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Fuel use and cookstove preferences in the SAVA region

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ABSTRACT

Madagascar's population relies almost exclusively on solid biomass, i.e., firewood and charcoal, for subsistence. The ongoing extraction of such natural resources is unsustainable, threatening endemic biodiversity with extinction, and jeopardizing the long-term livelihoods of local populations. Improved, or fuel-efficient, cookstove programs have been implemented in Madagascar for more than a decade to mitigate deforestation. The Duke Lemur Center-SAVA Conservation (DLC-SAVA) and other NGOs have subsidized "rocket" fuel-efficient ADES-brand stoves in the SAVA region as part of ongoing conservation activities. To re-assess our DLC-SAVA subsidy program, we conducted surveys in 15 communes in the SAVA region to document fuel use, cookstove preferences, and the potential impact of ADES-brand stoves. We show that: (i) firewood was used more frequently than charcoal in more remote villages; (ii) metal tripods were the most frequently used cooking structure despite their low fuel efficiency; (iii) ADES-brand stoves were rarely owned and oftentimes underused; and (iv) "cooking time" and "fuel efficiency" were the most commonly preferred stove features given by respondents using firewood-fueled and charcoal-fueled cookstoves respectively. The low incidence of ADES stoves in our sample calls for a larger-scale program to increase their availability and accessibility to the region, a more comprehensive training/advertising strategy, and more effective logistical planning to distribute and sell the stoves across larger regions far from urbanized centers. Moreover, NGOs could assist in providing training on fuel-efficient stove design to experienced individuals who are already producing and distributing stoves locally, as a way to support sustainability while promoting and leveraging local knowledge. We conclude that because a large portion of the population is using metal tripods on a regular basis, introducing any type of "fuel-efficient" stove at a large scale, is expected to make a difference in biomass consumption, in addition to reducing the burden imposed on biomass collectors and carriers.

RÉSUMÉ

La population de Madagascar dépend presque exclusivement d'une biomasse solide, c'est-à-dire du bois de chauffage ou du charbon de bois, pour sa subsistance. Le niveau actuel de l'exploitation des ressources naturelles n'est pas pérenne et menaçe d'extinction la biodiversité endémique en mettant en péril les moyens de subsistance à long terme des habitants. Des programmes destinés à la promotion de foyers améliorés ou économes en énergie ont été mis en œuvre à Madagascar pendant plus de dix ans pour atténuer la déforestation. Le Duke Lemur Center-SAVA Conservation (DLC-SAVA) et d'autres ONG ont subventionné des foyers améliorés d'une grande efficacité énergétique de la marque ADES dans la région SAVA dans le cadre des activités de conservation en cours. Pour ré-évaluer le programme de subvention DLC-SAVA, des enquêtes ont été menées dans 15 communes de la région SAVA afin de documenter l'utilisation de combustible, les préférences en matière de foyers et l'impact potentiel des foyers de la marque ADES. Les résultats obtenus ont permis de montrer que (i) le bois de chauffage est plus fréquemment utilisé que le charbon de bois dans les villages les plus reculés ; (ii) les trépieds métalliques sont la structure de cuisson la plus utilisée malgré son faible rendement énergétique ; (iii) les foyers améliorés de la marque ADES ont été trouvés en petit nombre et souvent sous-utilisés ; et (iv) le temps de cuisson et l'efficacité énergétique étaient les deux choix les plus souvent mentionnés par les répondants utilisant respectivement des fourneaux à bois et à charbon de bois. La faible incidence des foyers ADES dans notre échantillon montre qu'un programme à plus grande échelle doit être déployé et devra être élaboré sur une stratégie de formation et de sensibilisation plus complète avec une meilleure planification logistique pour la distribution et la vente de foyers améliorés dans l'ensemble de la région, y compris dans les zones éloignées des centres urbains. Les ONG pourraient participer à une formation spécifique des personnes qui ont déjà une expérience dans la production et la distribution de foyers au niveau local pour qu'elles acquièrent les compétences en matière de conception de foyers améliorés à haute efficacité énergétique, afin de favoriser la durabilité tout en

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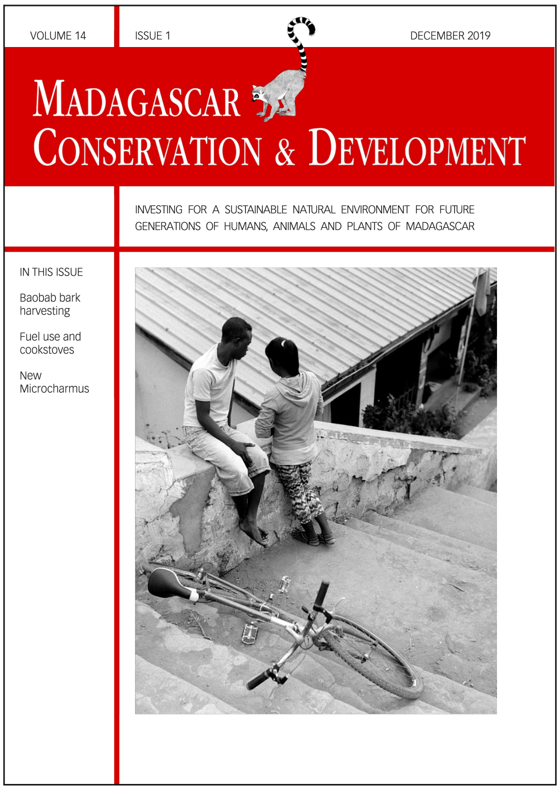

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profitant des connaissances locales. Comme une grande partie de la population utilise régulièrement des trépieds en métal, l'introduction de tout type de réchaud « économe en combustible » à grande échelle devrait faire une différence dans la consommation de la biomasse, en plus de réduire les coûts liés à la récolte et au transport.

