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Assessing Energy Source Preference of Household and Stand Diversity in the Catchment Area of Bamako, Mali

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Abstract

Wood fuel as a domestic combustible plays a major role for the Malian population (more than 90% of households depend on it for domestic cooking). It is used in rural as well as in urban areas. This paper focuses on assessing the energy source preference of households and stand diversity in Bamako catchment area. We have surveyed 200 households and 70 firewood and charcoal sellers in the District of Bamako. Forest inventory was carried out in Famana and Kassela within the Bamako catchment area where plots have been established (10 plots of 50 x 20 m per site). Plots were separated from each other by 50m. Results showed that the use of charcoal is higher than firewood in the urban households due to its availability and easy handling. 71.50% of households in Bamako use charcoal for cooking meals. Charcoal has become the most preferred source of energy for households in Bamako. The main factors for this trend are related to poverty, cooking habits of households, and urbanization. The two sites (Famana and Faya) are characterized by high diversity. Famana has a Shannon Diversity Index of 2.92 while Faya has 2.55. The study revealed a strong capacity of woody formations to provide species such as *Combretum glutinosum, Combretum micranthum, and Lannea velutina which is* very convenient for domestic combustion. These species have a rapid regeneration capacity and can grow in many types of ecological environments. Species such as *Parkia biglobosa, Vittelaria paradoxa, Ficus*

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gnaphalocarpa, and Khaya senegalensis (protected species) that are highly appreciated by households of Bamako have a great economic value and are constantly under threat. Households demand for these species exceeds the production capacity of forests. Immediate actions are needed to promote modern energy in order to ensure sustainable development.

Keywords: Wood fuel, energy preference, household, stand diversity, Bamako

Introduction

Fuel wood as domestic energy is one of the oldest sources of energy in the world. It was used not only for household energy through cooking and heating but also as a source of energy to run industries. Nowadays, the issue of domestic energy consumption has become a major concern around the world mainly in developing countries (IRENA, 2019). Most African countries remain dependent on traditional energies such as firewood, charcoal, and agricultural residues for cooking (Bangirinama et al., 2016).

In the Sahel region, households rely entirely on biomass for domestic cooking which affects human health, forest survival, and ecological balance leading to climate change (Jagger & Kittner, 2017). Firewood and charcoal continue to attract more and more people because of the affordable price and easy access (CEREEC, 2015). The high demand expressed by households has led operators to use all types of wood species without taking into account the ecological factor, the impact on the environment, and the sustainability (Teplitz-Sembitzky & Schramm, 1989). People depending on fuel wood will increase by 2030, and this is a call on stakeholders to tackle factors influencing the growing demand (Bentsen & Felby, 2012). As a result, deforestation continues to threaten natural environment through the loss of biodiversity, soil erosion, ecosystem degradation, and climate change (Nicolas, 2011; Zilihona et al., 2011).

In Mali, wood fuel plays a major role in meeting energy needs which represents 90% of domestic energy consumed by households (Fonabes, 2017a). The impact of consumption on forests especially in the vicinity of Bamako is increasing. The persistence of biomass energy use is partly due to the non-competitiveness of modern energies (electricity, butane gas, solar energy). This is also due to the lack of reliable information regarding social and individual benefits of energy transition (Schlag & Zuzarte, 2008). The high cost and poor infrastructures have prevented many countries to adopt new technologies. Due to its easy handling and storage, charcoal has become the most appreciated domestic energy for households in Bamako (Gazull, 2009).

Currently, the trend of demand of firewood and charcoal from the population of Bamako is associated with the rapid population growth and rampant urbanization (Gazull et al., 2013). Therefore, these populations lack option for modern energy due to poverty. Cooking meals depending on fuel wood represents more than 90% of households consumed energy (Keïta, 2014). Cuts intensity is preventing new species from reaching their full capacity from growing. Protected species such as *Vitellaria paradoxa* (Shea) and *Parkia biglobosa* (Néré) which play a considerable economic part in the life of rural populations are directly threatened. Those activities generate a huge income for rural populations but reduce the ecosystem services and the carbon stocks of forests (Gingrich et al., 2019). As a result, forests are exposed to a gradual degradation.

