Electric cookstove adoption and energy attitudes in rural Namibia: The role of youth and sustainability education in advancing household energy

Samantha Lindgren (salindgr@illinois.edu)
University of Illinois Urbana-Champaign https://orcid.org/0000-0002-9905-1224

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Abstract

Efficient cookstoves are popular solutions in international energy development for their presence in multiple Sustainable Development Goals. However, adoption of these devices remains a challenge. Among the barriers known to limit adoption is effective household communication, yet rarely are all stakeholders purposefully engaged in activities that support uptake and sustained use. The findings of two studies conducted in rural Namibia indicate that youth-oriented sustainability education is an effective communication tool in cooking energy development, and has the potential to shift attitudes and behaviours, within households and across communities. Households with children who participated in sustainability education programming were significantly more likely to prefer efficient fuels and be less committed to biomass cookstoves than similar families without such children. Further, a longitudinal study of children who attended the programming indicates that their preferences about common cooking fuels shifted toward sustainable ones, and that these changes persist over time.

Full Text

In Namibia, 90% of rural households prepare their meals by burning biomass indoors in unvented fires [1]. The resulting indoor air pollution is responsible for chronic and fatal health concerns for Namibians [2–4], as well as for the 3 billion people around the globe who cook similarly [4,5]. Cooking with biomass is also associated with economic hardship [6–8] and environmental degradation [9–11]. Efficient cookstoves have been a popular solution for addressing these issues and have been a prominent piece of sustainable energy development efforts for several decades [12–14].

Efficient cookstoves, defined here to include those combust biomass more completely thereby requiring less fuel and producing fewer emissions, as well as electric, LPG, and solar stoves, have been less popular with their intended users [15]. Unlike other technological advances that ostensibly seek to improve the quality or convenience of life (e.g., mobile phones, internet), widespread embrace and uptake of these devices have eluded the broader cookstove community [15,16]. The challenges and barriers to efficient cookstove adoption, including the necessary behaviour changes to reduce or suspend biomass use, are many and extensively documented elsewhere [17–24].

Efforts to overcome these barriers at the household or community level are multipronged approaches that often include engaging the intended user via behaviour change communication strategies. These efforts largely target adult women because they are often the household's primary cookstove user [25]. However, energy use is a family affair [26,27] and recent research indicates improvements of stove uptake when youth, current and future users of cookstoves, are purposefully engaged [25,28–30].

Situated in Social Cognitive Theory, which in part states that a person's behaviours are influenced by observing their peers and the environment in which the action is performed [31], the studies described herein are based on the premise that learning in a household is bi-directional, that is, parents and children

learn from one another. Evidence from related fields such as sanitation, sustainable agriculture, and sexual health indicate that household attitudes and behaviours shift as a result of youth-oriented education around these topics across global contexts [32–37]. While youth energy education is becoming an increasingly popular way of focusing conservation efforts in the United States, and there is some evidence of parent behaviour shifts as a result [26,38–41], there is limited evidence of the efficacy of this approach in resource-limited settings, or as a communication tool for residential cooking energy transitions [25].

To address this gap, a stratified survey of two rural communities in the Hardap Region of Namibia was undertaken alongside a longitudinal evaluation of learner and control group outcomes at a sustainability education camp for youth. Findings indicate that the community that sends a school group to the camp annually is more knowledgeable about, and receptive to, renewable energy. Further, households with direct experience with the camp have higher mean adoption rates of their electric stoves and are less committed to their open fires than similar households within their community and in the control town. At the same time, youth camp participants exhibit significant gains in energy knowledge and attitudes, are more receptive to solar energy and cooking, and prefer cleaner burning fuels after camp as compared to the control group. Some of the largest increases are attributed to students whose families primarily burn biomass in their homes. In a six-month follow-up, these gains persist.

Study Context

The Namib Desert Environmental Education Trust (NaDEET) Centre is a sustainability education camp located on the NamibRand Nature Reserve in the Hardap Region of Namibia. NaDEET primarily serves communities in the rural Hardap, where people are among the most economically disadvantaged, infrastructure lags, and education levels are amongst the lowest in the country [1]. School groups visit NaDEET Centre for five days and as a part of regular camp activities prepare all meals using efficient biomass cookstoves and solar cookers and learn sustainable lifestyle behaviours including the use of bucket showers, long-drop composting toilets, recycling and composting, and monitoring of energy and water. Through its 16 years of operation in a sparsely populated region, NaDEET has engaged nearly all Hardap communities at least once through grants from the national government and private donors.

Stampriet and Gibeon, are both small, rural towns approximately 100 km apart and more than 150 km to NaDEET Centre. The Stampriet community has sent at least one school group of fifth or sixth grade learners to NaDEET nine years between 2010 – 2019. By contrast, the community of Gibeon has sent just one group ever, in 2011. Gibeon has a higher overall socioeconomic status (SES) but the two towns are similar across several demographic variables, making Gibeon an appropriate control group for this study (Supplementary Note 1). Across the towns, 200 households were surveyed. In Stampriet, 34 of 100 respondents had prior NaDEET experience, either personally or through a family member.

Electricity Access & Usage

Access to the electrical grid is widespread throughout much of Namibia (Supplementary Note 2). However, access is not synonymous with usage. More residents in Stampriet (97%) have access to electricity than in Gibeon (84%), but respondents in Stampriet use significantly less electricity than those in Gibeon (Table 1). In Stampriet grid connectivity is nearly universal, yet only 70% of those with access own an electric cookstove, and just 54% (n = 38) use it daily. Rates of electric stove ownership and daily use are significantly higher in Gibeon (Table 1).

