Achieving universal access to clean cooking by 2030 will require a new approach to understanding end-user needs.

The Clean Cooking Alliance’s 2020 Systems Strategy named the struggle to design for the diverse needs of end-users as the number one challenge in the clean cooking sector today, citing the lack of data on household stove usage behaviors and an emphasis on behavior change rather than meeting core user needs. Affordability is a fundamental component of household needs, yet the majority of sales of clean cooking solutions require upfront, cash payments by households: a major barrier to access and usage among the poorest households as well as the uptake of modern energy solutions globally. Therefore, end-user data and end-user financing are critical needs in closing the energy gap for 3 billion households in the coming years.

Nexleaf developed the sensor-enabled climate financing (SCF) model using IoT technology to simultaneously support end-user technology and

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financing. The model uses the objective and rapidly available stove usage data from sensors to calculate individual-level short-lived climate pollutant (SLCP) emissions reductions. The related “Climate Credits” are paid to the households over the course of a project, offsetting the cost of the stove in proportion to the amount that the stove is in use.

Building on learnings from earlier pilots in India, Nexleaf piloted a variation of the SCF in Nigeria in partnership with the Rural Women’s Energy Security (RUWES) and with support from the Climate and Clean Air Coalition (CCAC). The pilot sought to answer the following questions:

- Can Climate Credits make a clean cookstove affordable for rural Nigerian women on a 1 year repayment timeline?
- Will households receiving Climate Credits sustain their usage of clean stoves throughout a one year period?
- What other factors will need to be evaluated or addressed in order for direct monitoring of stove usage to enhance end-user financing at a meaningful scale?

This report outlines lessons-learned from the implementation of the pilot in Nigeria and recommendations for how sensors and other forms of direct stove use monitoring can be applied to financing systems.

**BACKGROUND: DATA-DRIVEN SOLUTIONS**

The SCF model aims to address multiple challenges facing clean cooking programs.

1. **The affordability challenge and end-user financing.** In order to reach the poorest households, clean cookstoves must not only cost less overall, but need creative financing solutions at the end-user level. The ability to purchase on credit, Pay-as-you-cook models, partnerships with MFIs, and other alternative financing schemes can bring clean cookstoves into reach for households that might otherwise not be able to afford them.3

2. **Backing emissions reduction claims with real, objective data.** Conventional emissions impact verification methodology is based on self-reported data on general stove use. With compelling research showing that stove stacking is persistent globally4 and that actual clean stove use may decline over time5, it is likely that emissions impact is overestimated with even the most rigorous self-reported methods. Direct monitoring of stove usage, such as with sensors and IoT-enabled devices, can allow for an objective measurement of stove use.

3. **Putting women at the center of program design and encouraging sustained adoption.** In a conventional carbon market or climate finance scheme, the project implementers or developers claim carbon offset benefits, providing funding to developers and manufacturers to invest in their delivery model and potentially

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to reduce costs for households. While households still benefit in this conventional scheme, they are positioned as recipients rather than active players in climate change mitigation. Furthermore, conventional models granting a purchase discount may reduce the price but do not actively encourage usage over time. In a conventional model, the financial benefit is the same for a woman cooking all of her meals on her new stove as it would be for a woman only using her new stove intermittently.

SCF sought to address all of these issues simultaneously. The use of sensor technology allows for objective measurements of stove usage and a way to link individual stove usage to emissions impact estimates. Individualized payments then would acknowledge household climate mitigation contributions and offset stove costs while encouraging continued stove usage over time.

The RUWES-Nexleaf Nigeria Pilot

After a stove-selection phase in which 5 different stove models were evaluated in households for 6 months, 100 women in the community of Mararaba-Burum were recruited to participate in the SCF financial pilot and given the option of purchasing either an LPG stove or a forced-draft thermoelectric generator (TEG) stove. The women paid no up-front cost for the stove: instead, they received loans through the local microfinance bank Hasal Microfinance, and would pay in 12 monthly installments. As women cooked, they earned Climate Credits which went directly towards offsetting their monthly loan repayment. Their monthly payment was equal to 1/12 of their stove loan amount minus their earned Climate Credit. Climate Credits were calculated from the cooking time measured by Nexleaf’s StoveTrace IoT sensors, which use temperature as an indicator of cooking. RUWES Energy Entrepreneurs provided stove maintenance support, payment collection, and StoveTrace data collection. Stoves were distributed in February of 2020, with the 12-month payment scheme beginning on July 1 of 2020 and ending June 30 of 2021.

