Uptake of Alternative Energy Technology by Energy Poor Households in Rural Rajasthan, India

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Abstract

Nearly 3 billion people around the world use solid biomass, such as fuelwood and crop waste, for cooking and heating. The implementation of biogas, liquid petroleum gas, solar and other alternative energy cookstoves presents an opportunity to alleviate the burden of fuelwood collection and the health implications associated with inefficient biomass combustion while mitigating the negative ecological and climate effects of deforestation. Many governments and international development agencies have initiated programs to distribute alternative energy cookstoves, but the new technologies rarely achieve sustained use with consumers. While funds have been widely distributed to research the technical design of cookstove technologies, very little systematic research has been done to understand and improve implementation and use of the technologies in the complex markets they target.

One such market is the rural poor village. This paper describes the development of a system dynamics model of the implementation of biogas cookstove technology in villages of Rajasthan. Through field visits and an iterative modeling process, our team (consisting of two Systems Engineering undergraduates and a Social Work professor) investigates the drivers of adoption and abandonment of biogas in such villages. At the current modeling stage, we find the incidence of unit failure to be a key factor in hindering the acceptance of biogas technology.

Motivation

In this paper, we investigate the factors involved in the uptake and sustained use of alternative energy cookstoves in the rural developing world. A recent UNDP report on energy and sustainability and the International Energy Agency estimate that 3 billion people around the world use traditional biomass stoves for cooking and heating.[4] This energy source creates numerous pollutants, such as particulate matter, volatile organic compounds, nitrogen oxides, smog, exhaust, hydrogen sulfide, and acid rain, all

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[2] Washington University in St. Louis, USA. Partial funding for field logistics was provided by the Brown School Faculty funds to Dr. Gautam N. Yadama. This work is also made possible by funding to Gautam Yadama from McDonnell International Scholars Academy to advance collaborations on energy and poverty in India.

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[4] UNDP (2010). Energy for a Sustainable Future. Secretary General's Group on Energy and Climate Change, New York. And International Energy Agency. (2010). http://www.worldenergyoutlook.org/

of which are detrimental to the environment and the health of individuals. The air pollution produced by traditional biomass stoves cause 1.6 million deaths annually in developing countries.[5]

For several decades, organizations such as Envirofit[6] have developed "clean cookstoves" as alternatives to traditional biomass cooking methods, and many governments and NGOs have disseminated these stoves across the developing world[7]. These initiatives have focused on minimizing the emissions of these new stoves and their negative effect on health and the environment. However, few have investigated the issues important to the cookstove users themselves, issues which may extend beyond emission levels. In this paper, we underscore the importance of identifying the key factors involved in the decision of stakeholders to take up alternative cleaner energy technologies. Specifically, we narrow our focus to the rural region of northern India and biogas[8] as a specific case of alternative cooking technology. We present a system dynamics model that seeks to capture biogas adoption, use, and abandonment over time in this area of the world. Furthermore, while we base our analysis on a concrete region and type of energy, we seek insights applicable to many locations and technologies.

Project Phases

This project began in October 2010, and three modeling iterations have been completed since. The following is an overview of these iterations.

1. During the fall of 2010, we developed a concept model based on existing literature on energy poverty and the uptake on alternative energy technologies in rural India. We framed the problem in terms of the relative energy outputs of a given household from fuelwood and from biogas.
2. In January 2011, we traveled to two villages in Rajasthan, India and, in partnership with members of the Foundation for Ecological Security, gathered insights about the uptake of biogas from interactions with women there. After confirming pieces of structure with them, we began developing a new model, now framing the problem in terms of the number of households in a village who rely on biogas technology. This model was largely qualitative and did not contain simulation.
3. In March 2011, we began a new modeling iteration, still based on insights from the field but taking a simulation-based rather than a qualitative approach. After a discussion of insights gained from the field, the remainder of this paper will describe the structure of this current modeling iteration and insights gathered from simulation runs.

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[5] Millenium Development Goals Indicator. (2005). Progress towards the millennium development goals, 1990-2005. http://mdgs.un.org/unsd/mdg/Host.aspx?Content=Products/Progress2005.htm
[6] Organization website: http://www.envirofit.org/
[7] The Indian Ministry of New and Renewable Energy announced the National Biomass Cookstove Initiative in December 2009. Additionally, the U.S. Department of State announced a $60 million public private partnership called *The Global Alliance for Clean Cookstoves* in September 2010.
[8] See Appendix B for a relevant information on biogas cookstove technology.

