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# Protected areas and fuel choice: the case of Ivorian households

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## Abstract

The establishment of protected areas to combat deforestation could affect the fuel choice of Ivorian households, which are highly dependent on solid biomass for cooking. The aim of this study is to test this hypothesis using data from the 2015 Ivorian Household Living Standards Survey and a multilevel mixed-effects model. The results show the presence of a protected area influences households' choice of cooking fuel. It increases the likelihood of using purchased solid biomass versus clean energy (gas or electricity). Moreover, the impact depends on the type and level of protection of the protected area, as well as on the area of residence. Some factors, such as the characteristics of the household head and the socio-economic status of the household, affect the choice of cooking fuel by households in Côte d'Ivoire.

**Keywords:** *protected area, biomass, cooking fuels, Côte d'Ivoire*

# 1 Introduction

Côte d’Ivoire, a sub-Saharan African country once renowned for the extent and richness of its tropical forests, has seen its forest cover practically disappear in less than half a century for several reasons. Côte d’Ivoire has the greatest decline in its tropical rainforest (Vancutsem et al., 2021). Since 1990, the tropical rainforest has lost 79% of its surface area and if the rate of deforestation continues, the tropical rainforest will disappear between 2026 and 2029 (Vancutsem et al., 2021). This deforestation can be explained by the implementation of the "plantation economy" (Dao, 2004; Koné et al., 2014), certain agricultural practices such as increasing conversion of forest land to farmland, bush fires (Koné et al., 2014) and the population density. Indeed, according to the World Bank’s World Development Indicators, in 2021 Ivorian population density was estimated at 86.40 inhabitants/km<sup>2</sup>, still higher than the Sub-Saharan African average of 49.43 inhabitants/km<sup>2</sup> (World Bank, 2023). Furthermore, according to the results of the National Forest and Wildlife Inventory (IFFN), the country has a national forest area of 2.97 million hectares, of which 674,500 hectares are protected areas (Timber Trade Portal, 2023).

The availability of energy sources is very useful in meeting people’s energy needs for lighting or cooking. In developing countries, and more specifically in Côte d’Ivoire, plant biomass is the primary source of cooking energy. One of the reasons is that biomass is more affordable. The extensive use of forest biomass can also be a driver of deforestation. To alleviate this problem, Côte d’Ivoire introduced an action plan.

As part of the implementation of the ECOWAS Renewable Energy Policy (PERC), Côte d’Ivoire introduced a National Renewable Energy Action Plan (PANER) in 2016 (WHO, 2022). The main objective of the PERC is to increase the share of renewable energies in the region’s overall electricity mix to 10% by 2020 and 19% by 2030. The policy focuses primarily on the electricity sector, but also considers other issues including thermal uses in the domestic energy sector and the potential production of biofuels. The aim of the PANER is to contribute to the achievement of the PERC objective through the implementation of specific objectives. The first is to increase access to clean energy such as LPG (Liquified Petroleum Gas) and to reduce the demand for polluting energy, more specifically to reduce the amount of wood energy used. To achieve this, awareness-raising activities on the use of improved stoves and butane gas have been undertaken (Ministère du Pétrole et de l’Energie, 2016). The second is the reduction of polluting emissions (fine particles and greenhouse gases) and the preservation of the forest cover. Indeed, in terms of cooking, biomass energy (firewood, charcoal, vegetable waste) represents a little more than 2/3 of the total final energy consumption of households (Ministère du Pétrole et de l’Energie, 2016). In view of the consumption of wood-energy, the vegetation cover of Côte d’Ivoire risks disappearing if nothing is done, as the Ivorian forest has gone from 9 million ha in 1965 to 2.8 million ha in 2021 (Ministère du Pétrole et de l’Energie, 2016; TIMBERTRADE, 2022). To achieve this, the PANER aims to increase the share of the population consuming modern alternative cooking fuels such as LPG (Liquified Petroleum Gas) to 90% by 2030 (Ministère du Pétrole et de l’Energie, 2016). This objective is in line with that of the International Energy Agency, whose Africa Energy Outlook 2022 forecasts the elimination of the traditional use of bioenergy for cooking by 2030, thanks to universal access to modern fuels and technologies. Another important specific objective of

PANER is to achieve gender equity in terms of cooking fuel use ([Ministère du Pétrole et de l'Énergie, 2016](#)). Through PANER, Côte d'Ivoire is working to reduce the use of solid fuels such as coal and biomass.

In sub-Saharan Africa, forests are a source of livelihood for poor households living in their vicinity. For example, they find food or firewood there. To combat deforestation and preserve biodiversity, protected areas have been set up. According to the IUCN (International Union for Conservation of Nature), a protected area is *"a clearly defined geographical space, recognised, dedicated and managed, by any effective legal or other means, to ensure the long-term conservation of nature and its associated ecosystem services and cultural values"*. The IUCN classifies protected areas into six categories ([Day et al., 2012](#)), with decreasing level of protection. The first category is the "integral nature reserve", which is characterised by strict protection of biodiversity and geological/geomorphological features. Visits, use and human impacts are strictly controlled and limited to ensure that conservation values are protected. The last category is "Managed Natural Resource Protected Areas", which are characterised by management for sustainable use. Previous studies have looked at the impacts of the presence of protected areas and find an effect on deforestation ([Andam et al., 2008](#); [Clark et al., 2008](#)), household income ([Nepal, 1997](#); [de Sherbinin, 2008](#); [Naidoo et al., 2019](#)) and health ([Romagosa et al., 2015](#); [Puhakka et al., 2017](#); [Jiricka-Pürerer et al., 2019](#); [Buckley et al., 2019](#)). Given that the establishment of a protected area helps to combat deforestation, the objective of the study is to find out how the presence of a protected area shapes the cooking fuel choice of households living in the locality.

According to the literature, households' choice of cooking fuel in the event of a change in economic status follows two important hypotheses: Energy ladder hypothesis and Energy stacking hypothesis. In the Energy ladder hypothesis, households replace traditional fuels with modern ones, and this energy transition is motivated by increased income and socio-economic status ([Hosier and Dowd, 1987](#); [Van der Kroon et al., 2013](#)). Households may also decide to use several different fuels simultaneously. This is referred to as the fuel stacking or mixing hypothesis ([Masera et al., 2000](#); [Heltberg, 2004](#); [Ruiz-Mercado and Masera, 2015](#); [Choumert-Nkolo et al., 2019](#)). Given that the establishment of protected areas could reduce deforestation and affect the economic status of households in the surrounding area, the aim of the study is to find out whether this would lead to an energy transition to cleaner modern fuels, or to the simultaneous use of traditional and modern fuels by households.

This study stands out in several ways. First, to our knowledge, this is the first to examine the impact of protected areas on the fuel choice of Ivorian households. Second, given the non-random distribution of protected areas, we take into account the characteristics of the sub-prefecture that may influence the location of protected areas. Thirdly, we use a multilevel mixed-effects logistic model that allows to take into account the structure of the data, which in reality are household and sub-prefecture level data. And random effects at the household level are added to the model to take into account certain factors that may affect the household fuel choice. Finally, to answer the research question, we use data from the 2015 Côte d'Ivoire Household Living Standards Survey and the World Database on Protected Areas (WDPA). This study is the first to use these data to investigate the relationship between the presence of protected areas and household cooking fuel choice.

We find the presence of a protected area influences household cooking fuel choice. It increases the likelihood of using purchased biomass compared to clean energy (gas/LPG/butane gas or petroleum-powered appliances)<sup>1</sup>. Furthermore, the impact depends on the type and the protection level of the protected area, and the area of residence. Some factors, such as the characteristics of the household head and the socio-economic status of the household, affect the choice of cooking fuel by households in Côte d'Ivoire.

The rest of the study is organised as follows: the next section presents the literature review. The materials are presented in the third section. The fourth and fifth sections describes respectively the stylized facts and the econometric analysis. Then, the sixth and seventh sections are devoted respectively to the presentation of the robustness checks and the heterogeneity tests. The last section discusses the conclusion and policy implications.

## 2 Background

The following sections look at the different impacts of protected areas, with a particular focus on health effects, and the use of forests as a source of household fuel.

### 2.1 Socio-economic impact of forest protection

Forests provide important ecosystem services (Brandon, 2014). More specifically tropical forests have a major influence on weather patterns, freshwater, natural disasters, biodiversity, food and human health (Brandon, 2014). Forests contribute significantly to the livelihoods of the poorest households (Heubach et al., 2011) and also enable carbon sequestration (Jindal et al., 2008).

The establishment of protected areas helps to preserve forests. In addition to their role in natural water purification in wetlands and carbon sequestration in forests, protected areas are an important tool in the fight against deforestation. The impact of forest conservation policies on deforestation remains controversial (Brandt et al., 2016; Karsenty et al., 2017; Brandt et al., 2018). Several studies deal with the effect of protected areas on deforestation (Andam et al., 2008; Clark et al., 2008; Kere et al., 2017). These authors find that protected areas help to combat deforestation. Indeed, the fact that certain parts of the forest are protected discourages the population from deforesting these parts on pain of paying a fine. It is in this sense that Andam et al. (2008) show that between 1960-1970, 10% of the protected forests would have been deforested if they were not protected in Costa Rica. Clark et al. (2008) add that the establishment of protected areas makes it possible to fight deforestation but it is not known to what extent this leads to a displacement of deforestation. To add protected areas helped slow deforestation in the Brazilian Amazon between 2005 and 2009 (Kere et al., 2017) .