Cookstove Commitment and Adoption Behaviours

Globally most households use multiple stoves for different purposes in a process known as *stacking* [15,42]. In Stampriet and Gibeon the most common *stack* is a traditional, unvented fire and an electric hotplate-type stove. Since there is no standard definition for *cookstove adoption* in the literature [25], to better understand how a stove fits into a household's kitchen, Adoption Indices [43] were calculated. This index provides a quantitative snapshot of the stove's uptake and was used because it is designed to be flexible (see Methods). While the index was developed for efficient cookstoves, its flexibility was leveraged to calculate adoption indices for each stove used in a residence, including traditional cookstoves. At present, little attention is given to the factors that encourage a household to suspend or reduce solid fuel use[44] and there is no recommended metric for understanding a traditional cookstove's importance in relation to other devices in the household. As such, all cookstoves in the household were treated equally, and index scores were viewed as an indication of the household's *commitment* to each device.

While nearly all respondents report usage of traditional stoves, more households in Stampriet use firewood as their primary cooking source (M = 0.64, SD = 0.67) than in Gibeon (M = 0.40, SD = 1.02), as measured by a two proportion z-test, z = 1.98, p = .047. In Stampriet, the proportion of NaDEET households that use traditional cookstoves is commensurate with that of the town, z = 0.60, p = .546, yet these households are significantly less committed to their fires than other households in their community, including non-NaDEET households with children, as shown by an independent samples t-test, $t(90)$ = 2.74, p = .007, with a medium effect size[45], Cohen's d = 0.61. These NaDEET households were also less committed to traditional cookstoves than those who cook with them in Gibeon, $t(143)$ = 2.56, p = .011, d = 0.45 (Figure 1).

Similarly, electric stove commitment was examined across towns and within Stampriet. Gibeon, with its higher SES and associated ability to afford electricity, was significantly more committed to electric stoves than respondents in Stampriet, as measured by an independent samples t-test, $t(138)$ = 3.60, p < .001, d = 0.61. However, when NaDEET households in Stampriet were compared against Gibeon, the difference in electric stove commitment was nonsignificant, $t(95)$ = 1.77, p = .080.

Multivariate regression analyses were performed to explain the value of stove commitment based on SES and the respondent's highest level of education, variables previously shown to affect adoption[46]. Household NaDEET experience was added as a covariate. These analyses were done for both traditional and electric stoves, and both models were significant (Table 2). For electric stoves, SES was the only significant covariate indicating that poverty was the highest barrier to regular use of an efficient cookstove. Traditional cookstove commitment was negatively associated with all three.

An adoption index score equal to 70% of total adoption is considered "good" [43], interpreted here to mean a strong commitment to the device. As shown in Figure 1, NaDEET households in Stampriet were the least committed to their open fires. NaDEET households and those in the control group did not exhibit differences between rates of electric and traditional stove adoption, whereas non-NaDEET households with children were significantly more committed to open fires than their electric stoves.

The role of poverty in these two communities cannot be ignored. Respondents that can afford electric cookstoves, regardless of regularity of use, were significantly less committed to their traditional cookstoves ($M = 0.76$, $SD = 0.35$) than households without electric stoves ($M = 0.95$, $SD = 0.13$), as shown by an independent samples t-test $t(193) = 4.02$, $p < .001$, $d = 0.63$, meaning that access to an electric stove, even if it is rarely used, affects the user's overall commitment to their open fire. Similarly, an examination of the poorest respondents, those who live in informal settlements and primarily cook with wood, revealed that NaDEET experience does not lessen traditional stove commitment, $t(43) = 0.73$, $p = .472$, which, as the analyses show and the literature supports, is a function of household economics.

Energy Attitudes

While poverty limits energy-switching behaviours in the kitchen, attitudes about renewable energy are not constrained by household economics. Households with NaDEET experience had significantly more favourable attitudes about sustainable cooking energy than households without such experience. For instance, all respondents were asked to identify their ideal cooking fuel, regardless of actual use. Given their familiarity with electricity, it follows that residents in Gibeon preferred efficient fuels such as electricity, LPG, and solar significantly more than residents in Stampriet, as shown by an independent samples t-test, $t(197) = 2.89$, $p = .004$, $d = 0.41$. However, NaDEET households in Stampriet responded similarly to Gibeon and the difference was nonsignificant, $t(131) = 0.85$, $p = .067$.

Namibia has high solar irradiance[47] and renewable energy accounts for approximately 15% of the country's electrification[48]. Solar panels, even in rural areas, are becoming increasingly common. NaDEET Centre is powered by a small solar array and utilizes solar thermal cookers of the box and parabolic types. As such, respondents were asked a series of questions about solar energy, without specifying photovoltaics or thermal for cooking (Supplementary Note 3).

Despite pervasive use of biomass within the community, Stampriet respondents had more positive attitudes about solar energy than respondents in Gibeon, $t(197) = 2.40$, $p = .018$, $d = 0.34$, even when examining just the households in these towns that primarily cook with wood, $t(108) = 3.64$, $p < .001$, $d =$

0.71 (Figure 2). An effect is also detected when examining the impact of exposure to NaDEET's programming. Within Stampriet, respondents with NaDEET experience had significantly more favourable attitudes (M = 4.14, SD = 0.59) than those without (M = 3.78, SD = 0.72), $t(197) = 2.72$, $p = .006$, $d = 0.51$. Parents of past NaDEET participants also exhibited significantly more positive attitudes than other parents in Stampriet or Gibeon, $t(163) = 2.52$, $p = .013$, $d = 0.64$. This difference holds for parents who primarily cook with wood $t(98) = 2.91$, $p = .005$, $d = 0.76$.

