American Journal of Sciences and Engineering Research

E-ISSN -2348 – 703X, Volume 8, Issue 1, 2025

Estimation and Evaluation of Charcoal Production in the Dry Dense Forest of Mikea, Ankililoaka Rural Commune

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ABSTRACT: *In Madagascar, charcoal remains not only a source of income for the rural population of the southwest but also an essential energy source in the daily lives of Malagasy people. However, this activity requires a vast forest resource to meet the demand, not only in villages but also in large cities. This article aims to analyze charcoal production in the Ankililoaka Commune, near the dry forest of Mikea in southwest Madagascar. The study seeks to determine and describe: (i) the tree species used for charcoal production, (ii) the quantity of charcoal produced and the transportation methods to consumers, and (iii) the risks associated with charcoal production concerning the state of the forest. An inventory was conducted, identifying 15 tree species used for charcoal production in the Mikea National Park forest within the Ankililoaka commune. A tota l of 242 households were randomly selected across nine villages, including 39 charcoal producers. According to the survey, 161 out of 242 households use charcoal rather than firewood. Charcoal is transported from production sites to consumption centers and sales depots (Ankililoaka) using carts, human carriers (on the head), and pushcarts. Based on an average weight of 35 kg per sack, approximately 42,768 sacks of charcoal were produced in 2021. This study provided a diagnostic analysis of current charcoal production practices for each category of stakeholders and correlated these practices with the availability of plant species, household financial needs, and family labor capacity. There are four types of producers: type 1: Produces 80 to 100 sacks of charcoal per month, type 2: Produces fewer than 80 sacks per month, type 3: Produces between 100 and 300 sacks per month, type 4: Produces between 300 and 500 sacks per month. The study of charcoal production rhythms revealed that charcoal producers do not follow any predefined cutting rules. Instead, they adjust their production throughout the year based on household needs and additional economic activities.*

Keywords: *charcoal, charcoal production, charcoal-making practices, dry forest, Ankililoaka*

I. INTRODUCTION

In Madagascar, forest formations currently cover 12 to 13 million hectares, representing a little over 21% of the country's territory. These forests are highly diverse due to the variety of bioclimatic conditions (Cornet &

 Received-16-02-2025 Accepted- 27-02-2025

Guillaumet, 1976) and a high degree of endemism (Langrand & Wilmé, 1997). However, Malagasy forests are under threat. Deforestation, which affects 100,000 to 300,000 hectares annually, is among the most alarming in the tropical world. Studies by Green & Sussman (1990) and Sussman et al. (1994) indicate that the deforestation rate between 1950 and 1985 was 110,000 hectares per year. In the southwest, Razanaka (1995) reported that deforestation rates tripled between 1970 and 1980. The Mikea National Park has faced rapid degradation since the 1970s. In the southern region, charcoal production is the primary driver of forest clearing, as it supplies rapidly growing urban centers with fuel (Michel Grouzis et al., 2004). Wood fuel is the primary energy source for households, mainly used for cooking and survival activities such as artisanal baking (bread-making), aluminum foundries, and brick production (Schure et al., 2011). Today, charcoal production is at the center of international debates.

It remains the most used fuel by Malagasy households due to its low cost compared to alternative energy sources (Ramaromiharintsoa, 2005; Van Der Plas, 2006). Demand for charcoal increases with population growth (GISC, 2009). Charcoal production serves as a supplementary income for small-scale farmers, especially young people with limited farmland and seasonal migrant workers. Additionally, wood exploitation fosters settlement dynamics, where migrants begin as laborers on charcoal farms before acquiring agricultural land and settling permanently (Andriamifidy, 2014b). Given the rapid urban growth and persistent poverty, charcoal remains the most accessible energy source for many households, aligning with their low purchasing power. In rural areas, firewood is primarily used, whereas urban households rely on charcoal. However, charcoal production remains largely artisanal and unregulated, particularly in easily accessible forests near urban areas and along main roads, such as the Mikea forest. The objectives of this study are to: (i) Identify the tree species used for charcoal production, (ii) Assess charcoal production in terms of quantity, (iii) Determine the transportation routes used to distribute charcoal.

