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Chantale Oweggi, Pascale Combes Motel, Jean-Louis Combes, Manegdo Ulrich Doamba. Forest conservation policies in the kitchen: When protected areas influence household fuel choices in Tanzania. 2024. hal-04567226

HAL Id: hal-04567226

<https://uca.hal.science/hal-04567226>

Preprint submitted on 3 May 2024

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Forest conservation policies in the kitchen:

When protected areas influence household fuel choices in Tanzania.

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MAY 2024

Abstract

Tanzania enjoys humongous forest cover, and many of its forests are protected. Nevertheless, households are highly reliant on biomass. This study uses three-wave panel data (2008-2013) from the Tanzania National Panel Survey to estimate the effectiveness of protected areas in modifying household cooking fuel choices. We adopt a linear probability model (LPM) while controlling for region and wave-fixed effects. The findings suggest that while protected areas reduce the probability that households would use firewood, the likelihood of use of charcoal is increased, signaling a possible rebound effect given that firewood and charcoal are close substitutes. Overall, protected areas were not effective in reducing traditional biomass consumption. Our results highlight that environmental conservation policies such as the implementation of protected areas can generate negative consequences, especially given that the current charcoal production in Tanzania remains unsustainable.

Keywords: • Cooking fuels • Protected areas • Household fuels • Tanzania

JEL Classification: • O12 • Q57 • N5

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1 Introduction

Household use of sustainable energy sources is not just a question of choice within the household but a necessity in the face of the urgent climate change crisis. These choices have strong repercussions on the direct environment and more broadly on climate change, especially in developing countries where biomass remains a substantial source of household fuels. This is particularly compelling in Sub-Saharan Africa (SSA) where biomass, primarily firewood, and charcoal, dominates residential energy demand with more than 80% of the population relying on it (Senyagwa, 2022). Tanzanian households are no exception, with low electricity coverage of approximately 32.8%, households rely heavily on biomass for cooking, firewood and charcoal account for 85% of cooking fuels (Choumert-Nkolo et al., 2019). While relatively cheaper than modern household cooking fuels (Nyarko et al., 2021), the use of biomass as an energy source poses a significant threat to forests, biodiversity, and climate in Tanzania (Chidumayo, 2001; Girard et al., 2002). One of the most detrimental effects of biomass use is deforestation, which results from excessive wood cutting (Hofstad, 1997; Malimbwi et al., 2000). Authors find that deforestation disrupts the delicate balance of ecosystems and contributes to climate change (Gorte and Sheikh, 2010; Giam, 2017). In addition, literature has highlighted the negative impacts of the use of biomass on: health from indoor air pollution (Zidago et al., 2016), gender equality as women are majorly tasked with firewood collection (Farioli and Dafrallah, 2012; Lee et al., 2024), education (Biswas and Das, 2022), and labor productivity (Mosa et al., 2020)- as there exists an opportunity cost in time dedicated to collection and use of firewood.

Reducing deforestation is a key instrument in preserving biodiversity and mitigating climate change, and the establishment of protected areas (PAs) has been applied as a key strategy to reduce deforestation (Gullison et al., 2007). To examine household fuel choices and their linkages to environmental protection, Tanzania portrays particularly interesting characteristics as a country of study. On one hand, (Riggio et al., 2019) reports that Tanzania contains the greatest number, highest percent coverage, and highest overall areal extent of PAs in East Africa. Besides, McNicol et al. (2023) document that aboveground woody carbon stocks (AGC) have been stable in SSA in 2007-2010

and 2015-2018, on the contrary, Tanzania and Mozambique were exceptions since they experienced net losses. Moreover, literature documents the mixed performance of PAs to curb deforestation in East Africa from 2001 to 2009 (Pfeifer et al., 2012).

On the other hand, given the growing urban population, charcoal demand is increasing (Mwampamba, 2007). Mwampamba et al. (2013) states that a 1% increase in the urban population in Tanzania would lead to a 14% increase in wood consumption. Furthermore, a study on Uganda, points out that “charcoal is of particular importance due to its centrality in urbanization”(Branch and Martiniello, 2018). Existing literature illustrates that Tanzania is among the top 10 global charcoal producers (Nyamoga and Solberg, 2019). Nonetheless, the charcoal market in Tanzania is not sustainable (van Beukering et al., 2007). Seminal authors demonstrate that the current charcoal consumption trends could pose a significant threat to deforestation compared to firewood, which is collected only in small amounts to meet domestic needs (Van der Plas, 1995; Mwampamba, 2007; Mwampamba et al., 2013).

In addition, charcoal is traded in much larger volumes between rural areas and urban centers (Kimeu, 2022). Mwampamba (2007) states that around 50% of forests are protected in Tanzania, however despite these efforts, illegal logging is widespread largely due to poor regulations and management of PAs. In the same vein, recent studies focused on the impact of PAs on the carbon cycle while evidencing their contribution to preserving aboveground carbon stocks (Duncanson et al., 2023; McNicol et al., 2023). Moreover, Tanzania is a large forested country: in 2010 natural forest extended over 26% of the land area. However, forest loss is particularly acute. For instance, tree cover lost between 2001 and 2023 represents a 12% decrease in tree cover ¹. Tanzania is, therefore, a particularly well-suited study area for examining energy choices in a context of severe natural forest degradation.

Furthermore, energy policies have not led to a transition away from biomass in urban areas. Charcoal continues to be used on a massive scale because it is the cheapest energy after firewood (Doggart et al., 2020). Authors seeking to understand the historical importance of charcoal have stated that charcoal production is part of colonial history,

¹<https://www.globalforestwatch.org/dashboards/country/TZA/?category=forest-change&lang=en&location=WyJjb3VudHJ5IiwVFpBI10%3D&scrollTo=net-change>

and charcoal production around Dar es Salaam was a tool of underdevelopment that enabled the state to avoid investing in energy infrastructure — Moreover, the structural adjustment period (80s) also favored charcoal (Branch et al., 2022).

Some media outlets ² ³ have also highlighted the Tanzanian government’s efforts to ban the use of charcoal and firewood. If the newspapers are to be trusted, these two sources of energy will be banned by 2025. Literature highlighting ‘the war on charcoal’ suggests that the difficulty with a charcoal ban is that it could result in a loss of public revenue from forests (Mabele, 2020).

Our study unites two streams of literature, the first stream extensively highlights literature on the effectiveness of PAs (Andam et al., 2008; Joppa and Pfaff, 2011; Nelson and Chomitz, 2011). Indeed, some authors find PAs to be effective in reducing deforestation (Feng et al., 2021), while others find them to be non-effective (Hayes, 2006). The second stream of literature analyses household fuel choices (see e.g. Leach, 1992; Choumert-Nkolo et al., 2019; Oweggi, 2023) and authors find that these choices are driven by household characteristics such as income, location, household heads’ gender, education level, and marital status among others. In addition, other authors find that in the presence of property rights and forest conservation measures, distance to forests could reduce firewood consumption compared to charcoal (Gebru and Elofsson, 2023). Given the dominant use of biomass in Tanzania (Choumert-Nkolo et al., 2019), a growing urban population that is likely to exacerbate charcoal consumption coupled with poor management of PAs (Mwampamba, 2007), our study questions the effects of PAs in modifying household fuel choices.

In attempting to answer this question, we postulate two distinct hypotheses, first, proximity to PAs would reduce firewood consumption. Second, proximity to PAs would increase charcoal consumption. Our first hypothesis aligns with the argument that the establishment of PAs would reinforce forest property rights and send signals to households to limit firewood collection in nearby PAs (Gebru and Elofsson, 2023). Our second hypothesis is based on three premises. To begin with, charcoal remains the closest substitute to firewood, given its affordability compared to other modern cooking fuels such

²<https://www.theeastafrican.co.ke/tea/news/east-africa/tanzania-bans-charcoal-use-in-institutions>

³<https://theexchange.africa/countries/will-charcoal-ban-stop-tanzanias-appetite-for-firewood/>

as LPG gas and electricity. Allied with that, the charcoal market in Tanzania is competitive and could allow for charcoal transportation and consumption even in areas near PAs (Mwampamba et al., 2013). Lastly, given the widespread illegal harvesting of forest resources, the charcoal supply chain could be sustained, ensuring continued charcoal consumption despite the establishment of PAs. Against this backdrop, our study seeks to analyze the impact of proximity to PAs on household fuel choices. More precisely, we investigate the effect of having PAs in a 25 km buffer zone around a household on the household’s cooking fuel choice, studying firewood and charcoal separately.

We contribute to the existing literature in two distinct ways. To the best of our knowledge, this is the first study in Tanzania to analyze the implications of the proximity to PAs on household fuel choices. Second, in line with the literature (see Mwampamba, 2007), charcoal poses a greater threat of deforestation compared to firewood. Our study therefore distinguishes the separate effects of PAs on firewood and charcoal rather than studying the joint effects of biomass.

This study combines household data⁴ and data on PAs⁵. Using linear probability model (LPM), our results suggest that proximity to PAs modifies household’s cooking fuel choices. More specifically, having PAs in a 25 km buffer zone around the household reduces the likelihood of firewood consumption and increases the probability of charcoal consumption. Our results also illustrate that the type of protection offered by the PAs as well as geographical areas around the household are key factors influencing the effect of PAs on households’ choice of cooking fuel.

The remainder of this document is structured as follows: Section 2 will provide a comprehensive review of the literature, focusing on studies of household cooking fuel choices and studies on PAs. Section 3 will detail the data and methodology used, ensuring transparency and reproducibility. Section 4 will present our findings, shedding light on the influence of PAs on household fuel choice. Section 5 will present sensitivity analyses, testing the robustness and heterogeneity of our results. Finally, Section 6 will conclude our analysis by offering practical economic policy recommendations, based on the implications of our findings.