Current Modeling Iteration

Insights from Fieldwork

In January 2011, in partnership with the Foundation for Ecological Security's Bhilwara team in Rajasthan, we visited two rural Indian communities approximately 10 km apart – Gatuna ka Jhopda and Jalim ka Jhopda. Before 2005, all households in both villages depended completely on fuelwood combustion for cooking, and in 2005, biogas unit installation programs began in both villages. In Gatuna, approximately 90% of households were using biogas units at full capacity at the time of the visit in 2011. In Jalim, approximately 10% were using biogas units at full capacity. These differences allowed for a comprehensive exploration of the dynamics of both adoption and abandonment of biogas technology as a clean energy alternative to fuelwood.

In order to identify the factors responsible for these patterns, our team conducted discussion sessions with members from both communities as part of a community-driven system dynamics approach. Participants were all household women: in these rural communities, wives are almost exclusively responsible for tasks relating to fuel and cooking. Additionally, we observed household routines, biogas units in various stages of use (construction, regular use, and abandonment), and fuelwood stockpiles in various households. Interactions with community members resulted in valuable insights into the dynamics of biogas energy use in Gatuna and Jalim.

Gatuna

The group assembled was composed of about 15 women, many of whom were eager to speak about their experiences with fuelwood and biogas use. Among the many insights gained from conversation with them, three appeared particularly important in explaining the high rate of adoption in Gatuna.

- **The burden of collecting fuelwood creates the primary incentive to begin using biogas**. According to the women in the group, households who depend completely on traditional wood-burning chulhas burn 100 bundles each year, and about seven hours are required to collect one bundle. This time includes time spent walking to and from the forest, and each bundle can weigh as much as 40 kg (photo). The entire year's supply of wood is collected during the winter months in order to avoid the intense summer heat and conflict with agricultural seasons. By contrast, the women using biogas units only need 10 to 15 bundles each year as a back-up energy source. As a result, they save many hours of work each year and avoid the discomfort of carrying heavy, thorny bundles of wood long distances.
- **After using biogas for a period of time, users become more dependent on the technology.** Many women expressed the desire never to return to dependence on fuelwood because they didn't have to collect wood as much. Additionally, they said they preferred biogas because traditional chulhas take a long time to start, give off a large amount of smoke which burns their eyes, and are uncomfortably hot. While avoiding

fuelwood collection was the primary reason they installed a biogas unit, these other benefits reinforced their preference for biogas over biomass.

- **Witnessing successful biogas use increases confidence in the technology and further encourages nonusers to become users**. The first woman to purchase a unit had moved to Gatuna from a different village, where she had seen the technology used. She explained that when other village women saw her success, they expressed interest in obtaining units themselves and soon did so. Many others agreed that seeing their neighbors purchase and use biogas units played a large role in their decision to purchase and use one.

Jalim

Again, the session was comprised of about 15 women. In contrast to the group in Gatuna, these women were more hesitant to answer questions relating to their experiences with biogas technology. They did offer several important insights helping to explain the trends of abandonment in their village.

