A CBSD Study to understand stacking of solar induction and LPG cookstoves along with traditional biomass cookstoves

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Abstract
Transitioning rural households to adopt clean cooking solutions (such as LPG/ solar/ biogas/ electric) from the predominantly used biomass (unclean) is a major focus area worldwide. Clean cooking has significant health, and environmental benefits. Adoption of cookstoves is a very complex phenomenon, with social, economic, and cultural factors determining the adoption of cookstoves by a community. However, evidence from around the world shows us that stacking of cookstoves (using multiple cooking options together) will be the norm. So a more pragmatic approach will be to transition HHs from unclean stacking, say using LPG and biomass, to clean stacking, say using LPG and solar-based electric cookstoves. This paper presents a community-based system dynamics (CBSD) approach to understand the stacking pattern of different cookstoves in a rural community in India. The activity was conducted with a group of women, majority of them illiterate. Hence conducting the CBSD activity itself was challenging. This paper will shed light on the methodology adopted for conducting the activity and the findings that emerged from the activity. Many interesting factors such as seasonal variation, local food requirements, and cultural/ traditional beliefs were found to have an impact on the stacking pattern of cookstoves.

1. Introduction

There are 2.6 billion people around the world who cook using solid biomass fuels for cooking (IEA et al., 2021). Cooking using solid biomass fuels has various health, environmental and social consequences (Smith et al., 2014, Gordon et al., 2014, Jeuland et al., 2015, Lewis et al., 2016, Quinn et al., 2018).

Given these adverse consequences, cleaner cookstoves are being promoted all over the world. Improved biomass cookstoves, LPG cookstoves, biogas-based cookstoves, solar cook stove and electric cook stoves are the major types of cookstoves being promoted. Since the 1970s governments and other actors such as the NGOs have implemented a large number of programs wherein they distributed millions of clean/ improved cookstoves across the globe (Barnes et al., 1993; Barnes et al., 1994; Sarin, 1986). In India, the adoption of improved biomass cookstoves was very low in spite of aggressive promotion of these by the government (Khandelwal et al., 2017). The major reasons for the failure of the program in India are poorly designed cookstove (Bielecki & Wingenbach, 2014; Palit & Bhattacharyya, 2014; Thacker et al., 2014), the improved cookstove performance in the field not matching that of the claim (Aung et al., 2016; Johnson et al., 2008; Roden et al., 2009) and problems pertaining to program implementation (Khandelwal et al., 2017). Biogas cookstoves although effective in reducing the household air pollution, is not an appropriate solution for places where there is a lack of substrate (Mittal et al., 2018), scarcity of water (Bhatia, 1990). Lack of proper repair and maintenance services (Chalise et al., 2018) and the inability of the digestor to operate in colder climates (Kalia & Kanwar, 1998) also deter exclusive adoption of biogas based cookstoves. LPG cookstoves are widely accepted technology (Gould & Urpelainen, 2018), the only disadvantage of it being expensive for the poor to afford (Lewis & Pattanayak, 2012;

Puzzolo et al., 2016). Subsidies can be of great help in facilitating the adoption of LPG cookstoves. Brazil and Ecuador have had a successful transition from solid biomass fuels to LPG with more than 90% of the population in both countries using LPG as their primary cooking fuel (Lucon et al., 2004, Gould, Schlesinger, et al., 2018).

Shifting to clean cooking would directly help in achieving 4 of the 17 Sustainable Development Goals (SDG) - SDG 3 - Good Health and Well Being, SDG 5 - Gender Equality, SDG 7 - Affordable and Clean Energy, SDG 13 - Climate Action and SDG 15 - Life on Land (Rosenthal et al., 2018).