⁴From the Living Standards Measurement Study (LSMS)

⁵From the World Database on Protected Areas (WDPA)

2 Background

This section will present two distinct branches of the literature. We begin by presenting literature on household fuel choices. We proceed to discuss the literature on protected areas (PAs). Finally, our study draws links from these two branches and proposes various hypotheses on the implications of proximity to PAs on household fuel choices.

2.1 Household Fuel choices

Sub-Saharan Africa is plagued with low electrification rate and predominant consumption of biomass in the form of firewood and charcoal (Heltberg, 2005; Choumert-Nkolo et al., 2019; Oweggi, 2023; Gebru and Elofsson, 2023). Except for South Africa, biomass accounts for at least 75% of final energy consumption (Byer, 1987; Hoek-Smit, 1990). However, given the negative impacts of biomass fuel consumption on the various sustainable development goals including health (Zidago et al., 2016), environment (Mwampamba, 2007), gender (Farioli and Dafrallah, 2012; Lee et al., 2024), education (Biswas and Das, 2022), and labor productivity (Mosa et al., 2020), it is more than necessary to reorient towards more sustainable and modern energy sources.

The transition from traditional to modern energy sources was first conceptualized by the “energy ladder” hypothesis (Hosier and Dowd, 1987; Masera et al., 2000; Van der Kroon et al., 2013, 2014; Waleed and Mirza, 2023). This hypothesis argues that an increase in household income is expected to accompany a shift from traditional fuels toward modern fuels. Thus, on one hand, the most affluent households consume modern and clean fuels such as LPG, gas, and electricity and on the other hand, poorer households consume traditional fuels such as firewood. However, recent literature criticizing the energy ladder hypothesis makes a case that, while income is central to the energy transition process, a complete transition towards modern fuels is not often achieved. Instead, households continue the concurrent use of different fuels, a situation referred to as “energy stacking” (Masera et al., 2000; Heltberg, 2004; Broto et al., 2020). The authors identify various other determinants of household fuel choices such as location, size, and household head characteristics including age, gender, education level, and marital status among others.

As stated above, biomass in the form of firewood and charcoal is the main source of cooking fuel in Sub-Saharan African households (Wood and Baldwin, 1985; Sawe, 2012). Firewood and charcoal are different in various ways. First and foremost, firewood is majorly consumed in rural areas while charcoal is majorly consumed in urban areas (Hosier and Dowd, 1987; Girard et al., 2002). Allied to that, firewood is mostly collected by households in close proximity while charcoal enjoys a competitive market (Mwampamba et al., 2013). In addition, (Mwampamba, 2007) illustrates that charcoal consumption poses a significant threat to deforestation compared to firewood consumption due to the much larger volumes of wood involved. Moreover, in the energy stacking hypothesis, firewood is considered a traditional fuel while charcoal is considered a transitional cooking fuel, offering an improvement from traditional sources before finally reaching fuels higher up the ladder such as LPG gas and electricity (Choumert-Nkolo et al., 2019).

2.2 Protected areas (PAs)

PAs ⁶ are one prominent instrument of conservation policies. The establishment of PAs has been historically used for environmental conservation, biodiversity protection, and climate change mitigation (Andam et al., 2008; Dudley, 2008; Kandel et al., 2022). Therefore, important literature has focused on their effectiveness, namely their ability to reduce deforestation (Andam et al., 2008; Feng et al., 2021). For instance, concerning avoided deforestation, various authors find PAs to be effective (Feng et al., 2021) while others find PAs to be non-effective in reducing deforestation (Hayes, 2006; Combes et al., 2023). Other authors highlight that the effectiveness of PAs is contingent on factors such as the degree of forest protection and proximity to human settlements or roads (Pfaff et al., 2015; Combes et al., 2023).

Existing literature has greatly evolved in the study of PAs. Authors noted that previous methods of studying PAs were greatly biased given that PAs were not randomly assigned but rather determined by factors that also contributed to deforestation such

⁶The International Union for Conservation of Nature defines a PA as “an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, natural and associated cultural resources and managed through legal or other effective means”. <https://www.iucn.org/theme/protected-areas/about>.

as land productivity (Andam et al., 2008), highlighting possible biases in previous studies comparing PAs to non-PAs (Schleicher et al., 2020; Feng et al., 2021). Moreover, other authors find that possible biases could come into play if the establishment of PAs produces spillover effects in households in non-protected areas (Armsworth et al., 2006; Schleicher et al., 2020).

Research has broadened the scope since conservation policies can conflict with development policies. Thus, a second branch of literature has highlighted the impact of PAs on household welfare, estimating welfare through factors such as improvements in economic activities, income, and health among others (Vedeld et al., 2012; Canavire-Bacarreza and Hanauer, 2013; Miranda et al., 2016; Puhakka et al., 2020; Kandel et al., 2022). Authors find a positive impact of PAs on public health (Puhakka et al., 2020). Other studies on the nexus between PAs and household income find varying and sometimes conflicting results (Kandel et al., 2022). One stream of literature finds a positive impact (Canavire-Bacarreza and Hanauer, 2013), another a negative impact (Vedeld et al., 2012), and a third, no significant effect of PAs on household income in some regions such as Africa (Miranda et al., 2016; Kandel et al., 2022). The positive impact of PAs on socio-economic outcomes was driven by comanagement regimes that ensured community empowerment and maintenance of cultural and livelihood benefits of PAs (Puhakka et al., 2020).

With increasingly growing global concerns about climate change, reducing deforestation has emerged as a key way for climate mitigation hence, PAs have become key instruments in the discourse on climate action (Gullison et al., 2007). UNEP-WCMC (2021) reports that since 2010, PAs covering about 21 million km^2 have been added, recording a steady increase in areas under protection and accounting for around 16.64% coverage of terrestrial and inland water areas as of 2020. Indeed, such efforts have among other things, increased forest cover and decelerated the rate of deforestation (Andam et al., 2008).

However, as mentioned above, Tanzania like other countries in Sub-Saharan Africa is highly dependent on biomass in the form of firewood and charcoal for cooking. Firewood is often collected by households in rural areas, charcoal, on the other hand, is dependent on cutting trees from forest, and, preferred charcoal (dense and slow-burning) is produced

from slow-growing species of trees that are prone to overharvesting (Chidumayo, 1991; Girard et al., 2002). Charcoal has an existing competitive market in Tanzania worth about USD 650 million which is 5.8 times more than that of the tea and coffee industries combined, as of 2013 (Mwampamba et al., 2013). An analysis of the charcoal production in the East Arc Mountains of Tanzania, establishes that it generates USD 14 million a year which represents a substantial source of income accruing to local households (Schaafsma et al., 2012). Despite the frequently informal status of this trade, it is also a source of revenue for the government (Marandu et al., 2024). Tanzania's charcoal demand is high especially in urban areas (Boberg, 1993) because charcoal provides a cheaper alternative to expensive modern fuels such as electricity and LPG gas (Nyarko et al., 2021), in addition, it is a source of employment for various people working in the charcoal supply chain such as manufacturers, suppliers, and large and small scale traders (Mwampamba et al., 2013). With a growing population, charcoal demand is expected to increase (Mwampamba et al., 2013; Nyarko et al., 2021). As given by the energy stacking hypothesis, charcoal for cooking is still used concurrently with other modern fuels even among wealthier households (Choumert-Nkolo et al., 2019; Oweggi, 2023). For Tanzanian households, a complete energy transition is not yet achievable and the role of charcoal as a household fuel remains of central importance (Boberg, 1993; Girard et al., 2002; Mwampamba, 2007; Mwampamba et al., 2013; Choumert-Nkolo et al., 2019; Nyarko et al., 2021).

In this context, literature has analyzed the implications of charcoal consumption on forest resources (Girard et al., 2002; Mwampamba, 2007). Girard et al. (2002) proposes the view that charcoal consumption could pose serious threats to forest resources in Africa if there is a growing charcoal demand fueled by the rising urban population, coupled with the lack of proper forest management practices and regulations. Other authors find that charcoal consumption could threaten the long-term persistence of forests in Tanzania if: median charcoal consumption levels are maintained, production uses low kiln efficiencies, and when harvested forests are not sufficiently replenished (Mwampamba, 2007). In addition, in the absence of affordable modern fuel substitutes, charcoal consumption is likely to exert pressure on forest resources and likely contribute to deforestation.

Most forests in Tanzania are under the IUCN PAs classification ⁷. However, the literature shows contrasting results. On the one side, [Mwampamba \(2007\)](#) finds that illegal harvesting of forest resources remains very common. On the other hand, [McNicol et al. \(2023\)](#) finds that protection has a positive effect on above-ground carbon (AGC) with stocks increasing faster in PAs compared to non-protected areas. The authors also find no clear evidence between strict PAs versus non-strict PAs. Furthermore, [Riggio et al. \(2019\)](#) find that PAs are the only places where land has not been converted, exemplified by areas around the Moyowosi-Kigosi Game Reserve complex in northwest Tanzania, the western boundary of Serengeti National Park in northern Tanzania, and in Burundi, Rwanda, and Uganda. Against this background, our study seeks to analyze the implications of PAs on biomass consumption. More specifically, we wish to estimate the implications of proximity to PAs on household cooking fuel choices. We concentrate on cooking fuels exemplified by firewood and charcoal as these are the most dependent on forest resources. We separate firewood from charcoal and study them independently as literature shows that by combining the two groups, studies undermine the individual impact of charcoal on forests and PAs ([Mwampamba, 2007](#)).