II. MATERIALS AND METHODS

STUDY SITE

The study was conducted in southwestern Madagascar, in Toliara II District, specifically in the Ankililoaka Commune, Ankililoaka village. This research took place in seven neighborhoods of Ankililoaka (Ampasimanilika, Mangily, Amparehitra, Tsianaloka, Ambalakida, Soarano), where charcoal producers operate. Their production sites are located within the Mikea National Park forest. The study area in the Mikea forest was divided into four sites (Ankily, Anjahafolo, Anjapolo, Antampimbato). These sites were selected based on distinct characteristics, including geographical location (proximity to villages in the west), ecological differences (floristic interactions), and charcoal-making activities. Sampling plots were established using GPS, with guidance from charcoal producers, to compare areas with and without charcoal production.

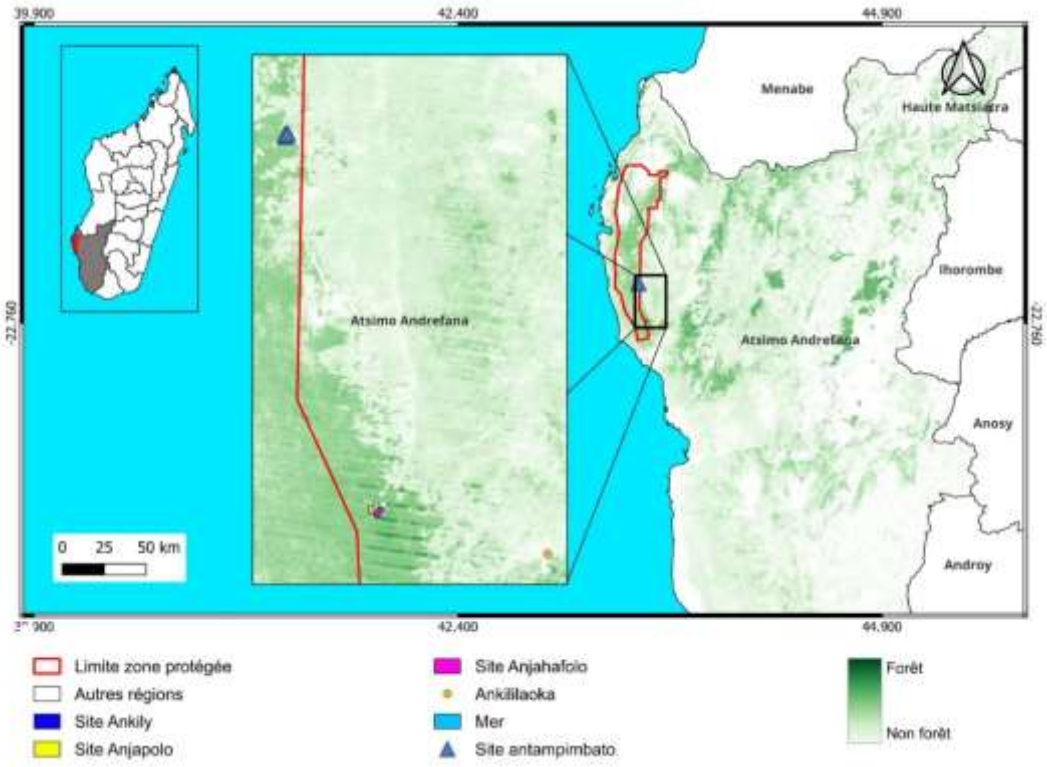


Fig.1 Study Site location

Description of Study Sites

Ankily Site: This is an abandoned charcoal production site or a former charcoal site. It is highly degraded, with few large trees remaining—only a few scattered ones. The site is mainly dominated by grasses. Additionally, traces of kilns can still be found.

Anjahafolo Site: This is the current charcoal production site, where numerous kilns can be observed—between 30 and 40 kilns in total across all surveyed areas, i.e., the ten surveyed plots. This is a highly disturbed site.

Anjapolo Site: This is a less disturbed site. Unlike the production site, where the density of abandoned charcoal kilns is high, only a few abandoned kilns were found in this area. In all installed inventory plots, fewer than five kilns were observed.

