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# Estimating wood charcoal supply to Toliara town in southwestern Madagascar, a comparison of methods[☆]

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A B S T R A C T

Wood charcoal is the main energy source used by households in developing countries. However, due to the impact of wood charcoal production on forests, it is difficult to maintain a sustainable supply of wood charcoal for towns located in semi-arid environments. The supply of wood charcoal to the city of Toliara is a major challenge in southwestern Madagascar, the most arid part of the island. To design and assess the feasibility of initiatives to address these socio-environmental issues, an accurate estimation of the town's wood charcoal consumption is required. This paper aims to estimate the annual quantity of wood charcoal consumed in Toliara and to compare the errors associated with two estimation methods: (i) observation of wood charcoal flows on the main roads entering the town, and (ii) survey among Toliara wood charcoal traders (wholesalers and retailers). The first approach provided an annual rate of wood charcoal entering Toliara of 43 460 ± 2 017 t (mean±standard error). The second approach estimated annual wood charcoal consumption at 31 247 ± 3 337 t. The difference may essentially be explained by the fact that the first approach is more comprehensive and includes all possible wood charcoal flows whereas the second approach only includes those foreseen in the value chain model. The first approach gave more accurate results, but is more difficult to replicate as it is more time-consuming and requires more human and financial resources. Tree plantation was suggested to increase wood charcoal supply in Toliara town. About 56 000 ha of eucalyptus plantations would be needed to meet the current wood charcoal demand. Less than 500 ha of tree plantations have been done until now essentially due to willpower and organisational problems.



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## Introduction

Fuelwood (firewood and/or charcoal) is the main source of domestic energy in many developing countries [13]. Firewood is used in rural areas while wood charcoal is mainly used in urban areas. The use of fuelwood as domestic energy in developing countries is essentially due to the inaccessibility of alternative energy sources such as electricity, gas and solar energy, which are not affordable [11]. The fuelwood market generally ensures the subsistence of poor households [17]. Wood charcoal is the primary household energy source for the majority of urban Africa, and its consumption is increasing with expanding urbanization [11,15]. Wood charcoal is an accessible, affordable and reliable energy source for millions of households and its production supports millions of rural and urban livelihoods through income generation [15]. However, fuelwood harvesting causes forest degradation by reducing forest biomass and tree abundance [13]. WC production is more detrimental to tropical forests than firewood harvesting because it involves cutting down green trunks while the latter is generally associated with dry wood collection [34,55]. Consequently, satisfying the growing urban demand for wood charcoal remains a challenge for many poor tropical countries.

This challenge is all the more difficult to resolve in tropical semi-arid areas where the sustainability of fuelwood production remains a socio-environmental issue [20]. Dry forest annual wood increment is overall low [31,49] and wood harvesting for fuelwood production in semi-arid areas is largely unsustainable [20,49]. Consequently, this activity generally leads to dry forest degradation [13,30]. Dry forests, accounting for 40% of tropical forests worldwide, represent a crucial conservation issue and are associated with high biodiversity [32]. These dry forests also are associated with low regeneration capability and resilience to disturbances [39].

In Madagascar, dry forests account for almost half of the forested surface area and are associated with conservation issues, high biodiversity and low resilience to disturbances [49,54]. Wood charcoal is the main energy source for cooking in Madagascar [34]. In the Central Highlands, wood charcoal comes essentially from exotic tree plantations, while in western Madagascar, it comes mainly from natural dry forests [7,12]. The main causes of deforestation and forest degradation in western Malagasy semi-arid areas are slash-and-burn agriculture and wood charcoal production [8,10,48,49]. Bertrand et al. [7] and Rafransoa et al. [40] have observed for decades that the fuelwood supply to towns in dry western Madagascar (Mahajanga in the north and Toliara in the south) was not sustainable. Applied research to define city fuelwood supply strategies was carried out in Mahajanga (1999–2000) and in Toliara (2007-2008). Available wood resources, fuelwood consumption of rural and urban households and fuelwood value chains were assessed [40]. One condition for sustainable wood charcoal production is that the weight of wood removed annually for wood charcoal production is lower than the annual wood biomass increment associated with production sites [8,44] and [45,49]. The case of the city of Toliara is of greater concern because it is in the most arid area of Madagascar (mean annual rainfall less than 400 mm and more than nine dry months per year) where annual biomass increment of natural forest is weak [18,49].

In southwestern Madagascar, wood charcoal production has contributed to the decline of the dry forest biomass and may lead to the local extinction of wood charcoal tree and shrub species within a couple of decades [49]. Toliara is the main town and the main wood charcoal consumer in southwestern Madagascar [4,29,49]. Wood charcoal production is a safety net activity for households essentially during the dry season [17,29]. The sustainability of Toliara's supply of wood charcoal remains problematic [4,49], because it is dependent on the conservation of the southwestern dry forest and local population growth. The dry forests also are an important source of livelihoods as they provide firewood, construction wood, non-timber forest products and pasture for goats [47,54].

The implementation of a fuelwood supply strategy in Toliara resulted in (i) the promulgation in 2012 of a regional decree governing the fuelwood sector (*Arrêté Régional* 022 MATD/RSO du 30 mars 2010), and (ii) the development in 2018 of a Regional Biomass Energy Plan (PREB) for the period 2019–2033 [51]. These two provisions serve to promote the following activities:

(i) identification of the main actors of the fuelwood value chain (producers, transporters, traders),
(ii) promotion of sustainable management of forestry resources through the transfer of forest management to local communities for wood charcoal production,
(iii) implementation of decentralised control systems and a decentralised tax system,
(iv) promotion of improved wood charcoal kilns.

These initiatives are implemented jointly by the regional branch of the Ministry of Forestry and international NGOs (WWF and GIZ). The availability of accurate and up-to-date data on wood charcoal consumption in Toliara is a key factor for the assessment of the feasibility and potential success of these initiatives. However, such data are scarce [1,4].

Furthermore, such an estimate of wood charcoal supply/consumption presents methodological challenges even at the international level. The approach that has been currently used to tackle this problem involves surveys of part or all the actors of the fuelwood (firewood and/or charcoal) value chain: producers, collectors, transporters, traders, consumers [6,35,38,55]. The objectives of such approach are the assessment of fuelwood consumption ([35] for charcoal; [52] and [55] for charcoal and firewood), the analysis of fuelwood value chains ([6] for charcoal; [38] for firewood) and/or fuelwood value chain sustainability analysis by comparing fuelwood consumption to biomass production at the harvest sites [19,20,28], for firewood; [5,14] for firewood and charcoal). An inference of data from actors of the fuelwood value chains (consumptions and/or supply quantities) is generally the method used by these previous studies to assess the amount of fuelwood supply/consumption.

Another approach is less widely applied, the observation of WC flows on the transportation axes connecting forest sites to urban consumers ([12,40] in Madagascar, [2] in Ethiopia). To date, there has been no critical analysis of this wood charcoal flow approach. Furthermore, hardly any study has examined the statistical errors associated with estimates of urban charcoal consumption, although the reliability of the estimations is contingent on these.