We postulate two distinct predictions, first, proximity to PAs would effectively reduce firewood consumption. We base this hypothesis on the assumption that the establishment of PAs, would reinforce property rights and signal households to no longer freely collect firewood from the PAs, effectively reducing the consumption of firewood. In our second hypothesis, we predict that proximity to PAs will increase the consumption of charcoal. We base this argument on three factors. First, charcoal remains the closest substitute for firewood given its affordable nature and given the fact that modern fuels such as electricity and LPG gas remain expensive to a great majority of the population ([Choumert-Nkolo et al., 2019](#)). Second, the charcoal market in Tanzania is competitive with multiple players such as producers, transporters, and vendors hence, charcoal from non-protected areas can be transported and consumed near PAs ([Boberg, 1993](#); [Nyarko et al., 2021](#)). Third, given the widespread and uncontrolled illegal harvesting of forests, a large-scale charcoal supply chain is sustained, ensuring continued charcoal provision despite the establishment or existence of PAs ([Mwampamba, 2007](#)).

⁷<https://www.iucn.org/content/protected-area-categories>

3 Data and Methodology

The following section will outline various data sources used and discuss the empirical methodology applied in the study.

3.1 Data

Our study combines household-level characteristics with data on PAs and data on forest cover to analyze the implications of proximity to PAs on household fuel choices.

3.1.1 Data sources

Household characteristics under study are derived from the Tanzania National Panel Survey (TNPS) provided by the World Bank Living Standard Measurement Survey (LSMS) over three waves, 2008/2009, 2010/2011, and 2012/2013. TNPS report 2017 states that in survey waves succeeding 2012/2013, the sample design was revisited, and the sample was refreshed, making it impossible to create panel data with succeeding waves. The study is therefore restricted to the three waves. The dataset is a balanced panel dataset of 3088 households followed over the three waves. The dataset outlines cooking fuels majorly used by households and also gives detailed data on other household characteristics, making it suitable for the study of household fuel choices.

Data on PAs is derived from the World Database on Protected Areas (WDPA). The TNPS provides household geocoded data, making it possible to join the point coordinates of WDPA and TNPS datasets using the software QGIS. Following existing literature (see among others: [Kotsadam and Tolonen, 2016](#); [Knutsen et al., 2017](#); [Wegenast and Beck, 2020](#)) we calculate 25 km buffer zones around the centroids of the households. From the WDPA data, we capture PAs within the 25 km buffer zones. Using the same tools and logic, from the Copernicus land cover database we construct one of our control variables - Total forest cover.

3.1.2 Variables of study

Household cooking fuel choices are the dependent variables of the study and are captured by dummy variables. Indeed, Tanzanian households are still highly reliant on biomass fuels in the form of firewood and charcoal (Choumert-Nkolo et al., 2019). Hence the first dependent variable represents firewood consumption and takes 1 if the household consumes firewood and 0 otherwise. The second dependent variable represents charcoal consumption and takes 1 if the household consumes charcoal and zero otherwise. Previous studies (see among others Choumert-Nkolo et al., 2019; Oweggi, 2023) use a multivariate classification of fuel choice with firewood as a traditional fuel taking the value 1, charcoal as a transitional fuel taking 2, and modern fuels such as electricity and gas take the value 3. Indeed this classification alludes to the energy ladder hypothesis which views household fuel choice as linearly correlated to income (Leach, 1992). This is however not suitable for our study for the following reasons. First, our study concentrates on cooking fuel choices, and literature (Choumert-Nkolo et al., 2019) shows that Tanzanian households are highly dependent on biomass for cooking. Indeed, around 70 % of households in our sample use firewood, 25% use charcoal, 0.4% use electricity, 1.3% use LPG, 2.3% use kerosene whereas other forms of cooking fuels such as animal residue and biogas account for less than 1% of cooking fuels.

The independent variable of interest measures the proximity of households to a PAs. As stated above, the variable captures PAs in a 25 km buffer zone around the centroid of a household. More precisely, the variable is a dummy variable that takes 1 if there is at least one PA in the 25 km buffer zone. The 25 km threshold is borrowed from existing literature on natural resource extraction and consumption (Kotsadam and Tolonen, 2016; Knutsen et al., 2017; Wegenast and Beck, 2020).

Following existing literature (see Hosier and Dowd, 1987; Leach, 1992; Choumert-Nkolo et al., 2019; Oweggi, 2023), we add variables that could influence household fuel choices such as household adult equivalent income, household size, household head's age, head's education level, head's gender, head's marital status and distance to district headquarters. Literature finds that proximity to forests influences household fuel choices by increasing firewood consumption compared to charcoal consumption (Win et al.,

2018). To control for this effect, we add total forest cover within a 25 km buffer of households. Table 1 provides definitions and sources of variables of the study, while Table 2 provides descriptive statistics.

Table 1: Definitions and sources of variables

Variables	Nature	Description	Source
Dependent variables			
Firewood	Dummy	Takes 1 if the household consumes firewood	TNPS
Charcoal	Dummy	Takes 1 if the household consumes charcoal	TNPS
Independent variable			
Protected Area	Dummy	Takes 1 if there is a protected area within a 25 km buffer around the household	WDPA
Control variables			
Log real per adult equivalent expenditure	Continuous	Total real annual household consumption expenditure divided by adult equivalent members	TNPS
Household Size	Continuous	Number of household members	TNPS
Household head's age	Continuous	The age of the household head in years	TNPS
Household head's gender	Dummy	Takes 1 if household head is male	TNPS
Household head's marital status	Dummy	Takes 1 if household head is married	TNPS
Distance to district headquarters	Continuous	Distance from household to district headquarters in kilometers	TNPS
Total Forest cover	Continuous	Total surface area covered by forests in the 25 km buffer around the household	Copernicus Land Service
Less than Primary school	Dummy	Takes 1 if the household head has less than primary school education	TNPS
Primary school	Dummy	Takes 1 if household head completed primary school	TNPS
Junior secondary school	Dummy	Takes 1 if household head completed junior secondary school	TNPS
Senior secondary school	Dummy	Takes 1 if household head completed senior secondary school	TNPS
Tertiary school	Dummy	Takes 1 if the household head has completed tertiary school	TNPS
Additional Control variables			
Employment in agriculture	Dummy	Takes 1 if the household head is employed in the agricultural sector	TNPS
Total shocks	Continuous	Total count of shocks experienced by a household	TNPS
Covariate shocks	Dummy	Takes 1 if household experienced: drought, famine, crop disease, pests, large fall/rise in prices of -crops, food or agricultural input	TNPS
Agroecological zones	Dummy	Takes 1 if the household is located in a tropical cool climate	TNPS

3.2 Descriptive statistics

Descriptive statistics from our study support the stylized facts presented from existing literature. For instance, figure 1 shows a predominance of traditional energy sources exemplified by firewood consumption at around 70%, and charcoal consumption at 25%. Other household fuels depict little to no consumption in Tanzania. Figure 2 also provides evidence that firewood is the main household cooking fuel in rural areas, accounting for 93% of cooking fuels in rural areas. In contrast, charcoal constitutes the most commonly used fuel in urban, accounting for 61% of cooking fuels in urban areas.

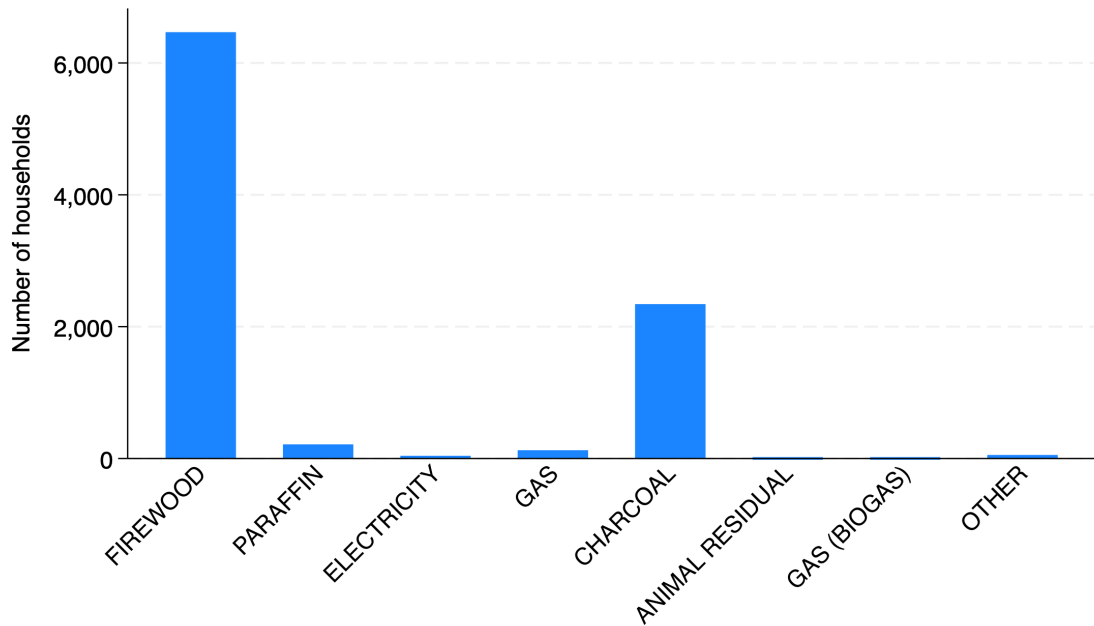


Figure 1: Graph showing the number of households using each fuel.
Source: Authors' compilation from LSMS

To provide a clear picture, we proceed to map PAs and households in our study sample as depicted in figure 3. The map clearly shows a strong presence of forest protection in Tanzania. Furthermore, the map illustrates that many households are in close proximity to PAs. It can be claimed, therefore, that this broad protection leads to great interaction between PAs and households since some households are even located inside PAs. This reinforces our intuition that PAs can influence household cooking fuel choices.