The objective of this work was to assess the energy source preference of household and stand diversity in Bamako catchment area. As the supply area of Bamako is expanding to the region of Sikasso and Kayes, new alternatives should be explored in order to reduce the increasing pressure of urban households.

Materials and Methods

Study Site

This study was conducted in three (3) locations within Bamako catchment area. The survey was done with households in Bamako city and completed with forests inventory in Famana (municipality of Keleya) and Kassela (municipality of Banguineda).

Bamako fuel wood catchment basin has 150 km^2, and it stretches over four (04) regions (Kayes, Koulikoro, Sikasso, Ségou) and the district of Bamako (Figure 1). It encompasses one hundred and fourteen (114) municipalities, plus the urban municipality of Bamako and ten (10) circles.

The village of Famana is located at -7.85401 longitudes and 11.86006 latitudes in the Bougouni circle, 3km from the village of Keleya, which is the main city in the commune. Forest massif of the village covers a total area of 1,219 ha, and this belongs to the village of Famana (Fonabes, 2017b). This massif is mainly exploited for firewood and charcoal production. The climate is tropical wet. The rainfall varies between 800 mm to 1200 mm per year which is favorable to the growth of many types of species. The annual average temperature is varying between 25 °C to 30 °C. As for the relief, a few small elevations are scattered across the commune. In general, the relief is flat. The hydrographic network is very poor and intermittent streams drain torrential water just after heavy rains. Their soils present very shallow depth, a gravelly structure with an accumulation of organic matter, favorable to the savannah area in which some species are convenient for domestic energy.

The site of Kassela is located in the protected forest of Faya in the region of Koulikoro (2nd administrative region of Mali), surrounded by the circles of

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Kati, Dioila, and Koulikoro. The RN6 (National roads) towards Ségou divides the massif into two distinct zones:

- To the south, the landscape is marked by vast Bowes which connects with the colluvium or alluvium near the rivers by fairly steep slopes (3 to 6%).
- In the North, the topography turns to a monotonous plain with a slope of around 1%. The climate is tropical and characterized by the rotation of three seasons (hot, cold and rainy).

The average rainfall recorded in the protected forest varies between 750 to 950 mm. The soil types encountered are depleted tropical ferruginous soils. These are pseudo-gley soils of depth with spots and concretions on clay colluvium at gravel level on shell. The hydrography of the protected forest of Faya is very rich. It is made up of the Faya River and its tributaries (Fardjalanko, Farako, Ounou, Solonko, Syenko, Zabanko, Sirakolobako, Tontanako, N'tjibougouko, Mousounko and Wankolen).