Since the forest is multifunctional, protected areas have the potential to affect many other things. A number of studies have looked at the various socio-economic impacts of protected areas. Some scholars find protected areas have an economic value because it improves the mental health and well-being of the population. Using the quality-adjusted life years (QALY), Buckley et al. (2019) show

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<sup>1</sup>We consider clean fuels to be those that are less harmful to household health

that this value amounts to 6,000 billion dollars per year in Australia. In the same vein, [Koss et al. \(2010\)](#) find a positive effect of protected areas on the mental health of volunteers who care for them. Visitors report protected areas have a positive effect on their psychological, physical and social health ([Jiricka-Pürerer et al., 2019](#); [Puhakka et al., 2017](#); [Terraube et al., 2017](#); [Romagosa et al., 2015](#)).

In addition, another group of studies agree protected areas affect the health of populations through improved nutrition. [Aswani and Furusawa \(2007\)](#) supports this idea by comparing two villages, one with a marine protected area and one without. The results show that the populations of the village with a marine protected area had a higher energy and protein intake than those of the other village without a protected area.

Also, some authors give protected areas the power to generate income for local populations, especially in sub-Saharan Africa. It is in this sense [Heubach et al. \(2011\)](#) prove non-timber forest products are an essential means of subsistence for rural households in Benin. [de Sherbinin \(2008\)](#) looks at the relationship between poverty and living near a park. By approximating poverty by the infant mortality rate, the results show an uncertain causal relationship between poverty and proximity to a protected area. In contrast, [Naidoo et al. \(2019\)](#) find a relationship between proximity to a protected area, poverty and general well-being. Indeed, households in the vicinity are richer and children do not show stunted growth compared to similar households that are far from the protected area. The authors explain this by tourism activities that generate income. This income could be used for medical consultations and the purchase of medicines. Also, wildlife conservation promotes the multiplication of animals that households can later sell. Furthermore, the presence of a protected area could encourage the construction of infrastructure, especially roads, and this facilitates the transport of the sick ([Naidoo et al., 2019](#)).

Although the creation of protected areas helps to reduce deforestation, they have other impacts too. This literature show that protected areas impact on people's health through their positive psychological, physical and nutritional effects. It also constitutes a source of income for some individuals and thus allow them to have the necessary resources to treat themselves. In this study we test the effect of the presence of protected areas on the household cooking fuel choice. On the one hand, the presence of a protected area could increase the opportunity cost of wood, but on the other, if proximity to the protected area could increase income-generating activities, this could stimulate demand for fuel. We would expect this to change their choice of cooking fuel.

## 2.2 The forest as fuel

The poor are dependent on natural resources such as forests, which provide them with goods and services: food resources, but also energy resources such as firewood ([Sukhdev, 2009](#)). Moreover, tropical developing countries are home to many endangered and threatened species. As a result, many of the newer protected areas are located in poor areas of the world ([Howlader and Ando, 2020](#)). Many poor households live around protected areas. These households are highly dependent on forest resources, for income or subsistence. According to [Velho et al. \(2019\)](#) the increase in income of households living around protected areas in India, does not necessarily affect the use of collected wood as cooking fuel.

It is in this same vein that [Khanwilkar et al. \(2021\)](#) finds that living near the forest slows down the adoption of LPG as a fuel by households in India. Also according to these authors, 90% of households using LPG continue to use firewood as fuel. The adoption of LPG does not necessarily encourage households to abandon the use of wood for cooking.

[Howlader and Ando \(2020\)](#) look at the impact of protected areas on the welfare of households living in their vicinity in Nepal. The results show that the establishment of protected areas reduces timber collection by 20-40% compared to the period when there was no protected area. According to [Pattanayak et al. \(2004\)](#), the increased cost of accessing the forest could reduce people's dependence on collecting fuelwood from the forests. In addition, there are other factors that contribute to the decline in wood collection. These include wealth, use of alternative fuels, ownership of paraffin stoves, construction of primary schools and roads.

From previous studies it can be seen the presence of a protected area could reduce ([Pattanayak et al., 2004](#); [Howlader and Ando, 2020](#)) or not the use of collected fuelwood ([Velho et al., 2019](#)). In this study, we examine the extent to which the presence of a protected area would change the cooking fuel choice of households living in the relevant sub-prefectures in Côte d'Ivoire. An important contribution of this paper is to fill the gap that exists in the literature regarding the link between protected area, forest and fuel choice in Africa. The following section look at the data used to do the analysis.

### 3 Materials

We will analyse the effects of the presence of protected areas on household cooking fuel choice using data from the 2015 Household Level Survey and an econometric method.

#### 3.1 Data

The data used in this study come from different sources. The unit of observation is the household, whose main characteristics are given by the 2015 Household living standards survey. The main purpose of the Côte d'Ivoire household living standards survey is to provide the information needed to improve planning and evaluation of economic and social policies. The survey provides information on household composition, education, employment and health, among other things. It was conducted by the National Institute of Statistics (INS) of Côte d'Ivoire. The sampling frame used to draw the sample is the 2014 General Census of Population and Housing. The sampling is based on a two-stage draw. The first stage consists of a proportional allocation of the Enumeration Areas (EAs). The second is a systematic drawing of 12 households per enumeration area. The total sample obtained consists of 12,900 African households residing in Côte d'Ivoire ([INS, 2023](#)). This study is based on a sample of 12899 households.

The information on protected areas comes from the World Database on Protected Areas (WDPA) ([UNEP-WCMC and IUCN, 2021](#)) which is a joint project of the United Nations Environment Programme (UNEP) and the International Union for Conservation of Nature (IUCN). The database



includes all terrestrial and marine protected areas (Chape et al., 2005). For the purposes of this study, we are interested in terrestrial protected areas. In the database, we identify several types of protected area such as classified forest, national park, nature reserve and partial nature reserve. To obtain data on protected areas by sub-prefecture, we use the QGIS software, which has enabled us to obtain the surface area of protected areas present in the sub-prefectures.

### 3.2 Outcomes variables

In the study, four indicator variables are used as dependent variables. It reveals the extent to which the presence of a protected area shapes the household's energy transition, especially as regards cooking fuel. These variables are constructed from the question "O17: Main cooking fuel sources". The possible answer modalities are: "charcoal, purchased wood, collected wood, gas, electricity, oil, not applicable". The household was asked to choose the first three sources of fuel used. We are only interested in the first fuel source to construct the four indicators used as dependent variables.

The first indicator "Biomass/no biomass" is 1 when the household uses purchased or collected biomass (wood or charcoal) and the value is 0 if the household uses clean energy (gas/LPG/butane gas or petroleum-powered appliances). This dependent variable allows us to see how the presence of a protected area influences the choice of fuel, regardless of the type of biomass supply used as fuel.

Then, the second indicator "Biomass collected/ purchased" is equal to 1 when the household uses collected biomass (collected wood) and 0 when the household uses purchased biomass (charcoal or purchased wood). The objective of this indicator is to provide information on the extent to which the presence of a protected area could encourage the household to choose between collected and purchased biomass. The use of this outcome variable is justified by the fact the protected area is sometimes considered a source of wood supply for some households, especially in rural areas.

The third indicator "Biomass collected/no biomass" is 1 when the household uses collected biomass and 0 if it uses clean energy (gas/LPG/butane gas or petroleum-powered appliances). The purpose of this variable is to show the extent to which the establishment of a protected area could force the household to choose between collected biomass and clean energy.

The fourth indicator "Biomass purchased/no biomass" is 1 when the household uses purchased biomass and 0 if it uses clean energy (gas/LPG/butane gas or petroleum-powered appliances). The objective is to see how the presence of a protected area might influence the household's transition from purchased biomass to clean energy.

### 3.3 Interest variable

Using QGIS software we obtain the protected area surface by sub-prefecture. On the Figure 1, it can be seen there is a great difference between protected areas in terms of surface area. The very large protected areas are more concentrated in the North-East and South-West of the country. In the

North-East, more precisely in the Savanes and Zanzan districts, is the Comoé National Park with a surface area of 1,149,150 hectares. In the south-western zone, there are large national parks such as the Mont Péko National Park, the Tai National Park, the Mont Sangbé National Park and the Azagny National Park. These parks were created in the 1960s, 1970s and 1980s.

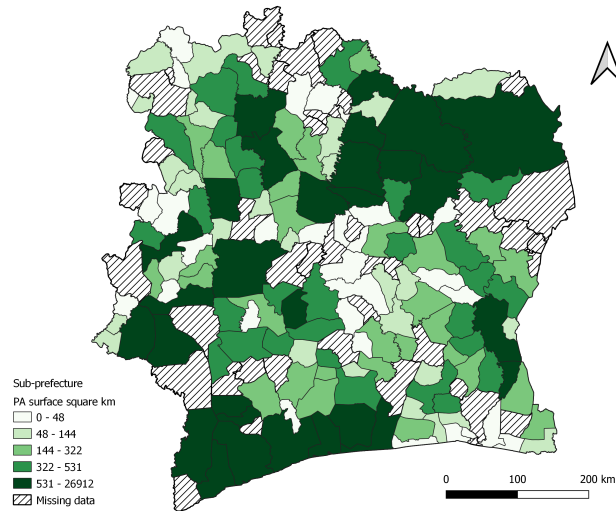


Figure 1: Size of protected areas by sub-prefecture  
Source : Author’s construction using the World Database on Protected Areas

### 3.4 Covariates

In order to better take into account the level of household wealth, we construct a wealth index. Indeed, the construction of the wealth index is very important because it allows us to measure the economic status of households. It is created by aggregating information on housing, physical capital and assets held by the household. Thus, the value of the index provides information on the living conditions of households that affect the well-being of individuals. The index is created through multiple component analysis. The synthetic index obtained is then normalised and thus lies between 0 and 1 with an average of 0.25 for urban households and 0.12 for rural households (Table A1). The higher the level of wealth, the closer the index will be to 1. The variables used and their definitions are found in Table B1 in Annex B.