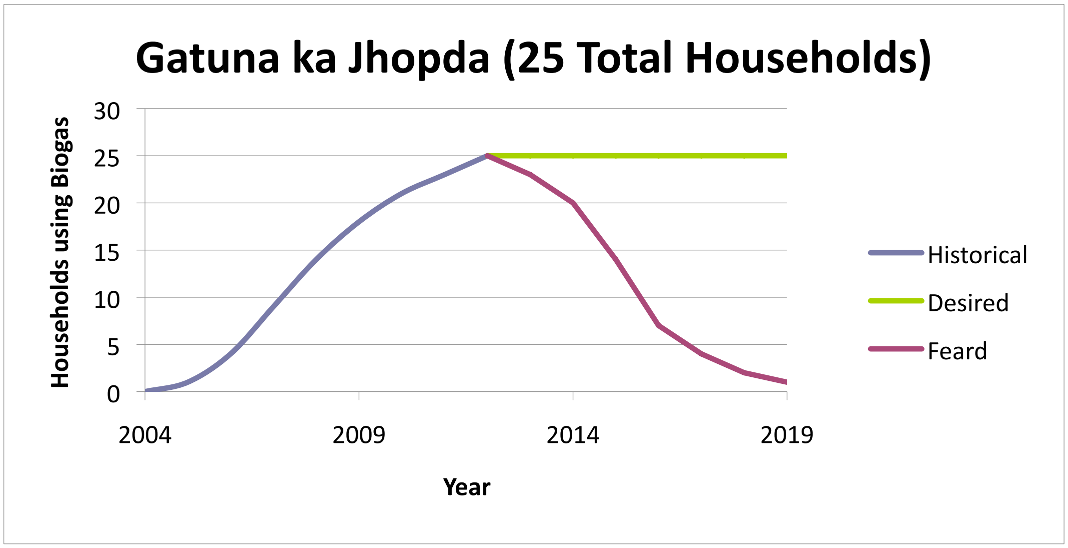
- **When technical problems arise with biogas units, time demands prevent households from repairing them.** A woman explained that when a valve in her unit broke last year, she did not have the time to repair it because she needed to perform other tasks such as collecting water and working for wages. She had not used her unit since the valve had broken several months before. Another woman's unit needed to be cleaned, a process which can take more than a month. Similarly, sacrificing other responsibilities in order to clean her unit was not worth it to her, and she discontinued using her biogas unit.
- **Household gender dynamics prevent women from repairing units.** Repair usually requires purchasing replacement parts. As several women related, men hold primary control of household finances and usually have no incentive to expend money towards maintaining stoves. Even if a woman desires to repair her biogas unit, she often cannot for this reason. This lack of influence by the woman on household finances was not apparent in Gatuna.

Additionally, many statements by women in the group offered explanations of the slower rate of adoption relative to Gatuna.

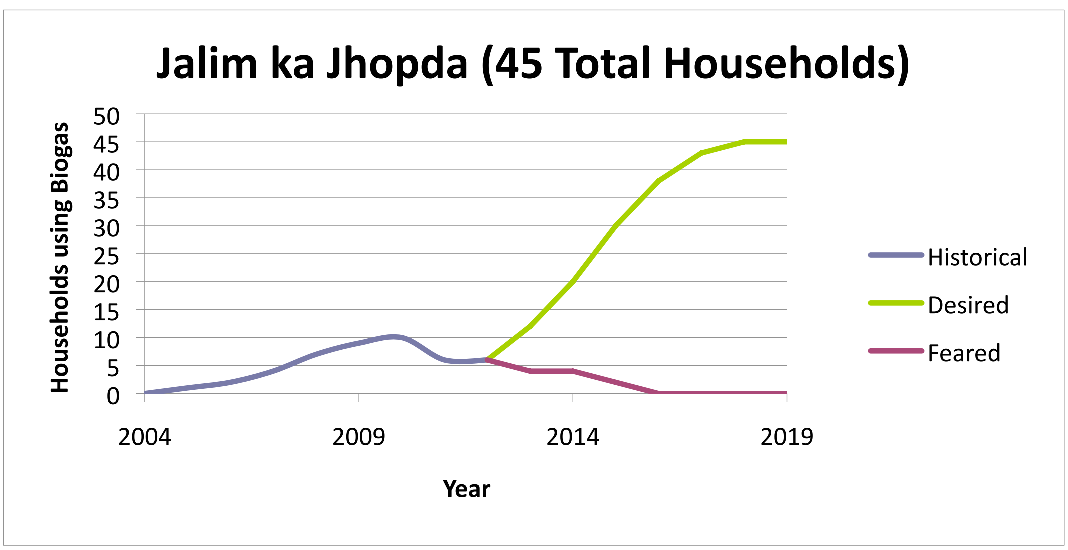
- **Household gender dynamics prevent women from purchasing units.** As it does with abandonment, the influence of women in the household plays a large role in adoption. Since men do not collect wood or cook, they don't experience the benefits of biogas technology to the same degree as women do. As a result, they aren't likely to justify spending money on a unit. Though reluctantly, a few women expressed that they would purchase one if they had more control over household finances.
- **Witnessing unit breakdowns deters households from adopting biogas.** As several units broke down, were not repaired, and fell into disuse, women who didn't have units feared that if they purchased one, the same thing would happen. Just as successful use of biogas increased confidence in Gatuna, unsuccessful use decreased confidence in Jalim. Several women without units said that if they saw others fix their abandoned units and begin to use them again, they would consider buying one.