It has also been observed that poor households tend to use traditional cookstoves even when they have access to cleaner options like LPG (Gupta et al., 2019). Using two or more types of cookstoves together is referred to as stacking. Stacking unclean cookstoves such as biomass cookstoves with clean cookstoves such as LPG is referred to here as unclean stacking. Stacking two or more clean cookstoves, such as LPG cookstoves and solar cookstoves is referred to as clean stacking. Recent evidence from clean cooking literature also points to the fact that stacking is here to stay (Benka-Coker et al., 2018; Gould, Jagoe, et al., 2018; Jagger & Das, 2018; Quinn et al., 2018). There is a need for a substantial reduction in the traditional cookstoves and solid fuel use, to have marginal health and environmental benefits (Gould & Urpelainen, 2018). Using both LPG and biomass cookstoves (unclean stacking), therefore compromises the health and environmental benefits (Gould & Urpelainen, 2018). Thus, it is worthwhile to look for pathways to move households from unclean stacking to cleaner stacking. This can help reduce the dependence of households on traditional cookstoves (Quinn et al., 2018). The motivation behind the study reported in this paper is to understand the factors affecting the stacking of cookstoves. We have chosen a village in India with access to three different cookstoves - solar, LPG-based, and biomass cookstove. The study aims to understand the factors that affect this cookstove use stacking pattern using Community-Based System Dynamics (CBSD) approach. We will primarily be focusing on user and community perceptions that drive the adoption of clean cooking technologies.

1.1 Need for a community-based systems approach

Surveys, ethnographic, and randomized trials are typically carried out to understand the factors that influence the household cooking choices (Jeuland et al., 2015; Shankar et al., 2015). Decades-long experience with IC programs has revealed that the adoption of a cookstove is a very complex multi sectoral problem involving many social, cultural, and economic factors(Rosenthal et al., 2017). The use of traditional biomass even when clean cooking fuels are made available, needs careful localized understanding, to plan for future transitions to cleaner cooking technologies (Ruiz-Mercado & Masera, 2015). CBSD model offers a comprehensive and localized map of socio-economic influences (Mendoza & Prabhu, 2005) and hence would be useful when used for understanding the cookstove conundrum. CBSD is a structured approach that helps in understanding the drivers for adoption at a household and community level (Hovmand, 2014). Systems modeling has been used in many fields such as household energy (Howells et al., 2005), public health (Sterman, 2006) and natural resource management (Pandey & Yadama, 1992).

2. Methods

2.1 Study Setting

The study was undertaken in Bancha village, Betul district, in the state of Madhya Pradesh in India. This village comprises 74 households, all of whom used only traditional biomass cookstoves until 2018. In 2018 and 2019, the village had been provided the solar-based induction cookstove (through a CSR initiative) and LPG connections (though Government of India initiative). Along with solar cookstoves, these HH were provided with vessels that are suitable for cooking. Hence, this village is the only village in India, or perhaps in the world, where the households have access to three types of cookstoves - traditional biomass, LPG-based and solar induction. Preliminary surveys were conducted in 2021 which reveals that households do use all three cookstoves, albeit at different usage patterns. The CBSD activity was conducted in September 2021.

2.2 Participants and CBSD Workshop

Fifteen women from the village participated in the CBSD workshop. The activity was arranged at an NGO campus outside the village. The location was specifically chosen so as to make sure that men or other members from the village who are not participating in the activity do not interfere with the workshop or influence the opinion of the women. This also ensured that women were completely invested in the workshop which had 5 sessions spread over 2 days. The major challenge in conducting the workshop was ensuring the participation of 11 illiterate members of the group. Pictures were used whenever anything was written down. The workshop involved coming up with behaviour over time graphs (BOTG), variable elicitation and developing causal loop diagram (CLD).

2.3 Behaviour over time graphs

The aim of coming up with BOTGs is to establish the dynamic nature of the problem at hand. In this study four BOTGs were elicited from the participants (i) number of HH regularly using solar cookstove, (ii) number of HH regularly using LPG, (iii) amount of firewood usage, and (iv) stacked seasonal graph for cookstove usage. The first 3 BOTGs trends were considered over the past 5 year (since 2017). . Participants were asked to recall a major event that happened during each of the years starting from 2017. To identify each year, a picture representing the most significant event for that year is drawn. This way the participants who were not able to read were also able to look at the image and identify the year.

Once the x-axis was fixed and drawn, participants were asked to use coins to indicate the value of the parameter on a relative scale. For example, suppose the BOTG to be drawn is the number of HH reg- ularly using solar cookstove vs year. Then the participants were asked to identify the year (starting from 2017) in which the number of HH using solar cookstove was the highest. For the column corresponding to that year ten coins will be put on the chart. After this, they were asked to fill in the other columns plus the hope and fear using coins relative to the highest. The process was repeated for other BOTGs as well.

