Responsible Scale and Data-Driven Stove Evaluation

METHODOLOGY AND LESSONS LEARNED FROM NIGERIA

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The clean cooking sector faces an immense challenge:

For clean cooking transitions to be successful, improved and clean cookstoves must not only reduce particulate emissions by a substantial amount, but they must also be culturally appropriate to a wide spectrum of cooking habits and foods, durable enough to withstand years of use in low-resource settings, and cheap enough that the poorest of the world's households can afford them.

Nexleaf's early work in clean cooking set out to use Internet of Things (IoT) technology to monitor the usage of improved cookstoves and use sensor data to measure emissions and climate impacts. As described in previous reports, patterns in sensor data combined with household feedback revealed that projects failed to achieve target impacts because the stoves did not meet a high enough standard for at least one of the following: emissions reduction, durability, user acceptance, or affordability. Sensor-monitored projects showed that usage of stoves started high, but dropped off steadily over the course of projects either due to declining user acceptance (households were not able to meet their full range of cooking needs and reverted to traditional stove use) or due to poor durability (stove parts broke or were otherwise rendered inoperable, with no easy system for replacement or repair). Stoves that did maintain high acceptance and durability were undesirable to scale either because they had only moderate emissions reductions or were not affordable for the poorest households.[1]

1 'Beyond Monitoring and Evaluation: Tracking Improved Cookstove Adoptions Continuously and Over Time to Achieve Lasting Success', Nexleaf Analytics and Tata Trusts, 2018, https://nexleaf.org/wp-content/uploads/2021/05/beyond-monitoring-and-evaluation.pdf

When these trends take place at the scale of tens of thousands of households, the result is not only wasted investments and limited emissions impact but also households burdened by broken equipment and the erosion of trust in the cooking and energy sectors.

Rural Women's Energy Security (RUWES) and Nexleaf Analytics partnered to use data to address this problem in Nigeria. With support from the Climate and Clean Air Coalition (CCAC), RUWES and Nexleaf developed and tested a stove evaluation approach that vets stoves for local context before large-scale stove distribution. This method supports the responsible scaling of stoves through a gradual process based on objective data and evaluation.

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Nexleaf's Clean Cooking Project Manager tests a TEG forced-draft biomass ICS at a training conducted in collaboration with RUWES.

The following outlines the methodology developed for a pilot in the Abuja Federal Capital Territory in Nigeria, as well as lessons learned and recommendations for future applications. This methodology and report aim to address the needs of small-scale NGOs and project developers running community-based programs utilizing local entrepreneurs and distribution models.

Nexleaf & RUWES Stove Evaluation Methodology

The stove evaluation methodology aimed principally to do two things: 1. Set a high standard for emissions reduction, particularly black carbon, and 2. To evaluate stoves for usability, acceptance, durability, and affordability through small-scale, real-world testing using the most objective measures available. The piloted methodology can be divided into three parts, as outlined below in Figure 1: 1. Pre-selection of potential stoves based on emissions reduction as well as an assessment of the manufacturer's ability to scale and provide after-sales support, 2. A six-month field trial combining sensor-monitored stove usage data with other direct learnings from the field and 3. Selection of the most viable stove models for the first "scale-up" to 100 households.

Figure 1. Stove evaluation methodology

	CRITERIA	DATA SOURCE
Pre-selection	Emissions	CCA Tier ranking
		Black carbon emissions lab test results
	Manufacturer support	Manufacturer interviews
Field Trial	Stove usage	Sensor-based stove-use monitors (6 months)
	User acceptance	Household qualitative survey
	Durability	Energy Entrepreneur records
	Affordability	Stove retail price, shipping costs, fuel cost, and availability
First Scale-Up: 100 Households	Stove usage	Sensor-based stove use monitors
	User acceptance	Household survey
	Durability	Household survey, Energy Entrepreneur records
	Affordability	Loan repayment records

PRE-SELECTION

Pre-selection aimed to set a high standard for emissions reduction, considering only stoves ranked Tier 3 and above in the Clean Cooking Catalog, and aiming for a black carbon emissions reduction of 70%.[2] Black carbon poses the most significant health risk among indoor air pollutants as the smallest-sized particulate, and also has significant climate implications as one of the highest contributors to climate change after carbon dioxide.[3] Black carbon is one of the four short-lived climate pollutants (SLCPs) contributing up to 45% of current global warming.[4] Black carbon emissions are generally closely correlated with the factors that contribute to the Tier ranking (thermal efficiency, carbon monoxide, and fine particulate emissions more generally[5]), but we chose to include a separate black carbon target to ensure that stoves would address those health risks specifically.