This paper tackles the socio-environmental problem of wood charcoal supply in semi-arid southwestern Madagascar and the methodological aspects involved in estimating urban wood charcoal consumption. The aims are to (i) assess the wood charcoal consumption of the town of Toliara, the main wood charcoal consumer in southwestern Madagascar, and (ii) compare the reliability of two approaches (corresponding to minimal error), wood charcoal flow observation on the main roads entering the town of Toliara and surveys of wood charcoal traders in the town.

## Methods

### *Study site*

The study site covers the Districts of Toliara I and II in southwestern Madagascar (Fig. 1). The climate is semi-arid with a high rainfall gradient. The climate is drier in the southern part of the study site ($P < 400$ mm/year; $\geq$ 9 dry months; [18]) and wetter in its northern part ($P = 600$–1000 mm/year; 7–8 dry months; [26]).

The natural vegetation of the study site (Fig. 1) is shrubby xerophytic thickets in the southern part, characterised by *Didiereae* and *Euphorbia* spp., <5 m height [47], and woody dry deciduous forest in the northern part, characterised by *Commiphora* spp. and *Euphorbia* spp., with emergent individuals >10 m height [41] and savanna dominated by *Heteropogon contortus* [42].

The population of Toliara I District, which includes Toliara town and its surrounding villages, was 169 760 inhabitants in 2019 [23] and the population of Toliara II District was 369 485 [23]. Local populations belong mainly to the *Tanalana, Bara, Masikoro* and *Vezo* ethnic groups.

### *Wood charcoal production at the study site*

Wood charcoal is mainly used to cook daily meals. Demand for charcoal in southwestern Madagascar comes essentially from Toliara, the main town in the area, and is increasing as the town grows [4,17,29]. Wood charcoal production is an important source of income for poor people who possess small herds of small ruminants and bovines and who do not possess extensive crop fields [29,36,50]. Wood charcoal is produced from between 9 and 12 months out of the year [29]. The current main wood charcoal production sites in Toliara II District are located within a circle of less than 40 km radius around Toliara town (Fig. 1), that is to say in the Ranobe dry deciduous forest and in the xerophytic thicket of the Belomotse Plateau [4,48]. The wood charcoal production process had been described precisely by Randriamalala et al. [47].

There are five main wood charcoal transport axes entering Toliara town, as identified in Fig. 1: (i) the RN9 highway, (ii) Maromiandra track, (iii) Miary tracks from Behompy and Belomotse Plateau, (iv) the RN7 highway and (v) Mahavatsy II harbour. The three first transport axes come from the Ranobe and Behompy forests in the north (Fig. 1). RN7 crosses the xerophytic thickets of the Belomotse Plateau in the southeastern part of the study site (Fig. 1). WC produced in the xerophytic thickets of the southern part of the study site (Soalara-Sud and Beheloka municipalities) is unloaded at Mahavatsy II harbour [49].

### *Direct observation of wood charcoal supply flow to Toliara town*

A census of the daily number of wood charcoal transports entering Toliara town was carried out during the dry (October 2017) and rainy (January 2018) seasons. The census was carried out from 5 am to 6 pm on the five main wood charcoal transport axes entering the town for one week (seven days) per axis (five axes) and per season (dry and rainy seasons). The main types of transport observed are listed according to their maximum height capacity [22]: (i) trucks, (ii) pirogues, (iii) private cars (essentially off-road vehicles), (iv) public transport vehicles (*minibus*), (v) taxicabs, (vi) ox-carts, (vii) man-hauled carts, (viii) motorcycles, (ix) bicycles, (x) tricycles (*cyclopousse*), and (xi) human carrying. The size and number of wood charcoal sacks are observable in all of these means of transportation except in trucks. To estimate the mean number of sacks transported by trucks, six wood charcoal unloads were observed to count the number of unloaded sacks and check their size. For each type of transport and for each type of sack, sampled sacks ($N \geq 6$) were weighed in order to estimate their mean weight.

Wood charcoal production is expected to be more intensive during the dry season, when transportation is easier and food shortages occur [50]. This is the reason why two seasons are distinguished, the dry and rainy seasons. The duration of the dry season is $d_s = 274$ days (365 days x 9 months / 12 months) and the duration of the rainy season is $d_h = 91$ days (365 days x 3 months / 12 months).

The weight of the wood charcoal, which is carried via roads and tracks to Toliara city, is estimated by multiplying the mean weight of charcoal sacks by the daily number of sacks, which enter the city, and the duration of the season. The calculation is completed by season, by road, by type of sacks, and by means of transportation, accordingly to Eq. (1):