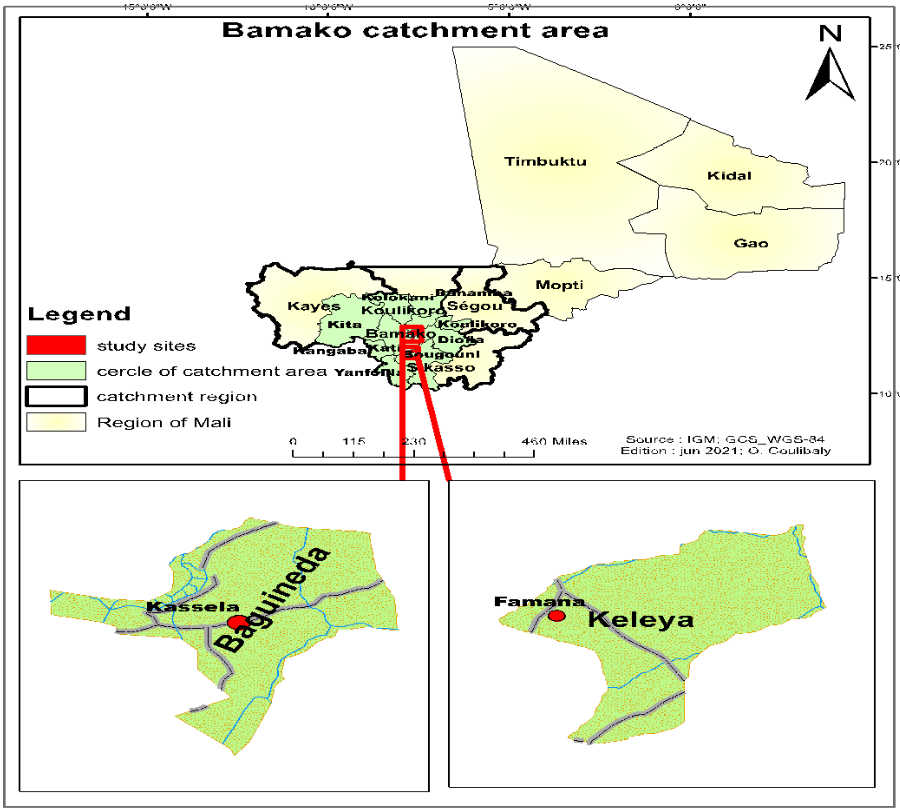

Figure 1. Bamako Catchment Area

Methodological Approach

We used qualitative and quantitative method. The qualitative method involved documentary research, field observations, and interviews. The

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quantitative method includes inventories of forest and questionnaire recorded with households in Bamako city.

Data Collection and Sampling

Field survey included questionnaires submitted to households and wood fuel suppliers in the Bamako District. The questionnaires included open and closed questions to allow respondents to provide as much information as possible. Many of our respondents were illiterate people. Questions were translated into the local language Bambara, the most spoken language by all residents of Bamako. The inventory work was focused on counting species and diameter measurements of adult individual tree at 1.30cm from the ground called Diameter at Breast Height (DBH). Species having a diameter greater than 10cm were selected and measured in a predefined direction as indicated by Thiombiano et al. (2016).

Household and Wood Fuel Suppliers

In total, 200 households were selected among residents within the six communes and 68 total neighborhoods of Bamako District by using multi-stage sampling. Multi-stage sampling is the process of selecting a sample with two or more successive stages (Statistique Canada, 2003). Neighborhoods were selected according to the mode of settlement, the formerly populated neighborhood, and the newly populated neighborhood. These neighborhoods were situated alongside both banks of the Niger River. The left bank was composed of old neighborhoods (Niarela, Bamako coura, Banconi and Hamdalaye) and the right bank of new neighborhoods (Kalaban coura, Yirimadio; Senou). In total, 7 neighborhoods were selected from those six communes in order to constitute the study sample. Systematic random sampling method was used to select households (Yiran et al., 2020). Thereafter, the random choice was used to select household heads or his representative in each dwelling. We then started with the neighborhood chiefs. From their houses, we continued in the same street and each 3rd house was selected (same process for the streets). The selection interval was randomly chosen. The use of systematic sampling method is justified by its simplicity, and it offers better precision. In order to obtain the numbers to be surveyed by neighborhood, we used the following formula:

$$\text{Sample size} = nh * N/NH$$

nh= number of households by neighborhood ; N= total number wanted (200)

NH= total of households in all neighborhood selected

In order to survey wood fuel suppliers, we assume that firewood and charcoal are sold in Bamako mainly in the central markets of every

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neighborhood, along roads by individuals, or door to door by carts. In this study, we focused on market sellers and those along roads. We started by targeting the central markets in the selected neighborhoods. In total, 60 wood fuel suppliers were randomly selected in those different markets, and 10 others were selected along the main roads through the six municipalities of Bamako. In total, 70 wood fuel suppliers were interviewed.

Forest Inventory

The fieldwork was conducted between May-June 2019. The inventory was focused on two sites (Famana and Faya). We have established 10 plots per site. Each plot measures 50 x 20m separated by 50m as indicated by Kakaï et al. (2016). In total, 4 ha were inventoried (2 ha per site). The site of Kassela was located in the protected forest of Faya (south side) and Famana, which is an old fallow land located to the east of the village. A random choice described by Kuma and Shibru (2015) was used to select these areas in order to avoid places populated by exotic species as much as possible. All collected firewood species were identified during field survey and the unidentified specimens were submitted to the national service of water and forests. We have used equipment such as:

- GPS to record the geographical coordinates of plots
- Measuring Tape of 5m, 30m, and 50m to measure the diameter of the inventoried species
- Stakes to delimit plots
- Data recording sheets and pencils to record all data collected

Data Analysis

We used descriptive analysis performed by SPSS software, IBM 25, and Excel. Thereafter, data were sorted to determine the energy source preference of households. Forest inventory data were recorded in Excel software in order to compute the Shannon diversity index (H) and Shannon equitability (EH). The use of this mathematical formula helps to obtain a lot of information on forest such as forest diversity and evenness (Maishanu et al., 2019; Zimudzi et al., 2013). The formula is as follows:

$$H = -\sum_{i=1}^{s} pi \ln pi$$

Where H is the Shannon index**;** Σ is the sum of the calculation**;** pi= *ni* /N; *n is* the number of individual tree present for species *i*, *N* is the total number of individuals; S is the total number of species; ln is the natural log

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EH= H/Hmax ; Where EH is Shannon equitability; H is the Shannon index; Hmax is lnS

Results

Determinants of Wood Fuel Consumption in Bamako

We noticed that charcoal is the most consumed energy by households in Bamako (Figure 2 and 3). This study showed that 71.50% of household heads have declared to use charcoal, and 28.50% preferred firewood as their main source of energy. Among those 71.50% using charcoal, 79% of them claimed to associate butane gas. Among the 28.50% of firewood users, 21% use butane gas as well.

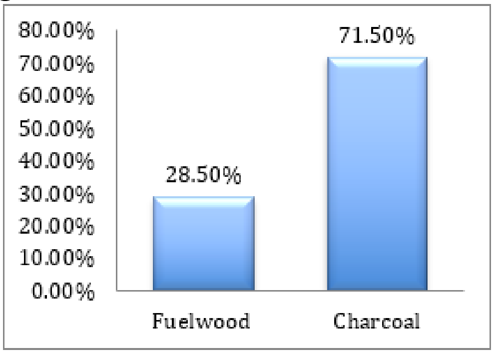

Figure 2. Main Energy Use by Bamako's Household

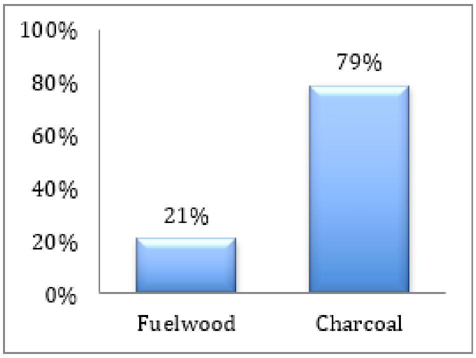

Figure 3. Household Combining Butane Gas with Wood Fuel Energy

The result showed the shift from firewood to charcoal consumption. In the city of Bamako, a great majority is stacking fuel (firewood, charcoal, and butane gas). Most of the household use butane gas as secondary energy to heat water and cook breakfast, but rarely for the main meals. The main reason behind this situation is the lack of financial resources. The findings revealed that 42.50% of households explained their choice by the low price of charcoal (poverty of households), and another 39% emphasized the easy handling of charcoal.

During the survey, some households reported that in rainy season, its use becomes more comfortable as it is very easy to procure and stack inside the kitchen. The stoves used for cooking foods are protected from humidity and rain. Around 18.50% emphasized the availability and the easy access because sellers are in every corners of the city. During the interviews, many head of households reported that they prefer to avoid butane gas because of its high cost and non-availability at all time. The cooking habits are considered to be another discouraging factor. Most traditional meals such as Toh (dish made of millet floor) beans and head of animals (lambs, beefs and goats) remain exclusively prepared with firewood. Therefore, this requires high calorific power and very long time of combustion. Some of them reported that

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butane gas is not convenient for Malian context. As a result, butane gas has become a back-up source of energy because of its rapid use, and especially during the month of Ramadan for heating meals and boiling water for coffee. Household size, cooking habits, and lack of space in houses raise some fears in the event of fire. In many households, the use of gas tank is prohibited for maid and children. Moreover, its availability is not guaranteed throughout the year due to external dependency and incapacity of the government to pay subsidy to suppliers on time. Therefore, butane gas is perceived by households in Bamako as source of energy for the Western country.

