dar es Salaam (%)



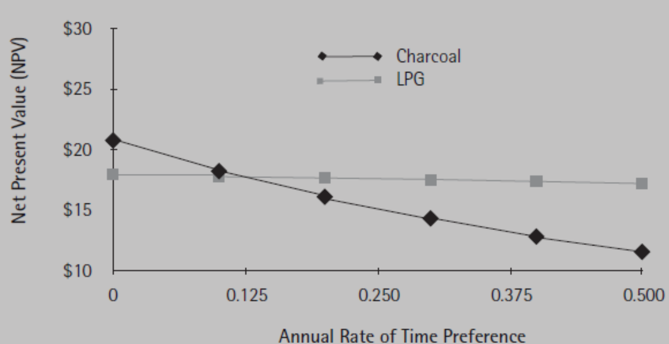
Sources: NBS, 2019 for 2001-2017 and EfD-DES, 2020 for 2020

Despite the rise in LPG adoption, its overall use is still low, particularly relative to charcoal. The adoption of LPG is closely related to income, with most users belonging to the middle- and high-income population groups. Recent evidence by EfD-DES (2020) shows that while between 35 percent and 50 percent of the middle to the wealthiest quintiles of Dar es Salaam households use LPG for cooking, only 11 percent of the households in the poorest quintile use this energy source. The situation is even more stark in rural and other urban (excluding Dar es Salaam) households where only 0.8 percent and 0.1 percent, respectively, use LPG as their main source of cooking energy (URT-NBS, 2019).

Key constraints are the high start-up costs associated with LPG stoves and cylinders, and the lumpsum refilling costs of LPG fuel compared to significantly smaller denomination[8] purchases made for charcoal fuel. In fact, the perceived high LPG fuel cost is mainly due to the households' inability to discern the distribution of the lumpsum cost (e.g., 15kg cylinder of LPG) across the total number of days for which the

Box 2. Cost of charcoal and LPG consumption from a consumer viewpoint

Assessments of costs of alternative fuels are generally made "ex-post"—in other words after the consumption has taken place. The costs of consumed amounts are added together for a given time period and compared against one another. However, this ex-post analysis does not take account of the intrinsic valuation of costs of a household, especially as regards its rate of time preference, which is generally expressed as a discount rate. Disregarding initial investment costs, which were estimated at US$83 for LPG and US$3 for a conventional charcoal stove, a household has a consumption choice between a total monthly cost of about US$18 for a refill of LPG (after abolishment of the VAT and import tariffs) or about US$20.80 for purchasing charcoal. The advantage of charcoal is that the household can phase its purchases, such as every two days, while the expenses for LPG have to be made in one payment up front. It can be seen that at rather low positive rates of time preference, charcoal purchases become preferable over LPG purchases. As other studies have demonstrated, rates of time preference for poor households in developing countries are rather high, easily reaching up to 100 percent and more. Based on this simplified calculation, the advantage of charcoal would diminish if LPG could be bought in smaller units, allowing households to phase purchases over time.



Some other factors not considered in calculation:

- Initial investment costs
- Maintenance costs
- Replacement costs
- Risk of unavailability of LPG at time of required refill
- Price fluctuations of LPG
- LPG with VAT and import tariff
- Uncertainty of availability of cash income for poor households

Energy expenses in US$	Days 1	2	3	4	5	...	10	...	20	...	31	Monthly Cost
Charcoal	1.3	0	1.3	0	1.3	...	1.3	...	1.3	...	1.3	20.80
LPG	18	0	0	0	0	...	0	...	0	...	0	18

Source: World Bank, 2009

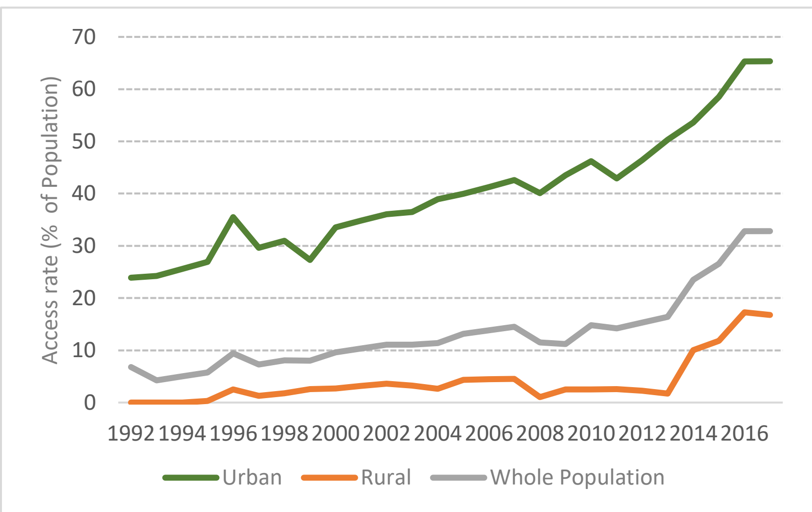
[8] LPG users are wealthier than charcoal users in terms of their total monthly expenditures (i.e., 727, 000 vs 534,000), which may suggest biasing the ratio for LPG households downward. However, LPG users often buy the fuel in bulk and for example a 15kg cylinder could last as much as 12 weeks for those households that mix LPG with other fuels. Alem et al (2020) shows that in a controlled cooking test, a typical household that only uses LPG would use the 15kg cylinder for 6 weeks. Actually, the back of envelope calculation that accounts for amortization of the LPG costs over its potential "lifetime" period suggests that LPG users have a lower percentage of energy to total expenditure, only 7.2 percent.

fuel is used. LPG users spend a smaller share of their total monthly expenditure on fuel than that spent by charcoal users (i.e., 15 percent versus 18 percent) (EfD-DES, 2020). These results are consistent with conclusions drawn in 2009, confirming rates of time preference for poor households in developing countries are rather high (box 2). The implication of this evidence is that, despite the existing government incentives (i.e., the removal of import duty and VAT), complementary and innovative efforts are needed to overcome liquidity and credit constraints that hinder the purchase of the stoves, cylinders and the gas.

Electricity is the cleanest source of energy for cooking, emitting zero household emissions thus making it a top priority in energy transition in the long-term. The starting point for a transition to electricity is availability and access. By 2017, the installed capacity for electricity was 1,457 MW of which 1,366 MW was for the main grid and 91 MW was for isolated mini grids (EWURA 2018). The recent years have seen a sharp increase in the rate of access to electricity with about two thirds of the population in urban areas connected to electricity (figure 12).

However, most connected households use electricity primarily for lighting and less as an energy source for cooking, even in urban areas. In 2017/2018, electricity was used by only 6 percent of urban households for cooking, compared to 64 percent of urban households using it for lighting (NBS, 2019). Rural households showed significantly lower percentages (e.g., 10 percent using electricity for lighting, and 0.3 percent for cooking).

Figure 12. Access to electricity in Tanzania (1992-2017)



Source: World Bank
https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=TZ&view=char

The domestic use of electricity as a source of cooking energy has several supply and demand constraints. The cost of electricity: for general domestic use of electricity, 1 KWh costs TZS 356 (including VAT and other charges). This makes it very costly for cooking, particularly if inefficient appliances are used (TaTEDO 2019). The initial investment costs relating to electric appliances are equally constraining, especially when compared with those of charcoal stoves. The cost of an electric stove is more than 15 times the cost of a charcoal stove. Initial costs associated with connecting a household to the electricity grid, and challenges with sharing electricity meters are further constraints.

Natural gas is another alternative fuel that can be used for cooking, though infrastructure investments are needed for its efficient distribution. Tanzania has abundant reserves of natural gas, amounting to 57.25 trillion standard cubic feet according to the Ministry of Energy (EWURA, 2019). Tanzania's Natural Gas Utilization Plan strategically aims to 'promote the use of natural gas as an alternative fuel to liquid fuel, charcoal and wood for domestic use.' The plan goes on to state that 'the importance of supply of gas as an alternative energy to biomass (mainly charcoal and firewood) makes it necessary for the

Government to strategically intervene and promote its implementation through appropriate policies in order to save the fast depleting natural forests.' The plan assumes that '10 percent of households in the country will be supplied with natural gas for cooking by 2045… a total demand of 0.5 trillion cubic feet for 30 years (2015 – 2045)' (URT, 2016b). In addition, the Power System Master Plan (PSMP) projects for natural gas to contribute to 40 percent of electricity generation by 2040 (URT, 2016b). The challenges in meeting demand for natural gas as a cooking fuel include limited infrastructure, which is currently restricted to parts of Dar es Salaam (EWURA, 2019). More investment is required to increase the processing capacity and extend natural gas transportation infrastructure to other regions.

Bioethanol cookstoves are a clean-burning cooking energy alternative to charcoal. Bioethanol can be purchased in small quantities and modern bioethanol stoves burn much more efficiently than traditional charcoal stoves. For example, while boiling 3 liters of water on a traditional charcoal stove takes about 33 minutes, it only takes 18 minutes on a UNIDO-supported bioethanol stove, currently on the market in Dar es Salaam (Project Gaia, 2020). These modern bioethanol stove designs have also incorporated safety features to prevent fires, and ethanol cookstove interventions have been found to result in some of the highest reductions in P.M. 2.5 exposure (Pope et al., 2017). Bioethanol can be sourced locally, while drawing on Tanzania's existing agricultural capacity in the production of sugarcane, cashew nuts and other agricultural products and residues. Bioethanol can be produced economically in modern, small or micro scale distilleries (commonly ≤5,000 liters per day) under the right conditions, thereby also stimulating local manufacturing.

On the other hand, large-scale bioethanol production would require agricultural land, potentially resulting in deforestation, competing land use and food insecurity. According to the Intergovernmental Panel on Climate Change (IPCC), in order to effect the climate action plan, about 4 million square kilometers of farmland is needed for the production of biofuels, which is ten times the current amount (Smith and Porter 2018). In addition, the Organization for Economic Co-operation and Development (2016) reports that biofuel production is expected to consume 10.4 percent and 12 percent of the global grain and vegetable oil production respectively by 2025. This projection raises alarm over the future of food security globally, especially in Tanzania, since most farms are subsistence and supply directly to household food requirements.

While the use of bioethanol as an alternative to charcoal is still limited, interest has recently increased in Tanzania and across East Africa. Previous efforts to promote bioethanol as cooking fuel in Tanzania were unsuccessful. For example, the promotion of the Moto Poa stove, a bioethanol-fueled gel-based cookstove, struggled with its low energy value and lacking heat. Similar gel-based stoves have failed in other parts of Southern Africa (World Bank, 2011). More recently, the Safi stove, a liquid ethanol stove, only lasted in the market for one year as a result of fuel supply shortages, regulatory and logistical problems resulting, at least in part, from a lack of preparedness by the distributor.[9] Data by EfD-DES (2020) indicated no households using bioethanol as cooking fuel. More recently again, interest has been spurred by a collaboration between the United Nations Industrial Development Organization (UNIDO), the

[9] The company's business model was based on selling carbon credits based on stove sales, rather than making money directly from stove sales. The carbon credit scheme was not approved by the government. In addition, regulatory problems related to fuel and stove imports took a financial toll on the business.

Ministry of Energy, and the Vice President's Office toward promoting bioethanol as cooking fuel.[10] Building on a pilot that was carried out in Zanzibar, efforts are currently targeting 500,000 households in Dar es Salaam through the creation of a market for the supply and distribution of bioethanol fuel and cookstoves.[11] Achieving a price for bioethanol that is competitive with charcoal will be a key challenge.