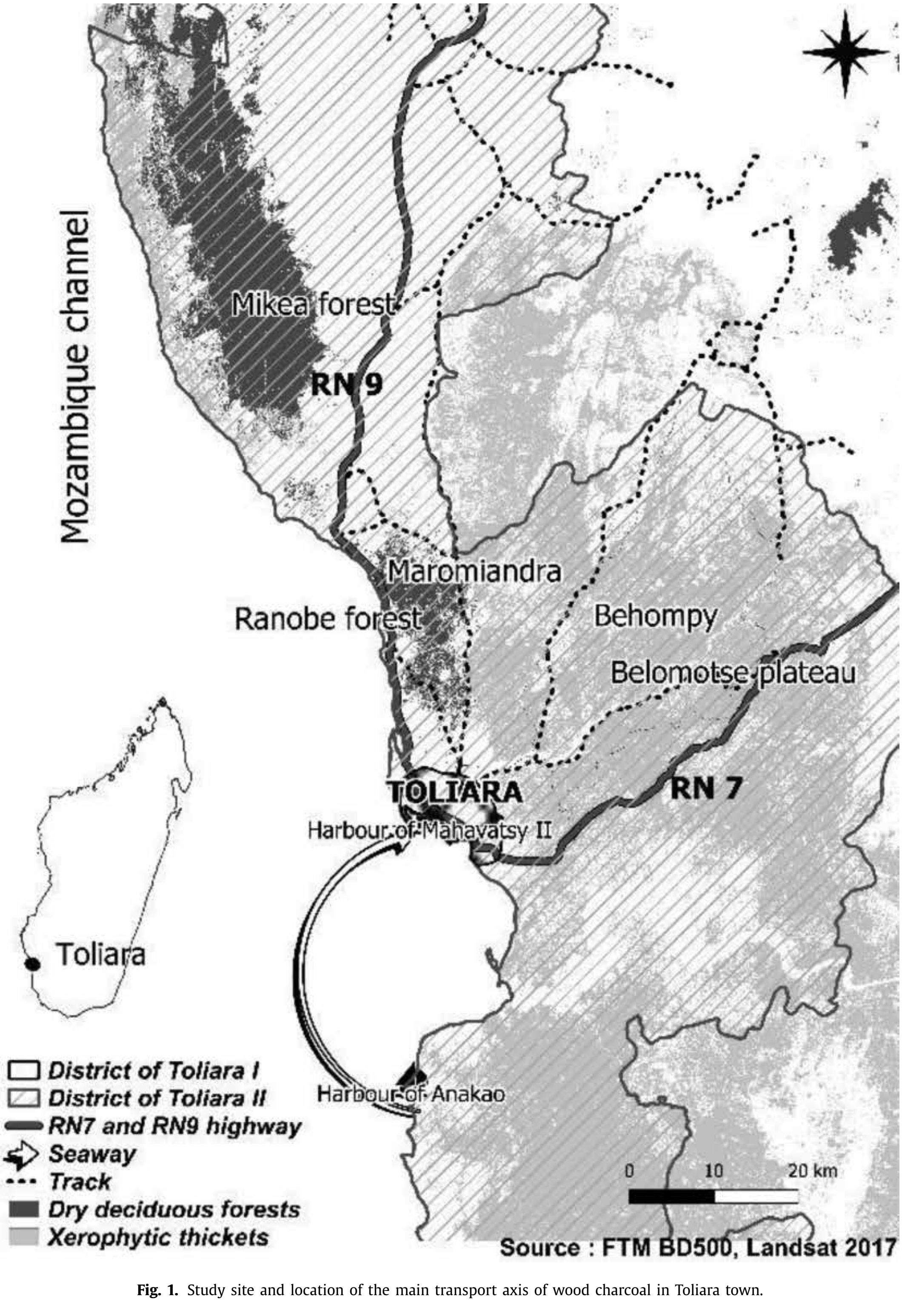


**Fig. 1.** Study site and location of the main transport axis of wood charcoal in Toliara town.

**Table 1**
Main error sources of wood charcoal trade surveys.

| Type of wood charcoal trader | Season | Monthly frequency of wood charcoal supply | Number of sacks at each wood charcoal supply | |
|---|---|---|---|---|
| | | | 1st type of sack (25.11 ± 0.51 kg; *n* = 10) | 2nd type of sack (51 ± 1.76 kg; *n* = 10) |
| Retailer | Dry season | 9.46 ± 1.50 | 7.79 ± 1.37 | |
| | Rainy season | 10.38 ± 1.60 | 7.35 ± 1.30 | |
| Wholesaler | Dry season | 6.91 ± 0.30 | 27.92 ± 1.62 | 29.78 ± 2.77 |
| | Rainy season | 2.96 ± 0.17 | 25.28 ± 1.92 | 29.64 ± 2.59 |

$$AW=\Sigma_{s(s=1-2)}\Sigma_{i(i=1-5)}\Sigma_{j(j=1-2)}\Sigma_{k(k=1-11)}\ E(W_j)\ x\ E(SN_{ijks})\ x\ d_s=[E(W_1)\ x\ E(SN_{1111})x\ d_1]+\ldots+[E(W_j)\ x\ E(SN_{ijks})\ x\ d_1]+\ldots+[E(W_2)\ x\ E(SN_{25211})\ x\ d_2]$$

Where AW is the annual weight of wood charcoal entering Toliara town (kg), $E(W_j)$ the mean weight of $j^{th}$ type of sack (kg), $E(SN_{ijks})$ the mean daily number of $j^{th}$ type of sack transported by $k^{th}$ means of transport on the $i^{th}$ transport axis during the $s^{th}$ season, and $d_s$ is the duration of the $s^{th}$ season (day).

Errors associated with WC weights entering Toliara town could be estimated by applying the errors propagation principle [16,25]. If Y is a function of $X_1$, $X_2$.....$X_n$ variables with uncertainties $\delta X_1$, $\delta X_2$..... $\delta X_n$, the error associated to Y can be calculated by the following Eq. (2):

$$\delta Y^2=([dY/dX_1]x\delta X_1)^2+([dY/dX_2]x\delta X_2)^2+\ldots+([dY/dX_n]x\delta X_n)^2$$

Where $dT/dX_i$ is partial derivative of Y with respect to $X_i$, $X_i$ variables represent mean sack weight $E(W_i)$ and mean daily sack number $E(SN_{ijk})$ in Eq. 1 and $\delta X_i$ are their standard errors.

The main error sources are the mean sack weight and the mean daily number of sacks. The error associated to wood charcoal weight unpacked in a particular sack type entering Toliara town through a particular transport axis, by a particular means of transport during a particular season can be calculated by the Eq. (3): $e=([d_s\ x\ E(SN)\ x\ \delta_W]^2+[d_s\ x\ E(W)\ x\ \delta_{SN}]^2)^{1/2}$Where e is the error associated to wood charcoal weight during a particular season (kg), $d_s$ the length of the season (day), E(SN) the daily mean number of counted wood charcoal sacks during the season, $\delta_W$ the error associated to the sack weight (standard error; kg), E(W) the mean sack weight (kg) and $\delta_{NS}$ the error associated to the daily mean number of counted wood charcoal sacks during the season (standard error; kg).

Total error associated to wood charcoal weight entering Toliara town can be calculated by the Eq. (4):

$$e=(\sum_{s(s=1-2)}\sum_{i(i=1-5)}\sum_{j(j=1-2)}\sum_{k(k=1-11)}\ e_{ijks}^2)^{1/2}=(e_{1111}^2+\ldots+e_{ijks}^2+\ldots..+e_{25211}^2)^{1/2}$$

Where e is the total error associated to wood charcoal weight entering Toliara town, $e_{ijks}$ the particular error taking into account season (s; two), transport axis (i; five), sack type (j; two) and means of transport (k; 11) (Table 1).

*Wood charcoal trade surveys in Toliara town*

Wood charcoal traders were surveyed in Toliara town to corroborate the data from the five transport axis observations. All of the wood charcoal wholesalers and retailers in the 40 *arrondissements* of Toliara town were inventoried by questioning the *arrondissement* chiefs or representatives, amounting to 185 wholesalers and 755 retailers. Monthly wood charcoal (i) supply frequencies and (ii) sales of random samples from 53 wood charcoal wholesalers and 52 wood charcoal retailers were surveyed. The sale units of wholesalers are the sacks that they make themselves. Retailers do not source from wholesalers because this would increase the cost of the wood charcoal. Retailers receive wood charcoal directly from producers and pay the transport costs [29], they then unpack sacks from producers to make retail sales.

The monthly quantity of wood charcoal supplied to a wood charcoal trader is the product of three factors: (i) the monthly frequency of supply, (ii) the number of sacks per supply and (iii) the average weight of the sack, which are shown in the Eq. 5:

$$w_i=f_ixN_ixE(SW)$$

Where $w_i$ is the monthly wood charcoal supply of the $i^{th}$ WC trader (kg); $f_i$ is the monthly frequency of wood charcoal supply of the $i^{th}$ WC trader, $N_i$ is the number of sacks at each wood charcoal supply of the $i^{th}$ WC trader; and E(SW) is the mean sack weight (kg).

To obtain the total monthly quantity that is supplied to a wood charcoal trader, repeat the above operation for each type of sack and add these up.