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6 Details about the stove selection process and data can be found in two reports “Responsible Scale and Data-Driven Stove Evaluation” and “Scaling Clean Cooking Responsibly.”

7 The COVID-19 pandemic struck as the pilot was beginning, immediately and severely impacting household income earning activities and restricting the ability to collect data and visit households. A 3 month grace period was added before starting loan repayment.
PILOT SETTING

The community of Mararaba-Burum is located in Abuja Municipal Area Council of the Abuja Capital Territory. Despite being only about 15 km from the capital city centre, the community of roughly 5,000 people is rural. Nearly all households rely on farming and agriculture for their livelihoods, and the majority of the population is considered poor, with no access to electricity and the river as their only source of water. Mararaba-Burum is a village of many tribes and ethnic groups (TIV, Gbagi, Fulani, Hausa) and is governed by a local Chief who is well respected and trusted to run the affairs of the community. Cooking is typically done with the traditional Three Stone Fire (3SF), with wood gathered locally or purchased at a low cost from fellow residents. LPG stoves and fuel are available nearby in the open market, but are uncommonly used.

Mararaba and Burum are two distinct sub-sections of the same community: Mararaba is oriented much closer to the main road, affording residents more connectivity and access to goods and services from other areas.

A survey of participants conducted at the beginning of the pilot provided additional details. Across all participants, the average household size was about 7 members, and roughly 60% of participants shared cooking responsibilities with at least one other member of the household. None of the participants had any experience having a loan. Virtually all participants named farming as their household’s primary economic activity, although TEG users were more likely to also name petty trading as their own income-generating activity. The choice of stove type overwhelmingly aligned with the sub-section of the community, with most residents of more connected and affluent Mararaba choosing the LPG stove and the majority of Burum residents choosing the TEG biomass stove. The most notable difference between LPG users and TEG users, aside from their location, was their motivation and rationale for stove selection. TEG users named the practical features of the stove and expressed an aversion to the idea of paying for fuel, citing how they could collect wood freely in the community. LPG users, on the other hand, seemed motivated by the idea of having a modern, clean stove, and cited relief from the stress of having to collect wood.
I want to utilize firewood for my cooking and I learned the stove doesn’t use too much fuelwood like my 3SF.

I wouldn’t need to purchase gas with my money. I can go deep into the thick bushes and fetch firewood.

-Participants on why they selected the TEG stove

I think the LPG stove is very good and would be useful to . . . the women that are obtaining it through this scheme because this is the first of its kind in this community transitioning us to cleaner alternatives.

I’ve seen other women use it and it’s very nice. And more so I don’t like using firewood to cook, but only do that because I have no other better alternative.

-Participants on why they chose the LPG stove

The two stove options offered substantially different user experiences and costs. The TEG stove had a higher retail cost and higher monthly payments, but low costs of use and minimal adaptation for households. The LPG stove had lower retail costs and lower monthly payments, but a much higher cost of use due to the need to purchase fuel, and substantial change of habits for households. The following figure outlines the stove costs, repayment schemes, and Climate Credit earning details for the pilot.
Figure 1. Payment and stove details

<table>
<thead>
<tr>
<th></th>
<th>TEG ICS</th>
<th>LPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total stove retail cost/loan amount</td>
<td>$72</td>
<td>$33</td>
</tr>
<tr>
<td>Monthly payment (12 installments)</td>
<td>$6⁸</td>
<td>$2.73</td>
</tr>
<tr>
<td>Est. monthly fuel cost at max usage</td>
<td>$0</td>
<td>$29⁹</td>
</tr>
<tr>
<td>Climate Credit rate/hour</td>
<td>$0.0335</td>
<td>$0.0455</td>
</tr>
<tr>
<td>(see emissions calculation methodology)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price of Co2e/tonne</td>
<td>$14</td>
<td>$14</td>
</tr>
<tr>
<td>Max. Climate Credit per month</td>
<td>$4.19</td>
<td>$5.68</td>
</tr>
<tr>
<td>(capped at 5hrs of daily use)</td>
<td>(70% of stove cost)</td>
<td>(200% of stove cost)</td>
</tr>
<tr>
<td>Lowest possible monthly repayment cost to HH</td>
<td>$1.81</td>
<td>-$2.93</td>
</tr>
<tr>
<td>with max usage (5 hrs/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total monthly cost of use to HH w/ max usage (inclusive of fuel)</td>
<td>$1.81</td>
<td>$26.05</td>
</tr>
<tr>
<td>Total households participating</td>
<td>52</td>
<td>48</td>
</tr>
</tbody>
</table>