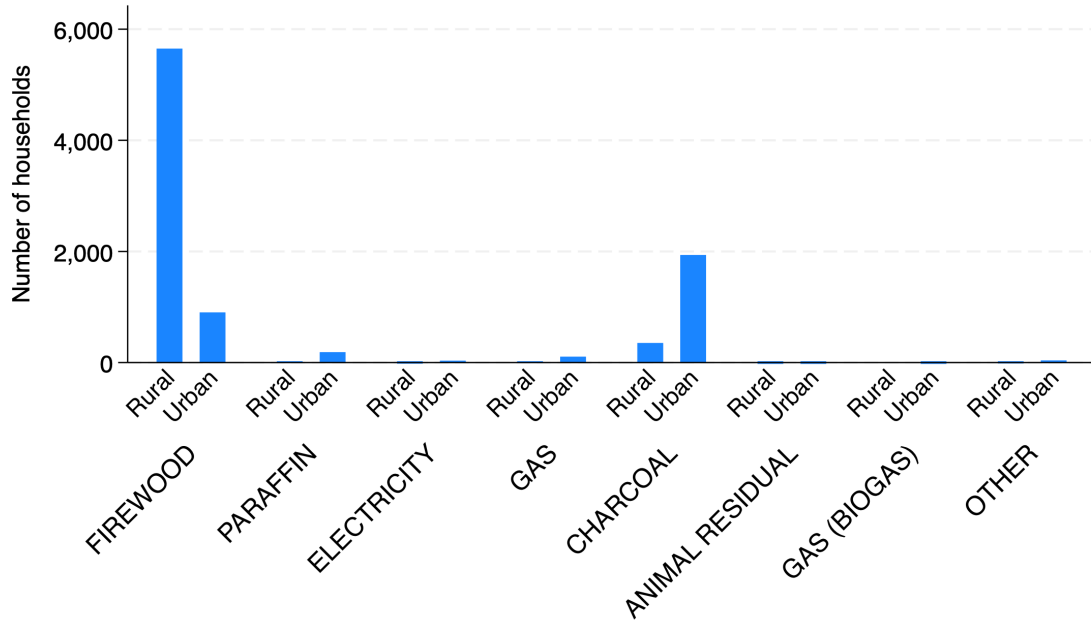


Figure 2: Graph showing the number of households using each fuel in rural and urban areas.

Source: LSMS and authors' calculation

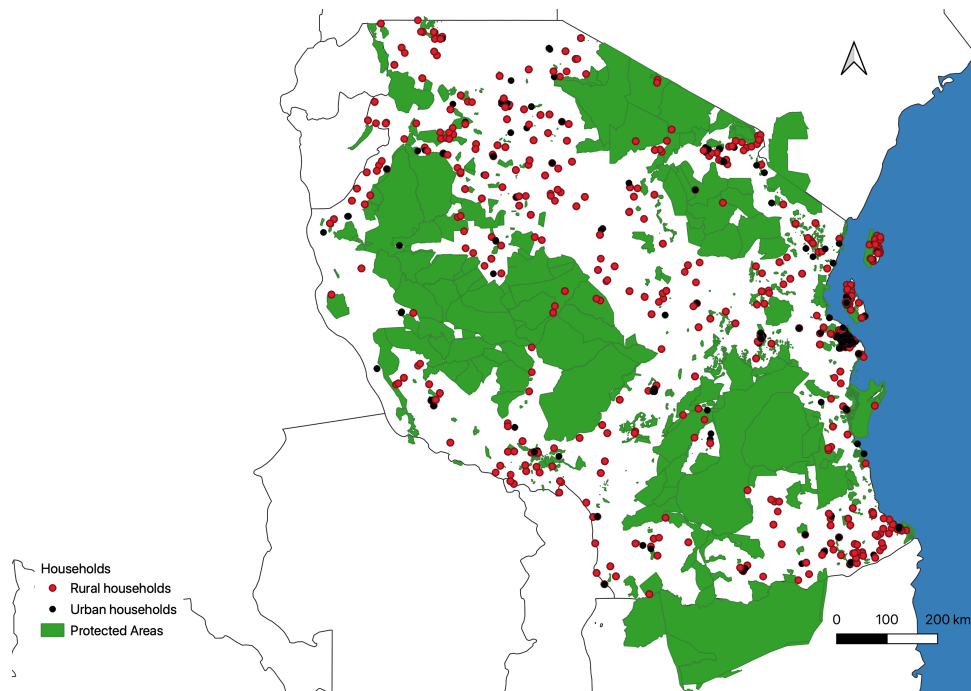


Figure 3: Map showing the position of households and protected areas.

Sources: LSMS, WDPA and authors' calculation

Table 2: Yearly summary statistics of explanatory and outcome variables

Variable	2008/2009					2010/2011					2012/2013				
	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N
Explanatory Variables															
Household Characteristics															
Primary School	0.14	0.34	0	1	3088	0.13	0.34	0	1	3088	0.15	0.36	0	1	3088
Junior secondary school	0.01	0.07	0	1	3088	0.01	0.08	0	1	3088	0.01	0.08	0	1	3088
Senior Secondary school	0.01	0.11	0	1	3088	0.01	0.11	0	1	3088	0.01	0.12	0	1	3088
Tertiary school	0.01	0.06	0	1	3088	0.01	0.06	0	1	3088	0.01	0.08	0	1	3088
Household head's age	46.15	15.41	18	102	3088	47.99	15.20	16	105	3088	49.53	15.8	17	107	3087
Household head's gender	0.76	0.43	0	1	3088	0.76	0.43	0	1	3088	0.76	0.43	0	1	3088
Household head's marital status	2.57	2.15	1	7	3049	2.66	2.13	1	7	3075	2.61	2.16	1	7	3073
Household size	5.08	2.84	1	46	3088	5.08	2.84	1	46	3088	5.20	2.90	1	23	3066
Socio-economic status indicators															
Log per-adult-eq. expend.	13.24	0.71	10.75	16.54	3088	13.24	0.71	10.75	16.64	3088	13.65	0.72	10.68	16.72	3066
Employment in agriculture	0.59	0.49	0	1	3088	0.58	0.49	0	1	3088	0.55	0.50	0	1	3088
Total shock	3.5	2.04	1	12	2796	3.18	2.06	1	14	2607	2.13	2.04	0	11	3088
Covariate shock	1.79	1.36	0	5	2796	1.60	1.40	0	5	2607	5	0	5	5	3088
Locational characteristics															
Urban household	0.35	0.48	0	1	3088	0.35	0.47	0	1	3088	0.34	0.47	0	1	3088
Total Forest cover	7.43	0.40	5.80	8.12	2830	7.43	0.39	5.85	8.15	3086	9.74	19.31	0	63	3059
Agroecological zones	0.26	0.44	0	1	3088	0.28	0.45	0	1	3088	0.28	0.45	0	1	3088
Distance to district headquarters	3.47	1.38	-1.30	7.37	2830	3.47	1.38	-1.30	7.74	3086	3.47	1.36	-1.30	7.37	3071
Dependent variables															
Firewood	0.72	0.45	0	1	3088	0.70	0.46	0	1	3088	0.67	0.47	0	1	3088
Charcoal	0.23	0.42	0	1	3088	0.25	0.43	0	1	3088	0.28	0.45	0	1	3088
Independent variable															
Protected Area	0.88	0.32	0	1	2.830	0.88	0.33	0	1	3086	0.88	0.32	0	1	3072

3.3 Methodology

We analyze the implications of proximity to PAs on household cooking fuel choices. Given the binary nature of our dependent variables (dummy variables that capture household cooking fuel choices- firewood or charcoal) existing literature recommends suitable models of binary choices such as logit, probit, and linear probability models (LPM).

Considering that the study is a panel analysis, composed of households located in different geographical areas of the country over a span of time, the inclusion of time-fixed effects (FE) would allow us to control for time-invariant unobserved or omitted variables (Wooldridge, 2010). However, fixed effects estimators of binary models such as logit and probit are often not ideal (Bambe et al., 2024). To begin with, large sets of fixed effects could give inconsistent slope estimates owing to incidental parameter problem (Neyman and Scott, 1948; Wooldridge, 2010). Second, fixed effects estimators would exclude from the analysis, all observations for which proximity to PAs perfectly predicts household fuel choice outcome (Zorn, 2005; Belloc et al., 2016). Even when the

incidental parameter problem is corrected for, such as by the introduction of conditional logit estimator, the estimator still does not report fixed effects, cannot estimate partial or marginal effects, and is not available for probit models (Stammann et al., 2016; Cruz-Gonzalez et al., 2017). Indeed, literature highlights that a major limitation of LPM is that the functional form of LPM estimators does not correctly account for the non-linear relationship inherently found between a discrete choice outcome and a continuous explanatory variable (Greene, 2003; Wooldridge, 2010; Deke, 2014). However, this limitation is actually an advantage in our study because, our independent variable -proximity to PAs, is equally a binary variable, hence, the study assumes the form of an impact evaluation. Literature (see e.g (Wooldridge (2010); Deke (2014))) finds that LPM is highly favorable in impact evaluation studies and if both the dependent and independent variables are discrete choice variables. Consequently, the LPM model remains the most suitable for our analysis and allows for the estimation of time and regional FE and, accounts for the panel structure of our analysis.

The econometric specification we estimate is the following:

$$Firewood_{i,j,t} = \alpha + \beta ProtectedArea_{j,t} + \delta X_{i,j,t} + \phi_j + \psi_t + \epsilon_{i,j,t} \quad (1)$$

$$Charcoal_{i,j,t} = \alpha' + \beta' ProtectedArea_{j,t} + \delta' X_{i,j,t} + \phi'_j + \psi'_t + \epsilon'_{i,j,t} \quad (2)$$

with households: $i=1, \dots, 3088$, regions: $j=1, \dots, 7$ ⁸ and waves: $t=1, \dots, 3$

Where in equation (1), $Firewood_{i,j,t}$ is a dummy variable that captures household cooking fuel choice and is equal to 1 if the household i located in the region j , uses firewood in the year t , and 0 otherwise. In equation (2), the same logic applies as in equation(1), albeit, $Charcoal_{i,j,t}$ captures the use of charcoal.