Finally, two more BOTGs as a stacked seasonal graph for cookstove usage were elicited to understand the seasonal preferences in cookstove usage in the village. We had planned for only one BOTG for capturing the seasonal variation assuming that the usage of cookstoves will be measured with respect to the time of use. But while conducting the activity it was found that, usage itself can be quantified in two ways - one with respect to the time of use and one with respect to the number of food items being prepared. The approaches will give different results and they are explained in the results section. For this BOTG, the x-axis had three seasons (Winter, Summer and Monsoon) and the y-axis had three different cookstoves. The participants were asked to keep ten coins for the cookstove they use most against the season in which they use it the most. With relative to this particular cell, other cells were filled by the participants.

2.4 Variable elicitation and prioritization

Variable elicitation was carried out in order to understand the key variables that affect the usage of cook- stoves. For this, they, the key prompts used were:

- What impacts the use of solar cookstoves?
- What is impacted by the use of solar cookstoves?
- What impacts the use of LPG cookstoves?
- What is impacted by the use of LPG cookstoves?
- What impacts the use of biomass cookstoves?
- What is impacted by the use of biomass cookstoves?

The variables that the respondents mentioned were first written down on a chart paper by a team member. There was an illustrator who drew the pictures for the variables. These pictures were put beside the variables written on the chart paper. Drawing the pictures took a little more time than writing the variables down. Once every variable was drawn, the participants were told what each picture depicts.

The next step was variable prioritization. For doing this, three dot stickers were given to the women participant. They were asked to put these dot stickers against the pictures of variables, that they thought were the most important. The maximum number of variables a person could choose was limited to three, however, they were free to keep two stickers on a variable if needed. Out of the total 50 variables elicited, around 18 of them were prioritized by the 15 women.

2.5 Causal loop diagram formulation

The concept of linkages and polarity were first explained to the participants using a simple example before starting with developing CLD. Developing the CLD started with the two most prioritized variables. The variables were written in the regional languages (Hindi) at the time of conducting the workshop. The participants were asked how these variables were related to each other and the linkages and polarity. The participants discussed and agreed on a linkage and polarity which was then transferred onto chart paper. For every variable written on the chart, a picture was drawn and the meaning of the picture was explained to the participants. The diagram was completed over 2 sessions. Once the CLD was completed it was explained to the group by one of the participants.

Figure 1: Participants during CBSD workshop with the final CLD

3. Results

3.1 Behaviour Over Time Graphs

Figure 2 shows the number of HHs using solar cookstove regularly for years starting from 2017 to 2021. It also shows the hope and fear that the participants have. As seen in the figure the number of HH using solar cookstove was maximum for the year 2018. 2018 is the year whenthe solar cookstoves were first installed in the village. We can see that the number of households using solar cookstoves reduced in 2021. Lack of appropriate vessels were cited as one of the reasons. Also, they mentioned that they would like to increase use of solar as their ‘hope’ and declining use of solar cookstove as their ‘fear’.

Figure 3 shows the number of HHs using LPG cookstove regularly for years starting from 2017 to 2021. The number of HHs using LPG regularly is maximum for the year 2018. This is because it was in 2018 that the village got free LPG connection through a government scheme. The number of HH using LPG regularly is minimum in 2020. The participants informed that the Covid-19 pandemic associated lockdown had reduced the income of most people in the village, which made LPG cylinders not affordable for many HHs. They hope to use less LPG and the fear is that they will have to rely on LPG more. The reasons for such a hope and fear, the participants informed, was that the cost of LPG and lack of upfront subsidy make LPG very expensive for the community.

Figure 4 shows the amount of firewood collected for years starting from 2017 till 2021. It also shows the hope and fear that the participants have. From the figure, we can see that there is a drastic decline in the amount of firewood collected from 2018 onwards. Clean cooking options being available is the reason for this. It was in 2018 that the village got both LPG and solar cookstoves. They hope to use lesser firewood than they presently collect. But they also fear the firewood collected will be too less. They see firewood as a fall back option in case they are not able to afford LPG and the solar system malfunctions. Hence they prefer to have enough firewood that could meet their cooking requirements. Currently, existing forest regulations put restrictions on firewood collection. The enforcement of these rules are particularly stringent for the community members since the officials are aware of the solar cookstove system being installed in the village.