Antampimbato Site: This is an undisturbed site, with no kilns present. It is located within Mikea Park.

Selection and Location of Study Sites

The selection of study sites was based on a combination of information from bibliographic research, various maps provided by MNP, MNP guides, ethnobotanical surveys, and field prospecting.

Ethnic Groups in the Villages

According to the survey, five ethnic groups inhabit the study area: Masikoro, Antandroy, Vezo, Betsileo, and Bara. Among them, the Antandroy are the most involved in charcoal production.

Main Activities

The charcoal production techniques observed are similar to those described by Randriamalala et al. (2016). The charcoal kilns are exclusively installed on red sandy soil. During field observations in the village of Ankililoaka, near the city of Toliara, charcoal was transported by bush taxis. However, from the forest to the village of Ankililoaka, it was transported by ox carts. There are five charcoal stockists in the village. Almost all charcoal production is sold to intermediaries, who then transport it to Toliara (Masezamana et al. 2013).

METHODS

Formal surveys were conducted among the local population. These were carried out at the household level and focused, among other things, on the production system (productive activities) and charcoal production practices (time allocated to this activity, quantity produced, income generated from charcoal, and its allocation). Each surveyed household was characterized by its financial independence, reproductive capacity (those who had not yet married were not included), and its home, which housed all dependents who could participate in productive activities. A total of 242 households were randomly selected. To achieve this, a field survey questionnaire was used to meet individuals in their usual environment based on their activities, in order to collect a significant amount of data related to the study (Sizer et al., 2005; Kusters et al., 2006). The study focused on the social, economic, and ecological aspects of the product, as well as the charcoal markets and production. Both quantitative and qualitative data were collected from the respondents. To characterize vegetation and charcoal production sites, randomly selected plots of (20 x 20) m^2 were used (Godron et al., 1983). Among the four sites, Anjahafolo is the current production site. A reasoned selection of about thirty producers was made based on their location and the role of charcoal production in their production system. For each of them, a monthly follow-up was conducted on the quantities of charcoal produced, selling prices, costs (labor and transport), and income.

1.1. Field Surveys

The data for this study were collected through surveys of households, charcoal producers, and local authorities in the commune of Ankililoaka using household questionnaires and interview guides. The household surveys took place from July to September 2022, using a stratified sampling technique to ensure that the sample represented all elements of the population. These strata were designed to cover the study's target population, ensuring that: Each category of the population was adequately represented in the sample. Each subject, object, or spatial unit was properly accounted for. In the case of a heterogeneous population, stratification allows for a more accurate representation (Maroi et al., 2000).

Qualitative Data Collection

Qualitative data were gathered using structured interview guides, which were submitted to key local informants.

Category of Surveyed Individuals

The surveys mainly targeted peasants (men and women), charcoal producers, charcoal and firewood users, drivers transporting charcoal to Toliara, and consumers.

Categories of Producers

In this production, there are four types of producers:

Type 1: Those producing 80 to 100 sacks of charcoal per month.

Type 2: Those producing less than 80 sacks per month.

Type 3: Those capable of producing 100 to 300 sacks of charcoal per month.

Type 4: Those producing between 300 and 500 sacks of charcoal per month.

1.2. Inventory

The inventory was conducted to estimate the availability of resources for charcoal production and to identify the most commonly used tree species to propose alternative solutions that would help preserve forest resources.

1.3. Data Analysis

Hierarchical Ascending Classification (HAC) was applied to analyze charcoal production in different sites (neighborhoods). HAC is a classification method that groups objects into hierarchical classes based on algorithmic calculations (Saporta, 1990). The classes must be as homogeneous and distinct as possible (Simier, 1998). This method was used to classify the surveyed individuals according to their charcoal production levels.

To conduct this classification, individuals were grouped using Hierarchical Ascending Classification. They were compared two by two, and those with similar characteristics were grouped together. This process continued until four distinct groups were formed, ensuring that the classification remained manageable. Individuals within the same cluster belonged to the same category.