Reference Mode and Dynamic Hypothesis

Our discussions with village women, along with further information from FES about biogas use trends since 2005, led to the following pair of reference modes, which show the biogas use behavior in Gatuna and Jalim. In building our model, we seek to capture the factors that cause the differing behaviors in the two villages.



In Gatuna, the number of households using biogas units has increased in an S-shaped pattern. Currently, nearly all households are using one. Desired behavior is continued use at this level, and feared behavior is a decrease in use, or abandonment of stoves.



In Jalim, an S-shaped adoption pattern occurred, though at a slower rate than in Gatuna. Then, the village experienced multiple cases of biogas unit abandonment in recent years. Feared behavior is a continuation of this abandonment trend, and desired behavior is readoption of units.

The insights we gained from discussion sessions in Jalim and Gatuna led us to the following dynamic hypothesis explaining these reference modes. The adoption of biogas technology in rural India is driven by a desire to avoid the burden of fuelwood collection, and in particular to avoid many hours of hard labor. As more households install and use units, others become more confident in the technology and are quicker to install their own. In villages such as Gatuna, households exhibiting sustained use of biogas become accustomed to the benefits of the technology, and the value they place on biogas increases.

Abandonment of installed biogas units is driven by an inability to maintain the units. This inability includes a lack of time and a lack of influence by women over household finances. As more households experience problems with and abandon their units rather than repair them, other households are deterred from installing a unit and adoption slows. The same male dominance which often prevents women from repairing their units also prevents other women from purchasing a unit. In addition to an inability to repair biogas units, a lack of reliance on the technology results in less motivation to repair units. The sustained use and resulting appreciation for the benefits of biogas in Gatuna are not a reality in Jalim because so many fewer households have adopted biogas.

Model Structure

The current model fits into a larger category of simulation models used to understand the diffusion of innovations. The central stock-flow structure below captures the problem defined in the field. As a community confronts biogas cookstove technology, stakeholders at the household level fall into three major categories with respect to cookstove technology.

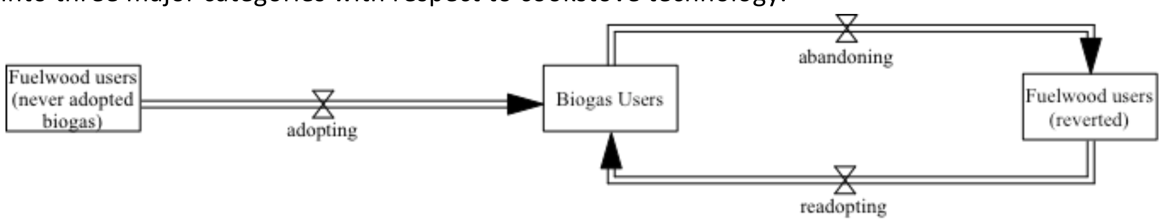


Figure 1: Central Material flow

First, "Fuelwood users (never adopted biogas)" are households that have never had a biogas unit and by default, rely entirely upon fuelwood combustion for cooking energy. Second, "Biogas users" are households that are either utilizing biogas technology for cooking or putting significant time into the construction or repair of their household biogas unit. Finally, "Fuelwood users (reverted)" are households that previously used biogas technology but now rely entirely on fuelwood. This third category is necessary because when a biogas user returns to reliance on fuelwood, she still possesses the physical structure of the system and other members of the system view her differently. These three stocks disaggregate the community into the major categories of interest, with the stock of biogas users as the central reference mode variable.

The most recent model version, shown below, disaggregates the stock of biogas users based on an aging chain of their biogas units. It operates on the basis of three major assumptions: (1) Due to the tightly knit nature of these small rural communities, the rate of interaction between households is high enough to be considered continuous. (2) All households with functional biogas units utilize them at the same level. (3) The only reason for a household to abandon biogas technology and revert to fuelwood is the failure of the household's biogas unit. (4) The dynamics of fuelwood availability and collection do not drive biogas use patterns.