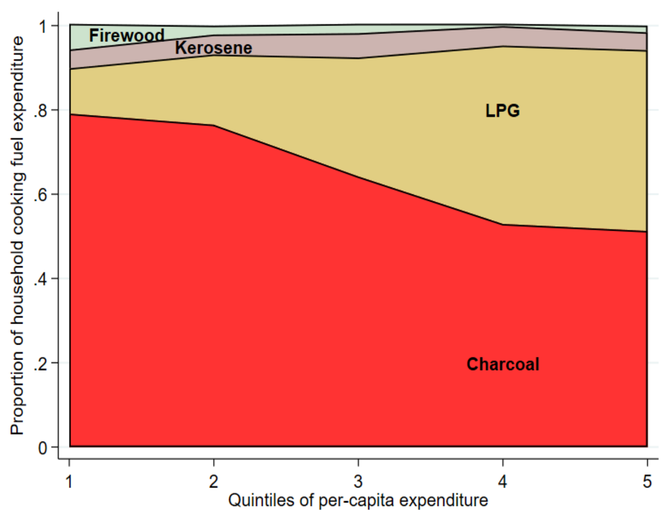
Finally, while it remains popular as a supplementary fuel, the use of kerosene as main cooking fuel has declined over the last decade from 12 percent in 2007 to 3 percent in 2018 (NBS, 2009). Kerosene is a fossil fuel that is derived from petroleum oil. Burning kerosene releases carbon, previously stored beneath oceans or land, into the atmosphere thereby contributing to climate change. Pollutants from kerosene include particulate matter, carbon monoxide and nitrogen dioxide (Lam et al, 2012). While this is also true of LPG, kerosene has a lower energy conversion rate than LPG. This contributes to higher CO2 emissions per unit of useful energy output.

2.4 Fuel stacking

Finally, even as households transition to alternative fuels, charcoal remains part of the energy mix. How household fuel use changes in the process of economic development has been characterized as the 'energy ladder'. The energy ladder theory proposes that as income and socio-economic status improves, households switch from using traditional fuels such as firewood and charcoal, to fuels such as kerosene, and eventually modern fuels such as electricity and gas. In contrast, various studies have shown that households increasingly use multiple fuel types concurrently depending on needs and economic circumstances – known as fuel 'stacking' (IEA, 2019; Choumert-Nkolo et al, 2019).

Fuel stacking is also a common practice in Tanzania (Choumert-Nkolo et al, 2019). In Dar es Salaam, about 80 percent of households use more than one fuel type for cooking, with more than half using two types (TFCG, 2018). A large proportion of households that use LPG as their main cooking fuel, also use charcoal. Stacking can be a strategy to reduce the financial risk of being dependent on one fuel in a context where prices may be volatile (Ruiz-Mercado and Masera, 2015). The same trend is reflected in how households allocate the money they spend on cooking fuels. Charcoal is used by households from across all

Figure 13. Proportion of household cooking fuel budget over the expenditure distribution



Notes: Households are divided into five expenditure groups, from the poorest (quintile 1) to richest (quintile 5). Electricity is excluded due to it not generally being used as a cooking fuel. Source: EfD-DES 2020

[10] GEF-funded project: "Promotion of Bioethanol as a Clean Alternative Fuel for Cooking in Tanzania". The project's objective is to support the government in promoting alternative energy to solid fuels, to reduce in-door air pollution and deforestation.

[11] The roll-out will take place in phases, the first of which was launched at end of 2019 and is targeting 110,000 households.

wealth categories, as shown in Figure 13. Even households in the top quintile spend over 50 percent of their total cooking fuel expenditure on charcoal.

2.5 Urban households will continue to use charcoal for the foreseeable future

Despite the negative impact of charcoal on the environment and health, it remains the most popular cooking fuel for urban households, due to its low cost and high availability. It is unlikely that this situation will change for at least the next 30 to 40 years. In terms of an energy transition, there is evidence that wealthier households are diversifying the fuels that they use, with LPG comprising a larger share of the market. Although clean, electricity is unlikely to be widely adopted for cooking, due to its higher price per unit of energy. Bioethanol remains at an experimental stage and risks increasing pressure on land and forests.

3. MAKING THE CHARCOAL VALUE CHAIN MORE SUSTAINABLE AND EFFICIENT

Recognizing that charcoal will continue to be used by households for the foreseeable future, this section examines opportunities to make charcoal production and use more sustainable and to increase the associated benefits. Opportunities exist at each step along the charcoal value chain – wood production, charcoal production, transport, wholesale, retail, and consumption. The greatest opportunities for positive change are at the wood production stage in the form of measures to improve natural woodland management. Further opportunities lie in increasing government revenues by reducing revenue leakage, in combination with sustaining employment and incomes for about 250,000 households. Efficiency gains, especially at the charcoal production and consumption stage, reduce energy loss along the value chain, which consequently influences the amount of wood needed to provide the cooking energy that households need. Potential energy gains are not being discussed in detail here, as they have been analyzed extensively in the past (World Bank, 2009; World Bank 2010).

3.1 Promoting sustainable forest management at the wood production stage

The governance framework of natural forests and woodlands in Tanzania rarely includes charcoal production. Tanzania has about 3.4 million ha of natural forests and about 44.7 million ha of natural woodlands. The remainder of about 40 million ha consists of bushland, grassland, cultivated land, open land, water, and other areas. Open woodlands cover about 41 percent of the land area and account for 53 percent of the growing stock. Villages are the main owners of woodland in Tanzania with a share of 45.7 percent or approximately 21.9 million ha, followed by central government with a share of 34.5 percent (box 3).[12] There are two key reasons for why charcoal production is barely included in the management of these areas, despite the large area they cover. First, few natural forest and woodlands have management plans in Tanzania, except for protected areas such as national parks and game reserves,

Box 3. Distribution of forests and woodlands by ownership

All land in Tanzania is considered public land, with the Land Policy of 1995, the Land Act Cap 113, and Village Land Act Cap 114 setting out the fundamental principles guiding land rights and management. The Land Act classifies land in three categories: (i) reserved land; (ii) village land; and (iii) general land. Ownership classification is based on the following:

- Central government land: Land administered by central government agencies such as Tanzania Forest Service (TFS) or Tanzania National Parks (TANAPA)
- Local government land: Land administered by Local Government Authorities (LGAs), including forest reserves decentralized to LGAs.
- Village land: Land held and administered collectively by village residents and the Village Land Act Cap 114, including communal land and land held by individuals.
- Private land: All tenure right types giving individual and collective occupancy rights within village, general or government lands.
- General land: Land that is not reserved and not village land.
- Not known: Ownership and management responsibility of the measured plot is not established.

Source: MNRT (2015)

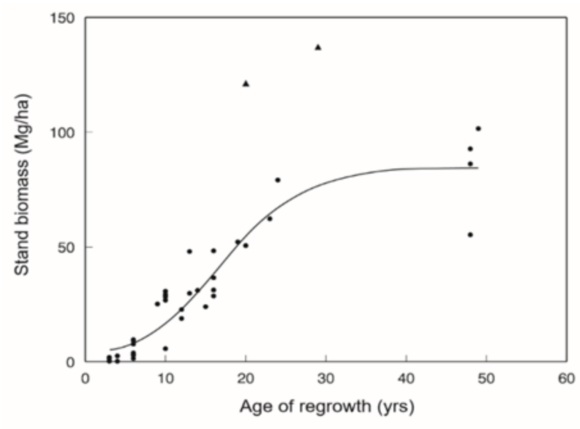
[12] Remaining ownership of forest and woodland areas includes: Private land (7.3 percent), local government (6.5 percent), and general land (5.7 percent).

where charcoal production is prohibited. Second, national policies have focused on reducing demand and regulating the trade of charcoal, rather than promoting sustainable charcoal production (Doggart and Meshack, 2017). As a result, there has been little investment in planning and implementing sustainable charcoal production in natural woodlands.

Changing the way that natural woodlands are managed could ensure their sustainability. The management of Tanzania's woodland would need to balance biomass loss as a result of harvesting, with biomass gains from natural regeneration (FAO, 2017) and reforestation. With at least 18 million hectares of woodland on village land occurring outside of any formalized forest management system (URT, 2015), and with few government forest reserves having sustainable harvesting plans, there are opportunities to improve forest management.

Determining a sustainable harvesting cycle to supply wood for charcoal production requires an understanding of how quickly biomass regenerates. This is best understood for miombo woodlands. Miombo woodlands are a disturbance-tolerant ecosystem. Miombo species readily regenerate from coppicing, and to a lesser degree, from seedlings. Management practices can be fine-tuned to enhance the regeneration process (Chidumayo and Frost 2006, Luoga et al. 2004). There is a considerable body of research on regeneration rates in miombo woodlands (Chidumayo, 1993, Chidumayo and Gumbo, 2013, Chidumayo 2019a+b, Frost, 1996, Malimbwi et al. 2005, Malimbwi and Zahabu, 2008,) and biomass accumulation rates have been documented (figure 13).

Figure 13. Biomass accumulation rates in miombo woodland



Source: Frost, 1996

Tanzania's natural woodlands could produce enough biomass to meet most of Tanzania's charcoal demand if well managed. The amount of biomass that natural woodlands gain each year is known as the mean annual increment. While the mean annual increment varies between woodlands, a figure of 1.4 tonnes/ha/year can be used to estimate the woodland area required to meet national charcoal demand.[13] Assuming that 2 million tonnes of charcoal are required annually in Tanzania and that biomass is converted to charcoal at a 20 percent efficiency rate, 10 million tonnes of woody biomass are needed each year. To produce 10 million tonnes of woody biomass, given a mean annual increment of 1.4 tonnes/ha, Tanzania would require approximately 7 million ha of woodland to be managed for charcoal production. This is equivalent to one third of woodlands on village land, which are estimated at about 21.9 million ha.

Overall household wood demand is covered by Tanzania's available wood supply. According to MNRT (2015c), the total supply of wood (growth) per year at a national level in Tanzania is 83.7 million m3. Out of this total supply, the woody biomass available for sustainable harvesting each year, known as the annual allowable cut, is 42.8 million m3 (URT, 2015c). This is slightly less than the estimated household

[13] Based on URT 2015 NAFORMA Report p. 46. Annual increment for closed woodland = 2 m3 / ha / yr and a conversion factor of 1 m3 of wood = 0.7 tonnes of air-dried wood gives a mean annual increment of 1.4 tonnes / ha / yr (Source of conversion rates: CamCo, 2012 p. xii).

wood demand at 43 million m3, which includes charcoal, firewood and other wood-use. Household wood demand is roughly equal to the available supply (table 2), however, Tanzania has an overall negative wood balance once losses caused by deforestation and other sources of loss are considered. For example, table 2 indicates that land use/land cover change results in a loss of 14.9 million m3 / year. The most widespread land cover change in Tanzania results from shifting forestland to non-forest land (URT, 2017), with most non-forest land being cultivated land (URT, 2015c). Biomass loss associated with land use/land cover change is of particular concern as this is more likely to result in a permanent loss of woody biomass i.e., deforestation, than wood product harvesting followed by forest regeneration.

Table 2. Wood balance analysis for Tanzania mainland.

Biomass supply and losses		
Supply		
Gross increment of all trees in Tanzania mainland	million m^3 / year	83.7
Legally available wood – annual allowable cut plus recoverable deadwood	million m^3 / year	42.8
Losses		
Household wood demand (0.96 m3 / capital)	million m^3 / year	43.0
Land use / land cover change (mainly deforestation due to the conversion of forest to cropland).	million m^3 / year	14.9
Other	million m^3 / year	4.4
Total losses	**million m^3 / year**	**62.3**
Wood balance	**million m^3 / year**	**-19.3**

Source: Adapted from MNRT, 2015, p. 47

If the overall forest area could be maintained, deforestation avoided, and reforestation facilitated, Tanzania could come close to balancing wood supply and demand (MNRT, 2015c). While wood loss caused by land use change results in deforestation, wood harvesting for charcoal or firewood is said to result in forest degradation as discussed in section 2. With the right management, degraded forests can regenerate to create a sustainable cycle of harvesting followed by tree growth. Protecting regenerating forests from activities that prevent natural tree growth, such as frequent fires, intensive grazing or conversion to other land uses, requires the scaling-up of natural forest management, particularly on village land. By allowing natural woodlands to regenerate after harvesting, biomass stocks and other ecosystem values can be recharged through natural processes without incurring costs associated plantation management.