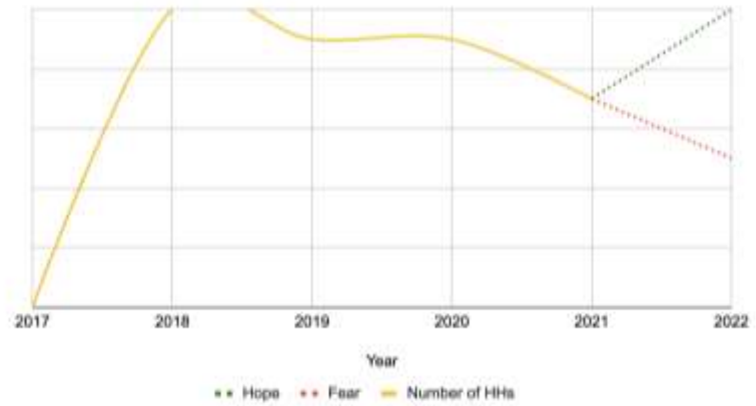

Figure 2: BOTG 1 - Number of HHs using solar cookstove regularly

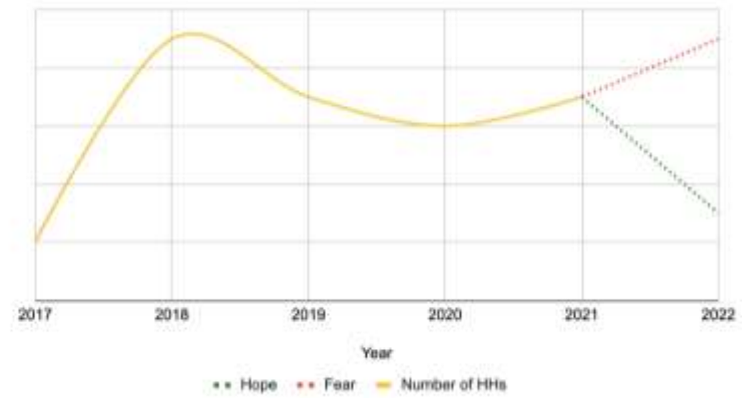

Figure 3: BOTG 2 - Number of HHs using LPG regularly vs year

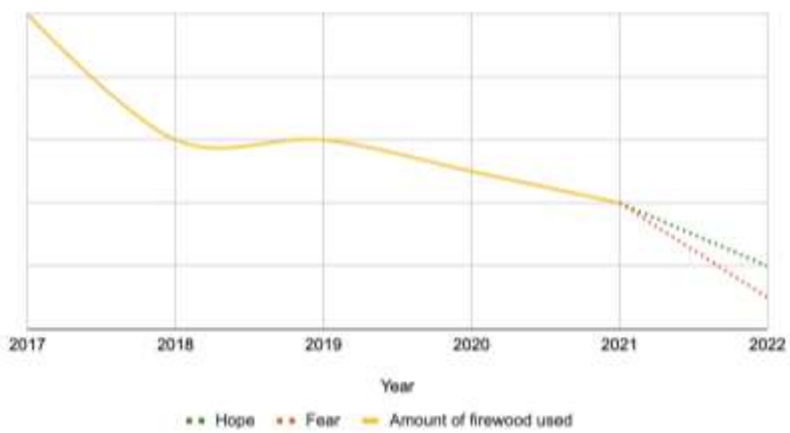

Figure 4: BOTG 3 - Amount of firewood used vs year

Figure 5 shows the seasonal variation in the usage of the three different cookstoves. The three seasons selected are summer monsoon and winter. Summer corresponds to months April, May, and June, monsoon months are from July to September and winter is from November to March. And this usage is with respect to the time spent in cooking in each cookstove. We can see that solar cookstove usage is the most in summer, LPG cookstove usage is most during monsoons and biomass cookstove use is maximum during winter.

Figure 6 shows the seasonal variation in the usage of the three different cookstoves. The three seasons selected are summer monsoon and winter. Summer corresponds to months April, May, and June, monsoon months are from July to September and winter is from November to March. And this usage is with respect to the number of food being cooked in a particular cookstove. We can see that solar cookstove usage is the most in summer, LPG cookstove usage is most during monsoons and biomass cookstove use is maximum during winter.