Charcoal Production Activity in the Dry Forest of MIKEA Park

Charcoal production sites are concentrated around villages. These camps are occupied by people whose main activities are charcoal production and firewood collection. The charcoal production techniques used are similar to those described by Randriamalala et al. (2016).

The charcoal-making process begins with cutting wood, which takes place at least one week before it is placed in the kiln. Tree trunks and branches larger than 1 cm in diameter are separated from smaller twigs, which are used to ignite the kiln.

The kiln is a hole approximately 80 cm deep, 300 cm long, and 200 cm wide, where the cut wood is arranged. The logs are placed across the width of the hole, with larger pieces on top and smaller ones at the bottom to facilitate ignition and initial combustion. This hole is dug near the area where the wood was cut. The entire setup is then covered with vegetation debris to prevent soil particles from infiltrating the kiln. The carbonization process lasts about 7 to 10 days.

Fig.2 Kiln charcoal Mikea Park

Fig.3 Photo of installed kiln

Fig.4 Photo of catching fire of woods

Fig.5 Photo of transportation charcoal in cart

Fig.6 photo of transportation charcoal in public transport

III. RESULTS

Since charcoal production is based on plant species, 15 tree species have been used for its production (Table 1), knowing that not all forest woods are suitable for making charcoal.

A total of 242 households were surveyed. Additionally, the exploratory survey allowed us to identify 39 forest exploiters (charcoal producers), 3 major stockists in Ankililoaka, and the exit route of the products. Given the small number of these actors, all those encountered were included in the survey. The most frequently mentioned charcoal-producing species by households are listed in Table 1.

Table 1: Average frequency of species in the sites

Vernacular Name	Family	Genus and Species	Frequency Percentage
Kily	Césalpiniacea	*Tamarindus indica* L.	0,01%
Maintifototsy	Ebenaceae	*Diospyros cupulifera* Perr	3,20%
Manary	Mimosaceae	*Albizia greveana* (Baill) Bar	6,13%
Sakoa	Anacardiaceae	*Poupartia caffra* (Sond) Perr.	14,58%
Sarikily	sapotaceae	*Capurodendron mandrarense*	0,17%
Sely	Malvaceae	*Grewia leucophylla* Capuron	2,94%
Vaovy	Fabaceae	*Tetrapterocarpon geayi* .Humbert	0,09%
Volivaza	Rubiacea	*Rothmannia* sp	0,25%
Hazomena	Ebenaceae	*Diospyros humbertiana* H. Pierrieri	2,76%
Hazomafio	Sapindaceae	*Cardiospermum halicacabum*	2,07%
Katrafay	Rutaceae	*Cedrelopsis grevei*	6,64%

Among these species, the most used ones are Tamarindus indica, with a frequency percentage of 0.01%, indicating that this species is less frequent in the sites and therefore the most exploited. Other frequently used species include Tetrapterocarpon geayi (0.09%) and Capurodendron mandrarense (0.17%). These species, known for their hard wood, are becoming increasingly rare in their natural habitat. Due to the scarcity of these hardwoods, charcoal producers resort to using softer species, which results in lower-quality charcoal.

Additionally, some species were mentioned during the survey but were not recorded in the floristic inventories. These include Operculicarya gummifera, Ziziphus mauritiana, Droceloncia reticulata, and Pithecellobium dulce. According to villagers, these species are used when the preferred ones for charcoal production are unavailable. They are usually found near villages.

Table 2: Distribution of households and charcoal producers in the Ankililoaka commune

Commune	village	Households	Charcoal Producers
ANKILILOAKA	MANGILY	20	5
	AMPAREHITSY	36	2
	TSIANALOKA	18	2
	ANKILILOAKA I	15	3
	ANKILILOKA II	17	0
	BARA	39	0
	AMBALAKIDA	56	4
	AMPASIMANILIKA	21	21
	SOARANO	20	2
TOTAL		242	39

242 households were interviewed: The neighborhoods do not have the same number of surveyed individuals, and all the people encountered were interviewed. The following neighbor
hoods had the highest number of surveyed households: Ambalakida (23.12%), Bara (16.11%), and Amparehitsy (14.87%). The other neighborhoods have almost the same numbers, around 8.26%.