While NaDEET programming was not found to affect cookstove commitments for the poorest Stampriet respondents, it does appear to have shifted their knowledge and perceptions about solar energy. NaDEET households that primarily use traditional cookstoves scored significantly higher on this instrument than similar households in Stampriet without NaDEET exposure, $t(64) = 2.03$, $p = .047$, $d = 0.56$. A large effect size was detected when comparing these households against similar households in Gibeon, $t(60) = 3.63$, $p < .001$, $d = 1.01$.

While the solar energy instrument is meant to be a scale (Supplementary Note 2), and thus no single item is likely to measure a specific construct, there were two of particular interest in terms of their relevance to criticisms of the viability of solar cooking, and thus worth examining. The first item asked about the respondent's understanding of solar energy for cooking, while the other inquired after their personal beliefs about a solar cooker's utility to meet local energy needs. Because these items are Likert-type, nonparametric tests were used to test for significant differences [49].

Energy from the sun can be used for cooking. The majority of Stampriet respondents, 91%, understood that solar energy can be used for cooking, regardless of household NaDEET experience, $c^2(2) = 2.37$, $p = .124$. In Gibeon, 70% agreed or strongly agreed with this statement, significantly fewer than in Stampriet, $c^2(2) = 12.76$, $p < .001$. This difference persists when examining different groups within the towns. For instance, amongst respondents who primarily cook with biomass, 91% in Stampriet and 61% in Gibeon agreed with this prompt, $c^2(2) = 13.94$, $p < .001$. Excluding NaDEET households and comparing the towns again yielded a significant difference, $c^2(2) = 6.65$, $p = .010$, indicating that these opinions are communitywide in Stampriet.

Solar cookers are accepted in my culture. Solar cookers are frequently criticized for their inability to meet the local cultural context into which they are introduced[18]. Thus if a respondent finds solar cookers to be culturally acceptable, then a more conventional cookstove, like an efficient biomass or electric stove, may be better accepted. The same series of comparisons made above were performed for this prompt. In Stampriet, 81% of all households agreed or strongly agreed that solar cookers are culturally acceptable, regardless of NaDEET experience, $c^2(2) = 0.67$, $p = .412$. In Gibeon, 61% of respondents agreed with this prompt, significantly fewer than in Stampriet, $c^2(2) = 16.26$, $p < .001$. Comparing Gibeon respondents to only the non-NaDEET households in Stampriet again yielded significant results, $c^2(2) = 10.84$, $p = .001$.

More telling, however, is the comparison between households that cook primarily with firewood across both towns. In Stampriet, 80% of households who cook primarily with wood found solar cookers to be

compatible with their culture as compared to 41% of similar respondents in Gibeon, $c^2(2) = 17.90$, $p < .001$. These findings indicate that this view was held by the majority of the Stampriet community, even the most socioeconomically disadvantaged.

One might expect more positive attitudes toward solar cooking and energy to be correlated with greater sensitivity toward the environment or climate change in general, however no such significant differences were detected (Supplementary Note 4). This underscores that the differences in energy attitudes between the two towns is due to the presence of an external factor, exposure to sustainable energy programming at NaDEET, and that this programming influenced knowledge and attitudes at the household and community levels.

Youth Outcomes

Alongside the community survey, a longitudinal study of 852 students who attended NaDEET Centre in 2019, or were part of a control group, was conducted. This paper examines just the 448 students from 8 participating Hardap schools of which 272 (61%) attended NaDEET Centre and 176 (39%) were learners in the grade below from the same schools, serving as the control group (Table 3). Each student took a series of three surveys; pre-camp, post-camp, and a six-month follow-up (see Methods).

Youth As Energy Stakeholders

While most students stated that their mothers are the primary cooks in the household, 75% reported cooking at least once a week with no difference between the treatment and control groups, $z = 1.88$, $p = .059$. However, females in both groups reported cooking significantly more often than their male peers, $z = 2.44$, $p = .015$. Just 9% of respondents claimed no responsibility for cooking duties, establishing that youth are in fact cookstove stakeholders, and that Hardap energy use is a household affair.

Most students (93%) reported access to the electrical grid, and 76% reported an electric stove in the home. Just 56% of these respondents reported that it is the home's primary stove, and 45% reported a *stack* of a traditional and an electric stove, confirming the findings in the community survey. Traditional fires, either as the primary stove or in combination with other devices, were reportedly used in 45% of respondents' homes. Because the cookstove community seeks to change the attitudes and behaviours of traditional cookstove users, as before, special attention is paid to this subset of youth in the following analyses.

Ideal cooking fuel

As in the community survey, learners reported their ideal cooking fuel. Across both groups, 70% stated a preference for the fuel used most often in their household. No significant differences in preferences were detected between NaDEET learners and the control group on the pre-survey. However, after NaDEET programming, significant differences emerged. NaDEET learners indicated a preference for an efficient fuel (e.g., electricity, gas, solar) for indoor cooking at a significantly higher rate than the control group which exhibited no change, as shown by a two-proportions z-test, $z = 2.56$, $p = .010$.

NaDEET learners exhibited an 11-point gain in preference for an efficient fuel between the pre- and post-survey. This gain was seen for both students who primarily used electricity for cooking at home, as well as those who reported firewood as the household's primary energy source. While the six-month follow-up survey is an incomplete data set due to school closures in early 2020 at the beginning of the COVID-19 global pandemic, for the 165 Hardap NaDEET learners whose responses were captured, this gain holds.