INTRODUCTION

Deforestation rates in Madagascar are among the greatest in the world, posing a threat to the survival of unique biodiversity but also, ultimately, threatening the livelihoods of local human populations. Land is predominantly cleared for subsistence agriculture, timber and firewood (Dasgupta et al. 2015). At current rates, extractive practices are unsustainable, a matter that is further complicated because most people in Madagascar (and indeed worldwide) are expected to rely on solid biomass energy, i.e., firewood and charcoal, for decades to come (World Bank 2011). For example, a 2010 report from the Living Standards Measurement Survey (LSMS), showed that ~99% of households depended on solid biomass for cooking in Madagascar, with more than 77% of households relying on gathered firewood and only 17% relying on charcoal (INSTAT 2011). When urban areas are compared to countryside regions, however, there is a significant divide in the predominant type of biomass used for cooking. Whereas people in the countryside seemingly rely more on firewood, those in urban areas prioritize charcoal (Dasgupta et al. 2013).

To tackle the global biomass challenge, international efforts, including governmental and non-governmental organizations (NGOs) are implementing "clean" or "improved" stove programs (Duflo et al. 2012). The relevance of cookstoves is undeniable: food is at the center of a household, and cookstoves and cooking practices have immediate implications for the economy of the household, the health of the users, and, more broadly, the environment. "Improvement" is a relative term, and "improved stoves" encompass a diversity of stove structures that are better, in some regards, to more simple or traditional stoves, such as three-stone open fires. Any improvements, for example, to increase energy efficiency or reduce smoke/air pollution will upgrade the cookstove's status (World Bank 2011). Improved stoves should also be affordable and relatively portable, so that they can be sold and distributed at a large scale. Traditionally, improved stoves have been promoted by international organizations to better economic and health conditions of communities across the globe, as growing scientific data link smoke production to the increase of infectious respiratory conditions (Dasgupta et al. 2015). More recently, however, proponents of clean stoves have emphasized their important role in addressing critical environmental concerns. The threat of global warming, resulting from the loss and ineffective burning of solid biomass, has led to programs aimed at minimizing the contributions of CO_2 production to the atmosphere. Despite the disparity of results across international programs, with some setbacks and failures, the implementation of fuel-efficient cookstoves can have a large environmental impact when conducted at a relatively wide scale (Adler 2010).

In Madagascar, one such effort has been spearheaded by ADES (Association pour le Développement de l'Énergie Solaire), which has been manufacturing fuel-efficient stoves since 2001 (Vetter 2006). ADES' "rocket" stoves comprise a fired-clay combustion chamber and a sheet-metal shell, rendering them durable and energy efficient. ADES claims that their wood and charcoal rocket stoves save 46–68% more fuel compared to traditional structures like a metal tripod or open fire (MyClimate.org 2006). The stoves come with a 3-year warranty and production costs are subsidized to keep them affordable. ADES currently operates nine regional centers for production, sales and maintenance of stoves in Madagascar (Antananarivo, Antsirabe, Ejeda, Fianarantsoa, Mahajanga, Morondava, two centers in Toliara and one mobile center in central-northern Madagascar). Because ADES does not have a regional center in the northeastern SAVA (initials from the main towns of Sambava, Andapa, Vohemar and Antalaha) region, the Duke Lemur Center-SAVA Conservation program (DLC-SAVA), established in 2011, has been supporting ADES stoves, by subsidizing transportation costs from the capital Antananarivo to SAVA. The introduction of ADES cookstoves was among the first community-based conservation activities supported by the DLC-SAVA program. Thus far, over 500 cookstoves, including both wood and charcoal models, have been imported and distributed in SAVA, particularly in the main town of Sambava and villages near Marojejy National Park.

The SAVA region in northeastern Madagascar is socially and environmentally complex. On the one hand, it is densely populated with four large towns at the region's corners: Sambava, Antalaha, Vohemar, Andapa; on the other hand, it includes one of the largest protected forest blocks in Madagascar (Anjahanaribe Sud, COMATSA, Makirovana/Tsihomanaomby, Marojejy, Masoala) (Rabearivony et al. 2015). This contrasting landscape results in a strong pressure on natural resources by local communities, even though most of the remaining forest is use-restricted and illegal to target by local populations. Moreover, the SAVA region, known as the vanilla capital of Madagascar, produces a significant portion of the country's exportable vanilla. This means that a large portion of the regional economy is shaped by vanilla market price fluctuations, with an unprecedented injection of cash in the local markets during the harvest periods. Despite differences in people's standards of living, occupation, and access to markets or bartering practices, it is unknown whether SAVA community members differ in cookstove use in any measurable manner across a social or economic spectrum and, if so, how those differences may affect their communities and surrounding environments.

OBJECTIVES

Although DLC-SAVA, along with other local NGOs, has imported hundreds of stoves to the SAVA region to date, we have not documented the use and distribution of the stoves to assess whether improved stoves are frequently used in the region. Thus, as part of our evaluation program, we conducted general surveys on the use and preferences of cookstoves in the SAVA region, with a focus on fuel source, stove type use, household economy, and preferred features in cookstoves. These data will inform our future intervention strategies and maximize our efforts by targeting communities based on their needs, consumer preferences and behaviors.