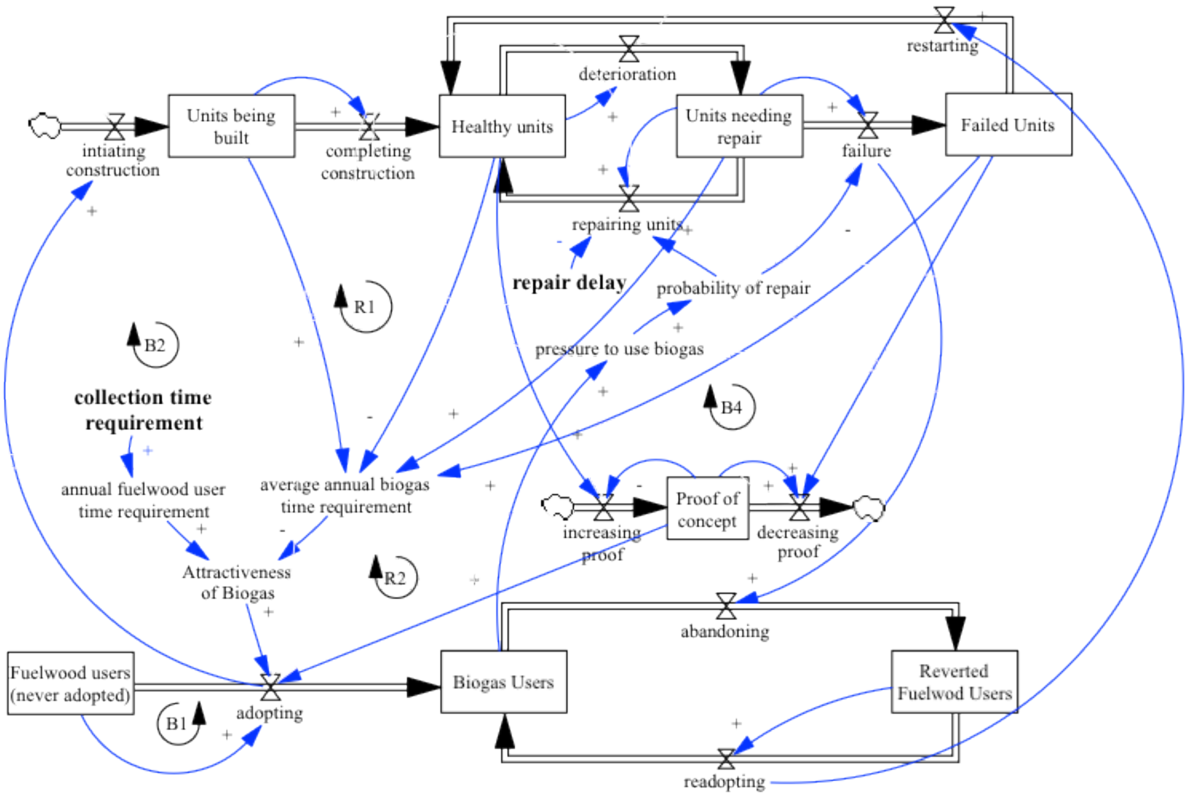


Figure 2: Most recent model iteration, filename: biogas-4.mdl

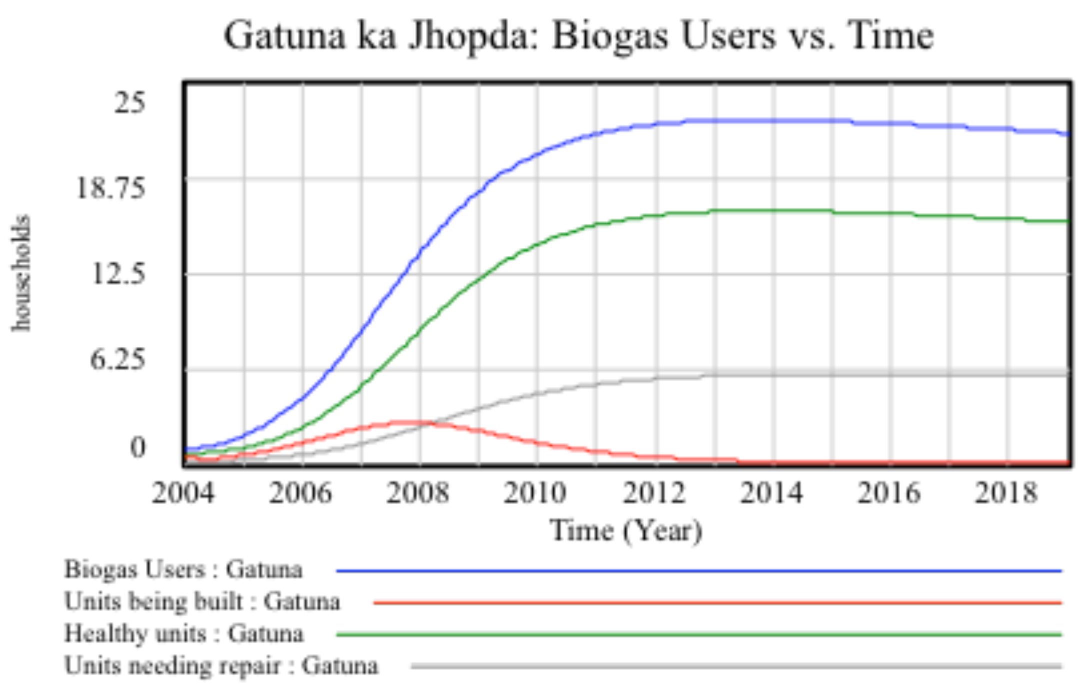
The first flow is the rate of adoption of biogas technology. The attractiveness of biogas and the level of proof of concept endogenously determine the fractional rate of adoption. Stakeholders in the field make it clear that the main attraction of biogas to fuelwood users is the time and labor a household can save by switching to biogas. When fuelwood users perceive that they will save a greater amount of time by switching to biogas, they have a greater desire for the technology. Also, many stakeholders discussed the impact of seeing their neighbors successfully demonstrate biogas technology on their own willingness to try. Households in the unstable environment of a dry-land agricultural community have learned to be risk-averse, so when encountered with a new technology, proof of concept is very important.