Energy Attitudes

Youth respondents answered a modified version of the solar energy knowledge and attitude inventory used in the community survey (Supplementary Note 3). There was no difference between NaDEET learners and the control group instrument scores on the pre-survey, as measured by an independent t-test, $t(388) = 1.20$ $p = .229$. However, paired t-tests revealed that NaDEET learners made significant gains between the pre- and post-survey, $t(151) = 2.11$, $p = .036$, $d = 0.20$, and that their attitudes were stable six-months later, $t(71) = 0.27$, $p = .791$. The control group exhibited no change over time.

Similar findings exist when we examine just those students who rely on firewood at home. Because the size of this subsample is small, and because of the limitations in collecting complete records as described earlier, an independent samples t-test was conducted at the group level rather than paired t-tests. This analysis revealed a significant and large effect on the post-survey between NaDEET and the control, $t(31) = 3.46$, $p = .002$, $d = 1.23$. No significant differences in scores between the second and third administrations of the survey were found, indicating a long-term shift in attitudes.

More telling is that significantly fewer NaDEET learners reported the presence of a traditional cookstove in their home on the post-survey than on the initial survey, as shown by independent samples t-test, $t(404) = 5.14$, $p < .001$, $d = 0.53$. There was no change between the second and third surveys, $t(285) = 0.16$, $p = .876$, indicating that this behaviour or attitude change persisted over time. The control group exhibited no changes across the three surveys. While there was no way to verify a behaviour change, a decrease in traditional cookstove usage, at a minimum this change represents a shift in attitudes or understanding. If, after attending NaDEET, participants understood the social, economic, and environmental issues associated with unvented biomass cookstoves, the change in their responses could be attributed to social desirability bias. Even so, this indicates a change in understanding.

Discussion

Taken together, the findings from these 2 quasi-experimental studies provide compelling evidence for the efficacy of youth-centric sustainability education in advancing sustainable cooking and household energy within the home and across communities. Households with a member exposed to local, youth-oriented sustainability education programming were found to have significantly more positive attitudes regarding solar energy and cookers and preferred more efficient fuels. For those that can more easily afford electricity, the sustainability education programming appears to support an increase in electric, and a decrease in traditional, stove commitments. The data also suggest that youth sustainability

education positively impacts the household's attitudes and knowledge in the absence of an affordable behavioural change.

Findings from Stampriet highlight the agentive capacity of youth. Households with children but without exposure to NaDEET's programming, preferred traditional cooking energy and stoves and were significantly less positive about electric stoves and other efficient energy sources than households with NaDEET experience. Similarly, the significant gains in sustainable energy knowledge and attitudes made by NaDEET's 2019 youth participants indicates that sustainability education programming has the potential to shift perceptions and understanding and demonstrates that youth do exert some influence over the attitudes and behaviours within their homes.

Moreover, attitudinal differences between non-NaDEET households in Stampriet and the control town suggest that NaDEET's youth programming has a positive impact on local communities. Students who attend NaDEET are not given stoves nor talking points for their return home, and yet improved energy attitudes and electric stove commitments occurred. This indicates that youth education contributes to a home environment in which attitudinal and behavioural changes are supported, a key pillar of Social Cognitive Theory. While this has implications for supporting development work committed to realizing the Sustainable Development Goals (SDGs) generally, the findings described herein may be of particular interest to the cookstove community, because of the behaviour dependent nature of cookstove uptake and sustained use.

While youth participants exhibited positive gains in attitudes and knowledge after just one week, it is not known how quickly these beliefs are transmitted through the household or broader community, though it is clear from the evidence presented here and elsewhere (blinded reference) that both do occur. To date, little research has been done on the role that this type of education has in shaping families' energy beliefs and consumption patterns, particularly in resource-limited settings. Locally led and contextually appropriate youth education is a potential mechanism for supporting cookstove adoption efforts.

Youth are not only household energy stakeholders, but also "critical agents of change" for their potential to act on a large scale and because they will be most impacted by a failure to realize the SDGs[50]. Today's youth will soon be in positions of energy decision-making for themselves and for their own households. Investing in education now has the potential to advance the long-term goals of both the SDGs and those of the cookstove community.

Methods

Community Survey Design

Household interviews in Stampriet and Gibeon, consisted of survey questionnaires and open-ended interview prompts, and were conducted in March and April 2019. A stratified design with random walk was utilized. Census enumeration maps available online from Digital Namibia and Google Earth images were used to segment each community into strata.

Based on aerial images available, each community was divided into 12-16 strata along naturally occurring divisions such as streets, dry river beds, etc. that were easily recognizable on the ground[51]. Because of the ways in which temporary structures are erected throughout the communities, including on property belonging to permanent homes, an accurate enumeration of households was not possible. As such, before interviews commenced in each stratum, the enumeration maps were checked for accuracy using a handheld GPS and existing maps during a walkthrough of each stratum. This process checked for gross inaccuracies in terms of segment size. Maps were found to be relatively accurate. That is, while the population may have grown, the on the ground realities appeared to proportionally match the aerial maps.

Households were selected using a systematic sampling method accomplished via random walk. The research assistants started in the southwest corner of each stratum and surveyed every 5th household. Abandoned homes were not counted. Four households declined to participate, and in their place, the next household was surveyed. In total, one hundred households in each community were surveyed. Without knowing the exact population size, an *a priori* power analysis was run to determine the sample size needed for a small effect size, Cohen's $d = 0.4$. A total sample size of $n = 200$ has enough power (80%) to detect this difference at the a = 0.05 probability level[45].