$ProtectedArea_{k,t}$ is the variable of interest that is expressed as a dummy variable that takes 1 if there is a presence of a protected area (PA) in a 25 km buffer zone from a household and 0 otherwise. Following existing literature (see among others Kotsadam and Tolonen, 2016; Knutsen et al., 2017; Wegenast and Beck, 2020), we settle for 25km

⁸The seven regions include: Central, Coastal, Lake, Northern, Southern highlands, Western and Zanzibar, with Central as the base of reference.

as a baseline distance considering the following factors. First, we assume that given an average walking pace of 5km/h, it would take 5 hours a day to cover the 25km distance to the PAs, this distance remains wide even when using bicycles and motorcycles. Second, our study preferred the 25km distance as it is large enough to capture possible spillover effects that could arise if the cutoff distance from household to PAs is much smaller (Shen et al., 2022).

$X_{i,j,t}$ is a set of household characteristics presented in Tables 1 and 2 and described in Section 3.1 including adult equivalent expenditure, household size, distance to district headquarters, total forest cover, household head’s -gender, age, marital status, and level of education.

Literature on Tanzania uses either administrative regions and districts or geographical regions and zones (see among others Choumert-Nkolo et al., 2019). Tanzania has 31 administrative regions (26 in mainland and 5 in Zanzibar) but the Tanzania demographic health survey (2022) states that “grouping of regions into zones allows for larger denominators and smaller sampling errors for indicators at the zonal level”. Following this context, our study uses 7 geographical zones or regions: Central, Coastal, Lake, Northern, Southern highlands, Western, and Zanzibar regions (Tanzania demographic health survey, 2022) as presented in appendix — Table 11. Region fixed effects estimators take into consideration some unobserved differences in regions that may be correlated with household proximity to PAs and the likelihood of a household choosing a specific fuel type (firewood or charcoal). ϕ_j therefore accounts for these region-fixed effects. On the other hand, ψ_t accounts for time-fixed effects which take care of any simultaneous changes in PAs that may influence the likelihood of a household to choose a specific fuel for cooking. Lastly, $\epsilon_{i,j,t}$ is the idiosyncratic error term.

4 Main findings

Table 3 reports the results of our main model from LPM estimates. Columns “firewood” and “charcoal” represent equations 1 and 2 respectively throughout the paper. Indeed, we began by estimating a model without FE (the results are reported in the appendix – Table 9 to save space). The results suggest that proximity to PAs reduces the probability

of using firewood by 3.7% and increases the probability of using charcoal by 2.3%. Following existing literature ([Bambe et al., 2024](#)), the exclusion of fixed effects could lead to biased estimates. The inclusion of FE - as in our main model increases the effects of proximity to PAs on both firewood (from 3.7 to 4.3%) and charcoal (from 2.3 to 3.6%) respectively. Moreover, the inclusion of FE also improves the goodness of fit, exemplified by the increase in R squared from 42.7% to 47.9% for firewood and from 31% to 36.6% for charcoal.

Columns [1-2] presents our baseline model with region and year fixed effects. Our main results with FE suggest that proximity to PAs is negatively correlated to the consumption of firewood and positively correlated with the consumption of charcoal. More precisely, having PAs in the 25 km buffer zone around the centroid of a household reduces the probability of households choosing firewood for cooking by approximately 4.3% while it increases the probability of choosing charcoal by 3.6%.

Our results accentuate the risk of jointly studying firewood and charcoal in one broad category as biomass. Indeed, in the TNPS, all other household fuels were bought except firewood, suggesting that firewood was more often collected than bought in Tanzania. The establishment of PAs could therefore minimize the simple firewood collection by individuals, however, tradable charcoal could still be consumed. From our initial hypothesis, we posit that charcoal consumption could continue even in the face of protection as it is the nearest and cheapest substitute to firewood, second, the charcoal market in Tanzania is vast and competitive. Charcoal can be transported from one region to another, allowing for continued use of charcoal with the establishment of a PAs. Finally, in the face of illegal logging and poor PAs regulations, large-scale and organized charcoal enterprises could still participate in the market and maintain charcoal consumption. The substitution of firewood for charcoal can be interpreted as displaced deforestation: the protected area discourages households living nearby from exploiting the forest resource. But the increased use of charcoal increases the pressure on the forest resources overall. Charcoal markets could be considered as a distance driver of deforestation.

Regarding our control variables, our results show that an increase in household income has a negative correlation with firewood and a positive correlation with charcoal. These results give evidence for the energy ladder hypothesis (see among others [Hosier](#)

and Dowd, 1987; Leach, 1992) which posits that an increase in household income would lead households to choose fuels higher up the energy ladder. Indeed, our results corroborate previous findings (see e.g. Choumert-Nkolo et al., 2019; Oweggi, 2023) which find that due to the limited use of modern cooking fuels, charcoal as a transitional fuel is still used among rich households in some developing countries.

Turning to other control variables, our results find that households with heads that are older or married were more likely to use firewood. The same applies to households in proximity to larger forest covers and households located far from district headquarters, probably because these households are further away from markets. On the other hand, using “less than primary as a base of references” higher levels of education reduced the likelihood of using firewood, suggesting that education could improve fuel choice. With regards to charcoal consumption, our results find that households with older heads, male heads, closer to larger forest cover, and further from district headquarters were less likely to choose charcoal. In contrast, households with primary education and larger households were more likely to use charcoal.

Table 3: Main Model with Linear Probability Model and additional control robustness

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Firewood	Charcoal	Firewood	Charcoal	Firewood	Charcoal	Firewood	Charcoal
Protected Area	-0.0408*** (0.0108)	0.0344*** (0.0111)	-0.0420*** (0.0107)	0.0350*** (0.0110)	-0.0370*** (0.0112)	0.0321*** (0.0114)	-0.0367*** (0.0111)	0.0317*** (0.0114)
Forest	0.1956*** (0.0162)	-0.1537*** (0.0149)	0.2059*** (0.0166)	-0.1594*** (0.0152)	0.1888*** (0.0171)	-0.1498*** (0.0157)	0.1808*** (0.0171)	-0.1427*** (0.0157)
Log Real-AEE	-0.1888*** (0.0069)	0.1433*** (0.0073)	-0.1879*** (0.0069)	0.1428*** (0.0073)	-0.1915*** (0.0071)	0.1469*** (0.0077)	-0.1898*** (0.0071)	0.1458*** (0.0076)
Male Head	-0.0114 (0.0131)	-0.0528*** (0.0138)	-0.0111 (0.0131)	-0.0529*** (0.0138)	-0.0131 (0.0136)	-0.0514*** (0.0144)	-0.0128 (0.0136)	-0.0513*** (0.0143)
Head age	0.0037*** (0.0002)	-0.0029*** (0.0002)	0.0037*** (0.0002)	-0.0029*** (0.0002)	0.0037*** (0.0002)	-0.0029*** (0.0002)	0.0037*** (0.0002)	-0.0028*** (0.0002)
Head married	0.0665*** (0.0135)	0.0137 (0.0144)	0.0662*** (0.0135)	0.0139 (0.0144)	0.0668*** (0.0140)	0.0157 (0.0150)	0.0621*** (0.0140)	0.0195 (0.0150)
Primary	-0.1549*** (0.0172)	0.1121*** (0.0198)	-0.1561*** (0.0172)	0.1128*** (0.0198)	-0.1432*** (0.0176)	0.0974*** (0.0203)	-0.1431*** (0.0174)	0.0969*** (0.0201)
Junior secondary	-0.1145 (0.0746)	0.1250 (0.0798)	-0.1143 (0.0745)	0.1249 (0.0798)	-0.1172 (0.0760)	0.1230 (0.0818)	-0.1230* (0.0745)	0.1279 (0.0805)
Senior secondary	-0.2471*** (0.0324)	0.0921 (0.0630)	-0.2459*** (0.0327)	0.0914 (0.0629)	-0.2203*** (0.0353)	0.0761 (0.0663)	-0.2222*** (0.0356)	0.0769 (0.0669)
Tertiary education	-0.2152*** (0.0330)	-0.0930 (0.0891)	-0.2119*** (0.0339)	-0.0949 (0.0893)	-0.2006*** (0.0328)	-0.1168 (0.0945)	-0.2092*** (0.0322)	-0.1101 (0.0948)
HH size	-0.0001 (0.0014)	0.0025* (0.0014)	-0.0000 (0.0014)	0.0025* (0.0014)	-0.0002 (0.0014)	0.0023 (0.0014)	-0.0001 (0.0014)	0.0024* (0.0014)
Logdisthqdistrict	0.1103*** (0.0040)	-0.1037*** (0.0042)	0.1097*** (0.0040)	-0.1034*** (0.0042)	0.1095*** (0.0042)	-0.1029*** (0.0044)	0.1075*** (0.0042)	-0.1010*** (0.0044)
Tropicalcool			-0.0329*** (0.0091)	0.0184** (0.0090)				
Shock					0.0113*** (0.0020)	-0.0084*** (0.0020)		
Covariateshocks							0.0324*** (0.0033)	-0.0281*** (0.0032)
Observations	8965	8965	8965	8965	8196	8196	8196	8196
R^2	0.4791	0.3657	0.4802	0.3661	0.4878	0.3705	0.4923	0.3749
Regional & Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table reports the results of the impact of proximity to PAs on cooking fuel choices. Columns [1-2] display the baseline results, estimated from the linear probability model (LPM). Columns [3-8] include additional controls. Robust standard errors are reported in parentheses. The constant is included, but not reported in the table. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5 Sensitivity

This section outlines sensitivity measures, highlighting various robustness and heterogeneity tests estimated in our study.

5.1 Robustness

We undertook a series of tests to demonstrate the robustness of our results and to confirm the accuracy of the estimates made in the main model. These are discussed below.