The size of the household influences the household’s choice of fuel (Bofah et al., 2022; Twumasi et al., 2021). Indeed, the larger the household, the more fuel expenses increase because a large quantity of food must be cooked. Under these conditions, a low-income household would have to choose a cheaper fuel, i.e. biomass. The average household size in the sample is about 4 members with a maximum size of 26 members in urban area and 36 members in rural area (Table A1).

The household head age is a very important characteristic that could affect the consumption choices of household members. Through an empirical study on the determinants of the transition to cleaner cooking energy in Ghana, Bofah et al. (2022) find that youth-headed households have a low probability of using dirty energy compared to elderly-headed households in Ghana. The authors explain this by the decrease in income of the elderly head of household. As a result, the household chooses

cheaper fuels that unfortunately pollute a lot. To add, the author’s result could be explain by the fact that these elderly-headed households do not have information about the harmful effects of using dirty energy.

The gender of the head of household is an important determinant in the choice of cooking fuel. [Bofah et al. \(2022\)](#) shows that female-headed households are about 1.3 times more likely to use dirty cooking energy (i.e. wood and charcoal). Indeed, female-headed households are likely to be poorer than male-headed households ([Javed and Asif, 2011](#)). This could be explained by the fact these women do not have financial support from a spouse either because they are single, divorced or widowed.

Furthermore, the level of education and the type of occupation of the household head are also essential factors in the choice of cooking energy. Indeed, [Bofah et al. \(2022\)](#); [Twumasi et al. \(2021\)](#) show that the choice of fuel is influenced by the level of education of the head of household and non-agricultural employment. Having a high level of education would enable the household head to better understand the adverse effects of biomass use on the health of household members. The type of occupation of the household head informs about the economic conditions of the household.

In addition to the information that allows us to understand the socio-economic status of households, which strongly influences household fuel choice, we need to take into account the characteristics of the sub-prefecture. To this end, we include rainfall, temperature and the number of mammals and birds in the analysis. This information could influence the establishment of a protected area in an area.

The following section provides an understanding of the correlations between the presence of protected areas and household fuel choice.

## 4 Stylized facts

Biomass is widely used in developing countries. This is the case in Côte d’Ivoire. [Figure 2](#) shows the main source of cooking fuel used by households. It can be seen that around 57% of households use collected biomass for cooking. Also, a significant proportion (14.95 %) of households use charcoal. Just a small proportion (4.29%) use purchased wood. [This graph 2](#) shows that around 76.1% of households use plant biomass for cooking. One might imagine that this enormous use of biomass would not be without effect on Côte d’Ivoire’s forest cover.

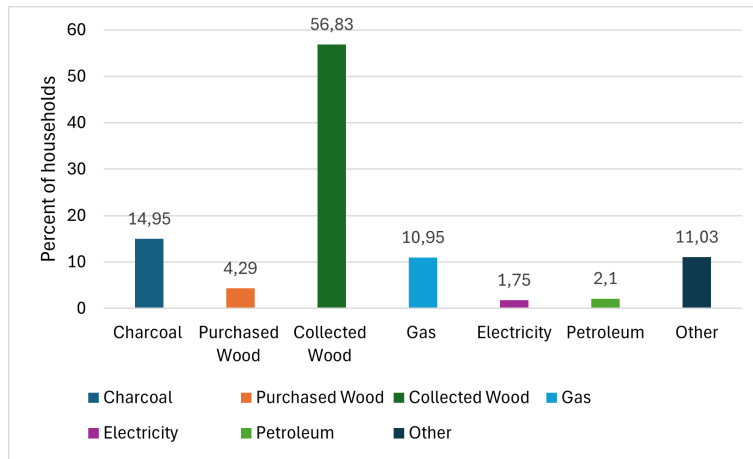


Figure 2: Primary source of cooking fuel used by household

Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

In terms of modern cooking fuels, only 10.95% (graph 2) of households use gas. This proportion is set to rise, as the Ivorian government plans to have 90% of the population using alternative modern cooking fuels (e.g. LPG) by 2030, thanks to the implementation of the PANER program.

Before the econometric analysis, it is important to look for a possible correlation between the use of biomass for cooking and the presence of protected areas. The Figure 3 is in line with this idea. It shows that 52.58% of households in the sample that use biomass (firewood and charcoal) live in sub-prefectures where there is a protected area.

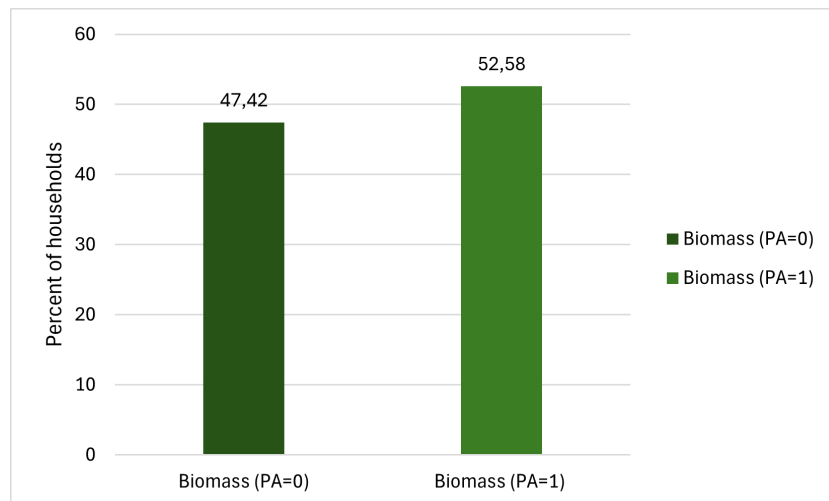


Figure 3: Households using biomass for fuel by presence of protected areas

Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

Furthermore, the presence of a protected area could alter households' fuel choices in several ways. This is the logic behind the Figure 4. The Figure on the left shows that 73.8% of households that use purchased biomass (fuelwood or charcoal) are located in sub-prefectures where there is a protected area. In view of these figures, it is tempting to say that the presence of a protected area would discourage households from using collected biomass, and more specifically collected wood. In other words, the presence of a protected area could mean that it is forbidden to harvest timber if it is an integral protected area. This restricts the geographical possibilities for collecting wood. This situation would

force some households to buy biomass instead of collecting it.

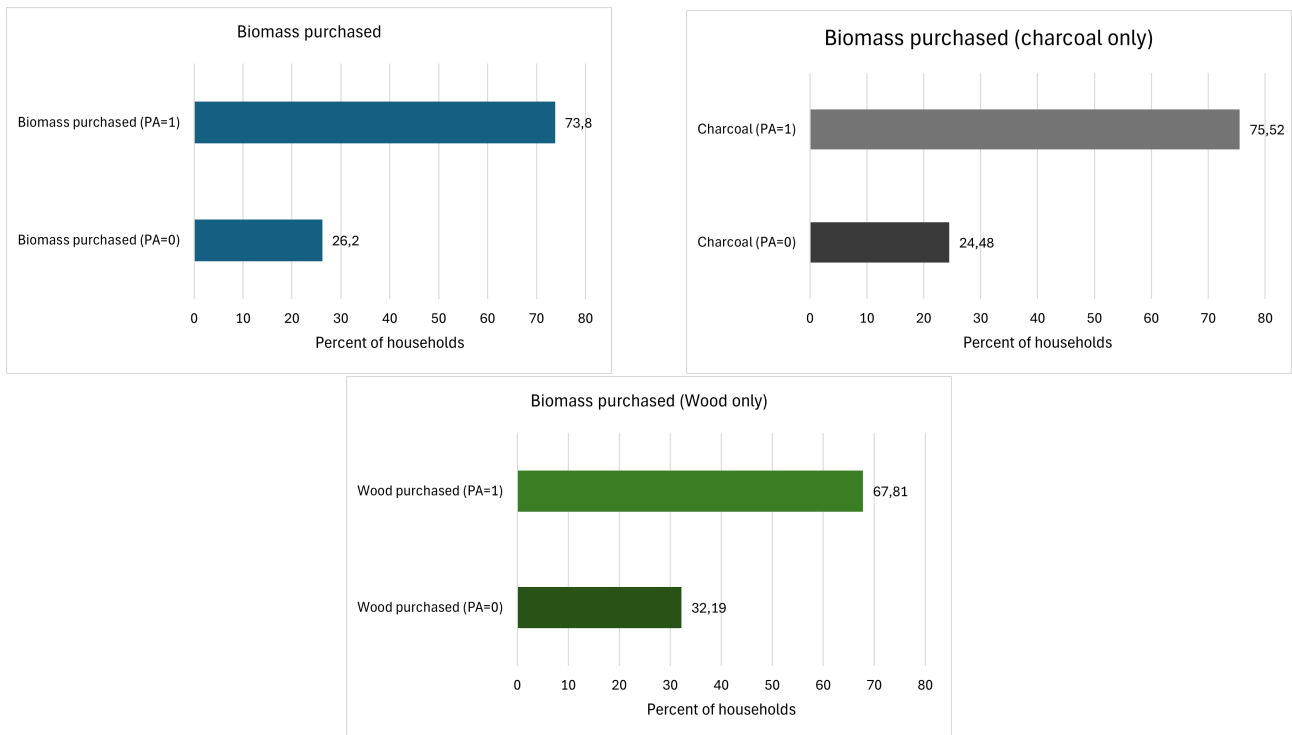


Figure 4: Households using purchased biomass according to protected area presence  
Source: Author's construction using the 2015 Côte d'Ivoire household living standards survey

In order to deepen the analysis, we focus on households that use purchased charcoal. According to the data, of households using purchased biomass and living in sub-prefectures with PAs, 75.52% use charcoal. In addition, among households using purchased biomass and living in sub-prefectures without PAs, 72.62% use charcoal. Furthermore, the Figure on the right (graph 4) shows around 76% of charcoal-using households live in sub-prefectures with a PA. The last graph in Figure 4 focuses solely on households that use purchased wood. It can be seen that around 68% of households that use purchased wood for cooking live in areas where there is a protected area. From this graph 4, one might imagine that there is a positive correlation between the presence of PAs and the use of purchased biomass, and more specifically charcoal.