The annual quantity of wood charcoal supplied to all of the wood charcoal traders in the city of Toliara is the sum of the quantities of wood charcoal per season (Eq. 6):

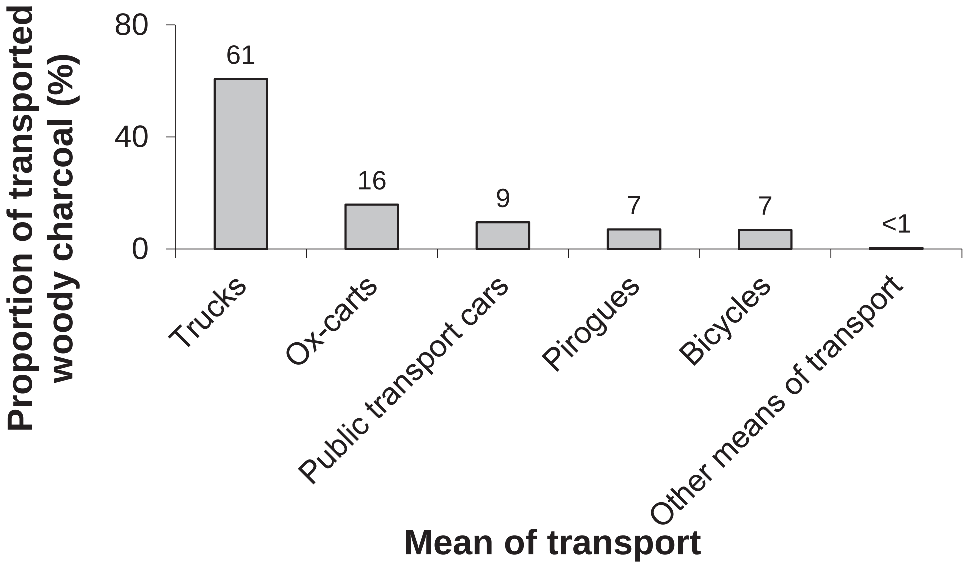


**Fig. 2.** Share of the different means used to transport WC supplies to Toliara town (% of 43 460 t wood charcoal) [Other means of transport: private cars and taxicabs, tricycles and motorcycles, man-hauled carts and human carrying].

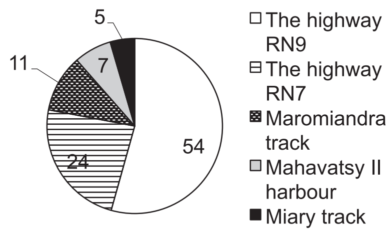


**Fig. 3.** Provenance of wood charcoal supplies to Toliara town (% of 43 460 t wood charcoal).

$W = (E[w_{1ds}]xNRxd_{ds})+(E[w_{1rs}]xNRxd_{rs})+(E[w_{2ds}]xNWxd_{ds})+(E[w_{2rs}]xNWxd_{rs})$Where $E[w_{1ds}]$ is the mean monthly wood charcoal weight supplied to retailers during the dry season (kg), NR is the total number of retailers in Toliara town (=755), $d_{ds}$ is the duration of the dry season (months), $E[w_{1rs}]$ is the mean monthly WC weight supplied to retailers during the rainy season (kg), $d_{rs}$ is the duration of the rainy season (month), $E[w_{2ds}]$ is the mean monthly wood charcoal weight supplied to wholesalers during the dry season (kg), NW is the total number of wholesalers in Toliara town (=185), $E[w_{2rs}]$ is the mean wood charcoal monthly weight supplied to wholesalers during the rainy season (kg).

The sources of error in the calculations are (i) the average frequency of monthly supplies, (ii) the average number of sacks per average monthly wood charcoal supply, and (iii) the average sack weights (Table 1). The same propagation error rules (Eqs. (2)–(4)) were applied to estimate errors associated to the results.

## Results

Two main types of wood charcoal sacks were reported: small sacks with a mean weight of 25 ± 0.51 kg ($N = 10$) and large sacks with a mean weight of 51 ± 1.76 kg ($N = 10$). These large sacks are only used by wholesalers (Table 1).

### *Wood charcoal supply flow to Toliara town*

The annual weight of wood charcoal entering Toliara town is 43 460 ± 2 017 t (Table 2; Eqs. (1)–(4)). Trucks are the main means used to transport wood charcoal (>60% of the annual wood charcoal weight; Fig. 2). Most of the wood charcoal supplies for Toliara town (Fig. 3) arrive via RN9 (>50% of total weight) and RN7 (>20%).

### *Wood charcoal trade surveys in Toliara town*

The annual weight of wood charcoal supplied to Toliara traders is about 31 247 ± 3 337 t The share supplied to retailers (16 910 ± 3 158 t) is roughly equal to that supplied to wholesalers (14 337 ± 1078 t). Trucks are the main means used to transport wood charcoal supplies to wholesalers. The number of wood charcoal retailers is greater but their total wood

**Table 2**
Annual weight of wood charcoal by transport axis (Value±Error calculated by error propagation principle). First type of sack weight=25 ± 0.51 kg ($n$ = 10); Second type of sack weight=51 ± 1.76 kg ($n$ = 10).

| Axis of transport | Means of transport | Dry season | | | Rainy season | | |
|---|---|---|---|---|---|---|---|
| | | Mean daily number of 1st type of sack | Mean daily number of 2nd type of sack | Wood charcoal weight entering Toliara town (t) | Mean daily number of 1st type of sack | Mean daily number of 2nd type of sack | Wood charcoal weight entering Toliara town (t) |
| Mahavatsy harbour | Pirogues | 40.86 ± 13.52 | 107.14 ± 28.33 | 1 782.56 ± 411.05 | 61 ± 58.53 | 57.86 ± 40.48 | 1 230.23 ± 232.08 |
| Maromiandra track | Ox-carts | 436.86 ± 73.27 | | 3 002.90 ± 506.42 | 726.86 ± 56.43 | | 1 594.30 ± 129.45 |
| Miary track | Ox-carts | 187.14 ± 30.78 | | 1 296.41 ± 212.60 | 327.57 ± 35.44 | | 658.80 ± 73.26 |
| | Tricycles (*cyclopousse*) | 0.71 ± 0.71 | | 4.91 ± 4.91 | | | . |
| | Bicycles | 0.71 ± 0.36 | | 4.91 ± 2.47 | | | . |
| RN7 highway | Trucks | | 380.29 ± 54.38 | 5 330.08 ± 502.11 | | 411.98 ± 69.67 | 1 924.75 ± 332.12 |
| | Bicycles | 302.14 ± 6.31 | | 2 076.89 ± 60.67 | 368.29 ± 21.44 | | 843.85 ± 160.55 |
| | Public transport cars (*minibus*) | | | . | 26.57 ± 3.20 | | 60.88 ± 7.43 |
| | Private cars (essentially off-road vehicles) | | | . | 7.00 ± 1.38 | | 16.04 ± 3.18 |
| | Ox-carts | 1.71 ± 1.71 | | 11.78 ± 11.79 | | | . |
| | Man-hauled carts | | | . | 3.00 ± 3.00 | | 6.87 ± 6.88 |
| | Tricycles (*cyclopousse*) | | | . | 0.38 ± 0.38 | | 0.00 ± 0.86 |
| RN9 highway | Trucks | | 1 045.19 ± 106.67.00 | 14 657.73 ± 1 577.40 | | 950.71 ± 146.33 | 4 441.74 ± 700.41 |
| | Public transport cars (*minibus*) | 411.29 ± 52.30 | | 2 827.12 ± 364.12 | 538 ± 53.64 | 216.29 ± 37.93 | 1 232.71 ± 125.45 |
| | Ox-carts | 26.71 ± 5.93 | | 183.63 ± 40.91 | 51 ± 6.02 | | 116.86 ± 13.99 |
| | Private cars (essentially off-road vehicles) | 11.14 ± 0.91 | | 76.59 ± 6.45 | 7.14 ± 1.37 | | 16.37 ± 3.16 |
| | Tricycles (*cyclopousse*) | 1.00 ± 0.72 | | 6.87 ± 4.98 | 7.43 ± 3.18 | | 17.02 ± 7.30 |
| | Bicycles | 0.86 ± 0.55 | | 5.89 ± 3.81 | 7.00 ± 1.23 | | 16.04 ± 2.85 |
| | Human carrying | 0.57 ± 0.37 | | 3.93 ± 2.54 | 2.43 ± 0.87 | | 5.56 ± 0.48 |
| | Taxicabs | 0.86 ± 0.40 | | 5.89 ± 2.78 | | | . |
| | Motorcycles | | | . | 0.14 ± 0.14 | | 0.33 ± 0.33 |
| | Total | | | 31 278.10 ± 1 830.06 | | | 12 182.35 ± 847.80 |