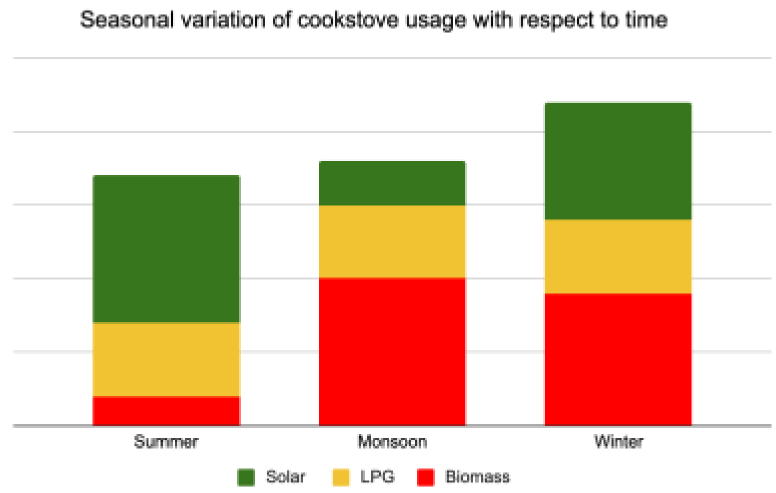

Figure 5: Seasonal variation in cookstove usage (wrt to time)

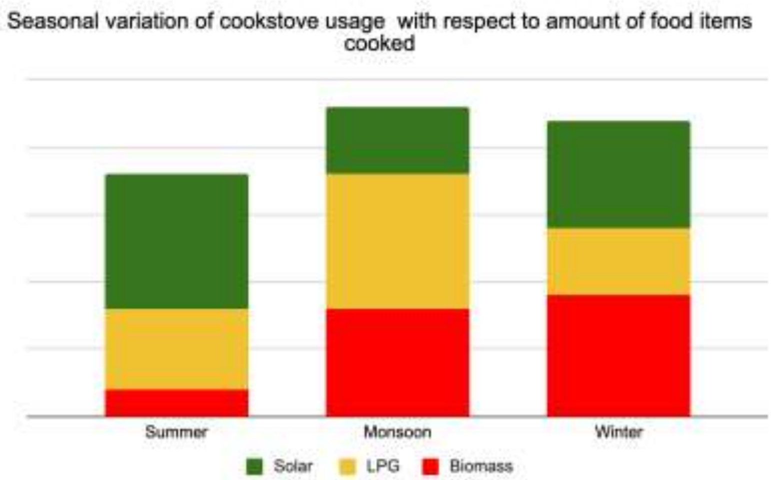

Figure 6: Seasonal variation in cookstove usage (wrt to number of food items being cooked)

3.2 Causal Loop Diagram

Figure 7 shows the causal loop diagram which was developed through the CBSD activity. The CLD developed after two sessions with the participants of CBSD activity was refined further during discussions and the final refined CLD is the one in Figure 7. The diagram captures the factors that influence the usage of the three different types of cookstoves present in the village. There are three main reinforcing loops that influence the usage of cookstoves. The reinforcing loop of solar cookstove is as follows: (left part of the figure 8) As the *usage of solar cookstoves* increases, this positively affects the *habit of using solar* cookstove, which in turn increases the *preference for using solar cookstoves* which further increases the *usage of solar cookstoves*. Similarly, (from middle/right part of the figure 7) we can see the *usage of LPG/biomass cookstoves* positively increasing the *habit of using LPG/biomass cookstoves* which increases the *preference for using LPG/biomass cookstoves* which in turn increases the *usage of LPG/biomass cookstoves*. The preference of using one cookstove also has an impact on the preference of using other cookstoves. An increase in *preference to use solar cookstove* decreases the *preference to use LPG cookstove* as well as biomass cookstove. An increase in *preference to use LPG cookstove* also decreases the *preference to use solar cookstove.*Now let us consider each cookstove as a subsystem.