Figure 5 looks at households that use collected biomass (collected wood). The Figure shows around 55% of these households live in sub-prefectures without a protected area. This finding could lead us to believe that there is a negative correlation between the presence of a protected area and the use of collected fuelwood.

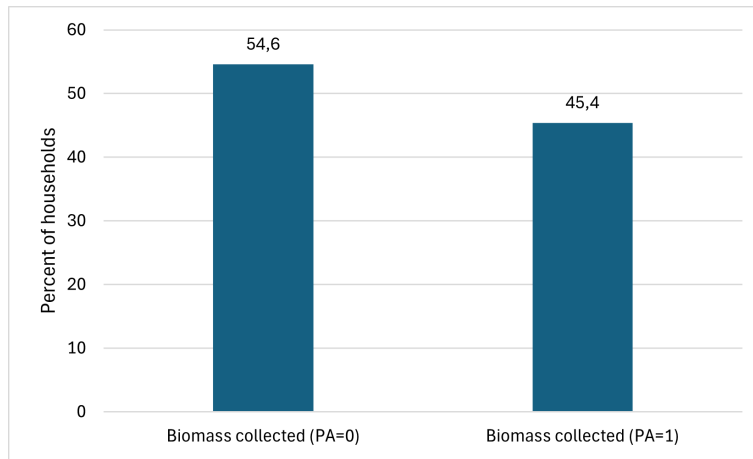


Figure 5: Households using collected biomass for fuel by presence of protected areas  
 Source: Author’s construction using the 2015 Côte d’Ivoire household living standards survey

Several types of fuels can be used. Some of these fuels are less harmful to the health of households: we consider this as clean energy in the study. Indeed, in the data we notice that some households use clean energy as cooking fuel. This type of fuel is less polluting but expensive for poor households. According to the sample, 1638 Ivorian households use clean fuels (gas or electricity or petroleum-powered appliances) for cooking. A large majority of these households (81%) live in sub-prefectures with a protected area (graph 6). From this figure, one might imagine that there is a positive co-evolution between the presence of a protected area and the use of clean energy for cooking.

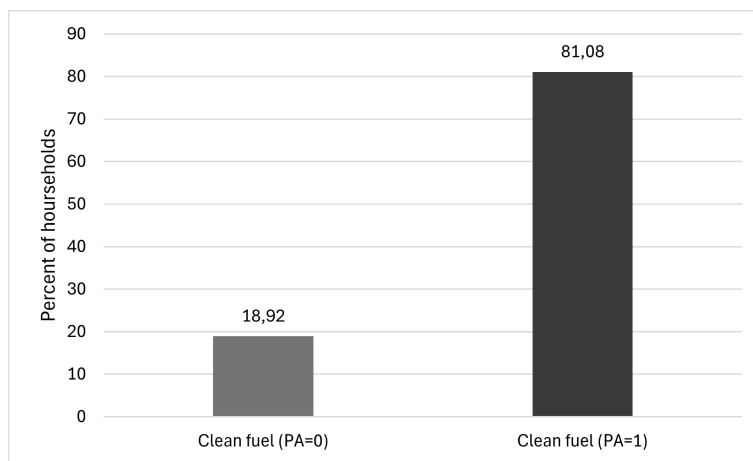


Figure 6: Households using clean fuel (gas/electricity/petroleum-powered appliances) by presence of protected areas

Source: Author’s construction using the 2015 Côte d’Ivoire household living standards survey

We looked at the level of wealth of the households in the sample through the wealth index. The index values show that households using clean energy (gas/LPG/butane gas or petroleum-powered appliances) are on average wealthier (0.4) than those using biomass (0.17). In addition, households living in sub-prefectures where there is a protected area are on average slightly richer (0.23) than households living in sub-prefectures without a protected area (0.16).

The remainder of the study will focus on econometric analysis to verify the stylized facts that have just been discovered.

## 5 Econometric analysis

This section describes the endogeneity problem, the econometric model and the main results.

### 5.1 Endogeneity problem

The distribution of protected areas is non-random (Joppa and Pfaff, 2009; Sims, 2010; Amin et al., 2015). Their location is chosen according to certain characteristics of the area. These protected areas are generally located on land characterised by low soil fertility, the presence of slopes and poor accessibility: land that is not favourable for agriculture (Albers et al., 2006). Failure to take these characteristics into account could lead to an omitted variable bias that will subsequently lead to an endogeneity bias in the analysis. This endogeneity bias could lead to a bias in the estimation of the impact of the presence of protected areas.

Protected areas are located in areas with low agricultural profitability, which could in turn affect the income of economic agents and their choice of location and fuels. To resolve the endogeneity bias we take into account certain characteristics of the sub-prefectures such as rainfall, temperature and biodiversity. These characteristics are crucial in the establishment of protected areas. Data on temperature and rainfall are taken from NASA databases. Biodiversity data is from the Schipper et al. (2020) database. All these data are satellite data extracted using QGIS software.

### 5.2 Econometric model

In this study a dichotomous model is used where the explained variable has two modalities (0 and 1). We can choose between two types of dichotomous models: probit model and logit model. Difference between the two models lies in the mathematical law of the distribution function used. Logistic model uses the distribution function of the logistic distribution while probit model uses the distribution function of the reduced centred normal distribution. These two models provide fairly similar results because of the similarities between logistic and the reduced centred normal distribution. However logit model has advantages in the interpretation of marginal effects. Furthermore, data is at 2 levels: sub-prefecture and household. Indeed, beyond the characteristics of each household, several households live in common sub-prefectures. Also, it is important to take into account the "context effects" in order to estimate the impact of the variables without bias (Kere et al., 2017). Therefore, for the econometric analysis, we choose the multilevel mixed-effects logit model because it allows to take into account the hierarchical nature of the data and to use random effects. So we add random effects at the household level as this allows to take into account the influence of certain factors that affect household fuel choice. These could include the type of food cooked, cultural characteristics, etc.

The likelihood-ratio test is computed to evaluate the goodness of fit of the chosen model. The test is done between a model with the control variables (unconstrained model) and another model without the control variables (constrained model). The P-value of the test results are in the results tables.

### 5.3 Baseline results

An increase in the cost of access to the forest through the establishment of a protected area could have an impact on the cooking fuel use patterns of households living near these protected areas. In Table 1 (column 1), we find that the presence of a protected area in a sub-prefecture increases the probability of a household using biomass compared to clean fuel by 2.58 percentage points. More precisely, in column 4, the presence of a protected area has a positive marginal effect of 6.78 percentage points on the likelihood of using purchased biomass compared to clean fuel. These two results show that the presence of a protected area increases the probability of using biomass purchased as cooking fuel. In view of these results, one might think that the presence of a protected area has no effect on wood collection, but it positively influences the use of purchased biomass (charcoal and wood) compared to clean fuel by the households.

Furthermore, the characteristics of the household head affect the fuel choice of the household. Firstly, the results show that the household head age is a relevant factor in the household's choice of fuel (Table 1). Indeed, an increase in the age of the head of household has a positive marginal effect (0.118 percentage points to 0.208 percentage points) on household fuel choice (column 1 to 4 Table 1). This can be explained by the drop in income of elderly heads of household, and this drop in income encourages them to use dirty fuels which are more accessible financially. Also, this result can mean these elderly-headed households do not have information about the harmful effects of using dirty energy.

Also, the fact the household head is a man increases the likelihood of using the biomass collected by 6.92 percentage points (Table 1 column 2). This can be due to the fact a male household head can participate in the collection of wood.

The level of education of the household head is an important factor in the household's choice of cooking fuel. Having secondary and higher education has a marginal negative effect on the likelihood of the household using biomass for cooking (Columns 1, 2, 3 and 4 Table 1). A plausible explanation is that having a high level of education helps to understand the negative health effects of using biomass as fuel.



Table 1: Baseline results

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA presence	0.0258** (2.05)	-0.00193 (-0.12)	-0.000960 (-0.08)	0.0678*** (2.61)
Head age	0.00142*** (5.10)	0.00169*** (5.28)	0.00118*** (4.60)	0.00208*** (3.58)
Head gender (male)	0.00375 (0.46)	0.0692*** (6.45)	0.00646 (0.81)	-0.00729 (-0.45)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0132 (-1.30)	0.00527 (0.40)	-0.000625 (-0.06)	-0.0238 (-1.15)
Secondary education (head)	-0.0218** (-2.37)	-0.0482*** (-3.58)	-0.0113 (-1.22)	-0.0259 (-1.43)
Higher education (head)	-0.106*** (-5.42)	-0.0217 (-0.59)	-0.115*** (-4.50)	-0.174*** (-5.65)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.101*** (-6.81)	-0.308*** (-9.95)	-0.155*** (-7.92)	0.0964** (2.55)
Other occupation (head)	-0.0929*** (-8.72)	-0.291*** (-24.68)	-0.133*** (-12.43)	0.111*** (3.22)
Wealth index	-0.676*** (-26.72)	-1.558*** (-35.03)	-0.821*** (-28.98)	-0.901*** (-17.67)
Household size	0.0139*** (8.01)	0.00656*** (3.47)	0.0108*** (6.61)	0.0244*** (7.27)
Rainfall	-0.155*** (-12.15)	-0.131*** (-7.66)	-0.141*** (-11.35)	-0.238*** (-9.05)
Temperature	0.0316*** (11.62)	0.000728 (0.23)	0.0222*** (9.24)	0.0667*** (11.12)
Mammals & birds	0.178*** (22.06)	0.105*** (7.18)	0.160*** (18.84)	0.284*** (18.07)
<i>Observations</i>	7209	5751	5207	3460
LR test p value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses.