Systematic sampling, a probability-based sampling method, was used because of its ease of application, especially in contexts where the sampling frame was unlikely to represent the communities as they currently existed, and where updating the sampling frame may be difficult, or nearly impossible, in some areas due to access, as it was in Stampriet and Gibeon. This sampling method, however, is associated with unequal probabilities of item, or household, inclusion. Nevertheless, systematic sampling behaves as simple random sampling and typically has the same precision for variables involving human populations [52].

All strata were sampled ensuring that the survey results were as representative of the entire community as possible. At the time of survey design and strata designation, the social structure and organization of each community was unknown to the researcher (e.g., stratification based on wealth, religion, or ethnicity), but it was assumed that stratification within the community exists, and that there is a high degree of homogeneity within each stratum [53]. Thus, to yield a more precisely calculated sample mean for each variable, all residential strata were sampled.

Two Namibian research assistants were hired for the enactment of household interviews. A female interviewer was employed to maximize comfortability and ease of conversation with household respondents, the primary cooks, who were predominantly women or older children. A male driver was hired to assist with interviews, which were conducted primarily in Afrikaans, and to serve as an interpreter for interviews conducted in Khoekhoegwab, a local language in which he was fluent. Interviews were audio recorded, with participant permission, to allow for post-interview checking of respondent answers and for context. Recordings were later translated and transcribed.

Household Survey Specific Measures

The specific instruments included in the household questionnaire were chosen to make use of existing measures whenever possible. The aim of these instruments was to gather information about the primary cook's knowledge, attitudes, and behaviours toward efficient cooking technology and sustainability practices within the home. In some cases, the instruments were not designed, nor necessarily intended, for non-Western contexts and are thus used in an exploratory way only. This is described further in subsequent sections below. Efforts were taken to ensure that key dependent variables are measured in numerous ways. For instance, participant responses about types of fuel use was asked in two different ways, both in terms of the frequency of use of each stove within the household as well as the number of meals prepared on the traditional stove each week. Questions on the youth survey were also used to confirm observations made in the communities.

Adoption Index Survey

Behaviours are both difficult to change and to quantify. To determine whether experience at NaDEET affected energy-related behavioural changes at the household level, the degree to which households adopt their electric and traditional cookstoves was examined, where adoption score was used as a proxy for behaviour. This survey is part of a toolkit developed for the Clean Cooking Alliance [43,54] and includes 8 questions regarding the user's perceptions and reported use of an efficient cookstove, as well as a visual observation of the stoves used to confirm the participant's responses. These questions were asked for each type of cookstove or fuel in the home and occurred throughout the interview, rather than as a discrete set of questions. Based on the responses, the adoption index was calculated for each stove in residence. The adoption index (AI) is calculated as a function of four variables: the frequency of use of the cookstove (FCCS), overall condition of the cookstove (CCCS), level of satisfaction with the cookstove (LSC), and her interest in replacing the cookstove with a similar one at the end of the cookstove's lifetime (IRS).

Each variable mentioned above was given a score based on rubric that scores visual observations of the stove by the interviewer and the respondent's answers to the questions. Based on a cluster analysis of several case studies, the variables were weighted and the following adoption equation for an individual stove was developed [43,54].

$$AI=4(FCCS)+3(CCCS)+2(LSC)+1(IRS) \qquad (1)$$

The index is meant to be flexible and allows for dropping of terms and alternative weights to provide a snapshot of stove uptake at a moment in time[43]. The *condition* term was dropped for electrical devices since tinkering or making modifications to an electrical device is outside the expertise of most users. This

term, as well as the *interest in replacing* term are irrelevant in the context of traditional stoves, and thus also dropped from the equation.

Electric stove commitment was thus measured by equation 4

$$4(FCCS) + 2(LSC) + (IRS) \qquad (4)$$

and traditional stove commitment by equation 5.

$$4(FCCS) + 2(LSC) \qquad (5)$$

Adoption scores ranged from 0 to 7 for electric stoves, and up to 6 for traditional cookstoves (Table 4). A one-point difference between scores, based on the variables and weightings used, represents an additional two or three days of cookstove use per week, or an increase from ambivalence to high satisfaction with the stove's performance. To compare electric and traditional stove commitments, the index scores were normalized such that commitment was viewed as the proportion of full adoption according to the values listed in Table 5.

Attitudes about Solar Cooking

Mercy et al. (2008)[55] developed a short questionnaire for assessing women's perceptions and knowledge about solar cookers in Mali. These 10 questions are based on a 5-point Likert scale. Minor adjustments were made to the survey to replace references to Mali, the location of the instrument development, with Namibia.

Six Americas Short Survey (SASSY)

The Six America's Global Warming survey consists of 36 questions which assess a respondent's knowledge and attitudes about global warming and climate change. This survey has been used since 2008 to segment the American population into six groups based on their beliefs, attitudes, and level of concern about global warming [56]. The results of this instrument have been used in a variety of ways by researchers, educators, and policy makers. Most recently there has been interest in its use for tailoring communication about climate change to specific audiences [56]. Several other countries have used or adapted this instrument, including a British Broadcasting Corportation survey of 33,000 residents from six countries in Asia with the explicit goal of improving their communication strategies [57]. The instrument has also been used on small, sub-groups such as farmers in the corn belt of the United States [58], but to date, no studies exist in which rural residents of LMICs have been surveyed. A subset of four questions has been used to reliably assess an individual's perceptions about global warming risks, expected harm to future generations, and how important the respondent finds these issues, as accurately as if the entire instrument was used [56]. These four questions were asked at the very end of the questionnaire as to not introduce bias into solar energy responses earlier in the interview.