We can see from the figure that the availability of appropriate vessels, condition of the solar cookstove system, and charge available in the battery are the factors that impact the usage of the solar cookstove. Cooking in solar cookstove is only possible with steel vessels, and not with aluminum and earthen vessels which were predominantly available and used by the households. The size of the vessel is also a constraint while using solar cookstove. Since the cookstove is of a standard size, vessels of larger diameter cannot used on the solar cookstove. This is not the case with biomass or LPG cookstove, both of which allow a certain degree of flexibility when it comes to the size of the vessel being used. The presence of a local *Mechanic* helped in the timely *maintenance* of the solar system, allowing for its continued use. The other factor that influences the usage of solar cookstove is the *charge* available in the battery. The participants reported a decrease in charge during monsoon because of the reduction in *sunlight*. We can also see that *water in the battery* and *cleaning of panels* also influence the *charge* available in the battery in turn affecting the *usage of the solar cookstove system*.

Usage of solar cookstoves impacted the *time available for parallel work*. The participants reported that they could keep food for cooking in the solar cookstove and engage in other household chores while the food is being cooked. They said this is not possible with biomass cookstove as they have to be present near the biomass cookstove in order to make sure the fire is alive and feed in firewood as needed. In the case of LPG cookstove, they said that since the flame is present they do not feel comfortable leaving it unattended to do other work.

In case of usage of LPG, there is another reinforcing loop other than the one involving *habit* and *preference to use*. Participants reported that cooking is quickest when done using LPG cookstove. An increase in the *usage of LPG cookstov*e increased the *time saved* from cooking. As the *time saved* increases they were able to put in more time towards other economically productive activities such as daily *wage labour, agricultural labour in their own or other farms*. As the time spent in other economically productive activities increases their *income* also increases which helps them in purchasing more LPG cylinders. This increases the *LPG cylinders* available and in turn, increases the LPG usage. It was also reported that the availability of agricultural labour and the work in their own farm is more during the rainy season. We can also find that purchase of LPG cookstove is affected by the *cost of LPG* and the *subsidy* given. As the *subsidy* given increases, the *cost of the cylinder* decreases which will increase the number of LPG cylinders purchases. From the figure, we see that as the usage increases the *LPG cylinders* available decrease forming a small balancing loop. Similar is the case with the number of *LPG cylinders* available and the *purchase of LPG cylinders*. We can also see that usage of LPG cookstove is impacted by the *time available for cooking*. Lesser the time available for cooking more the usage of LPG cookstove.

Another important parameter that impacts the preference to use LPG is the *delay in getting the subsidy*. As the *delay* increases the *preference to use LPG* decreases. This is because more often these communities do not have enough cash at hand to pay for the cylinder upfront. *Preference to use LPG* is impacted by *fear of gas cylinder exploding* and also the *quantity of food* to be made. *Fear of gas cylinder exploding* reduces the household's *preference to use LPG*. More the *quantity of foo*d to be made cooking using LPG cookstove is preferred. Participants said that during festival season when they have guests the number of people at home increases, during which they prefer using LPG cookstove.