We predict variation in the source of fuel, and stove type, as households are distributed from large towns to remote villages. Community members in more isolated villages may have access to forest fragments, or woody agricultural plots, i.e., fruit or commercial trees, for firewood, but be more limited in their access to charcoal (unless it can be produced locally). Similarly, and consistent with previous studies in different regions of Madagascar (Dasgupta et al. 2013), we predict that charcoal will be used more frequently in large towns (Antalaha, Andapa, Sambava) due to its availability in the markets, concomitant with a lack of firewood access.

As DLC-SAVA has concentrated its efforts for ADES distribution in Sambava and in several villages surrounding Marojejy National Park, we predict that these areas will have a greater prevalence and usage of ADES stoves, with Sambava specifically relying on charcoal models. With regard to Marojejy's surrounding villages (e.g., Ambohimanarina, Manantenina, Mandena and Maroambihy), perhaps ADES charcoal stoves will be used to offset the greater monetary cost and more limited availability of this fuel source. In contrast, perhaps ADES wood stoves will be more frequently used in villages around Marojejy National Park, where firewood can be gathered from nearby areas, without monetary expense.

Finally, we predict that, compared to charcoal users, firewood users will spend less money on fuel, but spend more time gathering it.

METHODS

SURVEY STRUCTURE. To gather information about household stove uses and preferences, we designed surveys (Table S1 in Supplementary Material) that recorded the household's basic location, including the name of the district, commune, *fokontany* (local village name); proxies of household economic status, including wall and roof materials; and information regarding stove use, including the number and types of stoves, fuel source, cooking space, and the money and time respectively spent buying or collecting fuel. We also included a list of cookstove features that respondents had to select based on their preferences: type of fuel, fuel efficiency, doesn't dirty pots, cooking time, amount of smoke, cost, durability, portability, size of cooking surface, other. The questionnaire was designed and implemented using the DataWinners software. The field surveyor (LJD) used a portable tablet to enter surveys responses, which were then stored in a password-protected DataWinners cloud.

We followed standard guidelines and practices for ethical conduct (Wilmé et al. 2016). At each village, the field surveyor (LJD) paired with a local community member, who became familiarized with the nature of the research and questionnaire. Surveys were conducted in Malagasy. Household visits started with a description of the survey and the surveyor indicated that participation was voluntary and could be interrupted at any time. Consent for the interview was verbally requested and, if the household member accepted, the surveyor explained the general objectives and emphasized that surveys were anonymous and that gathered information was untraceable to the respondents: e.g., no names or other identifiers were entered in the database. As reward for the time and effort (about 25 min per survey) all respondents were given phone credit worth ~US$0.35 (1,000MGA). All surveys were conducted between May and December 2017.

SAMPLING AND CATEGORIZATION OF VILLAGES. The surveys were conducted in villages and towns belonging to three districts in the SAVA region: Sambava, Andapa and Antalaha (Figure 1). Villages were selected randomly by picking names out of a bag. Villages close and relatively far from main, paved roads were specifically included in the sampling pool. At each village, the surveyor and a local assistant recruited ~ 20 participants per village, opportunistically walking along the central road. Selected villages

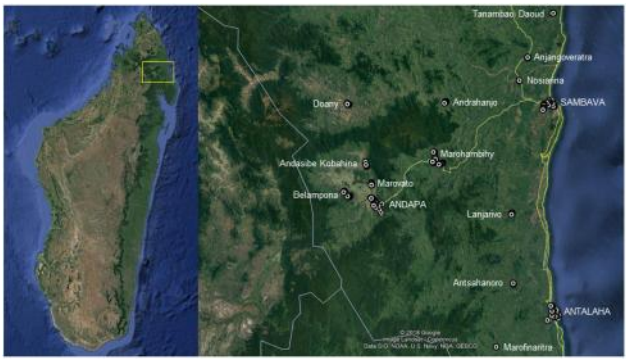

Figure 1. Maps of (left) Madagascar highlighting the study area and (right) pinpointing district capital towns (in caps) and the communes surveyed in this study.

were categorized by district affiliation as well as by their relative location with respect to a paved road, and thus their access to consumer goods. First, surveys were divided in three districts, which included their capital towns: Sambava, Andapa and Antalaha. Towns across districts may differ in terms of ethnic composition, economic status and in terms of how close they are to natural environments or protected areas. For example, villages in the Andapa and Sambava districts are closer to Marojejy National Park, Anjanaharibe Sud and COMATSA protected areas. Antalaha and Sambava districts concentrate vanilla businesses due to their proximity to airports and/or ports. Second, we binned surveys into three categories based on a village's distance from a main, paved road: (a) Villages on paved roads: This category includes surveys conducted in villages along the national road system that connects Sambava to Andapa (#3b) and Sambava to Antalaha (#5a to the south) or Vohemar (#5a to the north); (b) Villages on good, dirt (unpaved) roads: This category includes surveys conducted in villages found along well-travelled dirt roads, where cars and small taxis run frequently. This category only includes villages in the Andapa district; (c) Villages off roads: This category includes villages that are located at an aerial distance greater than 10 km from a paved road. Access to these villages varies seasonally and, in many cases, is limited only to foot.