Sampling Weights

Sampling weights were calculated to account for differential probabilities of selection based on unequal strata sizes in terms of number of households per stratum, to improve precision of mean population estimations. The sampling frame and data from the most recent Namibian census was used to determine the population size in individual, or groups, of strata used in this study to calculate the weights. For instance, according to the census, there were 513 people living in strata 1, 2, 3, and 4 in Gibeon in 2011. This data, combined with household size data collected during the study, was used to calculate sampling weights for each stratum. The total number of people in the houses sampled in these four areas was n = 196, yielding a base weight, the inverse of probability of selection, w_i = 2.62.

There were 4 nonresponses; 1 in Stampriet, and 3 in two different segments in Gibeon. Nonresponse weights,

$$w_{nr} = \frac{S_s}{S_p} \qquad (6)$$

where S_s is the number of cases sampled for the segment and S_p is the number of responses obtained for the segment, were calculated for segments containing a nonresponse. Nonresponse weights were multiplied by the base weight for an adjusted base weight. The relative weights, were then found by dividing the adjusted base weights by $\overline{w}$, the mean of all adjusted base weights for the community,

$$\overline{w} = \frac{[\Sigma(w_i)(n_i)]}{n} \qquad (7)$$

to yield the total sampling weight[53]. The survey design was declared in Stata 16 using these total sampling weights which were then used for all population mean estimations using Stata's *svy* commands for more precise estimate means and confidence intervals.

All reported independent samples and paired t-tests, and two proportion z-tests are two-tailed.

NaDEET Learner Survey

Pre-Survey

Two weeks before the students' visit to NaDEET Centre, surveys as well as consent documents and teacher instructions were sent to participating schools via NamPost Courier, the courier arm of national postal service. Teachers were instructed to read the questionnaire out loud to students as a group in

English, the language of instruction throughout Namibia, or in the children's primary language, as needed. Students recorded their answers on the questionnaire provided. Teachers were asked to check the questionnaires for completeness as the students turned them in to minimize missing data. The pre-survey consisted of demographic items and questions to establish the students' baseline knowledge and attitudes about residential energy and other sustainability-related concerns. The same solar energy questions asked of adults in the community survey were included on the student questionnaire (Supplementary Note 3). Like the community survey, this questionnaire used a mix of existing instruments and original questions written in collaboration with NaDEET leadership. Teachers were provided with a pre-paid envelope to return the completed surveys via courier.

Post-Survey and Six-Month Follow-Up

Students completed a post-survey two weeks after their visit to NaDEET Centre. The post-survey questionnaire was a shorter version of the pre-survey. Teachers returned the post-survey in the same pre-paid courier parcel as the pre-survey. Follow-up surveys were sent to schools approximately six months after their visit to NaDEET, again using NamPost Courier.

Control Group

Each participating school was asked to identify a class of students one grade below the students scheduled to attend NaDEET to serve as a control group. This ensured that the control group was similar to the NaDEET participants demographically, eventually eligible for the same opportunities, but without prior NaDEET experience. Surveys were administered to both NaDEET learners and the control group on the same schedule.

Missing Data

Missing data was handled in Stata using valid mean substitution (VMS)[59], a method appropriate for Likert-scale attitude items in which the minimum and maximum of all items are the same, and thus the theoretical means and standard deviations are equal[60]. When data is found to be missing at random, as it was in this study, VMS has been found to produce similar estimates as multiple imputation methods[61].

Both studies were approved by the [blinded university]'s Institutional Review Board. The Namibia Commission for Research, Science, and Technology and the Ministry of Education also issued approvals for these studies.

Limitations

While every effort was taken to systematically sample the entire town to achieve a representative sample of each community, it is possible that groups of households were missed due to the random walk method employed during sampling, interviewer errors, or households that were inaccessible or unobservable from the primary residential areas. This may be especially true for informal settlements outside of the neighbourhood centres. Two Namibian research assistants who speak fluent Afrikaans were employed to conduct the household interviews to minimize *social desirability bias*[62–64]. Given that the research assistants were in each community for approximately two weeks, it is likely that some respondents, especially those interviewed later in the process, already knew who the research assistants were and which organizations they represented.

Human behaviours and attitudes are informed by a tapestry of interwoven variables and influences. While there is evidence that points to NaDEET's impact at the household and community level, there is no way to know with certainty if observed differences are due to learning accrued at NaDEET, or if there is some other factor that was not uncovered by the interviews and time spent in these communities. Moreover, the researcher and her assistants were outsiders to the communities. Some nuance in responses may have not been detected due to a lack of understanding of cultural context, shared experience, and interpretation.

Troncoso's adoption index was used because it was already developed and promoted by the Clean Cooking Alliance, but there are some issues with it as an instrument, and though its developers advocate for its flexibility in use, it was heavily adapted for this study. Adoption as a construct is complex and this formula considers just four factors. For instance, while the index intimates fuel stacking by incorporating the frequency of use of the cookstove in question, it does not consider the degree of fuel stacking within the household, nor a stove's importance relative to other devices in the home. The instrument itself does not capture what the cookstove is replacing, or how many other fuels and stoves are used. In an attempt to address these limitations, the index was used for each stove in the household, but more work is needed in this area.

The long-distance nature of the youth survey adds to the limitations that exist by virtue of the methods employed. The reliance on a national courier system to deliver surveys across the vast Namibian landscape was more successful than expected. However, a few schools did not receive the surveys in the intended time frame, or at all, which made acquiring three sets of data points from each student impossible even if the COVID-19 global pandemic hadn't closed schools in early 2020, disrupting the third round of data collection.