When a community encounters biogas technology, two main reinforcing loops can drive a growing rate of adoption. The first is labeled as loop R1 (adoption → initiating → construction units being built → healthy units →average annual biogas time requirement → adoption).When adoption increases, more households begin building biogas units, and after the delay of building the units, the new units require relatively little time to maintain. Having more of these new units around makes biogas appear more attractive and leads to a higher rate of adoption. The second key reinforcing loop is R2 (adoption → initiating → construction units being built → healthy units →increasing proof → proof of concept). It shows that as more households adopt biogas and complete the construction of new units, the number of healthy units grows. As households use their healthy units over time, proof of concept accumulates, which leads to a higher rate of adoption. Both of these reinforcing loops are present in both Gatuna and Jalim, but their behavior is visible to different extents. For instance, since fuelwood collection takes much less time in Jalim, we do not see the effect of increasing attractiveness as strongly. In any case, these reinforcing loops will drive increasing adoption until they encounter a limit.

Several balancing loops represent the limits on adoption. First, B1 represents market saturation, the most ideal limit on the growth of adoption. As more fuelwood users adopt biogas, there are less fuelwood users available who need biogas and thus there is less adoption. This is the balancing effect we observe slowing the rate of adoption in Gatuna as the last few fuelwood users build biogas units. Loop B4 shows the double balancing effect of failed units. More adoption eventually leads to more failure, and failed units not only disprove the concept of biogas technology but also make biogas less attractive since a failed unit doesn't save any time from collecting fuelwood. Less proof of concept and less attractiveness both lead to less adoption. Since the fractional rate of adoption in Jalim is slow, the balancing effect of failure becomes dominant before the market is saturated.