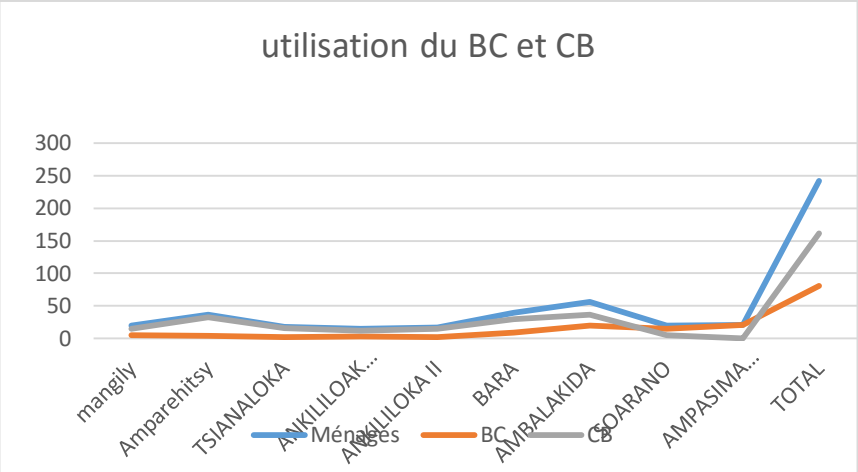


Fig.7 Curve showing the use of firewood (BC) and charcoal (CB)

Among the 242 surveyed households, 81 use firewood, while 161 use charcoal. Therefore, there are more charcoal users than firewood users.

The study of charcoal production rhythms showed that different types of charcoal producers were identified, and they do not follow any predefined cutting rules. Instead, they adjust their production rhythm throughout the year based on the household's domestic needs and the number of complementary activities.

Table 4: Charcoal production in each site (neighborhood)

Location	Exploitation Duration (years)	X° per fab	Fab frequency	X°/ month	Unit price	Sold/month
Ampasimanilika1	1,00	10,00	2,00	80,00	2500,00	200000,00
Ampasimanilika2	10,00	15,00	1,00	60,00	2500,00	150000,00
Ampasimanilika3	15,00	25,00	1,00	100,00	2500,00	250000,00
Ampasimanilika4	20,00	12,00	1,00	48,00	2500,00	120000,00
Ampasimanilika5	5,00	10,00	1,00	40,00	2500,00	100000,00
Ampasimanilika6	8,00	8,00	1,00	32,00	2500,00	80000,00
Ampasimanilika7	6,00	12,00	1,00	48,00	2500,00	120000,00
Ampasimanilika8	5,00	15,00	1,00	60,00	2500,00	150000,00
Ampasimanilika9	1,00	8,00	1,00	32,00	2500,00	80000,00
Ampasimanilika10	1,00	35,00	1,00	140,00	2500,00	350000,00
Ampasimanilika11	1,00	9,00	1,00	36,00	2500,00	90000,00
Ampasimanilika12	7,00	10,00	1,00	40,00	2500,00	100000,00
Ampasimanilika13	0,17	6,00	1,00	24,00	2500,00	60000,00
Ampasimanilika14	3,00	8,00	1,00	32,00	2500,00	80000,00
Ampasimanilika15	25,00	10,00	1,00	40,00	2500,00	100000,00
Ampasimanilika16	5,00	10,00	1,00	40,00	2500,00	100000,00