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

In addition, the type of occupation of the head of household influences the household's choice of cooking fuel. The fact that the household head is a "white collar" worker or "other occupation" worker has a marginal negative effect (10.1 percentage points and 9.29 percentage points respectively) on the likelihood of using biomass compared to a farmer household head (Column 1 Table 1). Going into more detail, it can be seen that the effect size is larger when it comes to the use of collected biomass compared to purchased biomass or compared to clean fuel (Columns 2, 3 Table 1). However, the effect changes sign when it comes to the likelihood of using purchased biomass (Column 4 Table 1). These results show that the fact that the household head is not a farmer reduces the likelihood of using collected biomass. This result seems to be consistent with the idea that a farmer may have access to wood when he goes to the field.

The level of wealth very significantly decreases the likelihood of using biomass as a cooking fuel (Table 1). This result shows that one of the essential determinants of cooking fuel choice is the level of household income. Indeed, a poor household will be forced to use biomass because it is the cheapest fuel the household can afford. A rich household, on the other hand, has a wide range of fuels it can use. As a result, the rich household would tend to switch to cleaner fuels. This result is in line with previous studies that found that poverty is one of the main factors driving households to use biomass (Pattanayak et al., 2004; Velho et al., 2019).

The size of the household has a great influence on cooking fuel choice (Table 1). Indeed, a large household size could mean a large amount of food to cook and therefore a large amount of fuel to use for

cooking. In this situation, a household would have an incentive to use biomass which is cheaper than clean fuels and therefore more affordable. Here again, we return to the household's socio-economic status factor. The results show that household size increases the likelihood of biomass use by 0.656 percentage points to 2.44 percentage points.

Furthermore, the characteristics of the sub-prefecture play an important role in the location of a protected area and could influence the cooking fuel choice of households living there. In Table 1, we can see that the level of rainfall marginally decreases the likelihood of using biomass as fuel. This result is explained by the fact biomass is not usable when it is wet. On the other hand, temperature has a marginally positive effect on the likelihood of using collected or purchased biomass compared to clean fuel (columns 1, 3 and 4 Table 1). Indeed, a rise in temperature as opposed to rain allows the biomass to dry better and it becomes even easier to use for fire. In addition, the mammal and bird stock in the sub-prefecture has a marginal positive effect (10.5 percentage points to 28.4 percentage points) on the likelihood of biomass use. This could be explained by the fact more biodiversity stock would mean more forest area, and when forest is accessible, it encourages the household to use biomass which becomes more accessible at lower cost.

The next section focuses on the robustness checks of the previous results.

## 6 Robustness checks

We test the robustness of the baseline results using Generalized Structural Equation Modeling (GSEM) (Table 2).

Table 2: Generalized Structural Equation Modeling

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA presence	0.288** (2.04)	-0.0152 (-0.12)	-0.0147 (-0.08)	0.399*** (2.60)
Head age	0.0159*** (5.08)	0.0133*** (5.21)	0.0182*** (4.61)	0.0122*** (3.56)
Head gender (male)	0.0417 (0.46)	0.544*** (6.32)	0.0991 (0.81)	-0.0429 (-0.45)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.146 (-1.31)	0.0413 (0.40)	-0.00932 (-0.06)	-0.137 (-1.15)
Secondary education (head)	-0.237** (-2.41)	-0.368*** (-3.65)	-0.166 (-1.24)	-0.149 (-1.44)
Higher education (head)	-1.025*** (-6.09)	-0.168 (-0.60)	-1.448*** (-5.32)	-0.969*** (-5.75)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-1.202*** (-6.86)	-2.280*** (-12.01)	-2.159*** (-9.56)	0.558** (2.53)
Other occupation (head)	-1.122*** (-7.69)	-2.183*** (-20.56)	-1.921*** (-11.48)	0.643*** (3.22)
Wealth index	-7.534*** (-22.87)	-12.26*** (-24.13)	-12.60*** (-22.37)	-5.304*** (-15.32)
Household size	0.155*** (7.87)	0.0517*** (3.46)	0.166*** (6.49)	0.144*** (7.10)
Rainfall	-1.729*** (-11.32)	-1.033*** (-7.54)	-2.165*** (-10.27)	-1.401*** (-8.68)
Temperature	0.352*** (11.76)	0.00573 (0.23)	0.341*** (9.50)	0.392*** (10.81)
Mammals & birds	1.982*** (18.72)	0.825*** (7.07)	2.451*** (15.75)	1.675*** (15.65)
<i>Observations</i>	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses  
\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$   
Robust standard errors

GSEM is used to examine the direct and indirect linear relationships of the variables in the model, taking into account the binary response variable. The results obtained are in line with the baseline results and show that the presence of a protected area increases the likelihood of purchased biomass use compared to clean fuel.

## 7 Heterogeneity

This section looks at the heterogeneity of the effect according to the level of development of the sub-prefecture, the type and surface of protected area.

### 7.1 Effect according to the level of development of the sub-prefecture

The influence of the presence of a protected area could vary depending on several factors. First, we look at how the influence of the presence of a protected area affects households' fuel choices according to the level of development of the sub-prefecture. In the Table C1, we use the level of nightlight to approximate the level of development of the area. The results show living in a sub-prefecture with a nightlight level below the median increases the likelihood of biomass use by 3.09 percentage points and of biomass collected by 2.28 percentage points (columns 4 and 6 Table C1). Then, still with a view to taking into account the level of development, in Table C2, we are interested in the heterogeneity of the effect depending on whether the sub-prefecture is urban or rural. Indeed, we assume that the more developed the area, the more households have access to clean energy compared to less developed areas. The results in Table C2 (column 2) show the presence of a protected area in an urban area

increases the probability of using purchased biomass by 8.01 percentage points compared to clean energy. However, the effect is insignificant when it is a protected area in a rural area. This could be explained by the fact that in urban areas households have few opportunities to collect biomass as they do in rural areas, and they may not have the time to do so because of other activities. In addition, the wealth index constructed shows that urban households are wealthier than rural ones. As a result, they may have the financial means to buy biomass.

## 7.2 Effect depending on the size of the protected area

The effect of the protected area on the choice of fuel could depend on its size, since size can affect the quality of management and thus the effectiveness of the protected area. A relatively small protected area might be easier to manage because it would require fewer human resources, for example, than a larger protected area. To this end, we divide the surface of protected areas into quartiles and the results can be found in Tables C3, C4, C5 and C6. We can see when the protected area belongs to the first quartile this affects households' choice of fuel, as they prefer collected biomass to purchased biomass or clean energy (columns 2 and 4 in Table C3). The presence of a protected area increases the probability of using collected biomass by 3 percentage points and 4 percentage points. Furthermore, a protected area with a surface in the second quartile increases the probability of using the biomass collected by 2 percentage points compared to clean fuel (columns 1 and 3 Table C4). On the other hand, the presence of a fairly large protected area (third quartile) reduces the probability of using collected biomass (by 5 percentage points and 7 percentage points) compared to purchased biomass and clean fuel (columns 1, 2 and 3 Table C5). Very large protected areas positively affect the use of collected biomass by 3 and 6 percentage points (columns 2 and 3 Table C6).

These results show the importance of taking into account the size of the protected area in understanding the influence of the protected area on households' choice of cooking fuels. Small/medium and very large protected areas have a positive effect on the probability of using the biomass collected, while the effect becomes negative in the case of large protected areas (third quartile). These results could be explained by the type of protected area that makes up each size group. We start with the second quartile because we have no information on the type of protected areas in the first quartile. Of the medium-sized protected areas (second quartile), 94.3% are classified forests, protected areas in the third quartile are made up of 61% classified forests and 38% parks, and protected areas in the last quartile are made up of 85% classified forests and 14% parks. These figures show the positive effect observed with the first, second and last quartile protected areas is due to the presence of a large proportion of classified forests and a small proportion of parks. A plausible explanation would be that a classified forest is more likely to be exploited than a park.

## 7.3 Effect depending on the type of the protected area

This part of the heterogeneity study looks at the effect of the presence of the protected area according to the type of protected area. The results in Table C7 show that the fact the protected area is a classified forest has no effect on households' choice of cooking fuel.

Furthermore, the fact that the protected area is a park decreases the likelihood of using collected biomass compared to purchased biomass by 9.82 percentage points. The presence of this type of protected area also decreases the likelihood of using collected biomass compared to clean energy by 5.01 percentage points (columns 2 and 3 Table C8). The park decreases the likelihood of use of collected biomass may be because it is more protected and its presence decrease the geographical possibilities of wood collection.

In the Table C9 (columns 1, 3 and 4), it can be seen the fact that the protected area is a nature reserve increases the likelihood of using biomass (20.8 percentage points), collected biomass (18.7 percentage points) and purchased biomass (41.6 percentage points) compared to clean energy.

The Table C10 looks at the heterogeneity of effect depending on whether the protected area is a national or international protected area. The terms "National" and "International" refer to the type of convention under which the protected area was established. Thus, the "National" protected area is derived from a national convention, whereas the "International" protected area is derived from an international convention. For example, a UNESCO World Heritage site would be an "International" protected area. Also, given that households might know the status of the protected area, we might expect a different impact depending on whether it's a "national" or "international" protected area.

Table C10 show the presence of a "National" protected area increases the likelihood of using biomass (2.68 percentage points) and purchased biomass (6.76 percentage points) compared to clean energy (columns 1 and 4). In contrast, the fact that the protected area is of the "International" type has a marginally low significant effect on the likelihood of using purchased biomass compared to clean energy (column 8). These nil or low significant results could be explained by the fact that the "International" type protected areas are very few compared to the "National" type.