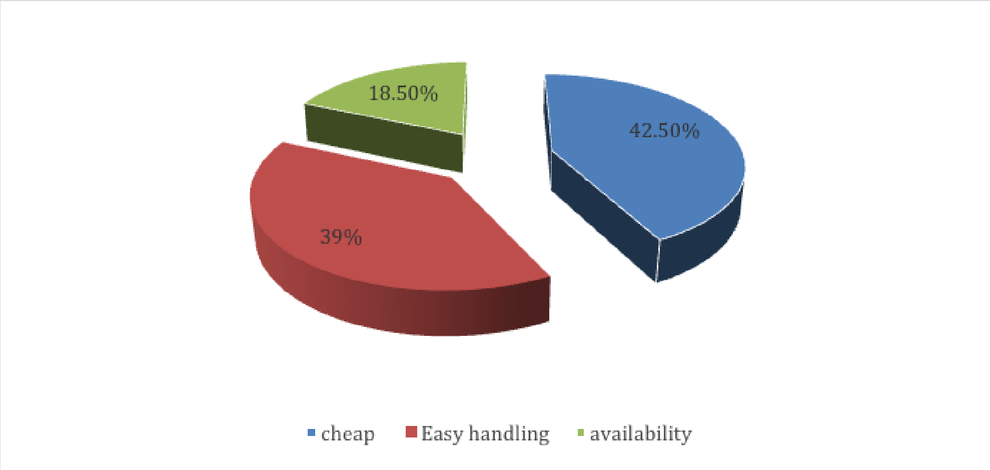

Figure 4. Determinants of the Choice of Households

Floristic Composition

The two sites selected have different floristic composition. The results showed that the site of Faya is abundant with species such as *Cassia sieberiana* (sinjan) with 92 individuals, *Lannea acida* (pekuni) with 72 individuals, *Combretum micranthum* (golobe) with 38 individuals, *Combretum glutinosum* (tiangara) with 32 individuals, *Anogeissus leiocarpus* (galama) with 21 individuals, *Vitellaria paradoxa* (shi) with 25 individuals, *Prosopis africana* (gelé) with 17 individuals, *Pterocarpus erinaceus* (guénou) with 16 individuals, and *Diospyros mespiliformis* (sunsun) with 14 individuals. In total, the site of Faya counts 32 species, 11 families, and 398 individuals (Table 1).

Regarding Famana site (Table 1), the dominant species are *Combretum glutinosum* (tiangara) with 76 individuals, *Detarium microcarpum* (taba koumba) with 56 individuals, *Combretum micranthum* (golobe) with 53 individuals, *Cassia sieberiana* (sinjan) with 44 individuals, *Guiera senegalensis* (kounjie) with 27 individuals, and *Afzelia africana* (lengué) with 20 individuals. Overall, the Famana site has 27 species, 11 families, and 486 individuals.

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Table 1. Abundance of Species Recorded in Both Site

Species	Faya	Famana	Total number of individuals
Acacia ataxacantha	0	13	13
Acacia macrostachya	0	15	15
Afzelia africana	0	20	20
Anogeissus leiocarpus	21	0	21
Bombax costatum	5	4	9
Boscia senegalensis	6	0	6
Burkea africana	0	6	6
Carapa procera	1	0	1
Cassia sieberiana	92	44	136
Cola cordifolia	0	9	9
Combretum glutinosum	32	76	108
Combretum micranthum	38	53	91
Combretum molle/velutinum	2	0	2
Combretum nigricans	6	0	6
Combretum paniculatum	0	1	1
Cordia myxa	6	0	6
Cordyla pinnata	0	2	2
Crossopteryx februfiga	0	18	18
Detarium microcarpum	3	56	59
Dichrostachys cinerea	1	0	1
Diospiros mespiliformis	14	0	14
Entada africana	2	0	2
Grewia mollis	3	6	9
Guiera senegalensis	0	27	54
Isoberlinia doka	0	13	26
Lannea acida	72	9	81
Lannea microcarpa	0	14	14
Lannea velutina	0	1	1
Lonchocarpus laxiflorus	1	0	1
Opilia celtidifoia	0	3	3
Parkia biglobosa	6	9	15
Piliostigma reticulatum	0	15	15
Prosopis africana	17	14	31
Pseudocedrela kotschyi	3	0	3
Pteleopsis suberosa	0	21	21
Pterocarpus erinaceus	16	0	16
Pterocarpus indicus	0	5	5
Pterocarpus lucens	2	0	2