Ampasimanilika17	3,00	7,00	1,00	28,00	2500,00	70000,00
Ampasimanilika18	10,00	40,00	2,00	320,00	2500,00	800000,00
Ampasimanilika19	12,00	35,00	1,00	140,00	2500,00	350000,00
Ampasimanilika20	1,00	55,00	2,00	440,00	2500,00	1100000,00
Ampasimanilika21	2,00	7,00	1,00	28,00	2500,00	70000,00
Mangily1	10,00	20,00	2,00	160,00	2500,00	400000,00
Mangily2	1,00	8,00	1,00	32,00	2500,00	80000,00
Mangily3	5,00	35,00	1,00	140,00	2500,00	350000,00
Mangily4	11,00	15,00	1,00	60,00	2500,00	150000,00
Mangily5	20,00	50,00	1,00	200,00	2500,00	500000,00
Amparehitry1	10,00	35,00	1,00	140,00	3000,00	420000,00
Amparehitry2	12,00	25,00	1,00	100,00	3500,00	350000,00
Tsianaloka1	15,00	20,00	1,00	80,00	2500,00	200000,00
Tsianaloka2	10,00	25,00	1,00	100,00	2500,00	250000,00
Ankililoaka 1	3,00	4,50	2,00	36,00	4000,00	144000,00
Ankililoaka 2	5,00	15,00	1,00	60,00	4000,00	240000,00
Ankililoaka 3	10,00	10,00	1,00	40,00	4000,00	160000,00
Ambalakida1	5,00	10,00	2,00	80,00	2500,00	200000,00
Ambalakida2	17,00	35,00	1,00	140,00	2500,00	350000,00
Ambalakida3	10,00	15,00	1,00	60,00	2500,00	150000,00
Ambalakida4	4,00	6,00	2,00	48,00	2500,00	120000,00
Soarano1	11,00	10,00	2,00	80,00	2500,00	200000,00
Soarano2	18,00	50,00	1,00	200,00	2500,00	500000,00

Type 1: 80 < P < 100
Type 2: P < 80
Type 3: 00 < P < 300
Type 4: 300 < P < 500

The price of charcoal was 2,500 AR per sack in 2021, during the period of our survey, but this has been increasing year by year. By 2024, the price has risen significantly, reaching up to 13,000 AR per sack in Ankililoaka and 15,000 AR to 18,000 AR in Tuléar. This price has remained steady until now.

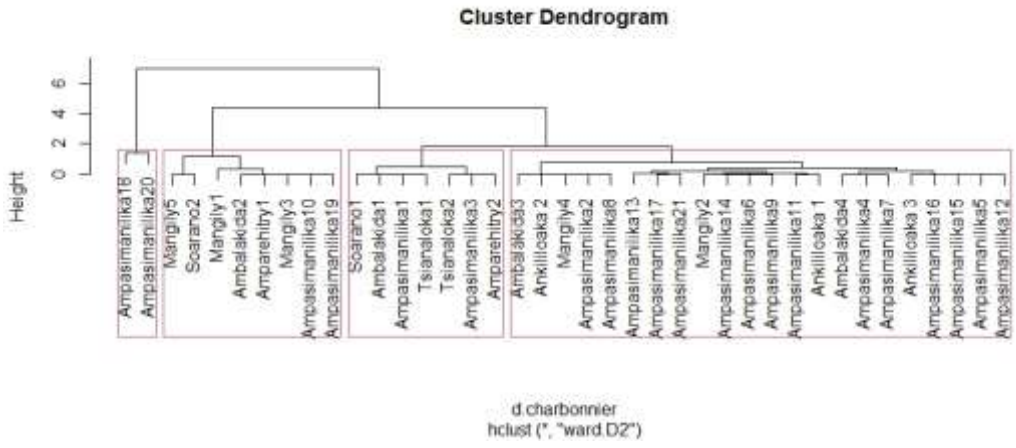
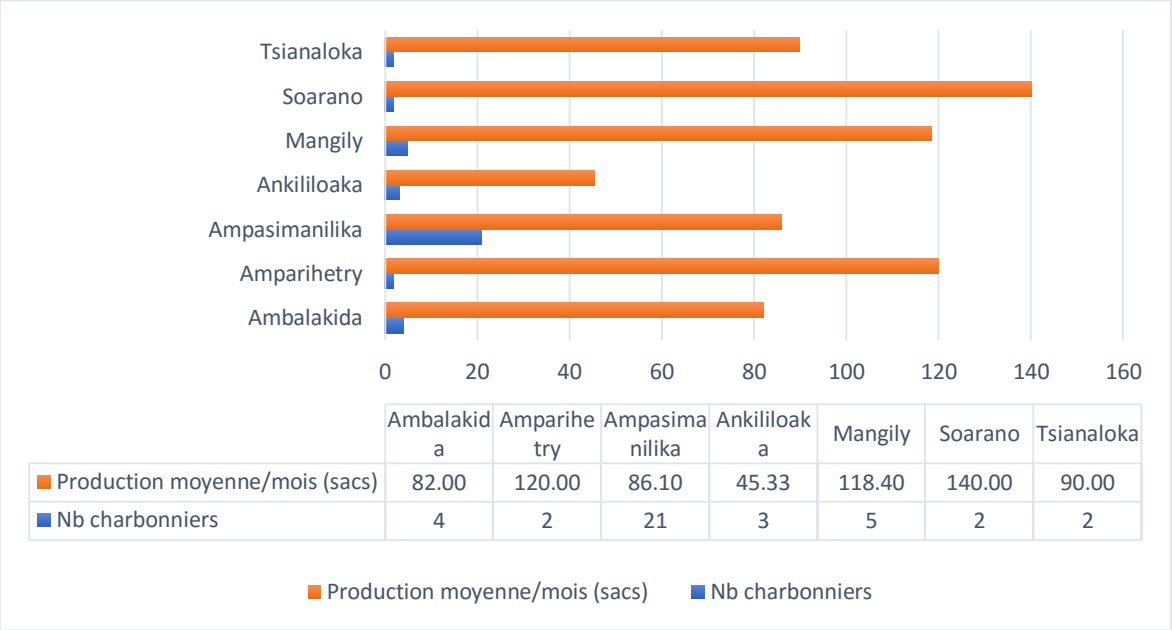