DATA

Data collected over the course of the pilot included:

1. A pre-survey of all households electing to participate in the pilot (n=87), conducted by Nexleaf and RUWES staff, asking about household motivation and factors affecting stove choice
2. StoveTrace stove usage data, monitored by sensor and data logger and collected by Energy Entrepreneurs.
3. Climate Credit earnings (calculated with stove usage data)
4. Monthly loan repayment per household, collected by Energy Entrepreneurs
5. Post-survey of all households, conducted by Nexleaf and RUWES staff, assessing household satisfaction with stoves and project, reasons for repayment rates (n=92)

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⁸ Most households collect wood in the surrounding area at no cost, however, wood is also sometimes purchased for a nominal amount
⁹ The Climate Credit earnings are capped at the equivalent of 5 hours per day. Nexleaf estimated the cost of LPG fuel if households were to cook at that rate. Fuel estimates were based on fuel consumption data collected during the stove field testing phase of the project. It is important to note that 5 hours per day would be very high, especially for an LPG stove. Actual usage and self-reported fuel purchase were substantially lower.
Emissions Reduction Calculation Methodology

Nexleaf developed an emissions reduction calculation methodology to estimate emissions impact per unit of time of ICS use. This structure is notably different from the conventional way of measuring emissions impact for carbon credit programs. These accepted methodologies calculate emissions reduction for an entire project period, comparing stove usage during a project duration to a baseline of TCS use. The Nexleaf method takes advantage of the rapidly available data from remote sensors and allows for an emissions estimate on a per-hour basis. It is important to note, however, that such methodology is not currently recognized by any climate impact certification bodies, and that the acceptance of such methodology would be a precursor to any meaningful scale of this or similar models.

Because the focus of the SCF model and project was on the reduction of black carbon (BC) specifically, the methodology calculated emissions reduction of black carbon-based on available laboratory data, and then converted the value to CO2 equivalent (CO2e) in order to create a carbon offset value. BC Emissions reduction per hour of ICS use is estimated using emissions rate data on TCS and ICS stoves respectively as well as the efficiency of ICS vs TCS and an assumption of displacement. These calculations could be refined with more data on TCS vs. ICS efficiency and displacement patterns.

\[
\text{efficiency factor \%} \times \left( \frac{\text{TCS BC emissions rate} - \text{ICS BC emissions rate}}{\text{CO2e per BC conversion}} \right) = \text{CO2e emissions reduction per hour}
\]

The Climate Credit payment rate is then derived as follows:

\[
\text{CO2e emissions reduction per hour} \times \text{Price of CO2e per tonne} = \$ \text{ earnings per hour}
\]

For the pilot, $14/tonne was used as the price of CO2e. It should be noted that the price of CO2 and CO2e is extremely variable, with global rates ranging from $9/tonne to nearly $50/tonne depending on verification bodies and other impacts factored into rates.

Sensor data derive minutes of cooking by separating temperature readings into cooking and non-cooking temperatures, detecting cooking events through temperature spikes, and calculating total minutes of cooking each day. This cook time is then multiplied by the CO2e emissions reduction rate and the price of CO2e per tonne to arrive at the hourly Climate Credit payment. Monthly Climate Credit earnings were capped at the equivalent of 5 hours of daily usage to disincentivize the manipulation of cooking.
Usage dropped off over time across both stove types, consistent with patterns of use commonly seen in cooking interventions. At the beginning of the pilot, the average use of the TEG stove was 243 minutes per day, and LPG was 58, but by the end of the pilot were 128 and 11, respectively. The drop-off in usage happens more as a reduction in the frequency of use rather than time spent cooking: that is to say, over time, there are more days in which households do not cook on their clean stoves at all, but on the days that they do cook, they use their stoves in a consistent way. Among cooking days, average usage held steady at 317-326 on TEG and 141-170 on LPG. Figure 2 below shows the minutes of stove use over the project period, household cooking v. non-cooking days, whereas Figure 3 shows the minutes over time on days of cooking only.