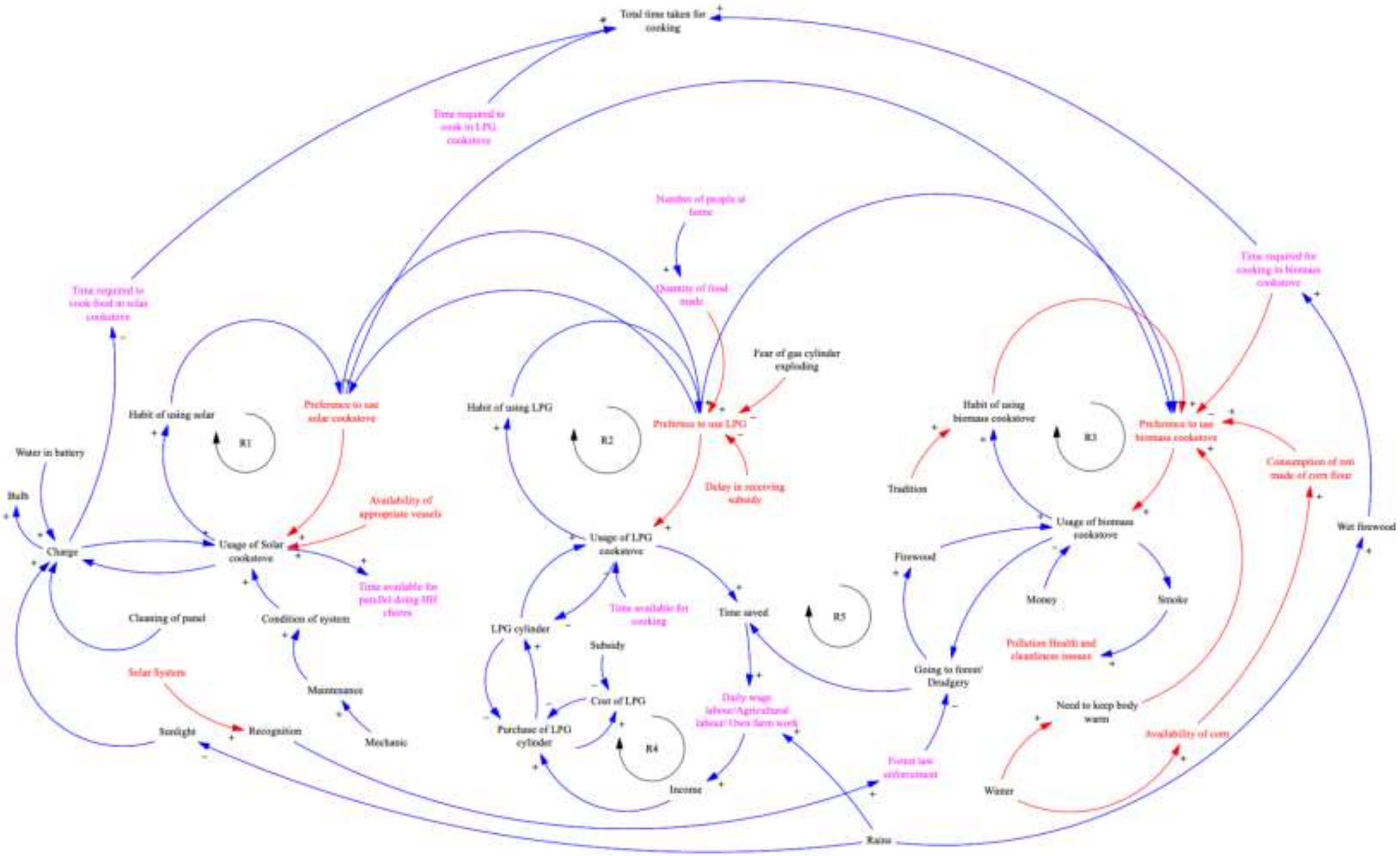

Figure 7: Causal loop diagram developed after CBSD session

Usage of biomass cookstove is impacted by *firewood* availability and *money* at hand. As the availability of *firewood* increases *usage of biomass cookstove*s increases. Also as *money* at hand decreases, the *usage of biomass cookstove* increases. *Usage of biomass cookstov*e impacts the *smoke* produced and *drudgery involved in firewood collection*. As the *usage of biomass cookstoves* increases, *going to forest* for collecting firewood increases which increase the availability of *firewood* at home for use in biomass cookstove which in turn increases the *usage of biomass cookstove*. This forms a reinforcing loop. There is another reinforcing loop that involves *usage of biomass cookstov*e. Increasing *usage of biomass cook- stove* increases *going to forest* for firewood collection which reduces the *time saved* which reduces the time for other economically productive activities. This reduces the household *income* reducing the pur- chase and ultimately the *usage of LPG cookstoves*. As the *usage of LPG cookstoves* reduce, the *habit of using LPG cookstove* reduces reducing the *preference for using LPG cookstove*. As *preference to use LPG cookstove* reduces *preference to use biomass cookstove* increases thereby increasing the *usage of biomass cookstoves*.