The sustainable production of wood for energy can be achieved through a diverse set of forest management systems that can be broadly differentiated into the following three categories. These include (i) natural forest management systems; (ii) planted forests, including, for example, large-scale plantations, planted forests, woodlots; and (iii) so-called Trees-Outside Forests (TOFs), especially agroforestry systems, but any other trees planted along fields, in orchards, and in the landscape as single trees that are eventually harvested for energy purposes (see also table 4). A necessary pre-condition that applies universally across all three policy options is that "the rules of the game" must be simple and short and should be developed in a participatory fashion, so as to remain accessible for communities with low literacy levels. In order to foster local "ownership", forest management plans and other aspects of the regulatory framework, including permissions to harvest trees and market wood fuels must also include the knowledge, experience and expectations of the local community vis-à-vis their forest.

Table 4. Issues and approaches for forest management interventions

Issue	Approach	World Bank	Key Partners
Unsustainable forest management (forest degradation, deforestation)	**Promoting sustainable forest management** a. Agro-forestry b. Community-based forest management c. Woodlots, plantations d. Out-grower schemes e. Modernize forest law enforcement and governance (FLEG) f. Strengthen tree and land tenure g. Build capacity h. Technical assistance i. Introduce innovative financing (REDD, FIP, etc.) j. Analytical and sector work	Energy; Environment; Agriculture and Rural Development; Social Development, International Finance Corporation (IFC)	Development partners working on forestry programs, environmental NGOs, CSOs, research institutions (e.g. ICRAF, CIFOR), private sector

Source: World Bank (2011)

The meaningful devolution of rights and responsibilities to create what has been termed "locally controlled forestry"[14] represents one of the key ingredients to success and remains one of the core bottlenecks in African countries, including Tanzania, for a broad-based sustainable production of wood fuels. The past decades have witnessed growing dynamics to empower local communities with rights and responsibilities with which to manage forest resources. Participatory or community forestry has taken root across many countries, including Tanzania, and uses a range of different models, including the full transfer of management rights and responsibilities (community-based forest management) and more collaborative arrangements, where forest management responsibilities are shared between government and communities (joint forest management). Despite the variety of approaches, one of the key lessons that has been learned across different countries is that security of tenure is a key factor that determines whether participatory forest management succeeds or fails—both from a forest management perspective, and from the perspective of securing and maintaining participation over the long term.

Considering villages are the main owners of woodland in Tanzania with a share of 45.7 percent or approximately 21.9 million ha, community-based approaches toward improving the management of forest resources need to be strengthened. The strive for empowering local communities to take over the control of forest resources management has produced a large number of examples for decision makers to draw from. The Growing Forests Partnership initiative by the Food and Agriculture Organization (FAO), the International Institute for Environment and Development (IIED), the International Union for Conservation of Nature (IUCN), The Forests Dialogue, and the World Bank alone lists 17 examples from all over the world that show how forest management can be put into the hands of local people in a meaningful way and produce desired sustainable management outcomes (Growing Forests Partnership, 2012). Addressing the specific example of commercial wood fuel management, the Energy Management

[14] For a detailed discussion of the concept of "Locally Controlled Forestry" see "Guide to investing in locally controlled forestry". Growing Forest Partnerships in association with FAO, IIED, IUCN, The Forests Dialogue, and the World Bank. IIED, London, UK. 2012.

Assistance Program (ESMAP) of the World Bank published a study in 2013 analysing the experience from three locally controlled wood production models, including country case studies from Madagascar, Niger, Rwanda, and Senegal where these models were piloted (World Bank 2013). The Madagascar example is of particular interest and relevance as to date more than 10,000 hectares of villager-owned tree plantations for charcoal production have been established on degraded land. It was analysed that these plantations have a conservation effect with regard to natural forests as they produce nine times the amount of charcoal per hectare compared to natural forests, directing extraction activities away from natural ecosystems (Rakoto Ratsimba, Ralainirina, et al., 2015).

One option in Tanzania could be to scale-up the community-based forest management (CBFM) approach toward increasing the number and extent of village land forest reserves to provide a

Box 4. Sustainable charcoal production in natural woodlands in the Morogoro Region

Since 2012, the Tanzania Forest Conservation Group (TFCG) and the Community Forestry Network of Tanzania (MJUMITA) have assisted villages in integrating sustainable charcoal production into the management of village land forest reserves.

Under the project model, villages allocate up to 20 percent of their village land forest reserve to forest management units (FMU) for sustainable charcoal production. FMUs for charcoal are divided into 50 x 50-meter harvesting blocks or coupes, which are harvested in a chequerboard pattern over 24 years. The species targeted for charcoal harvesting regenerate naturally through coppicing, root-suckers, and seedlings. A rotation period of 24 years has been adopted to reflect the growth period with the highest average annual growth rate. This is a conservative approach, adopted in order to mitigate the risk that regeneration may occur more slowly in the project area, than in the miombo study sites, from which regeneration rates have been published. Agriculture, livestock grazing, and burning are prohibited in the FMU to ensure that the harvested coupes will regenerate naturally over 24 years. Only trees larger than 15 cm diameter at breast height are to be cut for charcoal making. Other harvesting restrictions also apply to reduce environmental impact.

Harvesting is regulated by trained village natural resource committee members. Charcoal producers in the villages apply for the right to harvest a particular coupe and pay royalties to the village for each bag of charcoal they produce. They also pay per-bag fees to the district council. Charcoal produced by villages adopting the model is sold into the mainstream charcoal market. Under the Forest Act, 2002, resources harvested from village land forest reserves are exempt from central government forest royalties. Thus, villages can charge their own royalties and remain competitive in the market. As of 2019, 35 villages in three districts in Morogoro Region had adopted the system, with plans to scale-up to villages in another five districts underway from 2020.

Villages decide how to spend revenue from sustainable charcoal harvesting. Most villages choose to spend the charcoal revenue on improving social services including health, water, and education infrastructure, with some of the revenue being spent on forest protection. Even as a low value forest product, sustainable charcoal can provide substantial revenue for villages. Between June 2013 and November 2019, 21 village governments earned a combined total of US$ 0.75 million from charcoal royalties. In addition to generating income for villages, the model is helping to protect forests. As of November 2019, 35 villages under the sustainable charcoal model had included 133,579 ha of forests in village land forest reserves and deforestation has declined steadily since the introduction of the model. Charcoal is well-suited to integration in CBFM. The charcoal market is local and relatively easy to access. Charcoal production requires little start-up capital. Charcoal harvesting is easier to monitor and manage than timber harvesting. Sustainable charcoal harvesting can often be started within one year of starting the process of establishing CBFM. Thus, sustainable charcoal harvesting may be the easiest source of revenue for CBFM villages to develop and can play an important role as an early source of revenue to depend on, while villages develop other sources of revenue from CBFM.

sustainable supply of charcoal. CBFM allows communities to establish forest reserves on their village land to protect the communally owned forests (box 4) and is supported by Tanzania's national policies and laws (see section 2). Under the Village Land Act 1999 and the Forest Act 2002, communities are given considerable autonomy in managing village land and village land forests, consistent with country's decentralization by devolution approach to local government. Tanzania has an estimated 1,233 villages with village land forest reserves covering 2.3 million hectares. The average size of a village land forest reserves is 1,865 ha (URT, 2012b). As mentioned previously, approximately 7 million hectares of woodland are needed to supply the estimated 2 million tonnes of charcoal currently consumed. This could be achieved by integrating sustainable charcoal production into the management of some of the existing village land forest reserves and increasing the number of village land forest reserves. For example, if 60 percent of the existing village land forest reserves adapted their management plans to integrate sustainable charcoal production, it would still require an additional 5.7 million hectares to be included in village land forest reserves in order to produce 2 million tonnes of charcoal per year.

Scaling-up CBFM could also provide climate benefits. The most important measure that can be taken to limit GHG emissions along charcoal value chains is to allow natural woodlands to regenerate after harvesting (FAO, 2017). By integrating charcoal production into forest management, woodlands can regenerate rather than being converted to agriculture or other non-forest land uses. By combining sustainable charcoal production with CBFM, the opportunity therefore exists for a win-win on reducing emissions of greenhouse gases from deforestation and improving the environmental outcomes from charcoal. Given the steady demand for charcoal, this approach could provide long-term sustainable financing for the management of forests on village land. Access to forest products is also important in building communities' resilience to climate change. Forests and trees provide an alternative source of food and income for agricultural communities during periods of climate-induced stress. By safeguarding community access to natural woodlands, CBFM can therefore increase communities' resilience to climate change. Similarly, livelihood diversification is a key pillar in building resilience to climate change, particularly in agricultural communities. Charcoal production provides a valuable additional income source for many rural households which can help to mitigate shocks associated with agricultural losses linked to climate change (Jones et al. 2016).

3.2 Improving charcoal production and consumption efficiency

Charcoal production techniques can be adapted to improve sustainability and efficiency. In Tanzania, most charcoal is produced using basic earth kilns (TFCG, 2018). This traditional approach is popular across sub-Saharan Africa and requires little start-up capital. However, it is relatively inefficient compared with the improved basic-earth kilns that have been developed over the last 20 years. Depending on the size of a basic earth kiln, each kiln may generate 0.3 – 0.8 tonnes of charcoal over a period of 14 days. Charcoal production in a basic earth kiln involves layering pieces of wood and covering them with clods of earth to create a kiln. The kiln is then lit, and a process called pyrolysis breaks down the cellulose and lignin in the wood, removes the water and other volatile materials, leaving the carbon. The conversion efficiency of traditional kilns ranges from 10 to 30 percent (Malimbwi and Zahabu, 2008).

More recently, producers in Tanzania have begun to use improved basic-earth kilns introduced through various projects. These differ in the lay-out of the kiln and in using a chimney. Using improved basic earth kilns, the conversion efficiency can exceed 30 percent, and the pyrolysis rate is increased thereby reducing the number of days for the carbonization from 14 to as little as 4 days (Malimbwi and Zahabu, 2008).

Improving the efficiency of a kiln results in a higher yield of charcoal for a given amount of wood. This is more environmentally sustainable and increases producer income.

Whilst the type of charcoal kiln is important, producer skills are even more important. Full-time charcoal producers are, on average, 30 percent more productive than part-time producers, based on bags produced per day (van Beukering, 2007). Currently, there are no vocational or professional courses available on charcoal production and trade. Similarly, there are almost no extension facilities available. Building producers' capacity to adopt more efficient production techniques would reduce biomass wastage, greenhouse gas emissions and labour per unit of charcoal. Training for charcoal workers could also help to mitigate occupational health and safety risks such as smoke inhalation (Obiebi et al. 2017) and exposure to carbon monoxide during the carbonisation process (FAO, 1987).

Finally, improving charcoal production techniques can improve health outcomes for charcoal users. The amount and the types of pollution emitted when charcoal is burnt, are influenced by the production and transportation process (FAO, 1987). For example, charcoal that has been carbonised at a lower temperature will have a higher proportion of corrosive tarry residues and will produce more indoor air pollution when it is used for cooking. Similarly charcoal that has been exposed to the rain during storage or transportation, will have a higher moisture content and will therefore burn less efficiently than charcoal that has been properly managed along the value chain. Adopting improved practices along the value chain can improve the quality of the charcoal that is available to consumers in ways that increase efficiency and reduce emissions of pollutants. This requires a commitment to professionalize the trade including investing in building technical expertise among producers, transporters and extension workers. Reducing wastage during the transportation and re-packaging of charcoal. As much as 20 percent of a charcoal consignment can be lost between the kiln site and reaching a consumer (Gmunder et al, 2014). Losses are mainly caused by charcoal fragmenting into dust or small particles when bags are moved, or material is transferred between containers. Improving packaging and building the capacity of transporters and retailers to reduce charcoal losses could improve the efficiency of the value chain.