Figure 2. Mean minutes of cooking all stoves (May 2020-May 2021)

Figure 3. Mean minutes of cooking excluding stoves not in use (May 2020-May 2021)
There were substantial differences among households in terms of usage, strongly tied to repayment and Climate Credit rates. As expected, participants with the highest levels of repayment also had the highest levels of usage and Climate Credits. Households with high repayment and high Climate Credits also had a smaller decrease in cooking days.

**Figure 4. Repayment by stove use tritile by stove type**

In survey responses, households reported relatively little conscious influence of the Climate Credits on their decision on which stove to use (clean vs. 3SF) or how often to use it. TEG stove users, on the whole, reported the Climate Credits being more of a motivating factor for use, with 28 TEG users stating that they took Climate Credits into account either when thinking about which stove to use or whether to purchase fuel, compared to 19 LPG users.

**REPAYMENT**

Of the 92 households who remained in the program for the entire year, 30 repaid their loans in full (26 LPG and 4 TEG). An additional 13 households (9 LPG and 4 TEG) were above 75% repayment. In responses to post-survey questions about reasons for non-payment, 4 TEG and 6 LPG households expressed (unprompted) further intent to continue repayment. The figure below shows the distribution of households into levels of loan repayment at the end of the pilot among the two types of stove users. LPG overall repaid their loans at much higher rates, with a significant number earning Climate Credits beyond the loan amount.
Figure 5. Distribution of households by percentage of loan repaid

![Bar chart showing distribution of households by percentage of loan repaid.]

- Repayment over 100% reflects climate credits earned following full repayment.

Figure 6: Summary of repayment results

<table>
<thead>
<tr>
<th></th>
<th>TEG</th>
<th>LPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average % loan repayment</td>
<td>55% (54% if capped at 100)</td>
<td>100% (86% if capped at 100)</td>
</tr>
<tr>
<td>Average contribution of CCs to loan repayment covered by climate credit</td>
<td>33%</td>
<td>44%</td>
</tr>
<tr>
<td>Average loan repayment amount covered by the household</td>
<td>5800 Naira ($16 USD)</td>
<td>6800 Naira ($19)</td>
</tr>
<tr>
<td>Average total Climate Credit earning</td>
<td>8600 Naira ($23 USD)</td>
<td>5300 Naira ($14)</td>
</tr>
<tr>
<td>Average reported fuel costs</td>
<td>530 Naira ($1.45 USD)</td>
<td>1755 Naira ($4.8 USD)</td>
</tr>
<tr>
<td>Households dropped out of the pilot</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Household satisfaction:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intend to continue using the stove</td>
<td>72%</td>
<td>96%</td>
</tr>
<tr>
<td>Would participate again</td>
<td>44%</td>
<td>65%</td>
</tr>
<tr>
<td>Program made their life better</td>
<td>74%</td>
<td>100%</td>
</tr>
<tr>
<td>Total households at end of pilot</td>
<td>44</td>
<td>48</td>
</tr>
</tbody>
</table>
Survey results showed that participants appreciated the flexibility of the repayment program, as they would not have been able to afford the stove in a single lump payment. 72% of respondents (33 LPG and 33 TEG) said that the monthly pay structure and/or the Climate Credits made the stoves affordable in a way that they could not have envisioned in an upfront payment model.

Participants consistently reported that their plans to repay were disrupted by the consequences of the COVID-19 pandemic, with 28 households (20 TEG and 8 LPG) identifying disruption in their ability to make sales in petty trading as a primary cause preventing them from making payments.

Further, 29 (15 TEG and 14 LPG) cited unexpected expenses as a primary cause of non-payment.

On average, LPG households repaid the loan in full. The mean loan repayment was 100% due in large part to the 26 LPG households who continued earning Climate Credits after paying off the balance of their loan. By contrast, TEG households repaid 55% of total loan amounts on average.

Climate Credits accounted for 44% of LPG payments and 33% of TEG payments. In currency terms, this means that the mean LPG repayment was 12000 Naira (of 12000 owed), with 5300 of that contributed by Climate Credits. For TEG households, the average repayment was 14300 (of the loan principal of 26000), with 8700 contributed by Climate Credits. Among the 4 TEG households repaying above 100% of their loan, their average additional Climate Credit earning was 4600 Naira (18% of the cost of the loan), compared to 3200 Naira (27%) among LPG households. A significant number of LPG households earned Climate Credits beyond the cost of their stove, so when aggregated as a group there is no balance on the LPG stoves shown in the following figure.