5.1.1 Additional controls

The first robustness analysis that we implement is that of adding control variables, to ensure the stability of the coefficients. To this end, we successively included the variables “tropical cool” “shock,” and “covariate shocks” as additional control variables. The “tropical cool” variable controls the effect that may come from the agroecological zone to which the household belongs. With regards to shocks, literature (Oweggi, 2023) finds that shocks can modify household energy choices and force households to choose fuels lower down the energy ladder. More precisely, shocks can induce a sub-optimal allocation of household resources, which is likely to deteriorate the consumption behavior of both food and other goods such as household energy (Oweggi, 2023). In addition, shocks affecting groups of households can reduce accessibility to markets or create a scarcity of energy sources, thus impacting their consumption (Sawada et al., 2009). The TNPS provides household self-declared shocks. We, therefore, used two shock variables to control for these effects. The first variable, “shock” captures aggregate total shocks without any specific distinction, and the second variable, “covariate shocks” only captures shocks affecting household groups simultaneously.

Accounting for additional controls as illustrated in table 3, column [3-8] does not alter the results of our baseline model. We also find that households in tropical cool areas are less likely to choose firewood. A possible explanation could be that tropical cool areas receive more rainfall and literature suggests that during rainy seasons, the consumption of firewood declines as firewood can only be used when dry (Chidumayo, 2001;

Nyarko et al., 2021). Moreover, our shock variables corroborate the results from existing literature (Oweggi, 2023). Indeed, total aggregate shocks experienced by households increase the probability of households to consume firewood and reduce their probability to consume charcoal. This effect seems to be driven by covariate shocks which produce similar effects to total shocks.

5.1.2 Alternative Models

The second stream of robustness tests involves using alternative estimators.

Logit and probit models. Indeed, our dependent variables are binary. They take the unit value when using firewood or charcoal as a cooking fuel. This property dictates that appropriate binary choice models should be applied as described in Section 3.3. Our study applies LPM as the main model. Despite its desirability when using Fixed effects and its ease of interpretation, it has shortcomings nonetheless. A major criticism of the LPM model is that it can give probability values less than 0 for low levels of our variable of interest and probability values greater than 1 for high levels of the variable of interest (Greene, 2003; Wooldridge, 2010). The solution is to restrict the probability values between 0 and 1, a condition perfectly met by probit and logit models.

Moreover, with the linear probability model, the error terms are heteroscedastic and do not follow a normal distribution but rather a binomial distribution (Greene, 2003; Angrist and Pischke, 2009; Wooldridge, 2010). This however has been overcome in our model through the application of robust standard errors (Angrist and Pischke, 2009). Following this logic, therefore, we apply fixed-effects logit and probit models for robustness purposes and report marginal estimates for ease of interpretation.

Table 4: Alternative Model with Entropy Balancing ,Logit and Probit

	EB		Logit		Probit	
	(1)	(2)	(3)	(4)	(5)	(6)
	Firewood	Charcoal	Firewood	Charcoal	Firewood	Charcoal
Protected Area	-0.0999*** (0.0187)	0.0799*** (0.0193)	-0.0363*** (0.0106)	0.0314*** (0.0110)	-0.0406*** (0.0111)	0.0342*** (0.0114)
Forest	0.1554*** (0.0177)	-0.1094*** (0.0184)	0.1219*** (0.0151)	-0.0883*** (0.0127)	0.1245*** (0.0144)	-0.0978*** (0.0129)
Log Real-AEE	-0.2174*** (0.0141)	0.1685*** (0.0189)	-0.1495*** (0.0060)	0.1151*** (0.0067)	-0.1500*** (0.0063)	0.1127*** (0.0067)
Male head	-0.0255 (0.0164)	-0.0368* (0.0214)	-0.0038 (0.0121)	-0.0598*** (0.0128)	-0.0026 (0.0131)	-0.0557*** (0.0133)
Head age	0.0031*** (0.0006)	-0.0023*** (0.0006)	0.0032*** (0.0003)	-0.0025*** (0.0003)	0.0033*** (0.0003)	-0.0026*** (0.0003)
Married	0.0542*** (0.0175)	0.0247 (0.0205)	0.0519*** (0.0118)	0.0261** (0.0131)	0.0555*** (0.0128)	0.0171 (0.0134)
Primary	-0.1495*** (0.0256)	0.1345*** (0.0287)	-0.0747*** (0.0120)	0.0483*** (0.0131)	-0.0841*** (0.0123)	0.0524*** (0.0132)
Juniorsecondary	-0.0679 (0.1335)	0.1071 (0.1434)	-0.0100 (0.0402)	0.0277 (0.0424)	-0.0161 (0.0398)	0.0329 (0.0418)
Seniorsecondary	-0.2918*** (0.0454)	0.0847 (0.0971)	-0.1574*** (0.0369)	0.0122 (0.0398)	-0.1701*** (0.0391)	0.0152 (0.0370)
Tertiaryeducation	-0.2488*** (0.0405)	-0.0803 (0.0879)	-0.1961*** (0.0606)	-0.1003** (0.0415)	-0.2125*** (0.0684)	-0.0867** (0.0432)
HH size	0.0020 (0.0035)	0.0014 (0.0037)	-0.0013 (0.0012)	0.0031** (0.0013)	-0.0009 (0.0013)	0.0026* (0.0014)
Logdisthqdistrict	0.1247*** (0.0076)	-0.1236*** (0.0078)	0.0735*** (0.0025)	-0.0748*** (0.0027)	0.0744*** (0.0027)	-0.0741*** (0.0028)
N	8963	8963	8963	8963	8963	8963
R^2	0.5248	0.4173				
McFadden's Pseudo R^2			0.4936	0.3826	0.4855	0.3771
Regional & Wave FE	Yes	Yes	Yes	Yes	Yes	Yes

This table reports the re-estimates of the baseline model using Entropy balancing, Logit, and probit models. Column [1-2] displays the estimates from the Entropy balancing Model (EB), and Columns [3-4] and [4-5] report estimates from logit and probit models respectively (the coefficients reported are marginal effects). Robust standard errors are reported in parentheses. The constant is included, but not reported in the table. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Entropy balancing model. This study relies on household data that is largely self-declared leading to possible endogeneity problems that could arise from the omitted variable bias, self-selection bias, measurement errors, or simultaneous causality, factors that if not corrected, could lead to inaccurate and biased estimates in our results (Wooldridge, 1996).

First and foremost, we pose a critical question – Do households close to PAs differ significantly in characteristics from those further away? We find that indeed, using two sample T-tests (see in the appendix, Table 10), there is a significant difference in the mean of households with PAs in the 25 km buffer zone from the centroid of the house (for the sake of simplicity, we refer to these households as G households) compared to those without PAs in their 25 km buffer zone (referred to as D households). For instance, G households have higher mean adult equivalent expenditures and consume more charcoal compared to D households. G households also have lower mean firewood consumption and smaller household sizes compared to D households, signaling possible overt bias.

Our main model (LPM) corrects for the omitted variable bias by adding additional controls, while fixed effects correct for time-invariant endogeneity issues. However, the omitted variable bias could persist in case some unobserved factors influence household fuel choices. In addition, reverse causality could arise in case there exists a reciprocal causal relationship between household fuel choice and proximity to PAs. Allied to that, (Wooldridge, 2010) illustrates that self-selection could occur if there exists a correlation between explanatory variables and some unobserved variables. In our case, self-selection bias could occur if household proximity to PAs is influenced by unobserved economic and non-economic factors. For instance, households could choose to migrate to be in closer proximity to PAs for economic activities such as resource harvesting or to find employment. Non-economic factors could be underscored by personal preferences for environmental quality near PAs.

Recall, our interest variable is PAs and our dependent variables are household fuel choices. We now wish to observe the effect of our control variables on our interest variable. We proceed to regress PAs on our control variables. A LPM that estimates the effects of our control variables on PAs suggests that some of our controls such as adult equivalent household income, age of head, head with tertiary education, distance

to district headquarters, and total forest cover, positively influence the probability of being near PAs. Existing literature ([Andam et al., 2008](#)) suggests that if proximity to PAs is influenced by control variables that also, in the first place (our main model), influence fuel choices, we should apply methods that estimate cause-effect relationships with nonexperimental data that allow for matching. Given this context, literature (see among others e.g. [Andam et al., 2008](#); [Hainmueller, 2012](#); [Zhao and Percival, 2017](#)) suggests the use of impact analysis models and the application of covariate balance for estimating causal effects.

We estimate our third alternative model - entropy balancing (EB). EB is a multistage data processing technique that uses a reweighting system ([Hainmueller, 2012](#)). EB is a suitable alternative model for our study as it creates balanced samples by including covariate balance into the weight function applied to the sample units. Through this mechanism, EB generates more information in the processed data and can construct sufficient counterfactuals that match the observed outcomes ([Hainmueller and Xu, 2013](#)). In effect, EB imitates random assignment through the ex-post construction of a control group ([Andam et al., 2008](#)). Moreover, EB is non-parametric, minimizing parametric assumptions. It equally allows for the addition of region and time FE.

Table 4 reports the results of our alternative models - logit, probit, and entropy balancing models. All three models find evidence that proximity to PAs reduces the use of firewood and increases the use of charcoal. In the logit and probit models, proximity to PAs reduces the consumption of firewood by 3.6% and 4.1% respectively, while increasing the use of charcoal by 3.1% and 3.4% respectively. Results from our main model have slightly larger effects potentially due to the possibility that LPM captures better, the wave and region FE, nonetheless, these results robustly support our main model.