charcoal weight does not differ significantly from those of wholesalers because they are supplied by ox-carts, pirogues, bicycles and to a lesser extent by trucks. Urban households are the main wood charcoal customers of wholesalers and retailers. Other customers of wholesalers are restaurants, small restaurants (*gargotte*), and school canteens.

## Discussion

### *Which approach is the best to estimate wood charcoal supply?*

There is a considerable difference between the wood charcoal supply estimated from the observation of transportation axes (43 460 t) and that estimated from the survey of wood charcoal traders (31 247 t) (∼12 000 t; ∼28% of value obtained by transport axis observation). This may be explained by the fact that some wood charcoal goes directly to consumers, for example that transported by public transport vehicles (minibus) and private cars (essentially off-road vehicles). Moreover, some of the wood charcoal transported by bicycles, ox-carts and pirogues is delivered directly to urban households and does not transit through wholesalers or retailers. The higher value (43 460 t) estimated by the axis transport observation method thus may be nearer the real annual wood charcoal consumption of Toliara town. Moreover, the relative error (SE/mean) associated with the axis transport observation method (5%) was lower than that associated with the wood charcoal traders survey (11%). To our knowledge, an assessment of uncertainties related to annual urban wood charcoal consumption has never been carried out. The uncertainties associated with existing data, even at the international level, are generally not available.

The axis transport observation method seems to be more reliable because it includes all possible wood charcoal flows whereas the trader survey approach only includes those predicted in the value chain model (producer→transporter→trader→consumer) and may omit other unknown market circuits. Moreover, the observation method is more objective as it consists of direct observations of flows and does not depend on subjective information from wood charcoal traders. The structured interviews were conducted within a sample of wood charcoal traders with several limits. Human memory is not infallible [9,56] and responses from face to face interview can be biased as these can be influenced by question formulation [33] or by the interviewers themselves [3]. In addition, it has been shown that structured face-to-face interviews result in less honest responses than mail surveys [37]. Moreover, wood charcoal traders generally have an interest in minimising the reported values of their wood charcoal supply to protect themselves against possible increases in taxes payable to the forestry and fiscal authorities. All these factors may also explain the underestimation of the WC supply values obtained by trader surveys approach.

The interests of the axis transport observation approach are the possibility to repeat the observations at another date with the same protocol and to detect outliers results, but it requires more logistical and financial means (staff and their wages, duration and planning of observations). This approach is adapted to wood charcoal urban supply estimation and is difficult to generalise to a larger scale (district, province or country) as it would have to be implemented for at least all major urban areas.

### *Mean rate of wood charcoal consumption*

The annual wood charcoal consumption of Toliara town is far lower than that of Antananarivo town, the capital of Madagascar, which amounts to 230 292 t [12]. The difference in the population sizes of these two towns may be one reason behind this. In fact, the population of Toliara is seven times smaller than that of Antananarivo (169 760 vs 1 275 207; [23]). However, the wood charcoal consumption per capita of Toliara town (ratio between annual wood charcoal consumption and population size) is higher than the wood charcoal consumption per capita of Antananarivo town, 256 and 104 kg/year per capita, respectively [12]. The availability of alternative energy sources for cooking, such as gas and electricity, in Antananarivo may explain the lower wood charcoal consumption per capita than in Toliara. The cost of gas cylinders is higher in Toliara (∼1000 km from Antananarivo) due to the extra cost linked to transportation. Furthermore, the nature of the staple foods consumed in each town also may explain this difference: dry cassava, which takes more than one hour to cook, is the staple food of the *Masikoro, Mahafaly* and *Tanalana*, the dominant ethnic groups in Toliara, while rice, which can be cooked in a few minutes, is the staple food in Antananarivo. Moreover, because of their busier schedules, some inhabitants of the capital prefer street food for lunch or even dinner rather than preparing meals at home [12].

The annual wood charcoal consumption per capita in the study site is higher than that of rural and urban areas in Kenya (95–130 kg/year per capita; [24]) and Kampong Thom Province in Cambodia (120 kg/year per capita; [53]), while it is comparable to that of the rural area of Yedashe township in Myanmar (280 kg/year per capita; [55]). This variation of annual wood charcoal consumption per capita at the international level also may be explained by the availability of alternative energy sources, with those who use wood charcoal exclusively having a higher consumption rate, and by the nature of the country/population's staple foods with cooking durations that may vary.

### *Ranobe and Behompy forests, to the north of Toliara town, are the main current wood charcoal production sites*

Wood charcoal supplies for Toliara town mainly pass through the transport axes from the north: RN9 (54% annual weight), Maromiandra (11%) and Miary (5%); the flows of wood charcoal from RN7 (24%) and Mahavatsy harbour (7%) are

**Table 3**
Increase in wood charcoal annual consumption for the town of Toliara .

| Years | Wood charcoal annual consumption (t) | Wood charcoal methods | Sources |
|---|---|---|---|
| 1991 | 7 029 | Value chain survey | ABETOL |
| 2000 | 10 372 | Value chain survey | (2007) |
| 2007 | 33 391 | Flow observation | |
| 2017–2018 | 43 460 | Flow observation | This study |

less important (Fig. 3). Consequently, the current wood charcoal production sites supplying Toliara town are Ranobe forest and the Behompy xerophytic thickets that are connected to Toliara town by the first three transport axes (Fig. 1). The dry forest of Mikea has been spared so far because of its relative remoteness (>50 km north of Toliara town), but the recent asphalting of the RN9 over a distance of about 100 km from Toliara could change this relatively protected situation.

The importance of the xerophytic thickets of the Belomotse Plateau crossed by the RN7 as a charcoal production site is on the decline. This forest was the main wood charcoal production site supplying Toliara town in the 1990s [27]. Wood charcoal production and slash-and-burn agriculture have exhausted the woody resources of the xerophytic thickets of this RN7 site to the point that in some locations the roots of the shrubs are dug up to be used as wood charcoal biomass [48].

The share of the xerophytic thickets south of Toliara in the town's wood charcoal supply is low (7%; Mahavatsy II harbour; Fig. 1). The relative inaccessibility of the corresponding production sites by road may explain this phenomenon; pirogues are used to cross a distance of 30–35 km by sea. The depletion of woody resources on the Belomotse Plateau has shifted wood charcoal production sites to the Ranobe dry forest and the Behompy xerophytic thickets. When these are exhausted, the pressures on the xerophytic thickets south of Toliara town and on the Mikea dry forests to the north could exacerbate and accelerate their degradation or even their disappearance.