“It has really helped me in repaying my loan and has lessened my financial burden for the purchase of the stove.”

“When my business was functioning, I could finish up my loan, but as a result of COVID-19, I cannot.”

“I’ve been enjoying the stove so that made the loan repayment easy for me.”

“My improved cookstove saves me a lot of time.”
These repayment levels differed across households of different socioeconomic statuses (SES). Using a proxy measure compiled from pre- and post-survey results (including home ownership, access to bank accounts, forms of transportation, and other measures of status)\(^\text{10}\), we find that for both stove types, higher SES households were more likely to repay their loans than lower SES households, although the pattern is more pronounced among LPG households. This is not surprising on its face, but is made more salient in the context of COVID-19, which disrupted economic activities, leaving lower-SES households without the means they expected to be able to pay off their loans.

\(^{10}\) Bike ownership, car ownership, mobile phone ownership, TV ownership, rent/own home, paying school Energy Entrepreneurs for children, personal bank account, household bank account
Impact of Climate Credits

SCF’s incentive model decreases the cost to users who maximize their ICS usage, which impacts levels of repayment. Top Climate Credit earners were substantially more likely to repay their loans than middle- and low-earning groups. Among the top third of users, Climate Credits covered 68% of total LPG loan cost and 45% of total TEG loan cost, compared to 38% and 34% of the middle third of users, and 28% and 21% of the bottom third.

That increase is also associated with higher levels of overall repayment. Among the top third of CC earners, 93% of LPG (14/15) and 18% of TEG (3/17) repaid loans in their entirety. Further, 8 of 16 (50%) of the middle third of LPG users completed their loans.

Figure 9. Repayment by climate credit earnings by stove type

It’s important to note that overall repayment was also strongly correlated with socioeconomic status. According to our proxy measure, those who repaid had higher SES and were also more likely to report that they could have fully repaid their loan without the contribution of Climate Credits (with 22 LPG households and 10 TEG households indicating that they could have made full repayment absent additional contributions).

We envision this as the product of two interrelated benefits of the SCF program: lower costs bring down monthly costs and make stoves more affordable. Additionally, when lower costs are tied directly to use, it increases attachment to the program. With more frequent ICS use, users both decrease their costs and increase the usefulness of the stove for them, increasing the likelihood that they will make payments each month.
Other Factors and Influences

A number of circumstantial factors may have influenced the results of the pilot. 79% of TEG households reported being given updated information about the consequences of loan non-repayment from October-December 2020. Dissatisfied with what they perceived as low levels of repayment, Energy Entrepreneurs in Burum (where TEG stoves were primarily located) told users that Climate Credits would be discontinued and/or stoves would be repossessed absent more consistent repayment. Rather than increase payments among TEG households, these users largely stopped making payments on their stoves at all. Prior to this information spreading throughout Burum in late 2020, TEG repayment rates were slightly lower than LPG ones. After November 2020, though, LPG rates of payment improved and TEG rates declined, with many households reporting in post-surveys that they had received the misleading information from Energy Entrepreneurs. Additionally, some errors in cooking detection in the StoveTrace system falsely calculated the maximum CC payment for several LPG households in October-November of 2020, offsetting their payments for those months more than they should have been. The majority of those households did not report having noticed the increased payment, however, it may still have disproportionately helped them pay their loans.

The TEG households demonstrated higher levels of compliance during the program’s first five months, making it reasonable to expect that they would have repaid at higher rates in the second half of the pilot had they not received the misleading information from the Energy Entrepreneurs. The higher repayment rates among the LPG households are still expected, however, given the overall higher SES, lower stove failure rates, and higher reported stove satisfaction.

The TEG users reported a greater influence of the Climate Credits on their ability to pay and their choice of stove. 19% of TEG households said they could have paid the loan without Climate Credits, compared to 46% of LPG households. 58% of TEG households reported considering the impact of Climate Credits when deciding whether to buy fuel, compared to only 37% of LPG households. This pattern is also borne out in households' decisions about whether to use their TCS or ICS: 35% of TEG households reported “often” or “always” considering the impact of Climate Credits when deciding which stove to use, compared to 25% of LPG households.