Fig.8 Comparison of charcoal production from different sites

According to the hierarchical cluster analysis, Ampasimanilika 18 and Ampasimanilika 20 are the top producers, producing much more charcoal compared to others. However, in the Ampasimanilika area, there are also producers with lower output, such as Ampasimanilika 16, 15, 5, and 12 (table 4).

During the survey, the Ampasimanilika neighborhood had the most charcoal producers, but its average production is lower compared to other neighborhoods. On the other hand, in Soarano, there are only two charcoal producers, but their average monthly output is significantly higher than the others (table 2). The town center has the smallest output among all the other neighborhoods, with a production of 45.33 sacks per month (table 4).



	Ambalakida	Amparihetry	Ampasimanilika	Ankililoaka	Mangily	Soarano	Tsianaloka
Production moyenne/mois (sacs)	82.00	120.00	86.10	45.33	118.40	140.00	90.00
Nb charbonniers	4	2	21	3	5	2	2

Fig.9 Average Production of Charcoal in Sacks in the Study Area

The neighborhood with the highest number of charcoal sacks produced per month is Soarano, reaching 140 sacks, followed by Amparehitsy with 120 sacks, and Mangily with 118 sacks per month. In Ankililoaka, the commune's main village, the lowest production is recorded, with an average of 45 sacks per month. This explains the population situation in each neighborhood.

Product Transportation:

Producers: They are responsible for the charcoal production in the forest. All the producers are male, as the work of charcoal production is tough, from selecting the trees to cutting them down and packaging the finished products. Often, two people work together to assist each other, but during times when there are many workers in a household and their children are old enough to work, the entire family pitches in. Some producers own ox-drawn carts to transport their products to stockpilers. Charcoal production slows down for about four months each year. Some households stop producing charcoal during the agricultural season if it rains. Otherwise, charcoal production continues throughout the year.

Transporters: The ox-drawn cart is the only available and suitable means of transport for moving sacks of charcoal from the production site to the storage location. The transporters are often the owners of the carts, and they are responsible for transporting the charcoal from the forest to the village, consumption centers, and sales depots (Ankililoaka). The weight is always based on an average of 35 kg per sack. Occasionally, people carry charcoal on their heads, and rickshaws (pousse-pousse) are used to transport products from production areas to consumers. These are people who sell charcoal, carrying it on their heads. For rickshaws, intermediaries pay them to transport the products to the sales center or distribute them to consumers.