At the consumption stage of the charcoal value chain, efficiency can be improved by using improved cook stoves and by adopting more efficient cooking practices. There are several different kinds of charcoal stove that are used in Tanzania. The most basic, and least efficient, is a single-walled metal stove. More efficient are ceramic stoves, some of which have an external metal casing. Ceramic stoves can improve efficiency from 15 percent up to 30 – 40 percent relative to metal only stoves (UNIDO, 2015). Of the metal-cased ceramic stoves, the most efficient are the Jikokoa stove, made in Kenya (Johnson et al. 2019). Approximately 96 percent of charcoal-using households use ceramic lined stoves, with the remainder using traditional metal-only and ceramic-only stoves (EFD-DES, 2020). Scaling-up the use of the most efficient stoves could generate significant efficiency gains, while also reducing household fuel costs.

Actions and technology that reduce the amount of time that is required to cook food, are more energy efficient and can reduce household energy costs. Energy efficient cooking practices include soaking beans prior to cooking and using a pressure cooker. Promoting such measures can result in win-wins in terms of energy efficiency and savings on household energy costs.

3.3 Opportunities to generate more revenue from charcoal production

Overall, Tanzania's charcoal trade is worth approximately US$ 680 million annually. This is based on a trade volume of 2 million tonnes and a price of ~ US$ 0.34 / kg.

Charcoal production generates revenue for central and local government, with royalties constituting most of the revenue. The Forest Regulations, 2019 guide the production and trade in charcoal, according to which a person intending to produce charcoal from trees on village land, should first request permission from the village executive officer who forwards the request to the district forest officer. All applications are then considered by the district forest produce harvesting committee, convened by the Tanzania Forest Services agency (TFS). Successful applicants are subsequently issued with a non-transferable forest produce allocation certificate and must pay the requisite royalties. In addition, successful applicants must obtain a charcoal transit permit in order to transport the charcoal out of the district where it has been produced. All charcoal traders must register with TFS and pay an annual registration fee (box 5).

Box 5. Government revenue collection categories relevant to charcoal

Central government revenue collection through the Tanzania Forest Service (TFS) agency

a) *Fees payable on non-plantation forest produce (royalties)*: Fees for a bag of charcoal TZS 12,500/50 kg bag (TZS 250/kg). Of this, 95 percent or TZS 237.5/kg goes to TFS and 5 percent or TZS 12.5/kg goes to local government. These fees are also termed royalties, which are remitted to the treasury.

b) *License fees for forest produce dealers and traders for each site per year:* License fees to operate a forestry business are paid annually per site between July and September. The rate varies depending on the nature of the business. Current rates for charcoal dealers/traders are TZS 256,000 (US$ 112)/year

c) *Transit pass application fees*: Transit passes are required for the transportation of forest products, specifically for each trip from production site to point of sale. Transit passes are usually valid for 1 – 7 days. The rate varies depending on the size of the vehicle and it is paid to the TFS district forest manager: (i) for a 7-tonne vehicle or below TZS 7,700; and (ii) above 7 tonnes: TZS 15,400.

d) *Compounding fees* can also be collected in respect of illegally harvested natural forest produce.

e) *Tanzania Forest Fund (TFF) surcharge.* The TFF is a conservation trust fund established by the Forest Act Cap. 323 [R.E. 2002] under Sections 79 – 83. TFF's funding sources are a levy of 2 percent on every prescribed fee payable under the Forest Act; and a levy of 3 percent on any royalty payable under the Act[1].

Local government revenue collection

a) *Local Government cess or levy:* Based on the Local Government Act No. 9 of 1982, Local Government Authorities can charge a levy of 5 percent of the royalties charged by the central government. This is equivalent to TZS 12.5 (US$0.005)/kg.

b) *Tanzania Forest Fund tree planting levy:* A tree planting levy worth 5 percent of the royalty i.e. TZS 12.5 (US$ 0.005)/kg is collected for the TaFF. This is charged in addition to the TZS 250 (US$ 0.11)/kg royalty collected by TFS.

c) *Local Government charcoal bag fees*: Local government can establish by-laws requiring an additional fee on charcoal produced in their district. For example, Kibaha District charges TZS 1,600 (US$ 0.70) per 50 kg bag.

d) *Business licenses in the municipalities*: In urban areas where charcoal is being sold and used, municipal councils collect business license fees from traders.

Source: URT (2017b)

Few forest reserves have sustainable harvesting plans making it difficult for district committees to determine the sustainability of charcoal production permit applications. Although the Forest Act 2002 requires that a management plan is in place before issuing harvesting permits, authorities have found it difficult to adhere to this requirement as few forests have management plans. In addition, once charcoal is being transported out of the district, there is no mechanism in place to verify its origin. The Ministry of

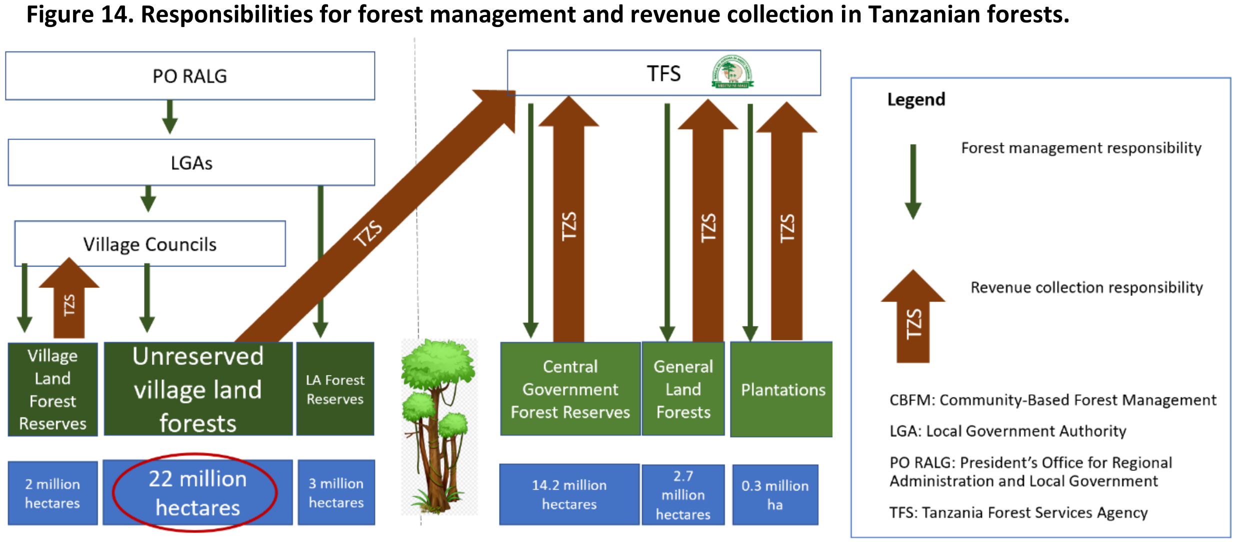
Natural Resources and Tourism (MNRT) operates checkpoints along key highways to check that traders have the necessary permits and have paid the required fees, however, some of the challenges that MNRT experiences in enforcing compliance at these checkpoints include traders understating charcoal loads and using inconsistent charcoal bag sizes; transit permits being re-used; and corruption. Traders may also evade checkpoints by using unofficial routes or by travelling at night when the checkpoints are closed.

Royalties collected by the Tanzania Forest Services Agency (TFS) are the largest source of central government revenue from charcoal. For 2020/21, TFS aims to collect TZS 18 billion (US$7.9 million) in charcoal royalties. Local government in areas where charcoal is produced, also collects fees, while municipal governments collect business license fees from those involved in retail and wholesale (box 5).

Reviewing and updating Tanzania's charcoal revenue collection system could help to increase government revenue. High rates of revenue leakage have characterized the charcoal trade. Historically, it has been estimated that the government revenue collection rate for charcoal royalties does not exceed 10 percent (Malimbwi & Zahabu 2008, Van Beukering, 2007). For 2020/21, the TZS 18 billion charcoal revenue target cited by TFS (TFCG – ESI, 2020) equates to revenues to be paid on 72,000 tonnes of charcoal at a royalty rate of TZS 250,000 per tonne. However, given an estimated annual charcoal supply of 2 million tonnes, if compliance were closer to 100 percent, the revenue could reach TZS 500 billion. Alternative structures of charcoal revenue collection could be designed that lead to higher revenue collection rates. While the current approach has been in place for many years, other revenue collection models are possible. These include empowering communities and local government to collect revenues at charcoal production sites, as occurs when CBFM is established. Other options include central government revenue collection at the retail end of the value chain, for example, by charging VAT.

Changing the structure of revenue collection for charcoal produced on village land could stimulate the scaling-up of CBFM. As explained in the previous sub-section, most charcoal is produced from forests and woodlands on village land, outside of village land forest reserves. Under the current system, royalties from charcoal and other forest products that are harvested from unreserved village land forests may be collected by TFS (figure 14). When forests and woodlands are included in village land forest reserves, the right to collect revenues switches from TFS to communities. This is because charcoal and other forest products from village land forest reserves are exempt from central government royalties. According to

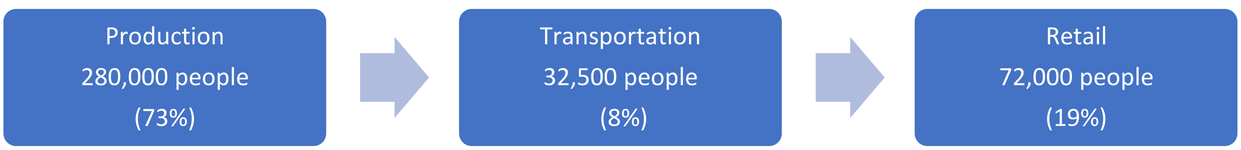
Figure 14. Responsibilities for forest management and revenue collection in Tanzanian forests.



the Section 78 (3) of the Forest Act 2002, ‘no royalties shall be required for the harvesting or extraction of forest produce within a village forest reserve or a community forest reserve by the resident of the village.’ The intention of this law was to allow communities to benefit directly from revenues derived from their village land forest reserves, thereby incentivizing communities to adopt CBFM and reduce deforestation. However, it has had the unintended consequence of setting communities into direct competition with central government over the right to collect charcoal revenues. Harvesting permits in village land forest reserves were traditionally issued at the village level. However, the 2019 Forest Regulations (Government Notice 417) have reallocated this role to district committees, weakening village-level control over harvesting in village land forest reserves. A thorough revision of the current charcoal revenue collection system could achieve higher revenue collection rates while also embedding incentives for more effective forest management and more cooperation between stakeholders.

Charcoal provides employment in both rural and urban areas. Charcoal production is an important source of income in rural areas, while trade and retail provide employment in urban areas. In Tanzania’s coast region, one of the main sources of charcoal for Dar es Salaam, charcoal is the main source of income for 5.4 percent of households (NBS, 2017). In other regions charcoal is the main source of income for less than 2 percent of households.

Figure 15. People employed in the charcoal value chain



Charcoal provides employment at each stage of the value chain (figure 15). Overall, an estimated 384,500 people were employed on a part- or full-time basis along the charcoal value chain in 2018.[15] Part-time charcoal production accounts for most charcoal-related employment. In terms of gender, both women and men are involved in the charcoal trade. A higher proportion of female-headed households (1.1 percent) sells charcoal as their main source of income, compared with male-headed households (0.5 percent) (NBS, 2017).

Opportunities exist to improve working conditions along the charcoal value chain. Charcoal producers and traders face many challenges in the course of pursuing their trade. These include high transaction

[15] Production: 280,000 people. This assumes total annual charcoal production = 2 million tonnes (see Section 2.1) of which 478,000 is produced by 42,209 full time producers (NBS, 2017 state that selling charcoal is the main source of income for 0.6 percent of rural households (total rural households = 7,034,837 (NBS, 2018 & UNDESA, 2018) therefore full-time producers = 42,209, each producing 11.29 tonnes/year (TFCG-DES, 2018). The other ~ 1.5 million tonnes is produced by 238,000 part-time producers, each producing 6.4 tonnes/year (TFCG-DES, 2018), giving a total of 280,000 people.