In addition to emissions, the pre-selection process also included an assessment of the manufacturer's ability to support the project. Specifically, RUWES and Nexleaf assessed the manufacturers ability to scale (eliminating stove models not yet past the R&D stage) and ability to provide adequate after-sales and fuel supply support.

Of the original 46 stove models vetted, 5 stove models were chosen for the field testing stage, offering multiple fuel choices and stove types.

2 Because black carbon test results are not publicly available and not commonly tested, black carbon emissions rates could not be obtained for all models during the pre-selection phase. Verification of black carbon emissions and estimated percent reduction was completed for the 5 stove models during the field testing phase.

3 Renee Cho, 'The Damaging Effects of Black Carbon', *State of the Planet*, Columbia Climate School, 2016, https://news.climate.columbia.edu/2016/03/22/the-damaging-effects-of-black-carbon/, (accessed 1 August 2021)

4 'Short-Lived Climate Pollutants', *Climate and Clean Air Coalition*, https://www.ccacoalition.org/en/content/short-lived-climate-pollutants-slcps (accessed 1 August 2021)

5 'Voluntary Performance Targets', *Clean Cooking Alliance*, 2018, https://cleancookingalliance.org/news/10-16-2018-voluntary-performance-targets/, (accessed 1 August 2021)

FIELD TESTING

Field testing aimed to test the other criteria in a real world setting at the smallest scale possible to receive meaningful data. The 6 month field test combined sensor data on actual stove usage, direct feedback from households, Energy Entrepreneur feedback, and pricing and fuel data.

Households in the community of Mararaba-Burum were recruited to participate in field testing of the 5 stove models. The five stove models would be distributed to 10 households each and monitored using Stovetrace temperature sensors for 6 months. The time period of 6 months was chosen because previous projects had revealed that 6 months is usually the period in which stove usage begins to decline or stoves suffer breakages. Working with RUWES's existing women's empowerment model, Energy Entrepreneurs from the community would distribute the stoves, provide training to households, download the sensor data using the Stovetrace mobile application, and provide stove repairs as needed throughout the pilot.

At the end of the 6 month period, RUWES and Nexleaf staff conducted a comprehensive survey of all households to determine how well the stove met their needs and their willingness to purchase the stove. In addition, a comprehensive assessment of stove affordability was made based on the retail stove value as well as fuel costs experienced by households. See Figure 2 for a list of the criteria and targets assessed during the pre-selection and field trial processes.

During the stove distribution in Mararaba-Burum, one of the households test out their new TEG forced-draft biomass ICS.

Figure 2: Pre-selection and Field Trial targets

	CRITERIA	TARGET/MEASUREMENT
Pre-selection: 50 stove models	Emissions	Tier 3+
	Manufacturer support	Ability to provide after-sales support, ability to scale to 10,000 households
Field Testing: 5 stove models 10 households each	Stove usage	80% of households cook an average of 1 hr per day over 6 months[6]
	User acceptance	Households positive feedback Willingness to purchase/take out a loan
	Durability	Low rates of breakage, Energy Entrepreneurs able to provide maintenance and training
	Affordability	Monthly total cost of ownership[7]

LPG stove with Nexleaf's remote temperature monitoring sensor attached.