Furthermore, the results from the entropy balancing model reiterate our main results. Proximity to PA reduces the likelihood of choosing firewood by 10% and increases the probability of using charcoal by 8%. Existing literature suggests that, unlike observable bias (corrected through the application of EB in our study), a hidden bias is often not recorded or observed ([Oster, 2019](#); [Rosenbaum and Rosenbaum, 2002](#)). We, therefore, apply Oster's method ([Oster, 2019](#)) to estimate how much a hidden bias, if any exists, compromises our estimates. The exercise involves identifying the value of delta, which

indicates a potential risk of bias from unobserved variables if the absolute value lies between 0-1, and no risks if the absolute value of delta is large. For our dependent variables firewood and charcoal, we find delta values greater than 1 i.e. 2.1 for firewood and 1.1 for charcoal respectively, suggesting that our results are not affected by hidden or omitted variable bias. We conclude that our results are robust to various measures and that proximity to PAs reduces the likelihood of firewood consumption and increases the likelihood of charcoal consumption.

5.1.3 Alternative Measures of Proximity to Protected Areas (PA)

We re-estimate our main model with an alternative measure of proximity to PAs based on different thresholds, 15 km and 50 km to the nearest PAs from households. The estimates presented in Table 5 corroborate our main results, indeed, the closer a household is (in Km) to a PA, the less likely they are to choose firewood and more likely to choose charcoal. More precisely, we find significant results for 15 km and no significant results for the 50 km distance. The results suggest that larger distances such as 50 km from household to PAs did not influence household fuel choices. Moreover, these results confirm our earlier assumption that the baseline distance of 25 km allows for the absorption of spillover effects. Indeed, the effects at 15 km are 1.7% and 1.4% larger for firewood and charcoal respectively in comparison to those at 25 km. Moreover, the effects disappear at 50 km.

Table 5: Alternative thresholds of distance to protected areas

	15 km		50 km	
	(1)	(2)	(3)	(4)
	Firewood	Charcoal	Firewood	Charcoal
15 Km	-0.0577*** (0.0093)	0.0481*** (0.0091)		
50 Km			-0.0245 (0.0233)	0.0138 (0.0245)
Forest	0.2021*** (0.0166)	-0.1605*** (0.0153)	0.1916*** (0.0161)	-0.1516*** (0.0148)
Log Real-AEE	-0.1835*** (0.0070)	0.1382*** (0.0073)	-0.1880*** (0.0069)	0.1420*** (0.0073)
Male head	-0.0129 (0.0132)	-0.0552*** (0.0137)	-0.0145 (0.0131)	-0.0538*** (0.0137)
Head age	0.0037*** (0.0002)	-0.0028*** (0.0002)	0.0037*** (0.0002)	-0.0028*** (0.0002)
Head married	0.0701*** (0.0136)	0.0146 (0.0143)	0.0711*** (0.0135)	0.0138 (0.0142)
Primary	-0.1557*** (0.0174)	0.1115*** (0.0200)	-0.1550*** (0.0174)	0.1109*** (0.0199)
Junior secondary	-0.0716 (0.0707)	0.0788 (0.0763)	-0.0675 (0.0707)	0.0755 (0.0759)
Senior secondary	-0.2619*** (0.0345)	0.0906 (0.0652)	-0.2596*** (0.0337)	0.0888 (0.0651)
Tertiary	-0.2159*** (0.0335)	-0.0918 (0.0892)	-0.2198*** (0.0330)	-0.0884 (0.0889)
HH size	0.0000 (0.0014)	0.0025* (0.0014)	-0.0002 (0.0014)	0.0027* (0.0014)
Logdisthqdistrict	0.1090*** (0.0041)	-0.1031*** (0.0042)	0.1098*** (0.0041)	-0.1037*** (0.0042)
<i>N</i>	8963	8963	8963	8963
<i>R</i> ²	0.4807	0.3673	0.4776	0.3648
Regional & Wave FE	Yes	Yes	Yes	Yes

This table reports the results of the impact of proximity to PAs under other thresholds.e. 15 km and 50 km using LPM. Robust standard errors are reported in parentheses. The constant is included, but not reported in the table.
* p < 0.1, ** p < 0.05, *** p < 0.01

5.2 Heterogeneity

We undertake a series of heterogeneity analyses of our main results. The first analysis concerns the level of protection of PAs. [Dudley et al. \(2010\)](#) present the classification of PAs under six categories from the most strict to least strict as follows: " I Strict protection (e.g. Strict nature reserves and wilderness areas), II Ecosystem conservation and protection (e.g. National park), III Conservation of natural features (e.g. Natural monument), IV Conservation through active management (e.g. Habitat/species management area), V Landscape/seascape conservation and recreation and VI Sustainable use of natural resources".

In our primary model, PAs are jointly considered. In our heterogeneity tests, we define PAs into two distinct categories: on one hand, “strict PAs” that do not allow the sustainable use of forest resources composed of categories I, II, III, and IV – we have no observations for households near category V PAs. On the other hand, “non-strict PAs” that allow for sustainable use –composed of category VI. We find that proximity to strict PAs is effective in reducing firewood consumption. On the contrary, proximity to less strict PAs increases firewood consumption, alluding to the possibility that establishing strict PAs reinforces property rights among small firewood collectors. [McNicol et al. \(2023\)](#), however, define strict PAs as categories I and II and non-strict PAs as other categories and found that in Tanzania, strict protected areas were not more efficient than their less strict counterparts in preserving aboveground woody carbon. This difference in effectiveness of protection can simply be explained by the difference in the definition of strict protected areas. In our case, strict protected areas are those which do not allow the sustainable exploitation of forest resources. Our study finds no significant results for charcoal with both categories.

Table 6: Heterogeneity depending on level of protection

	Strict PAs		Non-strict PAs	
	(1) Firewood	(2) Charcoal	(3) Firewood	(4) Charcoal
Strict PAs	-0.025*** (0.009)		0.020** (0.009)	
Non-strict PAs		0.017 (0.017)		0.012 (0.015)
Forest	0.201*** (0.017)	0.189*** (0.017)	-0.158*** (0.015)	-0.152*** (0.015)
Log Real-AEE	-0.188*** (0.007)	-0.189*** (0.007)	0.142*** (0.007)	0.143*** (0.007)
Male Head	-0.012 (0.013)	-0.013 (0.013)	-0.054*** (0.014)	-0.054*** (0.014)
Head age	0.004*** (0.000)	0.004*** (0.000)	-0.003*** (0.000)	-0.003*** (0.000)
Head married	0.069*** (0.014)	0.070*** (0.014)	0.012 (0.014)	0.012 (0.014)
Primary	-0.158*** (0.017)	-0.159*** (0.017)	0.118*** (0.020)	0.118*** (0.020)
Junior secondary	-0.076 (0.071)	-0.074 (0.071)	0.084 (0.076)	0.084 (0.076)
Senior secondary	-0.262*** (0.033)	-0.263*** (0.033)	0.103 (0.064)	0.104 (0.064)
Tertiary education	-0.214*** (0.035)	-0.214*** (0.035)	-0.122 (0.089)	-0.121 (0.089)
HH size	0.000 (0.001)	-0.000 (0.001)	0.002* (0.001)	0.002* (0.001)
Logdisthqdistrict	0.110*** (0.004)	0.110*** (0.004)	-0.104*** (0.004)	-0.104*** (0.004)
<i>N</i>	8964	8964	8964	8964
<i>R</i> ²	0.478	0.478	0.366	0.366
Regional & Wave FE	Yes	Yes	Yes	Yes

This table reports the results of the heterogeneity analysis depending on the protection level offered by the PA. Strict PAs are categories I, II,III and IV. Non-strict PAs are category VI. Robust standard errors are reported in parentheses. The constant is included, but not reported in the table. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In current literature, authors highlight significant heterogeneity depending on cities or regions (Boberg, 1993; Mwampamba, 2007). For instance, (Mwampamba, 2007) showed that Dar es Salaam region is the main consumer of charcoal in Tanzania. More broadly, the authors highlight the need for the implementation of environmental protection policies differentiated by region for greater efficiency. Following this logic, we analyze heterogeneity by region. Our results presented in tables 7 and 8 demonstrate that proximity to PAs reduces firewood consumption independent of the region, except for the Southern Highlands. Hence, although fuel choices vary depending on the region, the effect of PAs on household fuel choices does not vary from one region to the next, except for Southern Highlands.

Table 7: Heterogeneity by region for Firewood

	(1)	(2)	(3)	(4)	(5)	(6)
	Central	Coastal	Lake	Northern	Southern highlands	Western
Protected Area	-0.082*** (0.022)	-0.067* (0.040)	-0.020 (0.021)	-0.084*** (0.017)	0.027 (0.024)	-0.070** (0.032)
Forest	-0.138** (0.063)	0.229*** (0.042)	0.161*** (0.026)	0.230*** (0.032)	0.017 (0.039)	0.389** (0.153)
Log Real-AEE	-0.148*** (0.018)	-0.266*** (0.015)	-0.203*** (0.016)	-0.073*** (0.015)	-0.161*** (0.017)	-0.203*** (0.033)
Male head	0.017 (0.031)	0.007 (0.032)	-0.012 (0.027)	-0.093*** (0.028)	-0.002 (0.034)	0.164*** (0.059)
Head age	0.002*** (0.001)	0.002*** (0.001)	0.005*** (0.001)	0.003*** (0.001)	0.005*** (0.001)	0.002** (0.001)
Head married	0.024 (0.030)	0.029 (0.031)	0.098*** (0.029)	0.132*** (0.031)	0.087*** (0.034)	-0.033 (0.054)
Primary	-0.247*** (0.068)	-0.081*** (0.024)	-0.163*** (0.046)	-0.271*** (0.054)	-0.075* (0.043)	-0.377*** (0.114)
Junior secondary	-0.409*** (0.043)	-0.057 (0.059)	-0.046 (0.191)	0.080 (0.138)	-0.654*** (0.029)	-0.234 (0.237)
Senior secondary	0.000 (.)	-0.093** (0.037)	-0.338*** (0.083)	-0.082 (0.077)	-0.204 (0.331)	-0.508*** (0.071)
Tertiary education	-0.248*** (0.048)	-0.027 (0.031)	0.000 (.)	-0.066 (0.195)	-0.369*** (0.048)	0.000 (.)
HH size	-0.002 (0.002)	-0.023*** (0.004)	0.014*** (0.003)	0.008** (0.003)	-0.002 (0.004)	0.001 (0.005)
Logdisthqdistrict	0.153*** (0.011)	0.140*** (0.008)	0.098*** (0.011)	0.053*** (0.011)	0.112*** (0.008)	0.080*** (0.017)
<i>N</i>	740	2792	1230	1154	1439	286
<i>R</i> ²	0.471	0.569	0.447	0.236	0.416	0.432
Regional & Wave FE	Yes	Yes	Yes	Yes	Yes	Yes