Transportation: Assuming that 86 percent of charcoal is transported by lorry, and 14 percent by motorcycle; and that a motorcycle transporter does three trips per week, and a lorry transporter does three trips per month and employs one person to assist on the journey, this means that approximately 13,500 people are involved in transporting charcoal by motorcycle, and 19,000 are involved in transporting charcoal into the city by lorry.

Retail: Assuming that each retailer sells an average of 30 tonnes per year and each retail outlet involves an average 1.08 people (TFCG-DES, 2018), this would mean that approximately 72,000 people are involved in retail.

costs and uncertainty relating to the regulatory framework, low wages and high health and safety risks (TFCG, 2018). Raising the profile of the trade, providing extension services and streamlining compliance requirements could provide greater security and reduce costs for charcoal workers.

In summary, strategies are needed that capture the economic benefits of the charcoal trade while mitigating its negative environmental and health impacts. An open-minded reassessment of how charcoal could be aligned with national priorities on modernisation, industrialisation and revenue generation, could achieve significant environmental, economic and social benefits while simultaneously continuing to promote alternative cooking fuels.

4. ADVANCING THE TRANSITION TO ALTERNATIVE FUELS

The Tanzanian government seeks to transition towards the use of clean cooking fuels.[16] As discussed in the previous sections, while some clean cooking fuels and new technologies are widely available, households continue to choose to favour the use of charcoal. The availability of clean cooking stoves and fuel options does not automatically lead to a reduction of traditional cooking methods. Acknowledging these realities, and in an effort to overcome these constraints, it will be important for policymakers and stakeholders to focus on factors influencing the household energy transition.

This section presents a discussion of the key factors driving household energy transitions. These factors include (i) the accessibility of alternative fuels; (ii) the nature of upfront costs and lumpiness of usage costs of alternative fuels; (iii) strengthening awareness of the benefits of alternative fuels among consumers; and (v) recognizing the role of relative prices in household fuel choices.

4.1 Accessibility of alternative fuels

A key pre-condition for the uptake of cleaner burning fuels and stoves is to have reliable access at the household level. Because of the extensive development of the charcoal market, charcoal is readily available in close-proximity to households and in a near-continuous range of quantities. This means that households do not need to incur large time or transport related costs in accessing charcoal.

Time and transport related costs of accessing alternative fuels together with reliability can be a significant barrier to uptake. This is generally due to supply-side constraints associated with a lack of development of the supply chains of alternative fuels. For example, providing households with reliable access of high-quality bioethanol fuel has been a challenge for previous start-ups in Dar es Salaam and their failures in doing so have reinforced households' preferences for charcoal. This is especially important for the case of bioethanol, because it is subject to competing uses and supply for household use needs to be prioritised. In Ethiopia, for example, the government diverted ethanol from an ethanol stove program towards a state-run fuel blending program when production shortfalls caused a lack of supply. This resulted in over 3,000 stove users being left without ethanol fuel for almost 16 months (World Bank, 2011).

In other instances, such as in the case of natural gas, access is constrained by a lack of piping infrastructure for the transportation of natural gas to households. Renewable electricity is the ultimate goal for clean cooking. But for that to be an option, there is a need not only for renewable production and grid infrastructure, but also individual connections for each household, since shared connections are limiting electricity as a cooking option.

4.2 Overcoming high purchase costs

LPG is currently the second most common fuel for cooking in Dar es Salaam and the preference for wealthier households, but further adoption seems especially constrained by the high start-up cost for LPG stoves and cylinders. Such liquidity constraints are likely to be present for a variety of clean energy sources. Alem et al (2020) test whether subsidies or credit schemes induce the adoption of modern cooking stoves or whether low usage is likely caused by cultural factors. They show that a 75 percent subsidy or providing a convenient credit scheme, where households would be allowed to pay for the LPG

[16] 2015 National Energy Policy

on either weekly or even on daily basis to mimic their charcoal purchase pattern, increases LPG uptake and use among Dar es Salaam households. High credit repayment rates (90 percent) suggest that the latter approach is particularly effective and promising. These findings are consistent with Levine et al (2018) who find that clean stove uptake was higher (46 percent) in Uganda when they used a sale offer that combined a one-week free trial and gradual (time) payments within a 4 weeks period afterwards. The results by Alem et al (2020) suggest that policymakers have a wide range of instruments to stimulate the uptake of modern cooking fuels. Subsidies can be flexibly adjusted to households' financial situation and faded out once local uptake increases. Credit schemes include down payments, frequency and magnitude of payments, interest rate and other compliance measures as potential instruments. It is worth noting that instruments to overcome high purchase costs are unlikely to introduce negative side effects. Hassen & Köhlin (2017) provide evidence that households who did not pay the full price of efficient stoves in Ethiopia showed no reduction in usage. Bensch & Peters (2020) show that free stove distribution in Senegal did not reduce willingness-to-pay and would therefore not undermine future market establishment.

Internationally, there have been many examples where policy makers have supported the uptake of modern fuels through subsidies. In Indonesia for example, the government targeted kerosene users by providing them with a free LPG stove and a small cylinder used by low-income households, thus targeting the policy towards low-income households. This increased adoption (100% reduction in kerosene use by many households) and led to a decrease in per-capita fuel expenditure by 40 percent (Imelda, 2018). Similarly, Kar et al., (2019) find that the Indian Ujjwala program that allocated LPG stoves to 70 million rural women resulted in rapid growth in enrolments of LPG consumers and in LPG access. This echoes work by Gould et al. (2018) in Ecuador and Gould and Urpelainen (2018) in India. In Ecuador, after three decades of direct government subsidies for LPG, 90 percent of households now cook primarily with LPG (Gould et al., 2018). While satisfaction with LPG amongst fuel users is high, liquidity constraints remain a key problem and households generally continue to also use biomass energy (Gould and Urpelainen, 2018).

Providing energy services on a pay-as-you-go (PAYG) basis leverages technology-focused business models to overcome the affordability barrier faced by customers unable to afford the initial investment costs. PAYG solutions appear highly scalable and sustainable from the industry's perspective and could dramatically enable households to adopt LPG by allowing smaller purchases of fuel on an incremental, per-use basis. LPG-related PAYG meters, which have been piloted at a small scale in several countries, allow the household to purchase the LPG fuel on an incremental, per-use basis. The model mimics how most households currently purchase the charcoal fuel on a day-to-day basis, namely at a small denomination which makes the fuel perceivably cheaper than LPG. Following a low baseline adoption level of LPG stoves in Dar es Salaam and country at large (i.e., 32 percent and less, respectively), this innovative approach creates a potential market opportunity to a number of private companies that shall tap into the opportunity to supply the meters, cylinders and stoves. In addition, given that the LPG-PAYG model enforces filled gas cylinder delivery to the consumer, distribution companies could be linked in the entire value chain.

4.3 Building awareness of the benefits of alternative, cleaner cooking stoves and fuels

Raising awareness and sharing information of the advantages of clean cookstoves and fuels is critical in changing household preferences. Efforts are needed not only by the government but also relevant stakeholders to encourage a full transition to alternative fuels by changing consumer behaviour over time.

This includes educating households about the negative health effects associated with exposure to smoke from traditional cookstoves. Awareness also needs to be systematically raised for the comparable cost of for example LPG over longer periods of time in comparison with charcoal, reduced health risks of cleaner cooking stoves and fuels, and cooking practices.

Preferences for cooking with a particular fuel have been found to play a role in the uptake of modern fuels and the persistence of the use of traditional fuels (Jeuland et al., 2020; Masera et al., 2000). However, preferences are also often shaped by the information available to households. Jeuland et al (2020), for example, find that a lack of interest in improved cook stoves is correlated with a lack of awareness of the harmful effects of smoke inhalation. On the other hand, Alem et al (2020) find that preferences are not a significant factor in the uptake of LPG in Dar es Salaam. Moreover, while preferences are important to consider, it is worth noting that preferences are not unchangeable and are shaped by the information available to households.

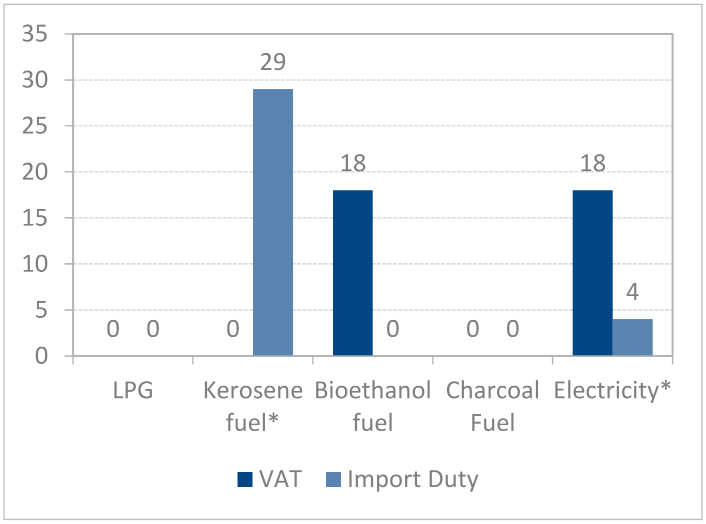
Promoting the lower costs associated with cleaner cooking stoves and fuels over time. There have been dramatic improvements in the efficiency and costs of alternative cooking appliances and fuels, bringing down cooking costs over longer periods of time. Improvements in the efficiency of electric appliances such as induction stoves, pressure cookers and LED-lighting, help reduce electricity consumption as well as the total size of the solar PV and battery systems required to run cooking and lighting appliances. Cooking with efficient appliances such as electric pressure cookers, electric rice cookers, induction cookers and thermal pots can be less costly than cooking with a hot plate, LPG and kerosene (TaTEDO, 2020).

4.4 Relative and absolute fuel and stove prices

The absolute and relative prices of alternative cooking stoves and fuels are fundamental factors determining the uptake and use of modern alternatives to charcoal. According to a recent survey, about 90 percent of households who use charcoal as their main cooking fuel, cite charcoal's affordability as the key factor driving their preference (EfD-DES, 2020).

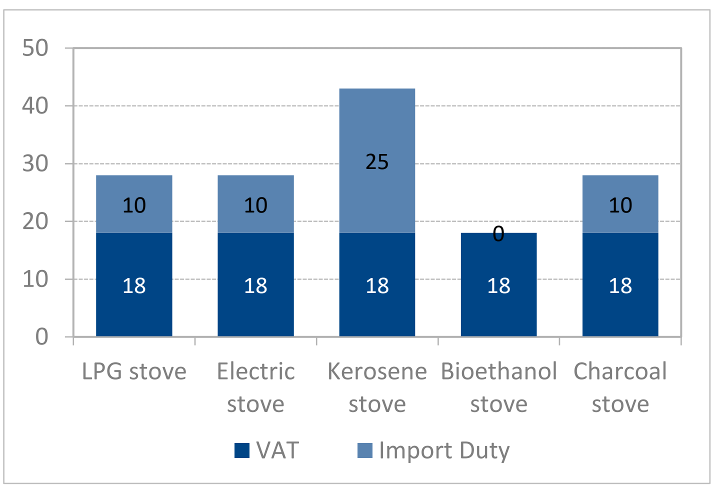
While production costs and profit margins are important components of cooking stove and fuel prices, fiscal regimes are equally relevant and can be used to change relative prices. Production related costs of imported products such as LPG, bioethanol and electric stoves are exogenous from the policy perspective, but policy makers can alter the fiscal regime to incentivize the adoption of these modern fuels (Doggart et al 2020). In Tanzania, cooking stoves are all subject to both import duties and value added tax (VAT), with the import duty ranging between 0-25 percent. However, bioethanol stoves are subject to a reduction in import duty, as are LPG and electric stoves. Further exemptions could be

Figure 16. VAT and import duty rates by fuel type (%)



Notes: *Other taxes is applicable for kerosene and electricity. For kerosene, other taxes are calculated as the share of excise duty (TZS 465/Ltr) and petroleum products levy (TZS 160/Ltr) out of unit price (i.e. TZS 2120/Ltr). For electricity, other taxes are the sum of REA and EWURA charges at 3% and 1% of unit cost, respectively. Sources: EWURA, TRA and TANESCO.