As shown in Figure 3 below, data pointed toward 2 stove models to be selected for scale-up for very different reasons. LPG had the highest user acceptance, with 8/10 households reporting a willingness to take out a loan for the stove, and positive feedback overall. Additionally, LPG has widespread availability and government support for expanded access. While usage was modest compared to the original target, LPG had by far the highest usage among the liquid fuel stoves as well as the best ranking in total cost of ownership. The TEG forced-draft stove was chosen as a second stove by a narrow margin in comparison to the other biomass option, a natural draft stove. Both biomass stoves showed far more consistent usage than the liquid fuel options (though it should be noted that no stoves met the original 80% target). The TEG stove, while much higher in total cost of ownership, received more positive feedback than the natural draft model for it's additional features and less negative feedback about smoke levels. With black carbon results revealing that the natural draft was unlikely to actually have 80% black carbon reduction in the field, the TEG stove was selected alongside the LPG for scale-up. More details about the sensor data and qualitative feedback can be read in the 2020 report "Scaling Clean Cooking Responsibly" and in the Stove Scorecard.

6 Nexleaf's 1 hr a day metric was used in previous projects for adoption comparison between biomass stove models. Results from this project indicate that the metric is less valuable for comparison across different fuel types, as liquid fuel stoves have substantially faster heat times and result in lower cooking times overall.

7 We did not have local income data to develop a target total cost of ownership (TOC), therefore we estimated total cost of ownership on a monthly basis and ranked them against each other as a factor in decision-making. Monthly TOC was calculated by combining the retail cost of the stove divided by 12 (relevant for a program with a 1 year repayment plan) plus the estimated monthly fuel costs if a household cooks for 1 hour a day. Fuel costs were calculated using actual fuel purchase data from households and sensor-based cook times.

Figure 3. Field testing results

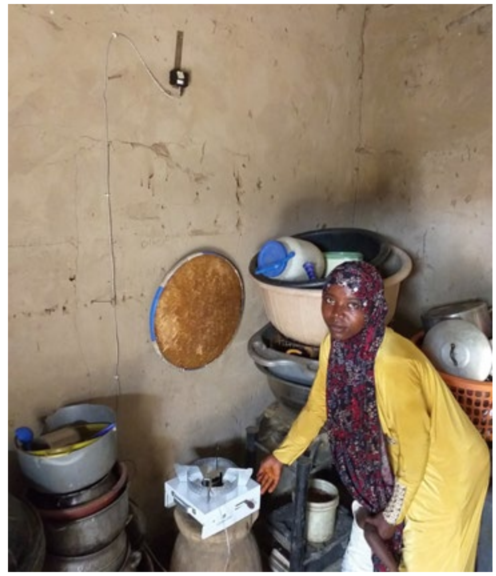
	ETHANOL	ETHANOL GEL	LPG	TEG FORCED-DRAFT BIOMASS ICS	NATURAL DRAFT BIOMASS ICS
Stove usage	Low 7% 1 hr avg use	Low 14% 1 hr avg use	Low-moderate 27% 1 hr avg use	Moderate 62% 1 hr avg use	Moderate 66% 1 hr avg use
User acceptance	Low	Low	High	Moderate-high	Moderate
Durability	Good (no issues)	Good-Fair (1 issue)	Good (no issues)	Fair (2 issues)	Good (no issues)
Affordability	Poor $10.82 monthly TOC	Poor $13.90 monthly TOC	Poor $10.75 monthly TOC	Fair $5 monthly TOC	Good $1.67 monthly TOC

LEFT to RIGHT: Examples of stoves tested: LPG, natural draft biomass ICS, forced-draft biomass ICS.

First level of scale-up: 100 Households

The goal of the pilot was not only to evaluate stoves objectively but also to scale gradually, with the first level of scale to just 100 households. Having been thoroughly tested against the criteria, the two stove models were offered for purchase to households. Households participated in a unique financial model whereby their loans were in part paid down with sensor-calculated "Climate Credits."[8] While testing the financial model, this 100 household phase offered the opportunity to determine if the field test results would hold up over a one-year period among a larger group of households and under real-life conditions in which households had invested in purchasing the stove. The 100 household phase aimed to see usage, durability, and acceptance remain high according to sensor, entrepreneur, and survey data, while also evaluating affordability through household's ability to repay loans within the year.