*Implication for wood charcoal governance in southwest Madagascar*

Toliara town's annual consumption of wood charcoal has increased by more than 600% since 1991 and by more than 130% in the last 10 years (Table 3). This annual consumption is increasing with population growth while the forest resources supplying wood charcoal biomass are shrinking year by year (annual forest loss >1%; [46]). A periodic update (every 5–10 years) of this annual wood charcoal consumption is necessary. Forest management authority agents with the support of the police forces could undertake such updates.

To date, no accurate study has assessed the balance between wood collection for wood charcoal production and the annual increase in biomass from the forests of the wood charcoal production sites supplying Toliara town. Only Randriamalala et al. [49] have made this balance assessment for xerophytic thickets located south of Toliara town, which account for less than 7% of the city's wood charcoal annual supply (Mahavatsy harbour; Fig. 3). They showed that wood charcoal production at this site would result in the disappearance of wood charcoal species in less than 20 years. The use of shrub roots to produce wood charcoal at some sites of the Belomotse Plateau (RN7 axis; Fig. 3; [48]) confirms this lack of sustainability of wood charcoal production in southwestern Madagascar, which will lead to the disappearance of wood charcoal species within a finite period. Consequently, the transfer of forest management to local communities for wood charcoal production purposes, and the biomass resources economy (improved kiln design) promoted by the fuelwood supply strategy in Toliara may not be sufficient. An increase in wood charcoal biomass supply through the plantation of fast-growing exotic species is necessary to complete this strategy.

Tree planting has been promoted by NGOs operating in southwestern Madagascar (WWF and GIZ; [49]). A community tree plantation program was undertaken 30–90 km north of Toliara town, where annual rainfall is higher (P=600–800 mm/year), during the 2008–2011 period [57]. *Eucalyptus camaldulensis* and *Acacia mangium* tree species were planted on plots with a total area of about 400 ha [49]. Results were mixed, while the survival rate of the trees planted was generally under 50% [49]. However, the program demonstrated that tree plantations in the semi-arid southwestern region of Madagascar are possible because the mortality was essentially due to poor organisation (late planting period at the end of the rainy season and lack of plantation monitoring). This kind of tree plantation could be undertaken successfully if these organisational problems are solved [21]. Moreover, this tree plantation can also be done in the savannahs to the north of the study site where the climatic conditions are wetter ($P > 800$ mm/year). About 56 000 ha of Eucalyptus plantations would be needed to produce the woody biomass for total wood charcoal production if we consider carbonisation yield of 0.125 [43], an annual wood increment of 10 $m^3$/ha of eucalyptus plantations [58] and a mass of 0.6 t for 01 $m^3$ of wood pile [58]. The implementation of this kind of large scale tree plantation would require a strong political will from the State. Indeed, reforestation is not yet a priority in environmental policies in Madagascar. It takes a back seat to the financing of protected areas and is generally included in the restoration activity of natural forests. Finally, this area of 56,000 ha does not take into account the contribution of natural dry forests. Assessments of annual biomass increment of southwestern Madagasy dry forests should be made in order to estimate more accurately the area of tree plantation to be implemented.

## Conclusion

The transportation axis observation method to estimate the annual wood charcoal consumption of Toliara town is reliable and can be replicated in other towns in Madagascar and other developing countries. However, it must be done periodically because wood charcoal consumption increases with population size. Sustainable wood charcoal production from xerophytic thickets vegetation around Toliara town seems to be unrealistic, so it is recommended to intensify the plantation of fast-growing exotic species to decrease the pressure on the native forest. Moreover, the sustainability of the wood charcoal supply for Toliara town should be evaluated in order to estimate accurately the annual deficit between wood charcoal biomass production and wood charcoal urban demand.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