This table reports the results the heterogeneity by region, coefficients for *firewood* as dependent variable are reported here. Robust standard errors are reported in parentheses. We only have six regions instead of seven as for the last region, distance to PA is invariant over time. The constant is included, but not reported in the table. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Heterogeneity by region for Charcoal

	(1)	(2)	(3)	(4)	(5)	(6)
	Central	Coastal	Lake	Northern	Southern highlands	Western
Protected Area	0.083*** (0.021)	0.091** (0.040)	0.023 (0.022)	0.046*** (0.010)	-0.032 (0.024)	0.068** (0.032)
Forest	0.097* (0.057)	-0.207*** (0.038)	-0.148*** (0.025)	-0.114*** (0.025)	-0.018 (0.038)	-0.403*** (0.151)
Log Real-AEE	0.148*** (0.018)	0.182*** (0.017)	0.166*** (0.019)	0.019* (0.011)	0.150*** (0.017)	0.189*** (0.033)
Male Head	-0.019 (0.028)	-0.202*** (0.036)	-0.035 (0.030)	0.018 (0.022)	-0.040 (0.034)	-0.147** (0.058)
Head age	-0.002*** (0.001)	-0.002*** (0.001)	-0.004*** (0.001)	-0.001*** (0.000)	-0.005*** (0.001)	-0.002 (0.001)
Head married	-0.023 (0.029)	0.188*** (0.036)	-0.025 (0.033)	-0.065*** (0.025)	-0.036 (0.034)	0.037 (0.052)
Primary	0.255*** (0.068)	0.012 (0.033)	0.138*** (0.051)	0.169*** (0.053)	0.083* (0.044)	0.386*** (0.115)
Junior secondary	0.416*** (0.044)	-0.006 (0.085)	0.087 (0.204)	0.036 (0.129)	0.654*** (0.029)	0.234 (0.237)
Senior secondary	0.000 (.)	-0.111 (0.085)	0.192 (0.178)	0.005 (0.019)	0.227 (0.330)	0.513*** (0.073)
Tertiary education	-0.748*** (0.050)	-0.299*** (0.113)	0.000 (.)	-0.115* (0.060)	0.387*** (0.049)	0.000 (.)
HH size	0.003 (0.002)	0.026*** (0.004)	-0.012*** (0.003)	-0.000 (0.003)	0.003 (0.003)	-0.001 (0.005)
Logdisthqdistrict	-0.151*** (0.011)	-0.133*** (0.009)	-0.092*** (0.012)	-0.024*** (0.009)	-0.111*** (0.008)	-0.084*** (0.017)
<i>N</i>	740	2792	1230	1154	1439	286
<i>R</i> ²	0.476	0.374	0.349	0.098	0.402	0.421
Regional & Wave FE	Yes	Yes	Yes	Yes	Yes	Yes

This table reports the results the heterogeneity by region, coefficients for *charcoal* as dependent variable are reported here. We only have six regions instead of seven as for the last region, distance to PA is invariant over time. Robust standard errors are reported in parentheses. The constant is included, but not reported in the table. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

6 Concluding remarks

In this study, we examine whether proximity to PAs determines household fuel choices. More specifically, we investigate the effect of having PAs in a 25 km buffer zone around a household on the household's cooking fuel choices. We find that proximity to PAs has a negative impact on firewood consumption and a positive impact on charcoal consumption. Our results are statistically and economically significant and robust to a wide range of robustness checks.

We equally find that these effects hold for strict PAs (categories I, II, III, and IV) compared to less strict category VI which allows for sustainable use of forest resources. In Category VI, proximity to PAs do not affect the household fuel choice. The results are in line with recent literature that highlights a growing charcoal demand fueled by the rising urban population in Tanzania and warns that charcoal requires more trees for its production compared to firewood, hence, charcoal consumption poses a greater threat of deforestation especially if PAs are poorly managed or regulated and forests are not sufficiently replenished.

Our results highlight the risk of jointly studying firewood and charcoal in one broad category as biomass, especially in the context of environmental conservation. We find that the effects of proximity to PAs were indeed different for firewood compared to charcoal consumption. From our initial hypothesis, we postulate that PAs minimize the simple collection of firewood by individuals, however, tradable charcoal could still be consumed. First, charcoal is the nearest and cheapest substitute to firewood compared to other modern cooking fuels. Allied with that, the charcoal market in Tanzania is vast, efficient, and competitive ensuring the supply of Charcoal even to households in close proximity to PAs. Lastly, with illegal harvesting of forest resources and poor PAs regulations, large-scale and organized charcoal enterprises could still participate in the market and maintain charcoal consumption.

These conclusions suggest the existing importance of charcoal as a household cooking fuel, especially given the minimal adoption of modern cooking fuels in Tanzania. Our results also highlight that some policies (such as the implementation of PAs) can generate negative consequences. Overall PAs do not contribute to reducing traditional biomass

usage. Our study proposes that the profound decrease in firewood and the increase in charcoal which are close substitutes, could be interpreted as a rebound effect. The intrinsic problem is that the charcoal sector is currently not sustainable.

This phenomenon is not new, charcoal has always been an important sector since the colonial period. Indeed, the contemporary unsustainable character embedded in the charcoal sector contrasts vehemently with the view held at the end of the colonial era which supported a vision of development based on a “modernised state-directed East African charcoal industry as a path to energy sovereignty and also for export” (Branch et al., 2022). Appropriate policies targeting diverse aspects related to the environment, economic, political, social, and historical significance and constraints of the charcoal sector, could enable a paradigm shift in household fuels in Tanzania.

Environmental conservation policies should ensure better effectiveness of PAs. However, policies could in the short run accept the crucial role of charcoal as a household fuel and encourage sustainable use of forest resources by encouraging forest replenishment programs at a rate higher than the current forest harvesting rate. In the long run, policies could encourage an energy transition to more sustainable and modern forms of cooking fuels with significantly minimal health and environmental risks.

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7 Appendix

Table 9: Main Model with Linear Probability Model without region and year Fixed Effects

	(1)	(2)
	Firewood	Charcoal
Protected Area	-0.0373*** (0.0106)	0.0226** (0.0109)
Forest	0.1175*** (0.0124)	-0.0870*** (0.0117)
Log Real-AEE	-0.1974*** (0.0065)	0.1484*** (0.0070)
Male Head	-0.0274** (0.0133)	-0.0386*** (0.0138)
Head age	0.0040*** (0.0002)	-0.0031*** (0.0002)
Head married	0.0819*** (0.0137)	0.0022 (0.0143)
primary	-0.1409*** (0.0173)	0.1021*** (0.0197)
Junior secondary	-0.0967 (0.0756)	0.0997 (0.0796)
Senior Secondary	-0.3020*** (0.0369)	0.1314** (0.0651)
Tertiary	-0.2964*** (0.0408)	-0.0166 (0.0894)
HH size	0.0014 (0.0014)	0.0012 (0.0014)
Logdisthqdistrict	0.1109*** (0.0040)	-0.1045*** (0.0041)
<i>N</i>	8963	8963
<i>R</i> ²	.4269	.3098
Regional & Wave FE	Yes	Yes

This table reports the results of the main model without region and year Fixed effects. Robust standard errors are reported in parentheses. The constant is included, but not reported in the table. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 10: T-test of Households in Protected areas(PAs = 1) vs Households in Non-Protected Areas(PAs = 0)

	Mean PA = 1	Mean PA = 0	Two-tailed p-value
Firewood	0.6703	0.8396	0.0000
Charcoal	0.2798	0.1433	0.0000
Forest	7.4479	7.4793	0.1248
Log Real-AEE	13.6702	13.3857	0.0000
Male Head	0.7436	0.7099	0.2307
Head age	48.2438	47.8532	0.6902
Head married	0.7167	0.7133	0.9039
primary	0.1601	0.0683	0.0000
Junior secondary	0.0065	0	0.0001
Senior Secondary	0.0134	0.0102	0.6141
Tertiary	0.0069	0	0.0001
HH size	5.2001	5.4487	0.1494
Logdisthqdistrict	3.3736	3.9309	0.0000

The results are statistically significant if the Two-tailed p-value is less than 0.05. A mean of 0 illustrates that no observations in the category.

Table 11: Geographical zones

	Geographical zones	Regions
1	Central Zone	Dodoma Singida · Tabora
2	Coastal Zone	Dar es Salaam · Lindi · Morogoro · Mtwara · Pwani
3	Lake Zone:	Geita · Kagera · Mara · Mwanza · Shinyanga · Simiyu
4	Northern Zone	Arusha · Kilimanjaro · Manyara · Tanga
5	Southern Highlands Zone	Iringa · Mbeya · Njombe · Rukwa · Ruvuma Songwe
6	Western Zone	Katavi · Kigoma
7	Zanzibar	Mjini Magharibi · Pemba North · Pemba South · Unguja North · Unguja South

This table reports geographical zones as used in this paper. They are created by grouping regions of Tanzania as described in Section 3.3.