Surprisingly, the LPG stove performed best in terms of repayment despite the high cost of fuel. The TEG stove, in contrast, had lower repayment rates and failed to meet durability targets throughout the year, with the majority of households reporting a need for repair and several needing the stoves to be removed temporarily for replacement parts. While a majority of households among both stove types reported that they intended to continue using their clean stove, a higher proportion of TEG users reported that the stove had not met their expectations (8/38 surveyed users vs. 4/46 surveyed LPG users). Additionally, 8 TEG users dropped out of the program within a few months of the pilot, and a significant number of users who did stick with the program to the end reported that if they could do the program over again, they would choose the LPG instead (14/38). In contrast, all LPG users said that they would participate in the program again with the LPG.



Participating household with Nexleaf's temperature sensor installed using an extended cable to monitor the usage of an ethanol gel stove.

Figure 4: 100 household results

	LPG	TEG FORCED-DRAFT
Stove usage	28%	72%
User acceptance	High	Moderate
Durability	Fair 17% reported need for repair	Poor 66% reported need for repair
Affordability	Fair 55% paid loan in full	Poor 8% paid loan in full

8 For more information about the Climate Credit financial model, see the accompanying report, "Sensor Technology for End-User Financing: Lessons Learned from Nigeria".

Lessons-learned and considerations for small-scale project developers and entrepreneur models

Black carbon emissions data is not readily available and testing is prohibitively expensive. As there are very few laboratories that conduct black carbon emissions testing worldwide, this pilot incurred significant costs for shipping stoves to testing centers and testing fees, which would likely not be feasible for a small-scale project developer or NGO. Additionally, black carbon test results are difficult to interpret and apply to the field context. Given present constraints, using black carbon emissions reduction as criteria is not realistic for small-scale projects. Policy support and cross-sector cooperation are needed in order to make black carbon testing more available and incorporate black carbon into emissions standards.

Local manufacturing or distribution of stoves is critically important for the cost-effectiveness and feasibility of responsible scale. While the pre-selection criteria for this project included an assessment of the manufacturer's ability to provide after-sales support (including warranty, technical support, etc.), the location of distribution should have been a larger factor. While cost and difficulty of shipment were a known factors, we deprioritized the importance of shipping concerns in the belief that once a stove was distributed at a larger scale the efficiency of shipping would be greater. However, given that the project intended to promote gradual scale, the reliance on future large-scale distribution to reduce costs was a large oversight. Additionally, the durability issues encountered in the 100 household phase highlighted that location of manufacturers is relevant not only to the original shipment of stoves but also for the availability of spare parts. The issues with the fans of the forced draft stoves would not, perhaps, have been as much of a problem if spare parts and repair services were locally available. For NGOs and small-scale projects, we would recommend using this approach with only locally available stove models, ideally, those not only distributed but manufactured in-country.

> In the long run, using objective stove usage data will hopefully become more feasible as IoT technology becomes more mainstream.

Sensor-based monitoring requires increased technical capacity of entrepreneurs and significant costs. Sensors and other IoT enablement of stoves offer detailed insight into cooking behavior that other means cannot achieve. Acquiring this data does involve significant additional costs, however, including the sensors and data collection equipment themselves, as well as the additional time and training among entrepreneurs. External sensors are additional equipment that, like the stoves themselves, require sensitization among households, maintenance, and occasional repair. The Energy Entrepreneurs for this pilot found the maintenance of sensors technically difficult, and additional technicians were required to do the more advanced troubleshooting of sensors. This type of data collection may become more cost-effective as stove manufacturers move to build IoT capacity into their stoves, with built-in sensors and other IoT-enabled features such as fuel metering. In the long run, using objective stove usage data will hopefully become more feasible as IoT technology becomes more mainstream.

Responsible scale and data-driven stove evaluation have the potential to better meet end-user needs in the long run by carefully assessing actual stove usage, user acceptance, durability, and affordability.

Organizations and companies with local distribution networks and close ties to communities have the ability to evaluate stoves in a user-centric way and may benefit from elements of this methodology in order to achieve lasting impact in the communities they serve.

Household participants in Mararaba-Burum receive their TEG forced-draft biomass ICS.