COOKSTOVE CATEGORIES. We classified cooking structures by fuel source: firewood vs. charcoal. Firewood-fueled structures were grouped in one of the following categories: (a) stone structure, (b) metal tripod, (c) brick structure, (d) ADES-wood, and (e) other (Figure 2). This last category encompassed variations of idiosyncratic stoves such as wood-chip burning stoves, which are found in low abundance in the region. Charcoal-fueled structures were grouped as: (a) simple metal, (b) brick-clay stove (with or

Figure 2. Examples of cooking stoves or structures, top, left to right, firewood-fueled: stone structure, metal tripod, brick structure, ADES-wood; bottom, left to right, charcoal fueled: simple metal, brick-clay stove with metal protection, brick-clay stove without metal protection, ADES-charcoal.

without a metal protective rim), (c) tile-cement structure, (d) ADES-charcoal (Figure 2).

STATISTICAL ANALYSIS. Simple summary statistics were used to calculate the proportion of survey responses within particular categories. We used contingency analysis and ran Pearson's Chi-square tests in JMP Pro 13, to specifically test for differences in fuel source and cookstove-structure prevalence when households are classified by distance to paved road or by district. To further test whether proximity to main roads, house quality, or cooking-space features had associations with fuel type, we computed a generalized linear mixed model using the glmmADMB package (Fournier et al. 2012) implemented in Rstudio. The response variable was fuel-type (two categories: firewood or charcoal) and entered as binary data: We therefore used the binomial distribution function. We used the following suite of explanatory variables: distance to paved road as a proxy for access to consumer goods (three categories: paved road, dirt road, off road); house wall materials as a proxy for economic status (five categories: bamboo, cement, *ravinala*, i.e., traveler's palm, tin, and wood); and kitchen structure as a proxy for smoke exposure (four categories on a gradient from most to least ventilated). *Fokontany* (i.e., small village unit) was ranked as a random variable. We reran the above model exchanging the response variable from exclusive firewood or charcoal use to also include households where both fuel sources were used.

RESULTS

ON FUEL USE. Out of 517 households surveyed, comprising 25 villages in 15 communes (Table S2 in Supplementary Material), 49% used exclusively firewood as a source of fuel, compared to 36% of charcoal-exclusive fuel users. An additional 16% use both firewood and charcoal as fuel sources. Other sources of fuel, such as gas, had a negligible presence in our sample (n=6) and were removed from the analysis.

When fuel use was analyzed against distance from paved road, there was a significant difference, with the use of firewood increasing when households were farther away from paved roads (Pearson's chi-squared test = 93.520, $p < 0.0001$). More specifically, only 34% of households on paved roads use firewood-exclusive stoves, whereas 75% of off-road households did so. These percentages increase to 48% and 88% respectively, when households using both fuel types are included. The proportion of households using firewood and/or charcoal did not vary by district (Figure 3).

When we compared district capital communes, Andapa, Antalaha and Sambava, to other smaller communes per district, large towns have the greatest proportion of charcoal use, supporting the prediction that there is an "urban" signature in charcoal use (Table 1).

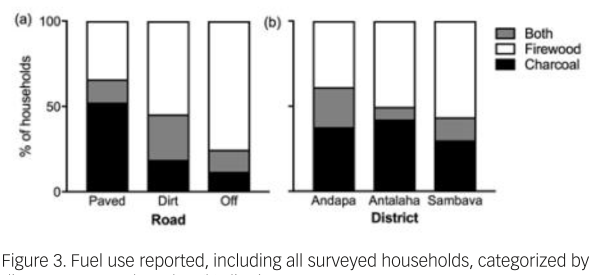

Figure 3. Fuel use reported, including all surveyed households, categorized by (a) distance to paved road or (b) district.

When fuel type was analyzed with respect to distance from paved road, house features and kitchen structures, firewood (including households where charcoal may be also used) was used significantly more often in off-road households, constructed with locally available materials, in contrast to more expensive materials such as cement/wood. Firewood use was also significantly correlated with "enclosed" kitchen structures, which appears counterintuitive from the ventilation perspective, assuming that smoke levels increase when firewood is compared to charcoal (Table 2).

ON THE MONEY AND TIME SPENT ON FUEL. As predicted, charcoal users spent more money (on average, weekly) than did firewood users. More than 80% of respondents, who were firewood users exclusively, reported that they spent no money on fuel; however, they spent more than 4 hours per week, on average, to gather firewood, and up to 20 hours per week in extreme cases (Table 3).

ON STOVE PREVALENCE. When firewood-fueled stoves were considered, the metal tripod was the most commonly used structure, and was well represented in all towns and villages, in proximity to or from paved roads. For example, 77% of households on paved roads, 65% of households on good dirt roads, and 78% of households off roads used at least one metal tripod stove. Such differences across types were significant when compared to distance from paved road (Pearson's chi-squared test = 42.762, $p < .0001$). After the metal tripod, brick structures tended to be used more often in the Andapa district (29%) compared to stone structures which were more common in the Antalaha district (16%). Such differences across types were also significant when

Table 1. Comparison between household in large towns (Andapa, Antalaha, Sambava) to other communes within their respective districts.