The *smoke* produced due to *usage of biomass cookstove* increases with usage which causes *pollution, health concerns* and makes the kitchen and vessels black (*cleanliness*). Blackening of vessels, in turn, leads to more time being spent cleaning. All these reduce the *preference for using biomass cookstoves*. Seasonal variation affects the usage of biomass cookstove in different ways. During *winter* there is a *need to keep the body warm*. This increases the *preference to use biomass* during winters compared to other two cookstoves. Also, it is during winter that corn harvest happens. So during *winter* months, the *consumption roti made with cornflour* increases. Roti made up of cornflour can only be cooked using biomass cookstove. This again increases the *preference to use biomass cookstove* during winter season. During rainy season, however, the *wet firewood* takes longer to burn, increasing the *time required for cooking in biomass cookstove*. This reduces the *preference to use biomass cookstove* thereby decreasing the *usage of biomass cookstove*.

We also found that *tradition*/cultural practice influences the usage of biomass cookstove. As per the communities believes it is required to offer some food cooked in biomass cookstove to their god. This requires them to fire the biomass cookstove every day. Once the cookstove is fired, they tend to use it to cook more food items. This relationship is captured by the variable *tradition* in the CLD. Another factor influencing the use of biomass cookstove happens to be the introduction of *solar cooking systems* in the village. As the solar cookstoves were installed the village began to be famous and recognized in the region. This made the *forest law enforcement* much more stringent for the HHs belonging to this village, making it difficult for them to collect firewood. This is found to be leading to decreased *usage of biomass cookstoves*.

4. Discussions and Conclusions

One major aspect that emerged out of the community-based activity was the differentiation the community members had between the time of use of cookstoves and usage of cookstoves. Time of use refers to the time spent cooking in a particular cookstove. Usage on the other hand refers to the number of food items being cooked. During monsoon, since the wood is wet, it takes longer for the firewood to burn and hence more time to cook food using biomass cookstove. That is, it will take more time in monsoon to cook the same amount of food in the same vessel, than that of say summer or winter. Due to this, the HHs tend to cook lesser number of food items in biomass cookstove during monsoon season.

A similar behavior is also (surprisingly) found in solar induction cookstoves. During monsoon, because of the decreased insolation, there is less charge in the battery of the solar cookstove system. The lesser charge leads to a lesser voltage across the battery terminals, which in turn reduces the eddy currents produced, resulting in longer cooking times in solar induction cookstove . However, this is not the case with LPG cookstoves which takes the same amount of time to cook food in all seasons. This is explicitly shown in figure 8. In the figure, we can see that time required to cook food in biomass cookstove is dependent on rains, and time required to cook food in solar cookstoves is dependent on sunlight available.

Because of the above-said reasons, the HHs tend to use LPG cookstove more during monsoon months. Women also reported that they tend to use LPG if they have to go for farm labour early in the morning (especially during monsoon) and they do not have enough time to make fire in the biomass cookstove. Making LPG cylinders available during these months can be a possible policy decision that would enhance the uptake of LPG.

It was seen that the availability of appropriate vessels was very important for sustained uptake of solar cookstoves. This will be the case with electric induction cooking in general. Rural households tend to cook most of their food in earthen or aluminium vessels when they are cooking on biomass cookstoves. So if they have to switch to induction cooking, steel vessels have to be made in the market at affordable rates. This should also be one of the areas that need focus when electric cooking based on renewable energy sources is being promoted. Certain cultural practices/ traditions prevailing in the community necessitated cooking using biomass cookstove. This is one of the reasons which makes a complete shift from biomass cookstove difficult.

We could also find that certain local foods, such as roti made of cornflour, necessitate cooking in biomass cookstoves. Firing the cookstove can lead to using it for much longer durations as well. During winter, biomass cookstove also does this additional job of keeping the house warm. All of these suggest that a complete switch from biomass cookstove to clean cooking options may not be that easy a transition. There are many social, cultural, and traditional practices that come in the way. A slow transition to using clean cookstoves is a more pragmatic method. This would mean that cookstoves, both clean and unclean, will be stacked before a household moves into using clean cookstoves exclusively. Local food requirements also play a decisive role in the adoption of cookstoves. Induction cook stoves may be much well received and adopted if deployed in parts where most of the food is cooked by boiling or frying.

The study revealed certain interesting aspects of cooking like the differentiation between usage and time of use which otherwise would not have been evident. It also brought out the social and cultural factors that influence the usage pattern. The study points to the need of a careful understanding of the local food requirement, cultural and social factors of a region before designing policies for deploying clean cooking alternatives.

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