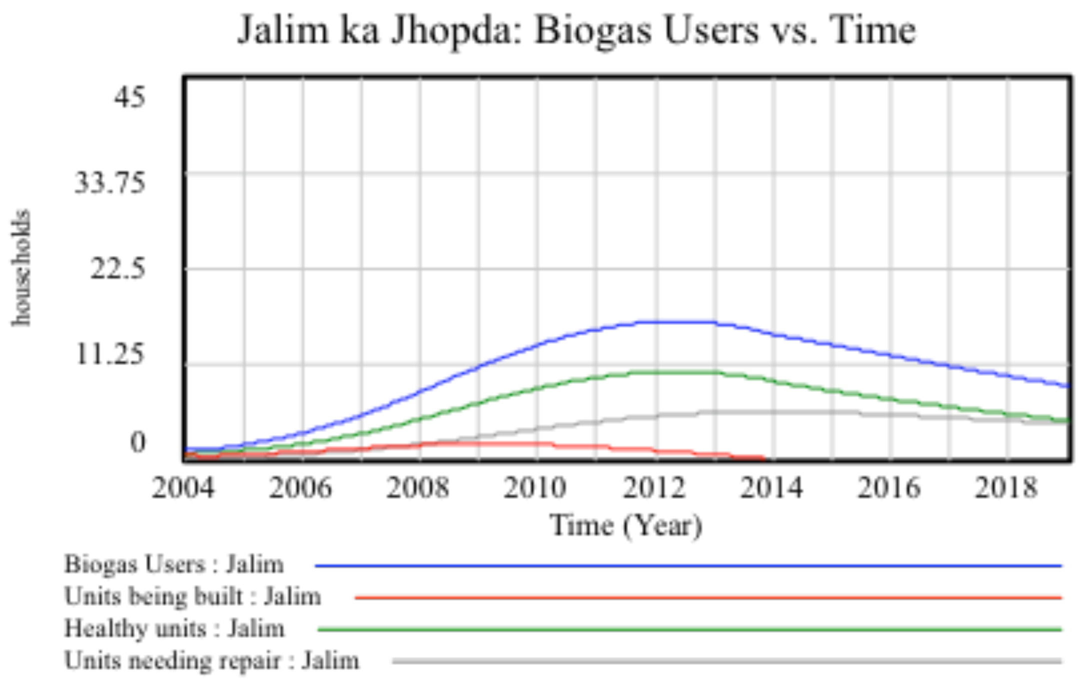
Simulations

The simulation model is initialized with one brave household halfway through with construction of a biogas unit and the rest as fuelwood users who have never used biogas. In both of the following simulation runs, The fractional rate of readoption was left at zero so that reverted fuelwood users can never return to be biogas users. The output for a simulation run of Gatuna is shown below. The fractional rate of readoption was left at zero so that reverted fuelwood users can never return to be biogas users. The simulation output for Gatuna is show below.



The simulation accurately reflects that fuelwood users quickly switch to the attractive biogas technology, reaching almost one hundred percent adoption by 2011. As the number of biogas units increases, the level of community pressure to maintain units increases. This leads to a higher repair rate and less frequent unit failures, sustaining higher levels of attractiveness and adoption rate. For this reason, the number of biogas units in the community stays high.

The next simulation, for Jalim, shows a very different outcome. The only exogenous difference between Gatuna and Jalim is that in Jalim it takes 4.5 hours to collect a bundle of fuelwood, while in Gatuna it takes 7 hours. The reason for this difference is greater proximity to fuelwood sources in Jalim and therefore less time spent walking.

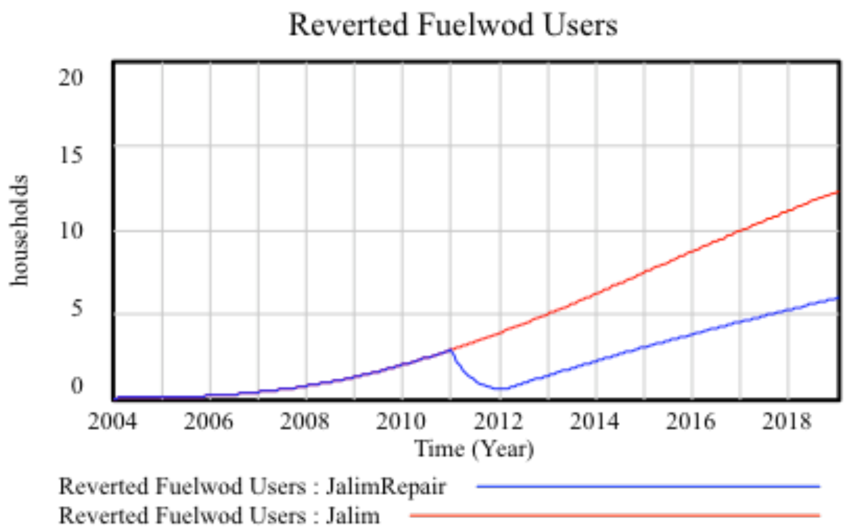


In this run, three units fail by 2011 and adoption slows to a complete halt by 2014. The balancing loop involving failure becomes dominant much more quickly than in the Gatuna simulation run, preventing the number of biogas units from reaching as high a value. Community pressure to maintain units does not build to the same level as in Gatuna, resulting in lower repair rates and even higher failure rates. While attractiveness and proof of concept have a reinforcing effect on number of biogas users in both villages, the balancing loop created by failure becomes dominant sooner in Jalim than it does in Gatuna. In other words, use of biogas is permitted to build to a higher level in Gatuna than in Jalim.