Commune	# households	Some charcoal use (%)	Only charcoal use (%)
Andapa town (urban villages)	60	88.3	75
Andapa communes (rural villages)	118	47.5	18.6
Antalaha town (urban villages)	60	86.7	78.3
Antalaha communes (rural villages)	64	15.6	6.3
Sambava town (urban villages)	55	85.5	72.7
Sambava communes (rural villages)	162	29.6	14.8

Table 2. Results of generalized linear mixed model using fuel type (firewood, charcoal) as response variable. (Significant codes: * $p \leq 0.05$, ** ≤ 0.01, *** ≤ 0.001)

	Std	Error	z value	Pr(>|z|)
(Intercept)	-1.153	0.568	-2.03	0.0424 *
Paved road to off road	2.316	0.733	3.16	0.0016 **
Paved road to dirt good road	1.58	0.78	2.03	0.0427 *
Bamboo to cement walls	-2.573	0.81	-3.18	0.0015 **
Bamboo to *Ravinala* stem walls	0.129	0.56	0.23	0.8173
Bamboo to tin walls	0.68	0.639	-1.06	0.2873
Bamboo to wood walls	-1.433	0.486	-2.95	0.0032 **
"Good" to "poor" ventilation	3.002	0.345	8.7	<2e-16 ***

Table 3. Time and cost estimations by fuel type. Conversion rate 1US$=~3,000 MGA. (*this household makes banana chips for sale, **if households with fuel costs of 0 MGA are excluded, the weekly average per household increases to 6,890 MGA)

Fuel type	Charcoal only	Firewood only	Charcoal and firewood
# of households	182	251	80
% of households that do not buy fuel	2.7	83.3	25
Fuel cost (MGA/week)			
average	11,982	1 154**	9,084
max	120 000*	20,000	105,000
Fuel effort (hours/week)			
average	0	4.4	6
max	0	10	20

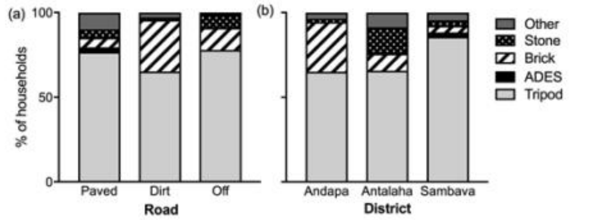

Figure 4. Firewood-fueled cooking structure prevalence, including all surveyed households, categorized by (a) distance to paved road or (b) district

compared by district (Pearson's chi-squared test = 60.508, $p < 0.0001$) (Figure 4).

When charcoal-fueled stoves were considered, two stove types are regularly used: the simple metal and the brick-clay stove. The latter was more frequently used in households on paved roads (53%), on good dirt roads (88%) and off roads (56%), whereas simple metal stoves took second place in households on paved roads (34%), on dirt roads (6%) and off roads (37%). Differences across types, however, were not significant (Pearson's chi-squared test = 10.881, $p = 0.0921$). When stoves were compared by district, brick-clay stoves were the most frequently used type in Andapa (78%), whereas simple metal stoves were the most common in Antalaha (45%). Both types were frequently used in Sambava district. These differences were significant (Pearson's chi-squared test = 26.625, $p = 0.0002$) (Figure 5). When "communes" were entered as the unit instead of households, there is more disparity, with some stove types preponderantly used in some communes, but not others: e.g., 6 households in Tanambao Daoud and 6 households in Doany used charcoal-fueled stoves: 100% of charcoal-fuel stoves were simple metal stoves in the former, whereas 100% were brick-clay in the latter. It should be noted, however, that overall the number of charcoal-fueled stoves was smaller when compared to the number of firewood-fueled stoves, reducing the statistical power of the analysis.

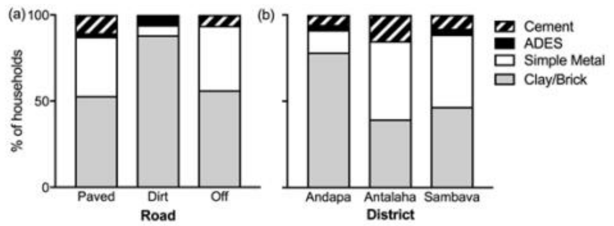

Figure 5. Charcoal-fueled cooking structure prevalence, including all surveyed households, categorized by (a) distance to paved road or (b) district

We found a very low incidence of ADES stoves in our sample, such that predictions regarding their distribution could not be tested. ADES wood stoves were only found at very low abundance in the Sambava District, on paved roads, representing a negligible portion of the samples. ADES charcoal stoves were only found in 2 households each in Andapa and Sambava districts. In sum, 3% of all households surveyed had an ADES stove (18 out 517 households). Of the 18 households, 72% (n = 13) had an ADES wood and 33% (n = 6) had both types of stoves: ADES wood and ADES charcoal. Interestingly, 28% of ADES owners reported not using their stoves, often giving the reason that "it is too slow to cook". Finally, most ADES owners also have other cookstoves that they generally use for cooking (Table 4).

ON THE COOKSTOVE PREFERENCE. Regarding preferred cookstove features, "cooking time" and "fuel efficiency" were the most common choices given by respondents, including firewood and charcoal users (Tables 5, 6).

For respondents using at least one firewood-fueled stove (i.e., firewood users exclusively, or firewood and charcoal users) the most important feature was "cooking time", regardless of whether households were compared by distance from paved road or by district. Second choices included "fuel efficiency" and "amount of smoke" when stoves were compared by distance from paved road, or "fuel efficiency" and "doesn't dirty pots" when compared by district, though these differences were not significant in this case (Tables S3, S4 in Supplementary Material). For respondents using at least one charcoal-fueled stove (i.e., charcoal users exclusively or charcoal and firewood users), first choices comprised "fuel efficiency" and "doesn't dirty pots" when stoves were compared by distance from paved road, and "fuel efficiency" and "cooking time" were compared by district (Tables S5, S6 in Supplementary Material).