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Saba senegalensis	0	2	2
Tamarindus indica	1	2	2
Terminalia macroptera	1	15	16
Vitellaria paradoxa	25	6	31
Ximenia americana	12	7	19
Ziziphus mucronata	10	0	10
Total	**398**	**486**	**923**

Species Richness

During plots investigation, the following results were obtained (Table 2). The Shannon diversity index of Famana site and Faya site are 2.92 and 2.55 respectively. These results showed a high floristic diversity of the two sites because they are all above the standard limit of 2.5, which is considered as the threshold of high diversity. Meanwhile, the Shannon equitability of Famana and Faya sites, which have 0.85 and 0.77 respectively, has an even community. Equitability assumes a value between 0 and 1 with 1 being complete evenness. The closer to 1, the more the evenness of the plant community is significant. By comparing both sites, Famana site is more even than Faya.

Table 2. Diversity of Famana and Faya

Site of Famana		**Site of Faya**
LAT: 11,86006 LONG: -7,85401		LAT: 12.5937 LONG: -7.66084
Abundance	486	398
Density	243/ha	199/ha
Number of species	30	27
Shannon diversity index	2,92(2,5)	2,55(2,5)
Equitability index	0,85 (1)	0,77 (1)
Family	11	11
Genre	22	23

Household Preference and Response of Forests

Household preference was studied according to the production potential of forest response in both sites. The result showed a high diversity of forests as the demand of household is increasing. Households were grouped by preference and compared to the supply capacity of Famana and Faya of each species. The following graph (Figure 5) indicates that a great potential of species such as *Combretum glutinosum, Combretum micranthum, and Lannea velutina are* very convenient for domestic combustion. These species appeared to have rapid regeneration rate and fit many types of ecological environments. However, species such as *Parkia biglobosa, Vittelaria paradoxa, Ficus gnaphalocarpa, and Khaya senegalensis* (protected species) are highly appreciated by households. They also have high economic value and are under serious threat. Households demand for these species exceeds the production

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potential of woody formations. Despite the ban, the market is still illegally supplied with these species.