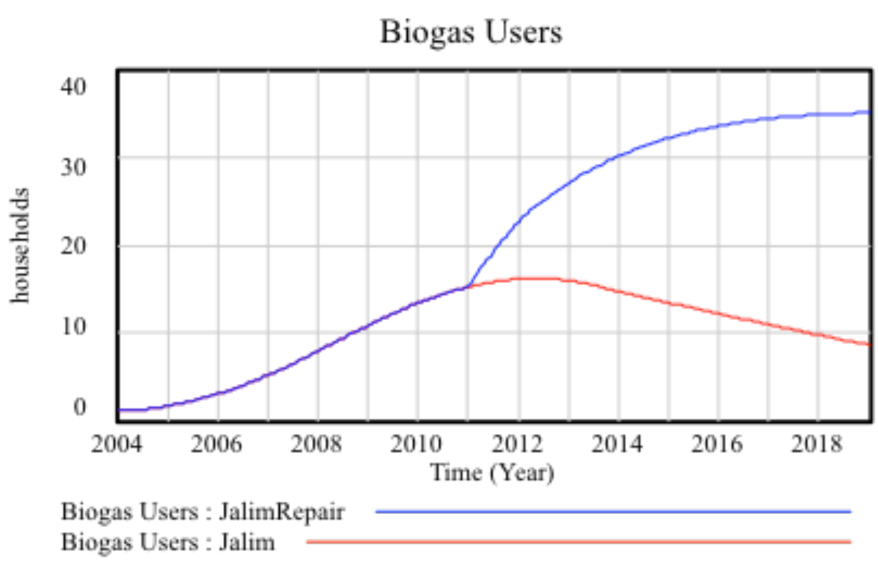
Model based insights

The number of biogas users is affected by two competing sets of structures: increasing attractiveness and proof of concept reinforce adoption of biogas, and unit failures decrease the number of users and slow adoption. In Gatuna, the reinforcing factors stay dominant long enough for the number of biogas users to increase to nearly one hundred percent. In Jalim, the number of biogas users increases only to about 30% before structure associated with failure become dominant, decreasing the number of users. At a general level, these results indicate that unit failure plays a significant role in hindering the uptake of biogas technology in rural villages. Therefore, decreasing the failure rate of biogas units is a wise place to begin in designing interventions.

A simple intervention may be for a third party (a local NGO, for example) to restart a number of failed units of households that have reverted to fuelwood, so they can readopt. A simulation of this type of intervention in Jalim is shown below. The red line indicates the baseline simulation, and the blue line shows the intervention. At the beginning of year 2011, there are about three households that have failed biogas units, and over the course of 2011, those three units are restarted.



When readoption occurs, reverted fuelwood users become biogas users and their failed units become healthy ones. Readoption restores proof of concept and the attractiveness of biogas, leading to an increased adoption rate. Both readoption and the resulting increase in the adoption rate lead to a higher community pressure to repair which leads less failure and a better long term outcome.



This intervention results in a much more successful trajectory of biogas use. Restarting only three units caused the peak value of biogas users to more than double. This provides support for restarting failed units for reverted fuelwood users as a strong leverage point, since it stimulates several important feedback loops that promote adoption and minimize failure.

Conclusion

In this paper, we have outlined a simulation model to answer the question of why biogas technology is successfully adopted in some rural villages but not in others. We have done initial testing to build confidence in the model; however, we have not yet returned to the field to validate the model with the stakeholders from whom so many of the ideas and assumptions in the models originated.

Although the model is not fully validated, we have begun to build confidence in our structure, and are prepared to give preliminary, general recommendations. The desired trajectory that we share with FES is that a community continues to adopt until market is saturated with biogas technology and that the community sustains a high level of use. According to our model, this will happen in a community that is located sufficiently far away from biomass resources (such as a forest). However, it is our wish that ALL communities, not just those geographically positioned for success, experience the benefits of biogas. In this light, we believe that maintenance and repair are of central importance to maintaining a positive perception of biogas long enough to allow the technology to reach it's full market potential.

Therefore, we recommend that an organization attempting to introduce biogas or some other alternative cooking technology to a community should prioritize establishing a comprehensive maintenance and repair program, with a focus on building capacity within the community. This will strengthen the reinforcing effect of repair while weakening the reinforcing effect of failure.

The next step in this modeling process will be to design group model building or PRA activities with the FES team in Bhilwara and to bring the model back to the original communities for further development and validation. Continued work with FES will lead to more insights, more confidence and the development of more specific recommendations that center on implementation.