Figure 17. VAT and import duty rates by stove type (%)



Source: EWURA, TRA and TANESCO.

considered in an effort to incentivize the purchase of cleaner cooking stoves. Similarly, bioethanol fuels are exempted from import duties in Tanzania, and LPG fuel is exempted from both import duties and VAT. The VAT exemption on LPG fuel has had a significant role in reducing the price of LPG in Tanzania. Similarly, most of the charcoal produced and sold in Tanzania is not subject to any form of tax, making it a relatively cheaper fuel in the region.[17]

The relative price of charcoal compared to LPG and electricity could be altered, by formalizing the charcoal market and imposing VAT and / or excise duty taxes on charcoal. The introduction of a VAT rate of 18 percent and a 25 percent excise duty on charcoal, while maintaining the current fiscal regime on all other fuels would increase the charcoal price to about TZS 64 per MJ, which is significantly higher than that of LPG. These fiscal mechanisms could also be an important aspect in encouraging a transition towards the production of sustainable charcoal. For example, a levy on charcoal produced outside of a formalized system that takes sustainable forest management into account, could help increase the uptake of sustainable forest management practices. Figures 15 and 16 present various tax rates charged across alternative cooking stoves and fuels in Tanzania. While some fuels are not taxed, almost all stoves are taxed with both import duties and the Value Added Tax (VAT). The import duty rate ranges between 0-25 percent while that of VAT remains at the same rate of 18 percent across the stoves types.[18] Bioethanol stoves are already

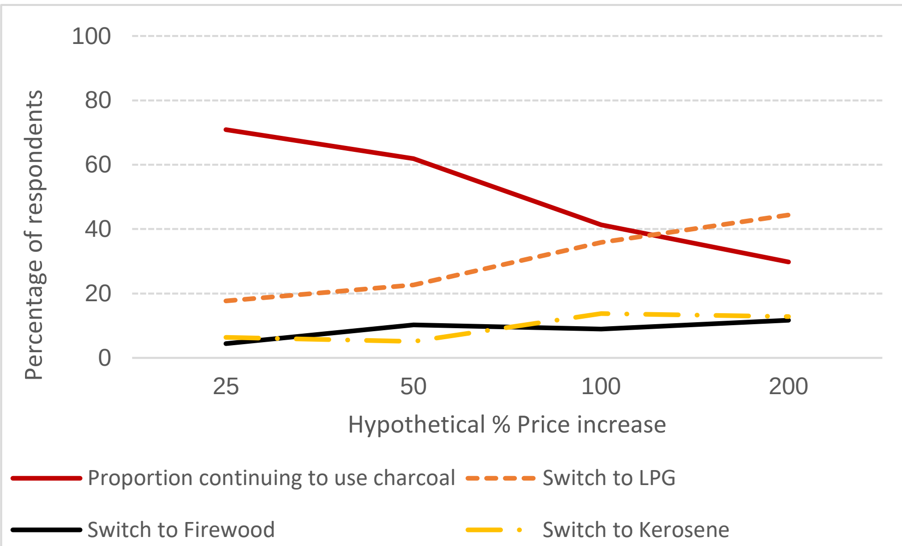
[17] Charcoal is charged a royalty fee of TZS 250/kg (equivalent to about 30 percent of the whole sale price) collected by the government. However, fees are effectively only paid for about 5 percent of total produced charcoal (TFCG, 2018). This makes effective tax rate on charcoal produced in the country near zero.

[18] Tanzania charges import duty of 25% for all consumer goods except those with exceptional treatments (charged at higher or lower rate), 10% for intermediate goods and 0% for all capital goods. LPG, charcoal stove and electric

granted a full reduction in the import duty (but not in VAT) in the country while LPG and electric stoves are among those enjoying a partial reduction in import duty, charged at 10 percent. Given that LPG and Electric stoves are among the costliest stoves but are cleaner cooking technologies, there is still potential to further lower the purchase costs of these stoves by granting a full exemption of the import duty tax on these stoves (i.e., 0 percent import duty).

LPG and Bioethanol fuels are already exempted from import duties and LPG fuel is also exempted from the VAT (Figure 15). The VAT exemption on LPG fuel has had a significant role in reducing the price of LPG in the country. However, charcoal and electricity, being domestically produced energy sources are not subject to import duty (hence a reason for the zero rate). Regardless, while electricity is charged at 18 percent for VAT and 4 percent for other taxes, most of the charcoal produced and sold in Tanzania does not face any form of tax.[19]

Figure 18. Household responses to hypothetical price increases of charcoal



Notes: Notes: N=672. Households who cook mainly with charcoal were asked how they would respond to hypothetical charcoal price increases. The Figure shows the proportion of households choosing to either continue using charcoal as their main cooking fuel, or switching to alternative fuels, for each price increase. Source: Own calculations using the EfD-DES (2020).

Policy aimed at increasing charcoal prices alone may fail to push poorer households up the energy ladder unless complemented with other efforts to lower the effective prices of clean cooking stoves and fuels. In an effort to establish how households, who primarily cook with charcoal, would respond to a hypothetical charcoal price increase of 25, 50, 100, and 200 percent, it became clear that only a small percentage would consider switching to alternative fuels (EfD-DES, 2020). Even though the percentage of households choosing to continue using charcoal decreases as price increases, a third of households would continue using charcoal (including at a 200 percent increase). Secondly, about a quarter of households indicated switching down the energy ladder, to firewood (figure 17). This suggests that while households do respond to price changes, policy makers should not rely only on prices to foster changes in demand for charcoal.

stoves are all consumer goods that have been granted reduced import duty to 10% while bioethanol stoves (which currently enter as intermediate for locally assembling enjoy 0% rate).

[19] Formally charcoal is supposed to be charged a royalty fee of TZS 250/kg (equivalent to about 30% of a wholesale price) collected by the government through Tanzania Forestry Services at some identified checkpoints. However, the presence of several loopholes and the fact that charcoal market is dominated by so much informality, less than 5 percent of total produced charcoal actually end up paying for the royalty (TFCG, 2018). This makes the effective tax rate on charcoal produced in the country to be less than 10%.

Increased government revenue and creation of jobs could be achieved by supporting a growing alternative fuel technology market. Despite government removal of the import duty and VAT on LPG appliances, expanding the tax base from increased businesses could create an opportunity for more of other forms of taxes such as corporate income tax from a newly created or growing business sector. In addition, a number of new (and relatively more decent) jobs could be created from improving the business environment for alternative fuel appliances such as LPG stoves and cylinder marketing, and smart meter installation and distribution.

.

5. AN INTEGRATED APPROACH TOWARD SUSTAINABLE CHARCOAL AND CLEAN COOKING FUELS

In the context of achieving sustainable development, Tanzania's goal of increasing access to clean and affordable energy remains a priority. At the same time, the continued role charcoal will play as part of Tanzania's cooking energy mix, needs to be recognized. Opportunities that will make charcoal production and use more sustainable will need to be identified as the country transitions to alternative fuels to ensure a balanced approach.

As Tanzania's population is rapidly growing and urbanizing, the demand for charcoal is growing apace, especially in urban areas. Tanzania's population is projected to reach 84 million by 2030, with the growth most noticeable in its expanding cities. The country's urban population is expected to increase from about 22 million in 2020 to over 35 million and 70 million, or 42 and 53 percent of the total, by 2030 and 2050, respectively (World Bank, 2018). Unless the transition to alternative cooking fuels be accelerated, charcoal demand will grow between now and 2050 and remain a significant source of household cooking energy. The ongoing COVID-19 pandemic and its impact on the global economy and Sub-Saharan Africa may further increase Tanzania's reliance on wood fuels, as it is likely to have a significant impact on household welfare, and consequently on economic activity and spending habits.

The current so-called charcoal nexus is thereby characterized by a combination of population growth and rapid urbanization where cooking in growing urban areas is typically done with charcoal as the dominant fuel. The dependence on charcoal is associated with negative effects on the environmental and human health. The complexity and inertia of the charcoal nexus demands a comprehensive, consolidated and decisive approach. In order to enable any alternative to the current situation the harvesting and trade of charcoal from de facto open access sources need to be better regulated. Successful implementation of such enforcement policies would facilitate both improved management of forests and woodlands for sustainable charcoal production and expanding alternatives to charcoal.

5.1 Integrating sustainability and revenue collection

In light of unsustainable wood harvesting and charcoal production contributing to forest degradation, in some cases deforestation, biodiversity loss, and GHG emissions, it is essential that illicit charcoal production and trade is prohibited. Tackling such illicit practices is also a fundamental step toward giving a chance for the adoption of alternatives such as sustainable charcoal production and modern clean-burning fuels.

The following actions are proposed to start such a process:

A. Preparing a national charcoal policy. While some aspects of charcoal production and trade are guided by regulations supporting the national forest policy, an opportunity exists to present a broader vision on how to achieve more sustainable charcoal production, trade and use. There is a strong need for a national charcoal policy and related policy instruments to guide the charcoal value chain toward more positive environmental and economic impacts. Such policy could guide the transformation of the charcoal value chain to align with national development priorities around improved livelihoods, good governance and a strong economy. Initial steps toward the development of a national charcoal policy have been taken, led by the Ministry for Natural Resources and Tourism (MNRT).

B. Reducing illegal and unsustainable charcoal production by strengthening forest reserve management planning and implementation in both productive and protected central and local government forest reserves. The monitoring and enforcement of regulations should be strengthened to minimize illegal and unsustainable activities, through improved capacity, awareness and incentives compatible with this mandate.
C. The rights to the different classifications of forest land needs to be clear and the rights need to be enforceable and the enforcement needs to be incentive compatible with sustainable management of the land. This is particularly important for land that is commercially viable for charcoal production.
D. As established in the previous sections, high rates of revenue leakage have characterized the charcoal sector in Tanzania, with the government collection rate of charcoal royalties not exceeding 10 percent. Improving the revenue collection system could increase government revenues substantially, and if it is efficiently applied on all charcoal production it would dramatically improve the competitiveness of sustainably produced charcoal. A new revenue collection system that promotes cooperation between different levels of government, from village governments up to central government would be desirable, with opportunities to strengthen transparency, accountability, compliance and planning. Restructuring the revenue collection system to incorporate incentives for sustainable forest management and stakeholder cooperation in revenue collection could generate the greatest dividends. Strengthening revenue collection capacity at central, district and village government levels would improve collection rates and could include scaling-up electronic revenue tracking and reporting systems for charcoal.

5.2 Toward sustainable charcoal production and use

Since charcoal will be part of the energy mix for Tanzania for the foreseeable future, its production should be made consistent with sustainable management of forest land and, as far as possible, strengthen the viability of CBFM. The following actions and recommendations are key for Tanzania to ensure improved sustainability for the charcoal value chain

A. Increase the use of CBFM for sustainable forest management at the wood production stage. Given the extensive area of forest and woodland remaining on village land and the clear indications of sustained demand for charcoal, more village forests and woodlands could be used for sustainable charcoal production. This could be achieved by scaling-up the integration of sustainable charcoal production into CBFM and supporting local authorities and communities by building on the experience of sustainable charcoal-producing communities in the Morogoro region. Pursuing a sustainable production pathway could achieve an environmental win-win scenario in terms of reduced forest degradation through improved forest management, alongside more energy-efficient production. Given ongoing deforestation and forest fragmentation on village land, there is some urgency to scale up CBFM while there remain forest blocks of sufficient size to accommodate sustainable charcoal production. Preliminary steps have been taken toward the development of a national CBFM strategy, which would add greater value if aligned with a charcoal master plan outlining how the supply of charcoal from well-management woodlands can meet projected demand. A charcoal master plan would also add value to the broader energy sector planning.
B. Strengthening local government capacity and intersectoral coordination. Strengthening capacity of local governments toward supporting CBFM and sustainable charcoal production should be

prioritized. In addition, the charcoal sector cuts across several government ministries and agencies, making it critical for these to coordinate and collaborate closely. In an effort to ensure such collaboration, inter-sectoral coordination should be strengthened between energy, forestry, environment, and land and agriculture on any charcoal-related matters.