Operational Learnings: Cost & Resource Assessment

The SCF model is built off of the collection of near-real-time stove usage data, presenting very different operational considerations than conventional methods of impact verification and after-sales service. These operational lessons learned are also important data for considering future applications of the model and sensor technology more generally. The following section outlines the operational components of the model, lessons learned during the pilot, and potential means to reduce resource intensity for future applications.

SENSOR TECHNOLOGY ACQUISITION, TRAINING, AND MAINTENANCE

The sensors and data logging hardware present a significant cost and operational component. The StoveTrace devices used for the pilot were shipped from India and manufactured at an approximate cost of $20. The sensors and data loggers are installed on stoves via a locally manufactured iron bar, requiring custom specifications for each stove type. Once the outfitted stoves are in a home, some maintenance
and monitoring must take place to ensure that sensors stay in place and continue to send accurate data. While the device was designed to withstand high temperatures and rugged conditions, some misplacement and damage are almost inevitable by virtue of being externally attached to the stove and home kitchen conditions. In the pilot, Energy Entrepreneurs regularly checked sensor placement on stoves and troubleshot issues, replacing or reattaching devices as needed. Two technicians were also hired to attend to issues that were beyond the technical capacity of the Energy Entrepreneurs.

Data collection uses mobile Android devices (phone or tablet) that download the data via Bluetooth connection to the data logger. The model, therefore, also requires the acquisition of this mobile technology. In the pilot, many of the Energy Entrepreneurs were not accustomed to using a mobile Smartphone and had to learn some basic Smartphone literacy and application training. The application did also require some troubleshooting work (mainly with software updates and operating system compatibility).

**ENERGY ENTREPRENEUR MODEL**

The model incorporated the structure of RUWES Energy Entrepreneurs: local field agents who are employed to conduct stove distribution/sales and after-sales service. Data collection was incorporated into the Energy Entrepreneurs’ existing responsibilities of stove maintenance, loan collection, and house visits. In theory, the Entrepreneur based distribution model allows for the mobile phone-based data download system to be easily incorporated without additional human resources. In practice, the maintenance of the data collection system did take significant time for the Energy Entrepreneurs, as described above.

**DATA QUALITY AND MARGIN OF ERROR**

Because Climate Credits were calculated on a per-hour basis, ensuring high-quality data was of utmost importance in order to ensure that households were paid fairly. Maintenance of data quality came into play in the physical maintenance of hardware and the data download process (as described above), as well as with the conversion of temperature data into cooking data, and the subsequent calculation of CO2e reduction. While these calculations and conversions were made automatically with StoveTrace’s set algorithms, data still had to be manually reviewed and manipulated when inaccurate usage data came through from broken or misplaced sensors and missing data.

**ADMINISTRATION AND RECORDKEEPING**

The individualized payments and monthly Climate Credit transfer posed significant administrative time and effort as well as a high standard for recordkeeping.
Adaptations for scale and model benefits

The most significant means to enhance the scalability of any kind of IoT-based monitoring is with the technology itself. Ultimately, integrating IoT capability into the stove itself would be the best means to achieve cost-effectiveness, both in terms of the lower price of a mass-produced device and to avoid the maintenance burden that comes from troubleshooting the externally placed sensor. Integration of IoT would also enable monitoring of other indicators of stove use, such as fuel consumption or fan on/off time, which could provide a more direct measure of stove usage than temperature. Stoves that are IoT-enabled for other purposes, such as Pay-As-You-Cook payment schemes, could easily incorporate elements of the model without taking on significant additional costs to do so.

A more simplified payment methodology would also reduce the administrative and data quality assurance burden. If payments were made based on tiers of usage, days of use, or some more generalized verification of stove use, it would reduce the burden of maintaining down-to-the-minute cooking data and the related burden of recordkeeping and quality control.

Overall, with current technological availability and constraints, the benefits of the model are not in cost savings or efficiency. The benefits, rather, come in the level of transparency and visibility into the actual performance of stoves in the field, and subsequent ability to measure impact at the household level. The real value of IoT-based systems will be unlocked when that transparency can be assigned a dollar value. If, for instance, systems verifying usage through direct monitoring could earn a higher price of CO2e per tonne than systems using self-reported data, the additional technological costs could be covered and multiple stakeholders could benefit from more accurate household data.