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Tables

	Stampriet Mean (sd)	Gibeon Mean (sd)	*z*	*df*	*p*
Access to electrical grid	0.97 (0.22)	0.84 (0.46)	2.65		.008
Electric stove ownership	0.72 (0.69)	0.86 (0.48)	1.70		.088
Daily electric stove use	0.55 (0.54)	0.83 (0.45)	4.02		.001*
Monthly electricity expenditures ($N)	275.34 (290.29)	391.50 (314.66)	2.71†	173	.007

Table 1. Estimated electricity usage in Stampriet and Gibeon. Two proportion z-tests results to compare electricity access and usage in Stampriet and Gibeon for households connected to the municipal grid.

** Indicates p-values less than 0.001*
† t-test scores as a result of a two-tailed independent samples t-test.

		B	*SE*	*b*	*t*	*p*
Electric	Socioeconomic Status	0.43	0.13	0.29	3.31	.001*
	Level of Education	0.01	0.05	0.01	0.13	.897
	NaDEET Experience	-0.25	0.37	-0.06	-0.67	.502
	$F(3, 135) = 4.49$, $p = .005$, $R^2 = 0.09$					
Traditional	Socioeconomic Status	-0.38	0.08	-0.32	-4.44	.001*
	Level of Education	-0.10	0.04	-0.18	-2.48	.014
	NaDEET Experience	-0.72	0.31	-0.15	-2.34	.020
	$F(3, 188) = 17.61$, $p < .001$, $R^2 = 0.22$					

Table 2. Summary of regression analysis for variables predicting electric and traditional cookstove commitment.

** Indicates p-values less than .001*

	NaDEET Mean (sd)	**Control Mean (sd)**	***t*(387)**	***p***
Age	13.04 (1.13)	12.44 (1.08)	4.91	.001*
Female Student	0.61 (0.49)	0.52 (0.50)	0.76†	.446
Family Size	6.60 (2.71)	6.85 (2.77)	0.79	.428
Electricity at Home	0.91 (0.28)	0.97 (0.18)	0.48†	.631
Prior Household NaDEET Experience	0.63 (0.48)	0.71 (0.46)	0.70†	.483

Table 3. Overview of NaDEET participants and students in the control group across key demographical variables. Two schools attended NaDEET Centre with little advance notice and pre-survey demographic information is missing from those students, and therefore not included in this table.

** Indicates p-values less than .001*
† z-test scores from two-proportion tests of binary variables

	Value				
	0	0.25	0.5	0.75	1.0
Frequency of use (FCCS)	Never	Once per week or less	2 to 3 days per week	4 to 6 days per week	Every day
Condition (CCCS)	Destroyed or in disuse	Modifications; performance impairment	Modifications; no performance impairment	Working with low maintenance	Perfect with good maintenance
Level of satisfaction (LSC)	Unsatisfied	Low satisfaction	Regularly satisfied	Satisfied	Very satisfied
Interest in replacing (IRS)	No		Maybe		Yes

Table 4. *Troncoso's rubric for scoring adoption index variables*[43]*.*

Percentage of Total Points	Adoption Description
0.90 – 1.0	Very Good Adoption
0.85 > 0.9	Good Adoption
0.70 > 0.85	Regular/Moderate Adoption
0.50 > 0.70	Bad Adoption
0.0 > 0.50	Very Bad Adoption

Table 5. *Modified Adoption Index scoring guide used for electric and traditional cookstoves in this study*[43]*. The total points available are determined from Equations 4 and 5 and the rubric shown by Table 4.*