#### **7.4 Effect according to the level of protection of the protected area**

Since the results obtained with the type of protected area do not allow us to clearly understand which characteristic of the protected area would reduce the use of biomass, in this section we study the effect according to the level of protection of the protected area. To do this, we create an "integral protected area" indicator, which is 1 if the protected area is characterised by strict protection for the conservation of its resources and 0 if the protected area's resources are used sustainably. We therefore consider nature reserves and parks to be integral protected areas and classified forests to be sustainably managed protected areas. More precisely, the "integral protected area" correspond to IUCN categories I and II.

The results in Table C11 show the fact the protected area is integral reduces the risk of biomass use (Columns 1, 2, 3 and 4 Table C11). Integral protected areas encourage the use of clean energy (gas). In fact, when the protected area is integral, this reduces the geographical possibilities of access to plant biomass. As a result, households cannot collect biomass directly or buy it because biomass sellers do not also have access to the forest. This result shows that the degree of protection of the

protected area is very important.

The Ivorian government could therefore be advised to set up integral protected areas that promote not only forest protection but also the use of clean cooking energy by households.

## 8 Conclusion

The establishment of protected areas to combat deforestation could also affect the fuel choice of Ivorian households, which are highly dependent on plant biomass for cooking. The aim of this study is to test this hypothesis. Using a multilevel mixed-effect model, data from the 2015 household living standards survey and World Database on Protected Areas, the results show the presence of a protected area influences household cooking fuel choice. It increases the likelihood of using purchased biomass compared to clean energy. Furthermore, the impact depends on the type and level of protection of the protected area, and the area of residence. Some factors, such as the characteristics of the household head and the socio-economic status of the household, affect the choice of cooking fuel by households in Côte d'Ivoire.

In terms of economic policy, Ivorian public decision-makers should prioritize the establishment of integral protected areas that promote not only forest protection but also the use of clean energy for cooking. Another recommendation concerns the implementation of policies aimed at strengthening the management of protected areas. These include policies to monitor protected areas so that their presence can help achieve the objectives set. The country could also put in place policies to facilitate access to clean energy. In addition, the population needs to be made aware of the harmful effects of plant biomass use on health. This would help reduce the use of biomass.

This study has limitations. The main limitation is the unavailability of data. We do not have information on the precise location of households. This type of information would allow to better target households living near protected areas based on a certain distance. We hope future surveys will provide this information. Future research would be to compare households that are close to the protected area with those that are not, in terms of their choice of cooking fuel. This would reveal how the choice of cooking fuel varies according to distance from the protected area.

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## A Descriptive statistics

Table A1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
<b>Urban Households</b>					
Fuel biomass / no biomass	5,087	.7179084	.4500619	0	1
Fuel collected / purchased	3,652	.4463308	.4971793	0	1
Fuel collected / no biomass	3,065	.5318108	.4990685	0	1
Fuel purchased / no biomass	3,457	.5849002	.4928105	0	1
Protected area presence	5,784	.700899	.4579037	0	1
Head age	5,583	40.60147	14.36152	15	120
Head gender	5,784	.7679806	.4221578	0	1
Head education	5,712	.947479	1.041449	0	3
Head occupation	5,784	1.515733	.7627603	0	2
Wealth index	5,784	.2548042	.1587832	0	.9911834
Household size	5,784	3.65612	2.478579	1	26
Rainfall	4,703	3.6193	.6366527	1.224417	5.102239
Temperature	4,703	28.72951	1.344109	26.22738	33.06827
Mammals & birds	4,703	8.526423	.8567235	5.851593	10.32386
<b>Rural households</b>					
Fuel biomass / no biomass	6,389	.9640006	.1863031	0	1
Fuel collected / purchased	6,159	.9254749	.2626448	0	1
Fuel collected / no biomass	5,93	.9612142	.1931004	0	1
Fuel purchased / no biomass	689	.6661829	.4719179	0	1
Protected area presence	7,115	.4559382	.4980898	0	1
Head age	6,966	41.70571	14.99268	15	105
Head gender	7,115	.8326072	.3733525	0	1
Head education	7,085	.4780522	.7716238	0	3
Head occupation	7,115	.8756149	.9758771	0	2
Wealth index	7,115	.1175171	.0814123	0	.8784604
Household size	7,115	3.722839	2.689577	1	36
Rainfall	3,718	3.755219	.7160107	1.735136	5.798827
Temperature	3,718	28.82315	1.594832	26.22738	33.06827
Mammals & birds	3,718	8.843544	.7041861	6.592516	11.02025

## B Wealth index

Table B1: Variables used for the wealth index construction

Variable classification	Variable definition
Housing	Housing tenure status Wall material Floor material Roof material Soil type Material fo the roof Number of rooms
Physical capital	Type of water supply Light source Latrine inside Having mobile phone Having TV Having a post radio Having refrigerator Having freezer Having ventilator Having air conditioner Having computer Having satellite dish Having car Having truck Having iron Having tablet computer Having sewing machine Having dining room Having living room Having chair Having table Having bed Having mattress
Assets	Pocess dwelling Owner of cropland

## C Heterogeneity results

Table C1: Heterogeneity by sub-prefecture development level

	biomass/no biomass nightlight>median	collected/purchased nightlight>median	collected/no biomass nightlight>median	biomass/no biomass nightlight<median	collected/purchased nightlight<median	collected/no biomass nightlight<median
PA presence	0.0127 (0.57)	0.00966 (0.39)	-0.0255 (-1.30)	0.0309*** (2.85)	0.0286 (1.46)	0.0228** (2.10)
Head age	0.00258*** (5.35)	0.00236*** (4.54)	0.00202*** (4.80)	0.000476* (1.67)	0.00156*** (3.90)	0.000664** (2.25)
Head gender (male)	-0.000605 (-0.04)	0.0599*** (3.49)	-0.0119 (-0.92)	0.000768 (0.10)	0.0597*** (4.61)	0.00391 (0.47)
No education (head)	ref.	ref.	ref.	ref.	ref.	ref.
Primary education (head)	-0.0113 (-0.64)	0.0181 (0.84)	0.00802 (0.46)	-0.00411 (-0.40)	0.0104 (0.65)	-0.00279 (-0.29)
Secondary education (head)	-0.0445*** (-2.83)	-0.0343* (-1.69)	-0.00748 (-0.48)	0.00254 (0.28)	-0.0483*** (-2.88)	-0.000357 (-0.04)
Higher education (head)	-0.160*** (-5.33)	-0.0854 (-1.23)	-0.160*** (-3.96)	-0.0399* (-1.86)	0.00361 (0.09)	-0.0546* (-1.83)
Agriculture (head)	ref.	ref.	ref.	ref.	ref.	ref.
White collar (head)	-0.127*** (-4.55)	-0.464*** (-10.50)	-0.246*** (-7.15)	-0.0576*** (-3.49)	-0.154*** (-4.59)	-0.0628*** (-3.11)
Other occupation (head)	-0.113*** (-4.90)	-0.386*** (-16.63)	-0.178*** (-8.19)	-0.0365*** (-4.50)	-0.193*** (-14.99)	-0.0580*** (-6.67)
Wealth index	-0.904*** (-21.25)	-1.486*** (-19.21)	-0.928*** (-18.02)	-0.303*** (-10.40)	-1.300*** (-22.93)	-0.465*** (-14.48)
Household size	0.0178*** (6.19)	-0.00335 (-0.99)	0.00903*** (3.35)	0.00994*** (4.85)	0.0121*** (4.90)	0.0108*** (4.90)
Rainfall	-0.202*** (-8.36)	-0.275*** (-9.67)	-0.180*** (-7.84)	0.0331** (1.98)	-0.00355 (-0.13)	0.0313* (1.84)
Temperature	0.0390*** (7.21)	-0.0159*** (-2.80)	0.00831** (2.12)	0.0134*** (5.21)	-0.000372 (-0.10)	0.0134*** (5.43)
Mammals & birds	0.247*** (18.84)	0.194*** (9.22)	0.208*** (15.04)	-0.0642*** (-3.57)	-0.0498* (-1.75)	-0.0644*** (-3.46)
Observations	3483	2254	2255	3726	3497	2952
LR test P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes	yes	yes

*t* statistics in parentheses  
\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$   
Robust standard errors

Table C2: Heterogeneity by residence

	collected/purchased urban	purchased/no biomass urban	collected/purchased rural	purchased/no biomass rural
PA presence	-0.0100 (-0.42)	0.0801*** (2.90)	-0.0144 (-0.97)	-0.0354 (-0.41)
Head age	0.00192*** (3.66)	0.00237*** (4.04)	0.000479 (1.63)	0.000760 (0.42)
Head gender (male)	0.0770*** (4.55)	0.00512 (0.31)	0.000872 (0.08)	-0.0734 (-1.13)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	0.00902 (0.42)	-0.0280 (-1.29)	-0.00418 (-0.33)	-0.0261 (-0.40)
Secondary education (head)	-0.0505** (-2.56)	-0.0387** (-2.10)	-0.00929 (-0.70)	0.0557 (0.84)
Higher education (head)	-0.0803 (-1.34)	-0.176*** (-5.48)	-0.0150 (-0.43)	-0.0165 (-0.12)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.400*** (-9.61)	-0.00456 (-0.09)	-0.0855*** (-2.94)	-0.00866 (-0.09)
Other occupation (head)	-0.364*** (-13.27)	0.000313 (0.01)	-0.0759*** (-7.81)	0.0978* (1.65)
Wealth index	-1.390*** (-16.85)	-1.001*** (-19.47)	-0.474*** (-9.09)	-0.193 (-0.80)
Household size	0.00729** (2.26)	0.0249*** (7.26)	0.00698*** (3.21)	0.0141 (1.16)
Rainfall	-0.154*** (-5.86)	-0.257*** (-9.27)	-0.0172 (-0.99)	0.371*** (2.83)
Temperature	0.0113** (2.20)	0.0628*** (9.68)	0.00856** (2.53)	0.0590*** (2.62)
Mammals & birds	0.106*** (5.27)	0.298*** (18.53)	0.0201 (1.12)	-0.324*** (-2.66)
Observations	2621	3087	3130	373
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses  
\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$   
Robust standard errors