At the same time, options should be explored of how the charcoal sector can contribute more effectively to the broader Tanzanian economy. The charcoal sector employs a number of people at each stage of the value chain facing challenges such as high transaction costs and uncertainty around the regulatory framework, low wages and health and safety risks. To better leverage the contribution of the charcoal sector to the economy, priority actions to be considered as follows:

A. Improving the working conditions and skills of those working along the charcoal value chain. Positive outcomes, in terms of improved livelihoods and reduced environmental impacts, can be achieved by strengthening technical capacity through training and provision of extension services; developing professional standards for producers and traders, and supporting professional bodies to represent charcoal workers. Achieving more positive outcomes for households involved in the charcoal value chain, would be facilitated by having more accurate and detailed information about charcoal-related employment. Supporting private sector initiatives to manufacture modern charcoal cookstoves could diversify employment opportunities.
B. Reducing health risks for charcoal users, producers and traders. Charcoal users, producers and traders are exposed to emissions and dust that can cause a range of diseases, as well as other health and safety issues unique to the charcoal trade (Das et al. 2017). The way that charcoal is produced and handled along the supply chain can influence the risks associated with the end use. Awareness raising and training could reduce these risks. Interventions for consideration include: promoting technical training and extension services to support charcoal producers and traders to adopt improved health and safety standards; encouraging the adoption of best practices in the production and transportation of charcoal in order to improve the quality of charcoal reaching the market; and promoting measures to improve efficiency and safety in the use of charcoal such as using improved stoves, good ventilation practices, avoiding inhaling the charcoal smoke and keeping children away from charcoal stoves.

5.3 Maintaining the focus on transitioning to cleaner cooking fuels

Maintaining a focus on transitioning to alternative cooking fuels will remain an important foundation for increasing access to affordable, reliable, sustainable and modern energy for all, in Tanzania (Sustainable Development Goal 7). The National Energy Policy 2015 (URT, 2015) provides a clear basis for increasing the supply of and improving access to electricity and fossil fuels. Despite early success in, for example, scaling up the use of LPG, clean cooking fuel adoption rates will need to increase significantly in order to outpace Tanzania's rapid population growth and urbanization, and to slow down the growing demand for charcoal. This will require investment toward further increasing access to LPG and natural gas and support to the private sector to help consumers overcome cost-barriers associated with transitioning to cleaner cooking solutions. Specific policy recommendations toward these goals are as follows:

A. Promoting affordable and convenient credit plans: Access to affordable and convenient credit plans is one of the solutions to addressing the "high start-up cost" constraint. The existing market interest rates (of up to 20 percent and beyond) and payment plans (often monthly) make it prohibitively expensive for the poor households to switch to LPG. While the government could step in to partly subsidize the interest rates taken for purchase of LPG stove package, the credit repayment modes can be designed to mimic their daily purchase of charcoal fuel (i.e., daily but much smaller amounts of repayments).

B. Promoting energy services on a pay-as you-go (PAYG) basis leverages technology-focused business models. PAYG solutions appear highly scalable and sustainable from the industry’s perspective and could dramatically enable households to adopt LPG by allowing smaller purchases of fuel on an incremental, per-use basis. LPG-related PAYG meters, which have been piloted at a small scale in several countries, allow the household to purchase the LPG fuel on an incremental, per-use basis.

C. Providing an enabling environment to attract investment in the alternative energy value chain. This includes long-term, consistent fiscal and non-fiscal policies and properly enforced regulatory frameworks based on international standards and codes of practice. Such a business environment is necessary, for example, to incentivize large private investors to distribute pay-as-you-go smart meters but also microfinance institutions which can establish a convenient credit product for the stoves package.

D. Increasing government revenue and creating jobs through a growing alternative fuel technology market. expanding the tax base from increased businesses could create an opportunity for more of other forms of taxes such as corporate income tax from a newly created or growing business sector. In addition, a number of new jobs could be created from improving the business environment for alternative fuel appliances such as LPG stoves and cylinder marketing, and smart meter installation and distribution.

E. Increasing public awareness-raising campaigns around the benefits of clean cooking and ways to transition. Opportunities exist to integrate messages around clean cooking into ongoing environmental awareness campaigns by the Vice-President's Office, as well as developing new campaigns involving private sector and civil society organizations. Sharing information on the harmful effects of smoke inhalation from traditional fuels, can help in informing household preferences. Access to clean fuels should also be understood as an issue affecting women's health and increasing access to alternatives could free up women's time to engage in income earning activities if they so wish.

REFERENCES

African Forestry and Wildlife Commission. 2020. Sustainable Charcoal Production for Food Security and Forest Landscape Restoration. In: Forests and Wildlife: *Africa's diversity for shared prosperity and security.* [online]. Skukuza – Mpumalanga, South Africa: Food and Agriculture Organization of the United Nations (FAO). Available at: http://www.fao.org/forestry/afwc/37735/en/ [Accessed 28 May 2020].

Agarwal, A., Kirwa, K., Eliot, M.N., Alenezi, F., Menya, D., Mitter, S.S., Velazquez, E.J., Vedanthan, R., Wellenius, G.A., Bloomfield, G.S. 2017. Household Air Pollution Is Associated with Altered Cardiac Function among Women in Kenya. *Am J Respir Crit Care Med*. [online]. 197, 958–961. Available at: https://doi.org/10.1164/rccm.201704-0832LE [Accessed 2 March 2020].

Alem,Y., Ruhinduka,R. and Berk, P. (2020), "Saving Africa's Tropical Forests through Energy Transition: A Randomized Controlled Trial in Tanzania", a research report.

Camco (Camco Clean Energy Tanzania). 2014. Biomass Energy Strategy Tanzania: Tanzania Biomass Energy Strategy and Action Plan.

Chidumayo, E. N. 1993. Responses of Miombo to Harvesting: Ecology and Management. Stockholm Environment Institute, Stockholm.

Chidumayo, E. N. and P. Frost 2006. Population biology of miombo trees. C. 3 in Campbell et al. The Miombo in Transition.

Chidumayo, E.N., Gumbo, D.J., 2013. The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. Energy for Sustainable Development 17, 86–94. Online: https://doi.org/10.1016/j.esd.2012.07.004 [Accessed 4 March 2020)

Chidumayo, E.N., 2019a. Management implications of tree growth patterns in miombo woodlands of Zambia. Forest Ecology and Management 436, 105–116. Online: https://doi.org/10.1016/j.foreco.2019.01.018 [Accessed February 8 2020]

Chidumayo, E.N., 2019b. Is charcoal production in Brachystegia-Julbernardia woodlands of Zambia sustainable? Biomass and Bioenergy 125: 1–7. Online: https://doi.org/10.1016/j.biombioe.2019.04.010 [Accessed February 7 2020]

Choumert-Nkolo, J., Combes Motel, P., Le Roux, L. 2019. Stacking up the ladder: A panel data analysis of Tanzanian household energy choices. World Development 115, 222–235. https://doi.org/10.1016/j.worlddev.2018.11.016

Doggart, N., Morgan-Brown, T., Lyimo, E., Mbilinyi, B., Meshack, C.K., Sallu, S.M., and Spracklen, D.V. 2020a. Agriculture is the main driver of deforestation in Tanzania. *Environmental Research Letters*, [online] 15:034028. Available at: https://doi.org/10.1088/1748-9326/ab6b35 [Accessed 27 May 2020]

Doggart, N., Ruhinduka, R., Meshack, C.K., Ishengoma, R.C., Morgan-Brown, T., Abdallah, J.M., Spracklen, D.V., Sallu, S.M., 2020b. The influence of energy policy on charcoal consumption in urban households in Tanzania. Energy for Sustainable Development 57, 200–213. https://doi.org/10.1016/j.esd.2020.06.002

Doggart, N. and Meshack, C. 2017. The marginalization of sustainable charcoal production in the policies of a modernizing African nation. *Frontiers in Environmental Science*, [online] 5:27. Available at: https://www.frontiersin.org/articles/10.3389/fenvs.2017.00027/full [Accessed 5 May 2020]

EWURA (Energy and Water Utilities Regulatory Authority). 2018. Regulatory Performance Report On Electricity Sub-Sector For The Year Ended 30th June 2017.

EWURA (Energy and Water Utilities Regulatory Authority). 2019. Regulatory Performance Report On Electricity Sub-Sector For The Year Ended 30th June 2018.

FAO (Food and Agriculture Organization). 2007. Manual on Deforestation, Degradation, And Fragmentation Using Remote Sensing and GIS. Strengthening Monitoring, Assessment and Reporting on Sustainable Forest Management in Asia. Food and Agriculture Organization of the United Nations (Vol. 5). Working Paper No.

FAO (Food and Agriculture Organization). 1987. Simple technologies for charcoal making. http://www.fao.org/3/x5328e/x5328e00.htm#Contents

FAO (Food and Agriculture Organization). 2009. Towards defining forest degradation: Comparative analysis of existing definitions. Rome: Food and Agriculture Organization.

FAO (Food and Agriculture Organization). 2015. Global Forest Resources Assessment 2015. Rome: Food and Agriculture Organization at the United Nations.

FAO (Food and Agriculture Organization). 2017. The Charcoal Transition: Greening the Charcoal Value Chain to Mitigate Climate Change and improve Local Livelihoods. Rome: Food and Agriculture Organization.

FAOSTAT (Food and Agriculture Organization Corporate Statistical Database). 2020. Forestry Production and Trade. [online] Available at: http://www.fao.org/faostat/en/#data/FO [Accessed 23 June 2020].

Frost, P. 1996. The Ecology of Miombo Woodlands. In 'Miombo in Transition'. Ed. Campbell. P. 33

Gould, C.F., Schlesinger, S., Toasa, A.O., Thurber, M., Waters, W.F., Graham, J.P., Jack, D.W., 2018. Government policy, clean fuel access, and persistent fuel stacking in Ecuador. Energy for Sustainable Development, Scaling Up Clean Fuel Cooking Programmes 46, 111–122.

Gould, C.F., Urpelainen, J., 2018. LPG as a clean cooking fuel: Adoption, use, and impact in rural India. Energy Policy 122, 395–408

IEA (International Energy Agency). 2019. Africa Energy Outlook 2019. France: International Energy Agency

IEA (International Energy Agency), IRENA (International Renewable Energy Agency), UNSD (United Nations Statistics Division), WBG (World Bank Group), and WHO (World Health Organization). 2019. Tracking SDG 7: The Energy Progress Report 2019. Washington DC, USA: World Bank Group

Imelda, I., 2018. The Response of Consumption to Fuel Switching: Panel Data Estimates. Universidad Carlos III de Madrid Economics Working Papers 18.

IRENA (International Renewable Energy Agency). 2017. Renewables Readiness Assessment: United Republic of Tanzania, International Renewable Energy Agency, Abu Dhabi.

Jeuland, M., Pattanayak, S.K., Tan Soo, J.-S., Usmani, F. 2020. Preferences and the Effectiveness of Behavior-Change Interventions: Evidence from Adoption of Improved Cookstoves in India. Journal of the Association of Environmental and Resource Economists 7, 305–343.