DISCUSSION

Subsistence practices in the SAVA region combine traditional rice agriculture and intensive vanilla cultivation. Differential land use is oftentimes reflected in economic disparities: a contrast between motorcycles and zebu carts, candles and generators, metal and thatch roofs. Despite these differences, our surveys indicate that relatively simple cookstoves are generally used, though this trend is accentuated in households that are more isolated from the

Table 4. Summary of households containing ADES stoves

Own ADES wood	Own ADES charcoal	USED?	Why Not?	Other stoves?
Yes	No	Yes		No
Yes	No	Yes		Brick structure
No	Yes	Yes		Metal tripod
Yes	No	No	too slow to cook	Metal tripod
Yes	No	Yes		Metal tripod
Yes	Yes	No	unclear-only used on special occasions	Metal tripod
Yes	Yes	Yes		No
Yes	Yes	No	unclear-only used on rainy days because wet firewood is difficult for metal tripod	Metal tripod
Yes	Yes	Yes		No
No	Yes	Yes		No
Yes	Yes	Yes		No
Yes	No	Yes		Metal tripod
Yes	No	No	too slow to cook	Brick-clay stove, Metal tripod
Yes	No	No	too slow to cook	Brick structure, Brick-clay stove
Yes	Yes	Yes		Brick structure
No	Yes	Yes		Metal tripod
No	Yes	Yes		No
No	Yes	Yes		No

Table 5. Preferred features in cookstoves including all households, compared by distance from paved road. Numbers in parentheses represent percentages of respondents selecting this choice; n represents the number of households. (Pearson $p < 0.0001$)

	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Paved road	Fuel efficiency (28) n=83	Cooking time (25) n=74	Doesn't dirty pots (11) n=33	Type of fuel (10) n=30
Dirt road	Cooking time (37) n=32	Fuel efficiency (30) n=26	Type of fuel (16) n=14	Other (7) n=6
Off road	Cooking time (27) n=38	Amount of smoke (19) n=27	Doesn't dirty pots (18) n=25	Fuel efficiency (12) n=17

Table 6. Preferred features in cookstoves including all households, compared by district. (Pearson $p < 0.0267$)

	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Andapa	Fuel efficiency (30) n=54	Cooking time (25) n=48	Type of fuel (16) n=28	Amount of smoke (8) n=14
Antalaha	Cooking time (32) n=40	Fuel efficiency (19) n=24	Other (14) n=17	Doesn't dirty pots (13) n=16
Sambava	Cooking time (27) n=59	Fuel efficiency (22) n=48	Amount of smoke (14) n=31	Doesn't dirty pots (13) n=29

large towns. Consistent with our first prediction, it appears that firewood is more frequently used when readily available, in households that are farther away from paved roads, and presumably closer to forest fragments or woody agricultural areas.

Although acquiring firewood may be "free", it adds a physical burden to the persons who procure and carry the fuel, not to mention the additional time investment of splitting, drying and transporting wood if the fuel source is relatively far from the household. Improved cookstoves are oftentimes promoted as "fuel efficient" when compared to more traditional structures like open fires. If basic information is gathered at target villages regarding average time investment by local members, a simple calculation can be made to illustrate how many hours per month, or year, can be saved by using an improved cookstove. Our results show that, on average, community members spend ~5 hours a week gathering firewood. These estimations are greater compared to the time spent by local villagers securing firewood at other eastern sites in Madagascar: e.g., ~30 minutes a day, or ~3.5 hours a week at Lac Alaotra (Borgerson et al. 2018), and between 15 and 30 minutes a day, or ~3 hours a week in villages around Betampona Strict Nature Reserve (Golden et al. 2014). We believe that these data should be discussed in the context of program implementation, in addition to advertising other potential long-term benefits of proposed cookstoves. NGOs or governmental organizations highly value the reduction of emissions to prevent long-term health complications, but cooks may prioritize other more pragmatic reasons: e.g., burning less fuel means less time for women, and possibly children, to spend gathering solid biomass (Adler 2010).

We were somewhat surprised by the very low incidence of ADES cookstoves in our sample. It was also interesting to note that, when present, ADES stoves were not always used. The low visibility of ADES in the region may be due to a variety of factors, including the fact that NGOs may not have introduced enough stoves to make a difference at regional scale. Moreover, efforts should be placed to target remote villages instead of focusing on a few selling locations as it has been done thus far. Moreover, DLC-SAVA has been selling stoves promoted by word of mouth, and we have had a few buyers purchasing several stoves at once, and likely concentrating their distribution in large towns, or "wealthy" households in small villages. This would mean that some households will use and or store multiple ADES, and that the number of stoves sold does not equate to the number of households owning one.

Including preference data could also help us understand the potential desirability of improved stoves like ADES. We showed that respondents using firewood-fueled stoves prioritize "cooking time" over other features like "fuel efficiency" (though the latter comes as a close second). Metal tripods, which are extensively used as cooking structures, allow for rapid transference of heat to pots, although at a greater fuel cost. Charcoal users, however, ranked fuel efficiency as a main feature they prefer in a cookstove, presumably in response to the greater monetary costs of charcoal. Other considerations, such as "doesn't dirty pots" and "amount of smoke" were also selected as top three choices indicating a clear desire for cleaner burning stoves and an awareness of the respiratory health costs of current practices.