Table C3: Surface equals first quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (first quartile)	0.00510 (0.34)	0.0395** (2.23)	0.0293** (2.18)	-0.0353 (-1.13)
Head age	0.00142*** (5.08)	0.00169*** (5.25)	0.00117*** (4.59)	0.00207*** (3.58)
Head gender (male)	0.00364 (0.45)	0.0688*** (6.42)	0.00642 (0.80)	-0.00724 (-0.45)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0136 (-1.33)	0.00453 (0.34)	-0.000574 (-0.06)	-0.0245 (-1.18)
Secondary education (head)	-0.0216** (-2.36)	-0.0482*** (-3.59)	-0.0105 (-1.13)	-0.0263 (-1.45)
Higher education (head)	-0.106*** (-5.46)	-0.0215 (-0.59)	-0.113*** (-4.41)	-0.175*** (-5.68)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.102*** (-6.84)	-0.307*** (-9.94)	-0.155*** (-7.92)	0.0914** (2.42)
Other occupation (head)	-0.0938*** (-8.79)	-0.291*** (-24.62)	-0.134*** (-12.48)	0.106*** (3.09)
Wealth index	-0.679*** (-26.83)	-1.555*** (-34.83)	-0.821*** (-29.29)	-0.913*** (-17.88)
Household size	0.0140*** (8.01)	0.00670*** (3.54)	0.0107*** (6.56)	0.0244*** (7.24)
Rainfall	-0.141*** (-12.04)	-0.123*** (-7.59)	-0.133*** (-11.60)	-0.211*** (-9.14)
Temperature	0.0311*** (11.44)	0.0000662 (0.02)	0.0220*** (9.09)	0.0664*** (11.05)
Mammals & birds	0.169*** (22.80)	0.101*** (7.17)	0.155*** (19.47)	0.267*** (19.36)
<i>Observations</i>	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

Table C4: PA surface equals second quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (second quartile)	0.0218** (1.96)	0.0117 (0.89)	0.0246** (2.20)	0.0337 (1.46)
Head age	0.00141*** (5.07)	0.00169*** (5.26)	0.00119*** (4.61)	0.00203*** (3.51)
Head gender (male)	0.00369 (0.45)	0.0694*** (6.47)	0.00635 (0.80)	-0.00702 (-0.44)
No education (head)	ref.	ref.	ref.	ref.
[1em] Primary education (head)	-0.0137 (-1.34)	0.00509 (0.38)	-0.000945 (-0.10)	-0.0258 (-1.24)
Secondary education (head)	-0.0217** (-2.37)	-0.0484*** (-3.60)	-0.0114 (-1.22)	-0.0272 (-1.50)
Higher education (head)	-0.106*** (-5.46)	-0.0216 (-0.59)	-0.115*** (-4.50)	-0.176*** (-5.73)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.102*** (-6.87)	-0.308*** (-9.95)	-0.154*** (-7.85)	0.0883** (2.35)
Other occupation (head)	-0.0939*** (-8.80)	-0.292*** (-24.68)	-0.132*** (-12.27)	0.103*** (3.00)
Wealth index	-0.681*** (-26.90)	-1.559*** (-35.07)	-0.821*** (-29.33)	-0.916*** (-17.93)
Household size	0.0140*** (7.99)	0.00647*** (3.42)	0.0109*** (6.63)	0.0245*** (7.27)
Rainfall	-0.134*** (-11.87)	-0.130*** (-8.08)	-0.135*** (-12.21)	-0.189*** (-7.96)
Temperature	0.0307*** (11.24)	0.000293 (0.09)	0.0211*** (8.64)	0.0650*** (10.79)
Mammals & birds	0.165*** (21.98)	0.105*** (7.37)	0.156*** (19.60)	0.255*** (17.10)
<i>Observations</i>	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

Table C5: PA surface equals third quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (third quartile)	-0.0312*** (-4.05)	-0.0685*** (-6.81)	-0.0465*** (-6.50)	-0.0130 (-0.76)
Head age	0.00141*** (5.05)	0.00171*** (5.34)	0.00120*** (4.73)	0.00205*** (3.53)
Head gender (male)	0.00375 (0.46)	0.0688*** (6.44)	0.00512 (0.64)	-0.00671 (-0.42)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0147 (-1.44)	0.00189 (0.14)	-0.00104 (-0.11)	-0.0258 (-1.24)
Secondary education (head)	-0.0223** (-2.44)	-0.0474*** (-3.56)	-0.00836 (-0.92)	-0.0275 (-1.51)
Higher education (head)	-0.106*** (-5.52)	-0.0217 (-0.60)	-0.106*** (-4.24)	-0.176*** (-5.74)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.100*** (-6.77)	-0.303*** (-9.95)	-0.151*** (-7.80)	0.0911** (2.41)
Other occupation (head)	-0.0922*** (-8.57)	-0.289*** (-24.39)	-0.131*** (-12.11)	0.105*** (3.06)
Wealth index	-0.670*** (-26.38)	-1.518*** (-34.02)	-0.798*** (-28.50)	-0.911*** (-17.89)
Household size	0.0140*** (8.05)	0.00647*** (3.45)	0.0107*** (6.60)	0.0246*** (7.27)
Rainfall	-0.131*** (-11.94)	-0.127*** (-7.96)	-0.129*** (-12.16)	-0.198*** (-8.84)
Temperature	0.0313*** (11.37)	-0.000346 (-0.11)	0.0225*** (9.31)	0.0656*** (10.95)
Mammals & birds	0.154*** (19.34)	0.0886*** (6.17)	0.139*** (16.91)	0.257*** (16.08)
<i>Observations</i>	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors



Table C6: PA surface equals fourth quartile

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA Surface (fourth quartile)	0.0284*** (2.60)	0.0602*** (4.99)	0.0312*** (3.10)	0.0109 (0.48)
Head age	0.00143*** (5.13)	0.00174*** (5.45)	0.00119*** (4.66)	0.00206*** (3.56)
Head gender (male)	0.00370 (0.45)	0.0687*** (6.41)	0.00577 (0.72)	-0.00682 (-0.42)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0140 (-1.37)	0.00454 (0.34)	-0.000452 (-0.05)	-0.0253 (-1.22)
Secondary education (head)	-0.0221** (-2.41)	-0.0465*** (-3.49)	-0.0106 (-1.14)	-0.0271 (-1.49)
Higher education (head)	-0.106*** (-5.49)	-0.0227 (-0.63)	-0.112*** (-4.48)	-0.175*** (-5.72)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.100*** (-6.78)	-0.305*** (-9.99)	-0.153*** (-7.90)	0.0920** (2.43)
Other occupation (head)	-0.0920*** (-8.60)	-0.287*** (-24.14)	-0.131*** (-12.18)	0.106*** (3.09)
Wealth index	-0.671*** (-26.32)	-1.522*** (-34.11)	-0.804*** (-28.28)	-0.910*** (-17.87)
Household size	0.0140*** (8.06)	0.00677*** (3.59)	0.0107*** (6.63)	0.0245*** (7.26)
Rainfall	-0.150*** (-13.44)	-0.151*** (-9.19)	-0.150*** (-13.64)	-0.206*** (-8.98)
Temperature	0.0326*** (11.93)	0.00326 (1.01)	0.0241*** (9.83)	0.0660*** (11.10)
Mammals & birds	0.166*** (22.90)	0.0990*** (7.02)	0.156*** (19.83)	0.262*** (19.19)
<i>Observations</i>	7209	5751	5207	3460
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

Table C7: Effect when PA is a classified forest

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_forest	0.0112 (1.02)	-0.00159 (-0.10)	-0.00699 (-0.59)	0.0419 (1.59)
Head age	0.00120*** (4.02)	0.00183*** (5.13)	0.00139*** (4.42)	0.00160** (2.20)
Head gender (male)	-0.00372 (-0.44)	0.0667*** (5.82)	-0.00220 (-0.23)	-0.0213 (-1.08)
No education	ref.	ref.	ref.	ref.
Primary education (head)	-0.00719 (-0.68)	0.00202 (0.14)	-0.00268 (-0.24)	-0.00921 (-0.36)
Secondary education (head)	-0.0105 (-1.09)	-0.0476*** (-3.23)	-0.00559 (-0.52)	-0.00247 (-0.11)
Higher education (head)	-0.0929*** (-4.07)	-0.0406 (-0.95)	-0.115*** (-3.59)	-0.183*** (-4.41)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.0728*** (-4.90)	-0.261*** (-7.72)	-0.113*** (-5.56)	0.0832* (1.92)
Other occupation (head)	-0.0645*** (-7.11)	-0.266*** (-21.56)	-0.110*** (-10.98)	0.119*** (3.19)
Wealth index	-0.550*** (-19.75)	-1.540*** (-32.87)	-0.829*** (-25.92)	-0.755*** (-11.24)
Household size	0.0163*** (8.00)	0.00644*** (3.21)	0.0123*** (5.59)	0.0341*** (7.60)
Rainfall	0.0177 (1.00)	0.0409 (1.61)	0.0470** (2.47)	0.0273 (0.62)
Temperature	0.0279*** (10.10)	-0.00731** (-2.12)	0.0210*** (7.63)	0.0681*** (10.53)
Mammals & birds	-0.00473 (-0.29)	-0.0935*** (-3.55)	-0.0395** (-2.23)	0.0110 (0.28)
<i>Observations</i>	5638	4957	4031	2288
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