Taxi-brousses (shared transport) also contribute to distributing charcoal to Toliara, the major consumption hub, at a cost of 3000 Ar per sack. They can carry up to 40 sacks in a Sprinter and 20 to 25 sacks in a Mazda in a single trip.

Fig 10. Photos of charcoal transport to Toliara (personal observation)

To transport these products to Toliara, the “taxi-brousse” places them on the luggage rack, sometimes covering them, and sometimes even under the seats in the vehicle when the intermediaries don’t have a sales or transportation permit for charcoal. The producers exploit natural resources illicitly, without authorization. Therefore, drivers must hide the products, leaving early in the morning to transport them and negotiating with traffic authorities, including police or gendarmes, even the ATT, paying money throughout the journey.

Fig 11.Transport of charcoal to the storage site (depot) (personal observation)

A cart can also be used to transport charcoal. It can carry 10 to 25 bags of charcoal at once. The producers handle tree selection, cutting, bush burning, fire monitoring, bagging, or preparing for transport, and directly pay the cart owner transport fees, ranging from 50,000 Ar to 60,000 Ar per bag, depending on the distance.

IV. DISCUSSION

The exploitation of ligneous resources for energy wood production generally generates subsistence income for rural producing populations. Charcoal production contributes to diversification strategies that allow farmers to increase their income. Charcoal production provides regular income for producers. However, this activity destroys trees and shrubs, whose leaves, fruits, and/or flowers form the essential natural forage for small ruminants during the dry season, about nine months of the year (Rabeniala et al., 2009). Moreover, it risks causing irreversible degradation of vegetation in grazing areas and may lead to desertification of the environment. Nevertheless, it is a revenue-generating activity and thus offers undeniable socio-economic advantages. Additionally, there is no problem in selling this product since charcoal is the most widely used fuel by Malagasy households due to its low cost compared to other energy sources (Ramaromiharintsoa, 2005; Van Der Plas, 2006). Around 41,000 charcoal bags were produced in the Soalary Sud bush in 2009 (Raoliarivelo et al., 2010), but for the dense dry forest of the Mikea Park, 42,768 bags were observed in 2021, meaning the Mikea Park forest produces more charcoal. The exploitation of charcoal, in its function, appears to be an essential activity for producers. The manifest or visible function shows that this production is a source of substantial income for the daily needs of populations (food, housing, healthcare, schooling, clothing). Charcoal production in southwestern Madagascar is mostly consumed in the city of Toliara, where the demand for it increases with the population (Gardner et al., 2015). A large part of Madagascar's dry forests has been destroyed, and few large blocks remain (Seddon et al., 2000; Blanc-Pamard et al., 2005).

Only trees and shrubs with hard, dense wood that can produce high-quality charcoal (slow-burning, durable, and producing little ash) are used.

In Ankililoaka, most people work as farmers (rice, dry beans, and some cultivate artemisia and cotton due to the presence of Bionex and Tianli Agri), or livestock breeders (sheep, goats, poultry). They are therefore busy with their work, and fewer people are involved in charcoal production. The neighborhoods with more charcoal bags indicate that charcoal production is their main activity.

V. CONCLUSION

Charcoal production is gradually becoming an environmental issue that is at the center of both national and international debates. Tropical forests, particularly dry forests, are drawing the attention of international institutions and Non-Governmental Organizations such as Madagascar National Parks (MNP), which manages the Mikea National Park. This particular attention is justified by the ongoing decline of this type of forest. While developed countries have always had controlled charcoal consumption, developing countries, especially in East Africa, continue to increase theirs. The recent interest in forest ecosystems has thus sparked reactions regarding the growing practice of charcoal production. The case of Madagascar is an example of one of the most exposed countries to these environmental damages. Indeed, Madagascar, in addition to being known for its unique forest cover, also has a high population growth rate. Socially, the income from charcoal sales is used for daily expenses. This includes primarily food, as the income from charcoal work is spent on buying food. Additionally, these earnings help cover school expenses (tuition, supplies, clothing). Culturally, the income from charcoal is also used in initiation rituals. The analysis shows a clear economic function in charcoal production, as the economic (income source), social (food, schooling, house construction) impacts are visible.

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