One question we did not fully address is whether people would be inclined to purchase a more fuel-efficient stove like ADES at a higher price. DLC-SAVA subsidies make ADES stoves highly competitive in the local market: at ~15,000 MGA a piece (~US$5; conversion rate 1US$=~3,000 MGA), they are cheaper or comparably priced to other options available in the region. For instance, an imported artesian clay stove is sold at ~25,000 MGA, and a local "dung" cookstove at ~25,000 MGA (Klug 2017 in Supplementary Material). Although "cost" did not make it to the top of the preference rankings across households, 83 respondents selected this option as one of the preferred features in a cookstove, and 19 respondents chose "cost" as the most important feature. Thus, increased prices for ADES cookstoves may lower their appeal or reduce local demands.

Selling stoves is more than showing the product – for instance, information about how to economize fuel, how to properly load a stove for maximum efficiency, how to avoid dirtying kitchen equipment, should be carefully explained (Adler 2010). Although we are aware that ADES designed pamphlets and training routines, we are not sure how many NGOs subsidizing stoves embraced the program to the maximum potential. For instance, as it is shown in this study many interviewees considered "cooking time" as an important feature in a cookstove. This may pose a challenge to make ADES and other fuel-efficient stoves appealing, because fire-clay combustion chambers may take additional time to heat up. Incidentally, once the chamber is fully heated, less fuel may be needed to maintain the same temperature for long periods. A more comprehensive discussion about trade-offs may help counterbalance traits that may be initially perceived as negative. It is clear from this study that receptiveness and willingness to learn is present.

Based on this preliminary study, we suggest a more strategic plan to introduce and distribute improved cookstoves such as ADES in the SAVA region: (i) we suggest matching stove models (wood and/or charcoal) with the most commonly used fuel source at any particular village, based on prior surveys like this. We would particularly favor the ADES wood stoves to be distributed in the more remote villages, where people greatly rely on gathered firewood. It is perhaps noteworthy that ADES wood stoves performed better than ADES charcoal stoves in terms of fuel consumption, when each one was tested against baseline stoves by a DLC-SAVA volunteer student (Klug 2017 in Supplementary Material): ADES wood used 3 times less fuel than a metal tripod, but ADES charcoal used only slightly less fuel than a basic metal stove; (ii) we suggest adding a short training/and or demonstration to highlight features that are perceived as important by community members. For example, ADES wood stoves may take longer to cook food, but they may not dirty pots as much as do metal tripods. Additionally, we should provide useful information to ensure the stoves are being used to their maximum potential. For instance, learning to load the stoves properly may, in fact, reduce the cooking time. In addition to training sessions by experienced users, a pictographic instructional pamphlet handed out with stoves might be useful; (iii) we suggest finding reliable local "partners" to sell stoves once they arrive to SAVA. This is no minor detail, as we have faced the problem of assistants re-selling stoves for profit.

It was commonly observed in the sampled communities that cooking habits and stove use were largely based on tradition, cost and availability, as opposed to practical long-term health benefits and/or environmental impacts. Future research in this area should seek to account for this when designing more fuel-efficient stove models and strive to educate and build capacity within their clientele and their resources. Although DLC-SAVA supports the continuation of the ADES program to disseminate these improved stoves to the SAVA region, and although we welcome more NGOs to do the same in this and other regions in Madagascar, we understand that there is no single ideal stove to solve the environmental crisis, and that a variety of options should be made available depending on peoples' socioeconomic levels, cultural traditions and geographic locations (Adler 2010). Technological advances are constantly introducing better products, that can provide multiple benefits at affordable prices. However, given the fact that large portions of the communities in the SAVA region are using metal tripods on a regular basis, introducing some type of "fuel-efficient" stoves at a larger scale than current distribution, is expected to make a difference in biomass consumption, in addition to reducing burden on collectors and carriers. Providing focused training on fuel-efficient stove design to experienced individuals who are already producing and distributing stoves locally could be an excellent way to support the sustainability of such efforts while utilizing and leveraging local knowledge.

Finally, for NGOs interested in community-based conservation, discussing the importance and potential impact of improved cookstoves in environmental education activities, can help communicate a message of sustainability and natural resource management, with implications for the daily lives of primary and secondary school student participants.

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SUPPLEMENTARY MATERIAL

Table S1. Survey questions.

Table S2. List of villages (*fokontany*) surveyed in this study, ordered by commune, district and distance from paved road.

Table S3. Preferred features in cookstoves including households using firewood, compared by distance from paved road.

Table S4. Preferred features in cookstoves including households using firewood, compared by district.

Table S5. Preferred features in cookstoves including households using charcoal, compared by distance from paved road.

Table S6. Preferred features in cookstoves including households using charcoal, compared by district.

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Supplementary Material

Table S1. Survey questions. (Questions have been adapted from original format in DataWinners, where responses were entered in a tablet with preset menu forms. Format consisted of textboxes and drop-down preset options for easy input)