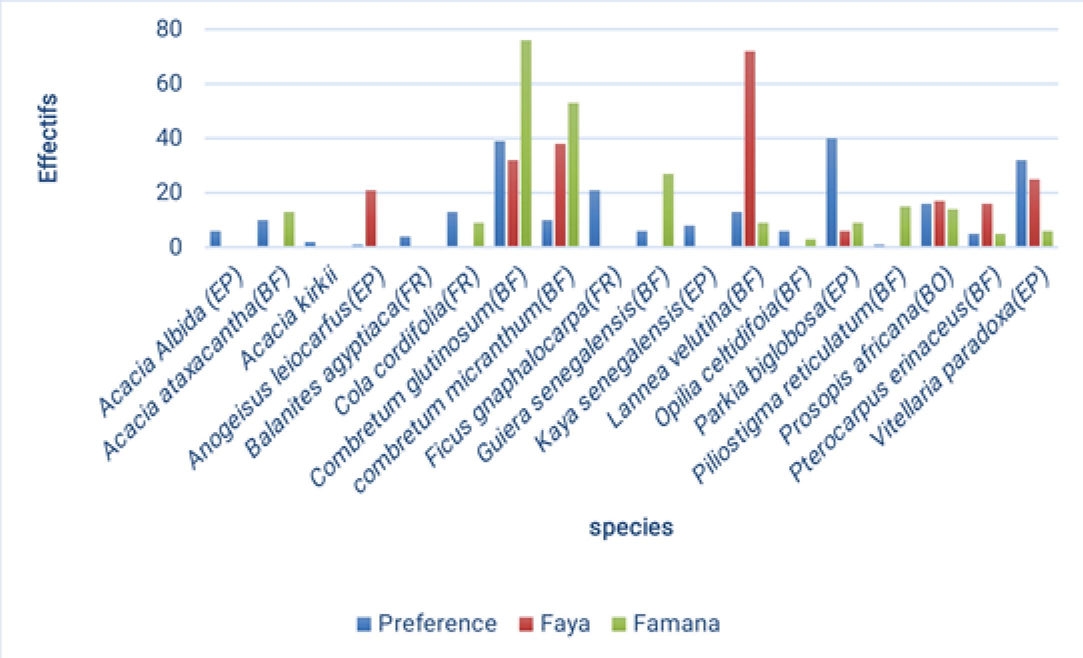

Figure 5. Household Preference and Forests Response

Discussion

Determinants of Wood Fuel Consumption

Energy transition is not yet reached in the Sahel countries (Gautier et al., 2007). This study reveals that charcoal is the most consumed energy by households in Bamako. The findings indicate that 42.50% of households justify their choice by the low price of charcoal (poverty of households), and another 39% emphasize the easy handling of charcoal. In rural areas, households use firewood, while in urban centers the choice is oriented towards charcoal combined with other modern energies (Doggart et al., 2020; Heltberg, 2004). In Bamako, charcoal is cheaper and available at every corner of the city. Additionally, low transportation cost, lack of smoke, and packing condition makes it more attractive as most formerly populated neighborhood have small size houses. High price of modern energy prevents low revenue households to buy it (Gazull et al., 2019). The poverty of households contributes significantly with 46.8% of households whose annual expenditure does not exceed 175,000 FCFA around $130 (EMOP, 2020). The consumption of charcoal increases with urbanization in many Sahelian cities because of poverty (Ouedraogo, 2006). Zou and Luo (2019) states that low-income households prefer stacking fuel (firewood, charcoal, butane gas and electricity).

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Urbanization through population growth increases the pressure on woody formation and become a major determinant (Babanyara & Saleh, 2010; Yiran et al., 2020). Population growth in the city of Bamako exposes many people to poverty because of unemployment. Volatility of price and unavailability of modern energy has led households to maintain their cooking habits. Furthermore, land speculation has changed the vocation of forests and cultivated lands (Diallo et al., 2020). This situation is aggravated with insufficient and poor distribution of precipitation. The decline in agricultural yields has brought peasants to uncontrolled loggings (Maiga et al., 2019). Nowadays, conflicts are recurrent between peasants, breeders, land speculators, and loggers in Bamako catchment area (Gautier et al., 2011).

Our findings are in line with Choumert-Nkolo et al. (2019), Gioda (2019), Onyeneke et al. (2015), Ouedraogo (2006), Sabuhungu (2016), and Sharma et al. (2019) studies. They indicate urbanization, poverty of households, and cooking habits as determinants of wood fuel consumption. These results are also similar to D'Agostino et al. (2015), who emphasize the packing condition, easy handling, and the absence of smoke. In most cities, firewood consumption is shifting to charcoal due to the preference of city dwellers. Charcoal has become more convenient and available in the city. The energy ladder hypothesis evoked by Choumert-Nkolo et al. (2019) indicates that the increase of the revenue of households reduces the use of traditional energies, which does not occur in Mali. As a result, we notice a shift from firewood to charcoal (Montagne, 2018). Firewood is no longer very appreciated by urban dwellers due to pollution generated and additional work required for its use.

Preference and Forests Diversity

The two forests (Faya and Famana) are rich and much diversified with a Shannon diversity index of 2.92 for the site of Famana and 2.55 for the site of Faya. Despite high pressure on woody formations, they present a high diversity. The Famana fallow land is denser and more diversified than the Faya forest. In the Malian context, the fallow formation actively contributes to the production of fuel wood, especially if the collection only focuses on dead wood, as illustrated by Morton (2007) in Dafela region of Kita (Nouvellet et al., 2003). As Famana site is part of fallow land, located on the edge of Guinean climate with substantial rainfall, in the non-protected domain, the fertility of soils promotes rapid regeneration and growth of new species. The fallow time, which is normally 5 years, has been exceeded contributing to the high diversity. Furthermore, this zone has been long time spared from the pressure of rural wood markets, which are important determinants for the intensification of cuts (Hautdidier, 2007).