Conclusions

Data and experiences from the pilot provide the following answers to our original pilot questions and more.

CLIMATE CREDITS AND SUSTAINED USAGE

While the Climate Credits bolstered household ability to pay and keep stoves in use, the relationship between usage and Climate Credit earnings does not appear to counteract the downward trend in clean stove usage over time. While many households did maintain their usage, overall usage among the group dropped, indicating that the promise of earned Climate Credits was not a strong enough motivating factor for stove use in comparison to other factors which influence household decisions, such as cultural habits and preferences, fuel availability, and culinary preferences.

Our findings add to the body of evidence that challenges the linear energy ladder model and the assumption that households who have access to clean cooking will progress forward in adopting clean cooking technologies. In this pilot, stove use was incentivized and stove models were carefully vetted and tested in the local context ahead of time: ideal conditions that, according to the energy ladder model, should have resulted in more sustained usage. The drop-off in usage offers evidence that even under ideal circumstances, fuel stacking—and even some increase in fuel stacking over time—is expected and perhaps inevitable.
This complements the growing evidence that fuel stacking is the norm\textsuperscript{11} and that continued research and data collection should focus on understanding stacking rather than viewing it as a problem that needs to be solved. The question then becomes, what is needed to continue to meet end-user needs after access is achieved?

**CLIMATE CREDITS AND AFFORDABILITY**

Ultimately, a majority of households were not able to meet the target of full repayment of stove loans within a one-year period. The Climate Credits undoubtedly made it easier to repay the loans and offset costs, but they did not completely level the playing field or eliminate the financial burden for households. A major variable is of course the price of CO2e, and it is fair to expect that a substantially higher price could have removed barriers more effectively by enabling households to offset their stoves completely even with lower-than-expected use of the stoves. Within the constraints of this pilot, the ability to pay was still largely influenced by socio-economic status and overall motivation to keep the stove.

The outcomes among the LPG users, however, do demonstrate potential for end-user financing of LPG specifically. The relative success of LPG repayment was surprising given how uncommon LPG use is otherwise in the community and the high cost of LPG relative to household income in the area. The fact that so many households repaid the majority of their loans and continued to use their LPG stoves (albeit with drop-off over time) indicates that end-user financing involving flexible, intervalled payments can make LPG accessible even to rural communities. These findings provide hopeful insight into a country that intends to use LPG as a transitional fuel and needs to penetrate a market of 99 million rural households.

**ENHANCING END-USER FINANCING AT A MEANINGFUL SCALE: WHAT’S NEEDED NEXT**

As discussed in Operational Learnings above, there are a number of factors that would make the SCF model cost-effective and therefore scalable, such as the development of built-in sensors or IoT-enabled fuel-metering, a transparency mark-up on the price of Co2e in the carbon market, and financial backing for the up-front cost of stoves. In addition, climate impact verification methodologies would need to be compatible with the sensor-based emissions calculations.

The creation and approval of appropriate verification methodology for IoT would also offer a number of

\textsuperscript{11} Price, Martin, Melinda Barnard-Tallier and Karin Troncoso. Stacked: In their favor? The complexities of fuel stacking and cooking transitions in Cambodia, Myanmar, and Zambia. Energies 2021, 14, 4457
benefits for impact verification and results-based financing generally. IoT-based systems for verification provide real-time or near-real time data on actual stove usage. If appropriate methodologies are available, there could be a dramatic reduction in the time between program implementation and receipt of payments, as well as the elimination of the need for field visits, reliance on unreliable self-reported data, and even the collection of baseline data. In recent years, there have been significant technological development and greater prevalence of IoT, which could lead to reduced cost over time. More fitting methodologies will enable more widespread use of IoT technology, effectively creating a market for the expansion and scale of transparent and objective data.

Outside of the role of technology, the lessons-learned from the pilot highlight a known factor in the clean cooking sector: households need financing options. While full repayment was not met across the board, the levels of repayment and reported satisfaction with the program among the LPG households is quite high considering that the pilot took place during a time when households had extremely limited economic opportunities (as a result of COVID-19 related market closures) and in a community in which LPG is considered out of reach for the majority of households. When given flexibility, low payments, and assistance, households remained motivated to pay for and utilize their LPG stoves. The project, therefore, contributes to the evidence base that end-user financing should be an essential element of LPG planning efforts.

Energy Entrepreneurs and participating households with an LPG stove.