[1] ABETOL, La Stratégie d'Approvisionnement en Bois-Energie de la Ville de Toliara. Toliara, Madagascar: PARTAGE/WWF, 2007.
[2] S. Alem, J. Duraisamg, E. Legesse, Y. Seboka, E. Mitiku, Wood charcoal supply to Addis Ababa city and its effect on the environment, Energy Environ. 21 (6) (2010) 601–609.
[3] H. Alshenqeeti, Interviewing as a data collection method: a critical review, Engl. Linguist. Res. 3 (1) (2014), doi:10.5430/elr.v3n1p39.
[4] R. Andrianarivony, V. Randriambola, N. Ratsifandriamanana, Réglementation de la filière bois-énergie dans la Région Atsimo Andrefana, Acquis et leçons apprises, 2008 à 2011, WWF (Programme WWF à Madagascar et dans l'Océan Indien Occidental, Antananarivo, Madagascar, 2012.
[5] R. Bär, A. Heinimann, A. Ehrensperger, Assessing the potential supply of biomass cooking fuels in Kilimanjaro region using land use units and spatial Bayesian networks, Energy Sustain. Dev. 40 (2017) 112–125.
[6] S. Baumert, A. Catarina Luz, J. Fisher, F. Vollmer, C.M. Ryan, G. Patenaude, P. Zorilla-Miras, L. Artur, I. Nhantumbo, D Macqueen, Charcoal supply chains from Mabalane to Maputo : who benefits ? Energy Sustain. Dev. 33 (2016) 129–138.
[7] A. Bertrand, B. Ramamonjisoa, P Montagne, Les filières péri-urbaines d'approvisionnement en bois-énergie des grandes villes de Madagascar, in: P. Montagne, S. Razafimahatratra, A. Rasamindisa, R. Crehay (Eds.), Le Charbon de Bois à Madagascar entre Demande Urbaine et Gestion Durable, CITE/CIRAD, Antananarivo, Madagascar, 2010, pp. 13–36.
[8] K. Brinkmann, F. Noromiarilanto, R.Y. Ratovonamana, A. Buerkert, Deforestation processes in southwestern Madagascar over the past 40 years: what can we learn from settlement characteristics? Agric. Ecosyst. Environ. 195 (2014) 231–243.
[9] P.M. Carrasco, M.M. Peña, M.J. Sueiro, The memory failures of everyday questionnaire (MFE): internal consistency and reliability, Span. J. Psychol. 15 (2) (2014) 768–776.
[10] T. Casse, A. Milhøj, S. Ranaivoson, J.M. Randriamanarivo, Causes of deforestation in southwestern Madagascar: what do we know? For. Policy Econ. 6 (2004) 33–48.
[11] P.O. Cerutti, P. Sola, A. Chenevoy, M. Liyama, J. Yila, W. Zhou, H. Djoudi, R.E. Atyi, D.J. Gautier, D. Gumbo, Y. Kuehl, P. Levang, C. Martius, R. Matthews, R. NasI, H. Neufeldt, M. Njenga, G. Petrokofsky, M. Saunders, G. Shepherd, D.J. Sonwa, C. Sundberg, M. Van Noordwijk, The socioeconomic and environmental impacts of wood energy value chains in Sub-Saharan Africa: a systematic map protocol, Environ. Evid. 4 (12) (2015), doi:10.1186/s13750-015-0038-3.
[12] M. Charpin, L. Legeay, N. Rabemanantsoa, R. Richter, Caractérisation des filières bois-énergie et élaboration du schéma d'approvisionnement en bois-énergie de la région Analamanga, Madagascar, Bois For. Trop. 340 (2019) 13–25.
[13] E.N. Chidumayo, D.J. Gumbo, The environmental impacts of charcoal production in tropical ecosystems of the world: a synthesis, Energy Sustain. Dev. 17 (2013) 86–94.
[14] V. Chiteculo, B. Lojka, P. Surovy, V. Verner, D. Panagiotidis, J. Woitsch, Value chain of charcoal production and implications for forest degradation: case study of Bié Province, Angola, Environments 5 (113) (2018). www.mdpi.com/journal/environments, doi:10.3390/environments5110113.
[15] FAO, The Charcoal Transition: Greening the Charcoal Value Chain to Mitigate Climate Change and Improve Local Livelihoods, Food & Agriculture Organization of the United Nations, Rome, 2017. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjP3qrYltPzAhXxxoUKHTRaBy4QFnoECBMQAQ&url=http%3A%2F%2Fwww.fao.org%2F3%2Fa-i6935e.pdf&usg=AOvVaw2mx7XflFYFxyJMumhavtqt.
[16] I. Farrance, R. Frenkel, Uncertainty of measurement: a review of the rules for calculating uncertainty components through functional relationships, Clin. Biochem. Rev. 33 (2012) 49–75.
[17] C.J. Gardner, F.U.L. Gabriel, F.A.V. St. John, Z.G Davies, Changing livelihoods and protected area management: a case study of charcoal production in southwest Madagascar, Oryx 50 (3) (2015) 495–505.
[18] D. Gaspard, A. Venegas-González, H. Beeckman, R.J. Randriamalala, M. De Ridder, M. Tomazello-Filho, T. Ramananantoandro, Tree ring responses to climate variability from xerophytic thicket of south Soalara, Madagascar, Dendrochronologia 49 (2018) 57–67.
[19] A. Ghilardi, R. Bailis, J.F. Mas, M. Skutsch, J.A. Elvir, A. Quevedo, O. Masera, P. Dwivedi, R. Drigo, E. Vega, Spatiotemporal modeling of fuelwood environmental impacts: towards improved accounting for non-renewable biomass, Environ. Model. Softw. 82 (2016) 241–254.
[20] A. Ghilardi, G. Guerrero, O. Masera, A GIS-based methodology for highlighting fuelwood supply/demand imbalances at the local level: a case study for Central Mexico, Biomass Bioenergy 33 (2009) 957–972.
[21] D. Hervé, S. Fidiarisoa, F.F. Elanandrasana, J. Ranaivo, D Razafimamonjy, Plantations locales opportunes en restauration de forêts sèches dégradées (Campagne 2017-2018, Toliara, Madagascar), in: D. Hervé, J.R. Randriamalala, H. Randriambanona, R. Ranaivoson, V. Rakotoarimanana, V. Rafidison, S.M. Carrière (Eds.), Valorisation Durable des Formations Sèches de L'océan Indien, IRD/CNRE/UA, 2021 (In press).
[22] D. Hervé, M. Randrianomanana, F.F. Elanandrasana, J.R Randriamalala, Modèle de flux des produits ligneux jusqu'à la ville de Toliara, question de productivité du travail, in: D. Hervé, J.R. Randriamalala, H. Randriambanona, R. Ranaivoson, V. Rakotoarimanana, V. Rafidison, S.M. Carrière (Eds.), Valorisation Durable des Formations Sèches de l'océan Indien, IRD/CNRE/UA, 2021 (In press).
[23] INSTAT, Troisième Recensement Général de la Population et de l'habitation (RGPH-3)Résultats Provisoires, USAID/Union Européenne/The World Bank/PNUD, Antananarivo, Madagascar, 2019.