Figures

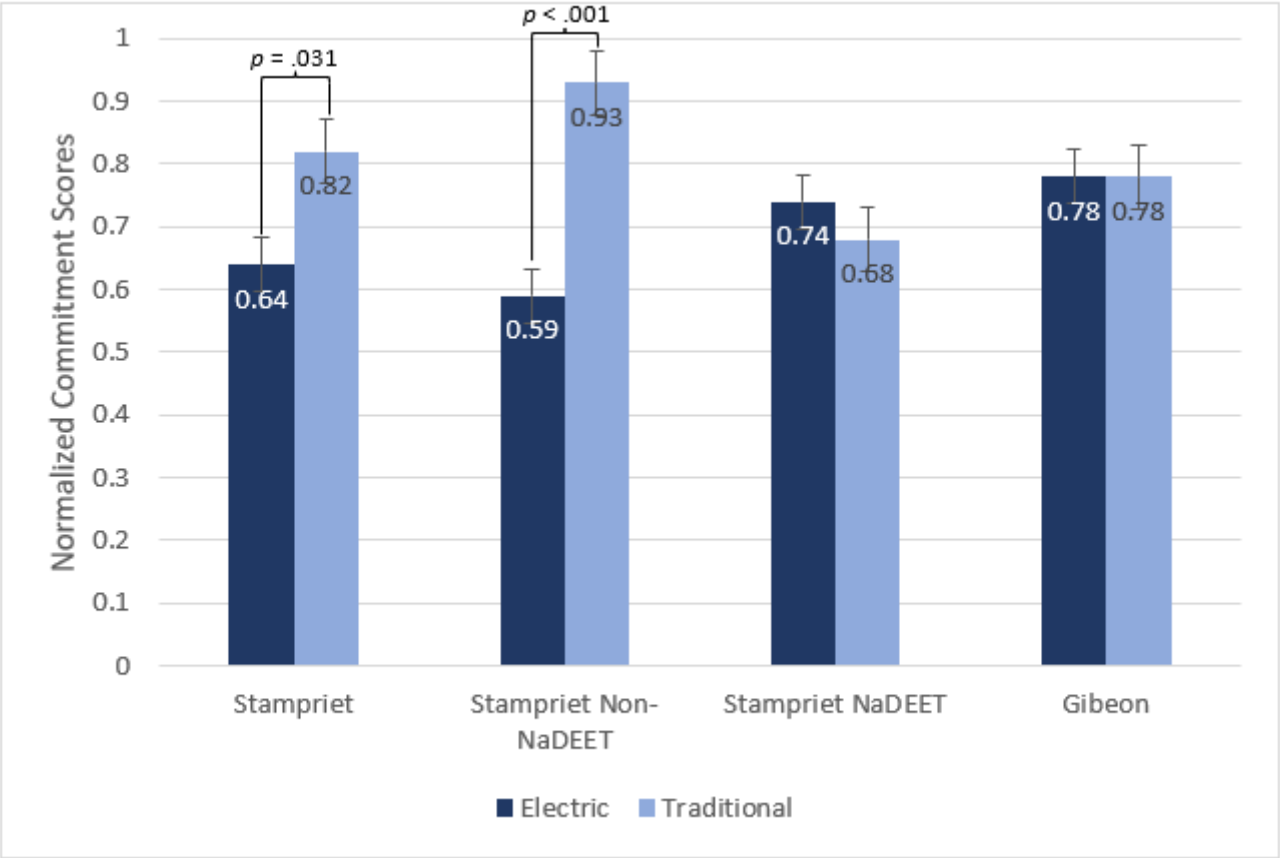

Figure 1

Commitment scores for electric and traditional cookstoves in Stampriet and Gibeon. The threshold for a strong level of commitment, or adoption is 0.70[43]. p-values for Stampriet overall and Non-NaDEET households in Stampriet (households with children but without NaDEET experience) are the result of a two-tailed t-test comparing their commitment scores for both types of cookstove. Error bars indicate standard errors, calculated as the standard deviation divided by the square root of the sample size.

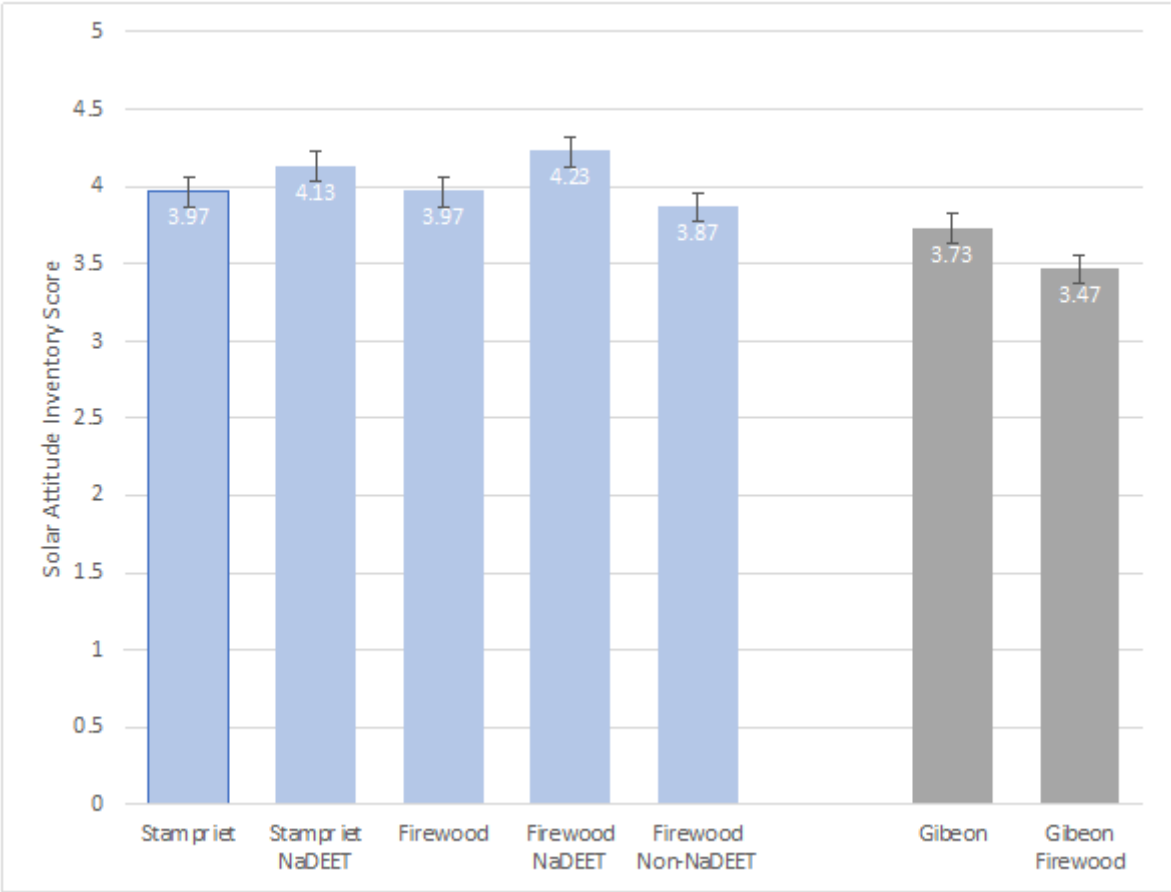

Figure 2

Mean solar attitude scores by groups of Stampriet respondents and those in Gibeon on a 5-point scale. Error bars represent standard errors, calculated as the standard deviation divided by the square root of the sample size.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementary.pdf