Table C8: Effect when PA is a parc

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_parc	-0.00130 (-0.04)	-0.0982*** (-4.11)	-0.0501*** (-3.00)	0.0771 (1.39)
Head age	0.00203*** (3.69)	0.000600 (0.94)	0.000846** (2.23)	0.00274*** (3.30)
Head gender (male)	0.0179 (1.08)	0.0613*** (2.90)	0.0183 (1.53)	0.0124 (0.51)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0313 (-1.49)	0.000787 (0.03)	-0.00641 (-0.41)	-0.0468 (-1.47)
Secondary education (head)	-0.0412** (-2.29)	-0.104*** (-3.68)	-0.00590 (-0.43)	-0.0470* (-1.75)
Higher education (head)	-0.103*** (-3.16)	0.00368 (0.06)	-0.0588* (-1.68)	-0.135*** (-3.31)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.225*** (-5.62)	-0.272*** (-5.21)	-0.199*** (-4.99)	-0.103 (-1.07)
Other occupation (head)	-0.219*** (-6.18)	-0.279*** (-10.71)	-0.186*** (-5.79)	-0.0993 (-1.05)
Wealth index	-0.896*** (-19.24)	-1.451*** (-15.33)	-0.685*** (-15.07)	-1.056*** (-14.60)
Household size	0.0141*** (4.35)	0.00493 (1.18)	0.00847*** (4.00)	0.0189*** (4.01)
Rainfall	-0.201*** (-5.48)	-0.108*** (-3.73)	-0.105*** (-5.21)	-0.312*** (-5.10)
Temperature	0.0460*** (4.75)	-0.0171*** (-2.83)	0.0137*** (2.83)	0.0925*** (4.26)
Mammals & birds	0.216*** (8.63)	0.127*** (5.83)	0.119*** (8.32)	0.311*** (7.16)
<i>Observations</i>	2363	1443	1751	1532
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

Table C9: Effect when PA is a nature reserve

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_ReserveNatur	0.208*** (3.10)	0.0137 (0.33)	0.187** (2.32)	0.416*** (3.74)
Head age	0.00182*** (2.64)	0.000931 (0.97)	0.00190*** (2.59)	0.00235 (1.52)
Head gender (male)	0.00462 (0.22)	0.0469 (1.60)	0.0158 (0.73)	-0.00646 (-0.15)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.00871 (-0.33)	-0.00190 (-0.06)	-0.0149 (-0.58)	0.000401 (0.01)
Secondary education (head)	-0.00663 (-0.28)	-0.106*** (-2.63)	0.000989 (0.04)	0.0197 (0.40)
Higher education (head)	-0.0434 (-0.99)	-0.120 (-1.09)	-0.0943 (-1.22)	-0.0617 (-0.75)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.135*** (-4.22)	-0.209*** (-2.76)	-0.159*** (-3.66)	-0.140 (-1.02)
Other occupation (head)	-0.151*** (-6.46)	-0.283*** (-9.60)	-0.184*** (-6.36)	-0.155 (-1.14)
Wealth index	-0.705*** (-10.35)	-1.382*** (-8.92)	-0.874*** (-10.51)	-1.070*** (-7.39)
Household size	0.0203*** (4.13)	0.00752 (1.33)	0.0119*** (2.60)	0.0399*** (4.28)
Rainfall	-0.0554 (-1.19)	0.136** (2.29)	0.0309 (0.72)	-0.206** (-2.13)
Temperature	0.0346*** (4.32)	-0.0295*** (-3.49)	0.0151** (2.12)	0.0909*** (4.50)
Mammals & birds	0.0646* (1.70)	-0.179*** (-3.00)	-0.0233 (-0.65)	0.213*** (2.74)
N	1038	866	742	468
LR test P value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

t statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

Table C10: Effect by PA type (national or international)

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
PA_National	0.0268** (2.10)	0.000794 (0.05)	-0.0000855 (-0.01)	0.0676*** (2.60)				
PA_International					0.105 (1.42)	-0.0242 (-0.42)	0.0126 (0.25)	0.360* (1.80)
Head age	0.00146*** (5.15)	0.00169*** (5.17)	0.00118*** (4.52)	0.00213*** (3.67)	0.00164** (2.46)	0.000794 (0.88)	0.00165** (2.38)	0.00224 (1.40)
Head gender (male)	0.00404 (0.49)	0.0699*** (6.44)	0.00634 (0.78)	-0.00670 (-0.42)	0.000670 (0.03)	0.0564* (1.95)	0.0112 (0.55)	-0.0144 (-0.33)
No education (head)	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
Primary education (head)	-0.0124 (-1.20)	0.00436 (0.33)	-0.000753 (-0.08)	-0.0219 (-1.05)	-0.00599 (-0.24)	0.00472 (0.15)	-0.00681 (-0.29)	0.000734 (0.01)
Secondary education (head)	-0.0228** (-2.45)	-0.0475*** (-3.49)	-0.0116 (-1.23)	-0.0277 (-1.53)	-0.00425 (-0.18)	-0.139*** (-3.33)	0.00101 (0.04)	0.0277 (0.52)
Higher education (head)	-0.107*** (-5.44)	-0.0246 (-0.65)	-0.116*** (-4.50)	-0.175*** (-5.68)	-0.0402 (-0.92)	-0.0485 (-0.56)	-0.0800 (-1.13)	-0.0684 (-0.78)
Agriculture (head)	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
White collar (head)	-0.103*** (-6.85)	-0.313*** (-10.02)	-0.159*** (-7.96)	0.0919** (2.42)	-0.130*** (-4.19)	-0.180*** (-2.70)	-0.140*** (-3.65)	-0.154 (-1.14)
Other occupation (head)	-0.0954*** (-8.80)	-0.295*** (-24.54)	-0.136*** (-12.43)	0.105*** (3.05)	-0.148*** (-6.73)	-0.253*** (-9.04)	-0.173*** (-6.76)	-0.168 (-1.26)
Wealth index	-0.677*** (-26.43)	-1.568*** (-34.96)	-0.828*** (-28.83)	-0.886*** (-17.38)	-0.695*** (-10.38)	-1.486*** (-11.03)	-0.869*** (-11.58)	-1.081*** (-7.28)
Household size	0.0138*** (7.84)	0.00676*** (3.53)	0.0108*** (6.50)	0.0238*** (7.10)	0.0208*** (4.25)	0.00255 (0.48)	0.0119*** (2.73)	0.0433*** (4.42)
Rainfall	-0.160*** (-12.25)	-0.137*** (-7.78)	-0.146*** (-11.38)	-0.239*** (-9.03)	-0.0474 (-1.05)	0.0350 (0.64)	0.0244 (0.60)	-0.182* (-1.77)
Temperature	0.0340*** (12.04)	0.000606 (0.18)	0.0234*** (9.48)	0.0708*** (11.58)	0.0302*** (3.73)	-0.0240*** (-3.36)	0.0132** (2.00)	0.0829*** (3.87)
Mammals & birds	0.183*** (22.47)	0.103*** (6.90)	0.163*** (18.95)	0.289*** (18.41)	0.0510 (1.37)	-0.0343 (-0.71)	-0.0205 (-0.60)	0.177** (2.09)
Observations	7076	5621	5092	3439	1070	898	791	451
LR test P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes	yes	yes	yes	yes

t statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors

Table C11: Effect depending on the level of protection of the PA

	Biomass/ no biomass	Biomass collected/purchased	Biomass collected/no biomass	Biomass purchased/no biomass
Integral PA	-0.0476*** (-4.51)	-0.0715*** (-4.89)	-0.0557*** (-5.85)	-0.0668** (-2.47)
Head age	0.00140*** (4.62)	0.00181*** (5.41)	0.00106*** (3.89)	0.00210*** (3.37)
Head gender (male)	0.00513 (0.59)	0.0700*** (6.17)	0.00360 (0.43)	-0.00306 (-0.18)
No education (head)	ref.	ref.	ref.	ref.
Primary education (head)	-0.0162 (-1.48)	0.00388 (0.27)	-0.00148 (-0.14)	-0.0286 (-1.29)
Secondary education (head)	-0.0229** (-2.36)	-0.0372*** (-2.65)	-0.0115 (-1.17)	-0.0311 (-1.62)
Higher education (head)	-0.114*** (-5.25)	-0.0191 (-0.48)	-0.117*** (-4.13)	-0.187*** (-5.63)
Agriculture (head)	ref.	ref.	ref.	ref.
White collar (head)	-0.0869*** (-5.41)	-0.313*** (-9.24)	-0.135*** (-6.51)	0.122*** (3.17)
Other occupation (head)	-0.0744*** (-6.42)	-0.291*** (-22.79)	-0.113*** (-10.52)	0.144*** (4.14)
Wealth index	-0.639*** (-22.96)	-1.550*** (-33.01)	-0.758*** (-24.73)	-0.864*** (-15.58)
Household size	0.0130*** (7.05)	0.00635*** (3.18)	0.0109*** (6.22)	0.0220*** (6.15)
Rainfall	-0.108*** (-6.92)	-0.116*** (-6.15)	-0.0967*** (-6.93)	-0.169*** (-4.86)
Temperature	0.0293*** (9.66)	0.00542 (1.62)	0.0210*** (8.49)	0.0602*** (9.07)
Mammals & birds	0.139*** (12.06)	0.0917*** (5.41)	0.127*** (11.43)	0.226*** (8.25)
<i>Observations</i>	6228	4962	4496	2998
LR test p value	0.0000	0.0000	0.0000	0.0000
Household RE	yes	yes	yes	yes

*t* statistics in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Robust standard errors