[24] E. Kituyi, L. Marufu, B. Huber, S.O. Wandiga, I.O. Jumba, M.O. Andreae, G. Helas, Biofuel consumption rates and patterns in Kenya, Biomass Bioenerg 20 (2001) 83–99.
[25] H.H. Ku, Notes on the use of propagation of error formulas, J. Res. Natl. Bur. Stand. 70 (4) (1966) 263–273.
[26] J.C. Leprun, M. Grouzis, H. Randriambanona, Post-cropping change and dynamics in soil and vegetation properties after forest clearing: example of the semiarid Mikea region (southwestern Madagascar), Comptes Rendus Geoscience 341 (2009) 526–537.
[27] P. Mana, S. Rajaonarivelo, P Milleville, Production de charbon de bois dans deux situations forestières de la région de Tuléar, in: S. Razanaka, M. Grouzis, P. Milleville, B. Moizo, C. Aubry (Eds.), Sociétés paysannes, Transitions Agraires et Dynamiques Écologiques dans le Sud-Ouest de Madagascar, CNRE/IRD, 2001, pp. 199–210.
[28] O. Masera, A. Ghilardi, R. Drigo, M.A. Trossero, WISDOM: A GIS-based supply demand mapping tool for woodfuel management, Biomass Bioenerg 30 (2006) 618–637, doi:10.1016/j.biombioe.2006.01.006.
[29] H.N. Masezamana, J.H. Andrianarisoa, L.I.B. Raoliarivelo, J.R. Randriamalala, Identification et analyse d'activités alternatives à la fabrication de charbon de bois dans le district de Toliara II, Ed. DERAD Diagnostic Environnemental et Recherches Appliquées pour le Développement en milieu rural/ESAPP Eastern and Southern Africa Partnership Programme, 2013 Q096 Project Final Report, 2013.
[30] F. Mbold, O.H. Abdulle, R. Vargas, Assessment of charcoal driven deforestation rates in a fragile rangeland environment in North Eastern Somalia using very high resolution imagery, J. Arid Environ. 75 (11) (2011) 1173–1181.
[31] C. Mbow, S. Chhin, B. Sambou, D. Skole, Potential of dendrochronology to assess annual rates of biomass productivity in savanna trees of West Africa, Dendrochronologia 31 (2013) 41–51.
[32] L. Miles, A.C. Newton, R.S. Defries, C. Ravilious, I. May, S. Blyth, V. Kapos, J.A. Gordon, A global overview of the conservation status of tropical dry forests, J. Biogeogr. 33 (2006) 491–505.
[33] J.A. Minson, E.M. VanEpps, J.A. Yip, M.E. Schweitzer, Eliciting the truth, the whole truth, and nothing but the truth: The effect of question phrasing on deception, Organ. Behav. Hum. Decis. 147 (2018) 76–93.
[34] B. Minten, K. Sander, D. Stifel, Forest management and economic rents: evidence from the charcoal trade in Madagascar, Energy Sustain. Dev. 17 (2) (2013) 106–115.
[35] T.H. Mwampamba, Has the woodfuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability, Energy Policy 35 (2007) 4221–4234.
[36] R. Neudert, J.F. Goetter, J.N. Andriamparany, M. Rakotoarisoa, Income diversification, wealth, education and well-being in rural south-western Madagascar: Results from the Mahafaly region, Dev. South. Afr. 32 (6) (2015) 1–27, doi:10.1080/0376835X.2015.1063982.
[37] P. Preisendörfer, F. Wolter, Who is telling the truth? a validation study on determinants of response behavior in surveys, Pub. Opin. Q. (2014), doi:10.1093/POQ/NFT079.
[38] Y. Puentes-Rodriguez, P. Torssonen, S. Ramcilovik-Suominen, S. Pitkänen, Fuelwood value chain analysis in Cassou and Ouagadougou, Burkina Faso: from production to consumption, Energy Sustain. Dev. 41 (2017) 14–23.
[39] M. Quesada, G.A. Sanchez-Azofeifa, M. Alvarez-Anorve, K.E. Stoner, L. Avila-Cabadilla, J. Calvo-Alvarado, A. Castillo, M.M. Espirito-Santo, M. Agundes, G.W. Fernandes, J. Gamon, M. Lopezaraiza-Mikel, D. Lawrence, L.P.C. Morellato, J.S. Powers, F De S. Neves, F. Rosas-Guerrero, R. Sayago, G Sanchez–Montoya, Succession and management of tropical dry forests in the Americas: review and new perspectives, For. Ecol. Manag. 258 (2009) 1014–1024.
[40] Z. Rafransoa, D. Andriatsimisetra, P Montagne, Approvisionnement urbain en bois énergie. Une méthode, deux régions d'application à une décade d'intervalle, in: P. Montagne, S. Razafimahatratra, A. Rasamindisa, R. Crehay (Eds.), Le Charbon de Bois à Madagascar, Entre Demande Urbaine et Gestion Durable, CITE/CIRAD, 2010, pp. 101–117. http://publications.cirad.fr/une_notice.php?dk=554590.
[41] S.M. Raherison, M. Grouzis, Plant biomass, nutrient concentration and nutrient storage in a tropical dry forest in the southwest of Madagascar, Plant Ecol. 180 (2005) 33–45.
[42] V. Rakotoarimanana, M. Grouzis, E. Le Floch, Influence du feu et du pâturage sur l'évolution de la phytomasse d'une savane à *Heteropogon contortus* de la région de Sakaraha (sud-ouest de Madagascar), Tropicultura 26 (1) (2008) 56–60.
[43] R.T. Ramaroson, Durabilité écologique de la Production de Charbon de Bois Dans le Sud Ouest malagasy, Cas Des Fourrés Xérophiles de la Commune de Soalara Sud (Toliara II, Atsimo Andrefana), Mémoire DEA, Ecole Supérieure de Sciences Agronomiques, Université d'Antananarivo, 2014.
[44] T. Ranaivoson, K. Brinkmann, B. Rakouth, A. Buerkert, Distribution, biomass and local importance of tamarind trees in southwestern Madagascar, Glob. Ecol. Conserv. 4 (2015) 14–25.
[45] T. Ranaivoson, B. Rakouth, A. Buerkert, K. Brinkmann, Wood biomass availability for smallholder charcoal production in dry forest and savannah ecosystems of southwestern Madagascar, J. Arid Environ. 146 (2017) 86–94.
[46] J.R. Randriamalala, B.H. Hosnah, S. Ranaivoarimanana, R.I. Ratovomalala, Dynamiques spatiales des fourrés xérophiles de Betioky-Sud et Soalara-Sud (Madagascar), in: D. Hervé, S. Razanaka, S. Rakotondraompiana, F. Rafamantanantsoa, S.M. Carrière (Eds.), Transitions Agraires au Sud de Madagascar. Résilience et viabilité, Deux Facettes de la Conservation, Actes du séminaire de synthèse du projet FPPSM, 10–11/06/2013, IRD-SCAC/PARRUR, Antananarivo, Madagascar, 2015, pp. 113–121.
[47] J.R Randriamalala, H.O. Radosy, S. Razanaka, H. Randriambanona, D. Hervé, Effects of groat grazing and woody charcoal production on xerophytic thickets of southwestern Madagascar, J. Arid Environ. 128 (2016) 65–72.
[48] J.R. Randriamalala, R. Rabeniala, H.N. Masezamana, Effets de la production de charbon de bois sur les fourrés xérophiles, cas du plateau de Belomotse, Madagascar, Madag. Conserv. Dev. 12 (1) (2017) 7–12.
[49] J.R. Randriamalala, T. Ramananantoandro, H.O. Radosy, H. Randriambanona, D. Hervé, Annual biomass increment of xerophytic thickets and sustainability of woody charcoal production in southwestern Madagascar, For. Ecol. Manag. 400 (2017) 139–149.
[50] L.I.B. Raoliarivelo, R. Rabeniala, H.N. Masezamana, J.H. Andrianarisoa, J.R. Randriamalala, Impact de la Fabrication de Charbon de Bois Sur la Production et la Disponibilité Fourragère de Pâturage en Zone sub-aride, Cas de la Commune de Soalara-Sud, Ed. DERAD Diagnostic Environnemental et Recherches Appliquées pour le Développement en milieu rural/ESAPP Eastern and Southern Africa Partnership Program, Antananarivo, Madagascar, 2010 Q909 project final reporthttps://boris.unibe.ch/69311/1/Q909_rapport_final_product.pdf .
[51] Région Atsimo AndrefanaPlan Régional sur l'energie Biomasse (PREB) Atsimo-Andrefana, Antananarivo, Madagascar: Région Atsimo-Andrefana, MEDD Ministère de l'Environnement et du Développement Durable, Ministère de l'Energie, de l'Eau et des Hydrocarbures, 2018.
[52] M. Serrano-Medrano, T. Arias-Chalico, A. Ghilardi, O. Masera, Spatial and temporal projection of fuelwood and charcoal consumption in Mexico, Energy Sustain. Dev. 19 (2017) 39–46.
[53] N. Top, N. Mizoue, S. Kai, Woodfuel consumption rates and flow in Kampong Thom Province, Cambodia, J. For. Plan. 9 (2003) 17–24.
[54] P.O. Waeber, L. Wilmé, B. Ramamonjisoa, C. Garcia, G.J.D. Rakotomalala, Z.H. Rabemananjara, Dry forests in Madagascar: neglected and under pressure, Int. Forest. Rev. 17 (2) (2015) 127–148.
[55] Z.C. Win, N. Mizoue, T. Ota, T. Kajisa, S. Yoshida, T.N. Oo, H. Ma, Differences in consumption rates and patterns between firewood and charcoal: a case study in a rural area of Yedashe Township, Myanmar, Biomass Bioenergy 109 (2018) 39–46.
[56] D.B. Wright, G.D. Gaskell, C.A O'Muircheartaigh, The reliability of the subjective reports of memories, Eur. J. Cognit. Psychol. 9 (3) (1997) 313–323.
[57] WWF, Reboisement Bois-Energie dans le Sud-Ouest de Madagascar. Le Bilan de Trois Campagnes, in: Toliara, Madagascar: Synergie Energie Environnement dans le Sud-Ouest (SEESO). WWF/MEEF/UE/Tany Meva, Rapport septembre 2011, 2011, p. 43.
[58] WWF/CIRADEtude de Faisabilité Pour la Plantation et l'exploitation Sécurisée d'Essences Forestières Destinées à l'approvisionnement des Utilisateurs de la Ville de Tuléar, WWF/CIRAD/MINENV/FFEM, Antananarivo, Madagascar, 2006.