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The protected forest of Faya very close to Bamako has been under exploitation since the colonial period. Firewood was exploited to run steam locomotive from Bamako to Dakar. Its location near Bamako with increasing population accentuated the pressure. In addition, the legislation enacted better management. Neighboring communities are still cutting firewood for commercial use, thereby preventing it to attain its full capacity of regeneration. These loggers as suppliers of wood markets infringe those restrictions (Raton, 2012). They have the feeling of being excluded by forest protection officers.

During exploitation, the rural communities have the choice to discriminate between species when cutting. However, we noticed a great potential of forests to provide species such as *Combretum glutinosum, Combretum micranthum, and Lannea velutina* which are ideally indicated for domestic combustion. They have a rapid regeneration capacity according to Ngom et al. (2012) and tolerate many types of ecological environment. Accordingly, its market offers great economic service to neighboring communities by alleviating poverty. The preference of households for these species is due to its accessibility and calorific power. They generate less pollution and produce more blazes. At the same time, they are very convenient to produce firewood and charcoal.

These results are confirmed by Kouyate et al. (2020) in the woody formations of Sikasso, in southern Mali, with shannon diversity index of 4.99 and that of Giliba et al. (2011) in the Miombo forest in Tanzania with Shannon diversity index of 4.27. The increasing demand for firewood and charcoal has not prevented the woody formation to be diversified.

This disparity between a fallow land and forest is in line with another study undertaken in Southeast Angola by Goncalves et al. (2018), which presents that a diversity of fallow lands are greater than forests.

This situation predicts a better future for the consumption of wood fuel in the Bamako catchment area. Given the preference of households, the exploitation of species has become selective. They are selected according to their calorific value, the combustion time, and the degree of pollution generated. These selective cuttings have positive effects on woody formations in term of good management (Hosier, 1993). According to the findings of his study in Tanzania, selective logging for charcoal is a good technique for keeping forests alive. It demonstrates the great capacity of woody formation to regenerate. Verburg and Van Eijk-Bos (2003) agree with these findings by indicating that selective logging does not have negative impact on forest diversity. Therefore, it facilitates forest regeneration and the growth of new species.

Hall et al. (2003) in Central Africa found similar Shannon diversity index between exploited forest and unexploited forest with H = 1.89 and H = 1.94 respectively. In addition, the high intensity of forest exploitation for firewood has low impact on the structure, composition, and regeneration of forests. Furthermore, it reduces the basal area of plant (Parrotta et al., 2002). Nowadays, the impact of selective harvesting depends on the intensity of cuts. If the intensity is low, it has less effect on forest degradation (Harun et al., 2017).

Conclusion

This study showed that poverty, types of meals, and cooking techniques are the main determinants of the use of solid energies in Bamako. The preference of households is reducing the capacity of forests to meet the growing demand of urban households. Species, such as *Combretum glutinosum, Combretum micranthum, and Lannea velutina,* ideally indicated for firewood are in abundance. However, households demand for species such as *Vittelaria paradoxa, Ficus gnaphalocarpa, and Khaya senegalensis* (protected species), highly appreciated by households, surpass the production potential of woody formations. Consequently, forests are under serious threat due to population growth and rampant urbanization. In addition, loggings intensity in Bamako catchment area would have negative impact on forest regeneration. Although Famana and Faya site remain diversified, efforts need to be made in order to accelerate the energy transition. Despite numerous policies initiated to shift from traditional energies to modern energies, wood fuel sector has developed a strong resilience and remains the preferred cooking energy of urban dwellers. Stands diversity appeared as boosting factor even though questions remain regarding the capacity of woody formations to respond sustainably to the growing demand of populations. Due to the need to implement new policies to organize and regulate forests logging, it would be necessary to assess the regeneration capacity of forests and explore new alternatives (modern energies, reforestation) in order to guaranty a sustainable supply chain for Bamako households.

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