General questions *[answered by surveyor]*
District name *[drop-down menu: Sambava, Antalaha, Andapa}*
Commune name *[enter name in textbox]*
Village name *[enter name in textbox]*
What is the roof of the house made of? *[drop-down menu: bamboo, cement, ravinala, i.e. traveler's palm, tin, other]*
What are the walls of the house made of? *[drop-down menu: bamboo, cement, ravinala, i.e. traveler's palm, tin, wood, other]*
Basic household demographics
Is respondent male or female? *[drop-down menu: Female, Male]*
Is the primary cook for the family male or female? *[drop-down menu: Female, Male]*
How many people live in the household? *[enter number in textbox]*
Cooking space, cookstove types and related questions
Where do you cook? *[drop-down menu: open space, outside/roof/no walls or weak, inside/3 walls/window, roof/strong walls/close]*
Stove type *[drop-down menu: stone structure, metal tripod, brick structure, ADES-wood, simple metal, brick-clay with metal protective rim, brick-clay without a metal protective rim, tile-cement structure, ADES-charcoal, other]*
Fuel type *[drop-down menu: firewood, charcoal, gas, other]*
How many stoves [same type] *[enter number in textbox]*
How many hours lit per day *[enter number in textbox]*
[repeat questions until all stove types are included]
Preferred material to start fire *[enter response in textbox]*
Do you own an ADES stove? *[drop-down menu: Yes, No]*
Do you use your ADES stove? *[drop-down menu: Yes, No]*
Why don't you use your ADES? *[enter response in textbox]*
How much money do you spend per week on cooking? *[enter number in MGA in textbox]*
How much time do you spend per week on collecting firewood? *[enter number on hours in textbox]*

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Supplementary Material

Table S2. List of villages (*fokontany*) surveyed in this study, ordered by commune, district and distance from paved road.

District	**Commune**	**Fokontany**	**Distance**	**# households**
Andapa	Andapa	Ambomitsinzo	paved	20
Andapa	Andapa	Andapa Sud	paved	20
Andapa	Andapa	Antangegny	paved	20
Andapa	Andasibe Kobahina	Andasibe Kobahina	good dirt	26
Andapa	Belampona	Ambody Pont	good dirt	21
Andapa	Belampona	Belampona	good dirt	19
Andapa	Doany	Doany	off road	32
Andapa	Marovato	Marovato	good dirt	20
Antalaha	Antalaha	Ambatomitraka	paved	20
Antalaha	Antalaha	Antananbao	paved	20
Antalaha	Antalaha	Belle Rose	paved	20
Antalaha	Antsahanoro	Antsahanoro	off road	22
Antalaha	Lanjarivo	Vohitsoa	off road	20
Antalaha	Marofinaritra	Marofinaritra	off road	21
Sambava	Andrahanjo	Andrahanjo	off road	22
Sambava	Anjangoveratra	Anjangoveratra	paved	19
Sambava	Maroambihy	Ambohimanarina	paved	16
Sambava	Maroambihy	Manantenina	paved	22
Sambava	Maroambihy	Mandena	paved	24
Sambava	Maroambihy	Maroambihy	paved	18
Sambava	Nosiarina	Nosiarina	paved	20
Sambava	Sambava	Ambatofitatra	paved	20
Sambava	Sambava	Ambodisatrana	paved	14
Sambava	Sambava	Sambava Centre	paved	20
Sambava	Tanambao Daoud	Tanambao Daoud	off road	21
Total households included in the analysis				517

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Supplementary Material

Table S3. Preferred features in cookstoves including households using firewood, compared by distance from paved road. Numbers in parentheses represent percentages of respondents selecting this choice; n represents the number of households.

	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Paved road	**Cooking time (34) n=48**	**Fuel efficiency (21) n=30**	Doesn't dirty pots (12) n=17	Amount of smoke /Type of fuel (9) n=12
Dirt road	**Cooking time (44) n=31**	**Fuel efficiency (20) n=14**	Type of fuel (17) n=12	Other (9) n=6
Off road	**Cooking time (31) n=38**	**Amount of smoke (21) n=26**	Doesn't dirty pots (14) n=17	Fuel efficiency (13) n=16

Pearson p=0.0019

Table S4. Preferred features in cookstoves including households using firewood, compared by district.

	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Andapa	**Cooking time (37) n=41**	**Fuel efficiency (22) n=24**	Type of fuel (14) n=16	Amount of smoke (8) n=9
Antalaha	**Cooking time (36) n=25**	**Doesn't dirty pots (16) n=11**	Amount of smoke (13) n=9	Fuel efficiency /Other (11) n=8
Sambava	**Cooking time (34) n=51**	**Fuel efficiency (19) n=28**	Amount of smoke (14) n=21	Doesn't dirty pots (13) n=19

Pearson p=NS

Table S5. Preferred features in cookstoves including households using charcoal, compared by distance from paved road.

	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Paved road	**Fuel efficiency (33) n=64**	**Cooking time (19) n=36**	Type of fuel (12) n=23	Amount of smoke (11) n=21
Dirt road	**Fuel efficiency (46) n=18**	**Cooking time (28) n=11**	Type of fuel (23) n=9	Portability (3) n=1
Off road	**Doesn't dirty pots (24) n=8**	**Fuel efficiency (21) n=7**	Cooking time (15) n=5	Amount of smoke/ Type of fuel (15) n=5

Pearson p=0.022

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Supplementary Material

Table S6. Preferred features in cookstoves including households using charcoal, compared by district.

District –all charcoal	Top 1 choice	Top 2 choice	Top 3 choice	Top 4 choice
Andapa	**Fuel efficiency (40) n=44**	**Type of fuel (20) n=22**	Cooking time (15) n=16	Doesn't dirty pots (8) n=9
Antalaha	**Cooking time (32) n=20**	**Fuel efficiency (27) n=17**	Other (15) n=9	Doesn't dirty pots (8) n=5
Sambava	**Fuel efficiency (29) n=28**	**Cooking time (17) n=16**	Amount of smoke (16) n=15	Type of fuel (14) n=13

Pearson p=0.0017