Johnson, M.A., Chiang, R.A. 2015. Quantitative Guidance for Stove Usage and Performance to Achieve Health and Environmental Targets. Environmental Health Perspectives 123, 820–826. Available at: https://doi.org/10.1289/ehp.1408681 [Accessed 5 May 2020]

Jones, D., Ryan, C. M., and Fisher, J. 2016. Charcoal as a diversification strategy: the flexible role of charcoal production in the livelihoods of smallholders in central Mozambique. Energy Sustain. Dev. 32, 14–21. doi: 10.1016/j.esd.2016.02.009

Kar, A., Pachauri, S., Bailis, R., Zerriffi, H., 2019. Using sales data to assess cooking gas adoption and the impact of India's Ujjwala programme in rural Karnataka. Nature Energy 4, 806–814.

Kelly, Timothy John Charles; Esselaar, Steve; Saldarriaga Noel, Miguel Angel; Swinkels, Robertus A; Fatima, Freeha; Nabeta, Loy; Mungunasi, Emmanuel A. 2020. *Tanzania Economic Update: Addressing the Impact of COVID-19* (English). Tanzania Economic Update; no. 14. Washington, DC: World Bank Group.

Leeuwen V.R., Evans, A. And Hysen, B. (2017), "Increasing the Use of Liquefied Petroleum Gas in Cooking in Developing Countries", A knowledge Note Series for the Energy and Extractives Global Practice, World Bank Group.

Luoga E.J., E.T.F. Witkowski, K. Balkwill. 2004. Regeneration by coppicing of miombo trees in relation to land use. For. Eco. & Man. 189: 23-25. doi.org/10.1016/j.foreco.2003.02.001

Malimbwi, R.E. Zahabu, Misana S. Monela, G.C., Jambiya, G.C. & Mchome B. 2005. Charcoal supplying potential of the miombo woodlands: the case of Kitulangalo Area, Tanzania. Journal of Tropical Forest Science, 17(2): 197-210.

Malimbwi, R.E. and E M. Zahabu 2008. Woodlands and the charcoal trade: the case of Dar es Salaam City. Working Papers of the Finnish Forest Research Institute 98: 93–114

Masera, O.R., Saatkamp, B.D., Kammen, D.M., 2000. From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. World Development 28, 2083–2103.

MNRT (Ministry of Natural Resources and Tourism). 2019. Status, ecological potential and sustainable management of forest resources in Mainland Tanzania. Dodoma, Tanzania: Ministry of Natural Resources and Tourism.

NBS (National Bureau of Statistics). 2014. Tanzania Household Budget Survey 2011/12. Dar es Salaam, Tanzania: National Bureau of Statistics

NBS (National Bureau of Statistics). 2017. Energy access situation report 2016: Tanzania Mainland. Dar es Salaam, Tanzania: NBS.

NBS (National Bureau of Statistics). 2019. Tanzania Household Budget Survey 2017/18 - Key Indicators Report. Dar es Salaam, Tanzania: National Bureau of Statistics

Obiebi, P., R. U. Ibekwe and G. U. Eze. 2017. Lung function impairment among charcoal workers in an informal occupational setting in Southern Nigeria. African Journal of Respiratory Medicine 13: 1.

OECD (Organization for Economic Co-operation and Development). 2016. OECD-FAO Agricultural Outlook 2016-2025. OECD Publishing.

Pope, D., Bruce, N., Dherani, M., Jagoe, K., & Rehfuess, E. 2017. Real-life effectiveness of 'improved' stoves and clean fuels in reducing PM2. 5 and CO: systematic review and meta-analysis. Environment international, 101, 7-18.

PrayGod, G., Mukerebe, C., Magawa, R., Jeremiah, K., Török, M.E. 2016. Indoor Air Pollution and Delayed Measles Vaccination Increase the Risk of Severe Pneumonia in Children: Results from a Case-Control Study in Mwanza, Tanzania. PLoS One 11. [online]. Available at: https://doi.org/10.1371/journal.pone.0160804 [Accessed 2 March 2020].

Project Gaia. 2020. Presentation by current distributors of CleanCook Bioethanol cookstoves in Dar es Salaam.

Rakoto Ratsimba H., Ralainirina J., Rabemananjara Z.H and Andriamanantseheno J. 2015. "Avoiding deforestation and reforestation: historical experiences in Northern Madagascar"; paper presented at the XIV World Forestry Congress, Durban, South Africa, 7-11 September 2015

Ruiz-Mercado, I., and Masera, O. 2015. Patterns of Stove Use in the Context of Fuel–Device Stacking: Rationale and Implications. *EcoHealth*. [online] 12, 42–56. Available at: https://doi.org/10.1007/s10393-015-1009-4 [Accessed 2 March 2020].

Smith, P. and Porter, J. R. 2018. Bioenergy in the IPCC Assessments. Gcb Bioenergy, 10(7), 428-431

TaTEDO (2019), "Save Energy, Money and Environment by Using Efficient Electric Cooking Appliances". Available at: http://tatedo.org/medias/news-articles/41-save-energy-money-and-environment-by-using-efficient-electric-ciiking-appliances [accessed 13th March 2020]

TFCG (Tanzania Forest Conservation Group). 2018. Dar es Salaam Energy Survey 2018. Dar es Salaam, Tanzania: Tanzania Forest Conservation Group.

Titcombe, M. E., and Simcik, M. 2011. Personal and indoor exposure to PM 2.5 and polycyclic aromatic hydrocarbons in the southern highlands of Tanzania: a pilot-scale study. *Environmental Monitoring and Assessment*, 180(1-4), 461-476.

UNIDO (United Nations Industrial Development Organization). 2015. Baseline Report of Clean Cooking Fuels in the East African Community. Pp. 1- 187. Online: https://projectgaia.com/wp-content/uploads/2015/12/Baseline-report-pdf-compressed-4.pdf [Accessed March 2 2020]

United Nations. 2014. World Urbanization Prospects. The 2014 Revision. New York, USA: United Nations, Department of Economic and Social Affairs.

URT (United Republic of Tanzania). 1998. National Forest Policy. Dar es Salaam, Tanzania: Ministry of Natural Resources and Tourism

URT (United Republic of Tanzania). 2012a. The Tanzania Long Term Perspective Plan 2011/12-2015/16 – Roadmap to a Middle-Income Country. Dar es Salaam, Tanzania: Vice President's Office, Planning Commission

URT (United Republic of Tanzania). 2012b. Participatory Forest Management: Facts and Figures. Dar es Salaam, Tanzania: Ministry of Natural Resources and Tourism

URT (United Republic of Tanzania). 2015a. National Biodiversity Strategy and Action Plan (NBSAP) 2015-2020. Dar es Salaam, Tanzania: Vice President's Office (VPO) - Division of Environment.

URT (United Republic of Tanzania). 2015b. National Energy Policy 2015. Dar es Salaam, Tanzania: Ministry of Energy and Minerals

URT (United Republic of Tanzania). 2015c. National forest Resources Monitoring and Assessment (NAFORMA) of Tanzania Mainland: Main Results. Dar es Salaam, Tanzania: Ministry of Natural Resources and Tourism

URT (United Republic of Tanzania). 2016a. National Five-Year Development Plan 2016/17 – 2020/21 – Nurturing Industrialization for Economic Transformation and Human Development. Dar es Salaam, Tanzania: Ministry of Finance and Planning

URT (United Republic of Tanzania). 2016b. United Republic of Tanzania Natural Gas Utilization Master Plan 2016-2016. Dar es Salaam, Tanzania: Ministry of Energy and Minerals

URT (United Republic of Tanzania). 2017. Tanzania's Forest Reference Emission Level Submission to the UNFCCC

URT (United Republic of Tanzania). 2019. Nationally Determined Contribution. Dar es Salaam, Tanzania: Vice President's Office

USAID (United States Agency for International Development). 2019. [to be added]

Van der Kroon, B., Brouwer, R., and van Beukering, P.J.H. 2013. The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and Sustainable Energy Reviews*. [online]. 20, 504–513. Available at: https://doi.org/10.1016/j.rser.2012.11.045 [Accessed 4 March 2020].

WHO (World Health Organization). 2018a. Household Air Pollution and Health: Key Facts. [online]. Available at: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health [Accessed 16 February 2020).

WHO (World Health Organization). 2018b. Global Health Observatory data repository. Deaths by Country. [online]. Available at: https://apps.who.int/gho/data/node.main.BODHOUSEHOLDAIRDTHS?lang=en [Accessed 16 February 2020]

World Bank. 2005. Introduction to Poverty Analysis, Chapter 2. Measuring Poverty.

World Bank 2009. "Environmental Crisis or Sustainable Development Opportunity? Transforming the Charcoal Sector in Tanzania: A Policy Note." Washington DC, USA: World Bank, No. 50207

World Bank. 2010. "Enabling reforms: a stakeholder-based analysis of the political economy of Tanzania's charcoal sector and the poverty and social impacts of proposed reforms (English). Washington DC, USA: World Bank

World Bank. 2011. Ethanol as a household fuel in Madagascar: health benefits, economic assessment, and review of African lessons for scaling-up: summary report. Washington DC: World Bank.

World Bank. 2013. Commercial Woodfuel Production: Experience from Three Locally Controlled Wood Production Models. Energy Sector Management Assistance Program (ESMAP); knowledge series 012/12. Washington, DC: World Bank.

World Bank. 2014. Clean and Improved Cooking in Sub-Saharan Africa – A Landscape Report. Washington, DC: World Bank Group.

World Bank. 2018. Open Data – Population Estimates and Projections. Washington, DC: World Bank Group.

Wylie, B. J., Kishashu, Y., Matechi, E., Zhou, Z., Coull, B., Abioye, A. I., ... & Hauser, R. 2017a. Maternal exposure to carbon monoxide and fine particulate matter during pregnancy in an urban Tanzanian cohort. *Indoor Air*. 27(1), 136-146.

Wylie, B. J., Matechi, E., Kishashu, Y., Fawzi, W., Premji, Z., Coull, B. A., ... & Roberts, D. J. (2017b). Placental pathology associated with household air pollution in a cohort of pregnant women from Dar es Salaam, Tanzania. *Environmental Health Perspectives*, 125(1), 134-140.

Zeufack, A. G., Calderon, C., Kambou, G., Djiofack, C. Z., Kubota, M., Korman, V., Cantu Canales, C. 2020. "Africa's Pulse, No. 21" (April). Washington DC, USA: World Bank

ANNEX 1

Year	Population of Dar es Salaam	HH size (persons)	Total number of HH	% HH using charcoal	Total HH using charcoal	Daily HH charcoal consumption kg / HH / day	Annual HH charcoal consumption kg / HH / yr	Annual HH charcoal consumption T tonnes / HH / yr	Total annual charcoal consumption tonnes / yr	% hh not using charcoal	Total HH not using charcoal
Scenario 1: Business as usual											
2018	5,962,824	3.9	1,528,929	88%	1,345,458	2	730.0	0.73	982,184	12%	183,471
2025	8,731,712	3.9	2,238,900	85%	1,903,065	2	730.0	0.73	1,389,238	15%	335,835
2030	11,466,186	3.9	2,940,048	80%	2,352,038	2	730.0	0.73	1,716,988	20%	588,010
Scenario 2: Energy efficiency											
2018	5,962,824	3.9	1,528,929	88%	1,345,458	2	730.0	0.73	982,184	12%	183,471
2025	8,731,712	3.9	2,238,900	85%	1,903,065	1.7	620.5	0.6205	1,180,852	15%	335,835
2030	11,466,186	3.9	2,940,048	80%	2,352,038	1.7	620.5	0.6205	1,459,440	20%	588,010
Scenario 3: Rapid fuel-switching											
2018	5,962,824	3.9	1,528,929	88%	1,345,458	2	730.0	0.73	982,184	12%	183,471
2025	8,731,712	3.9	2,238,900	40%	895,560	2	730.0	0.73	653,759	60%	1,343,340
2030	11,466,186	3.9	2,940,048	30%	882,014	2	730.0	0.73	643,870	70%	2,058,033