Technische Universiteit Delft

# Institutional innovation

## Solar electrification sustenance

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TU Delft

# Institutional Innovation

## Innovating institutions with technological innovations- Case study of sustenance of solar electrification projects in Rural India

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An electronic version of this thesis is available at http://repository.tudelft.nl/.

All the codes of this thesis are available at
https://github.com/rhythimashinde/electrification-india

The source of cover photo is Author herself (clicked in Mandsaur, India)


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# Preface

This document is an end product of 6 months research at Delft University of Technology. It is intended for anyone interested to understand the effects of different socio-cultural, technical, market and institutional impacts on the solar electrification projects of rural India. A basic knowledge about community settings in India and the technological components of the solar electrification project is expected, though it is briefly touched upon for those who would have completely no knowledge on these two matters. People interested in sustenance of electrification projects would find this thesis interesting. This is not a market level analysis or tariffs rates analysis, but rather an institutional economics perspective.

In terms of writing style and content, the document is kept very simple on language to ease up the reading for anyone from even a non-mathematical background. The codes for the model are not shown as the results are sufficient to show the major implications at policy level and the construction of model itself is not the core of the thesis. The crux of the thesis lies in developing theory and modeling is more of an extension and application of the theory.

An overview of the main parts of the thesis is provided in the Figure 1 below. The thesis goes from a phase of problem *definition*, followed by a *design* of framework based on literature, and *application* to the context of rural India. Final phase involves *re-designing* the framework based on *learnings* from the case.


Figure 1: Thesis Overview

To make the most of this document the reader should not skip chapters 4, 7 and 8. The chapter 9 discusses the implications of the case study back to the theory for a broader implication of the thesis in different domains, and also discusses different levels of policy implementation. For understanding just the major results of the thesis, the Executive Summary and the chapter 10 would be helpful. The personal story of the author's approach motivated by the department and the researches can be seen as reflections in chapter 11.

This thesis will be followed up by a second thesis in computer science faculty of Delft University of Technology and ETH Zurich on developing the algorithms for automation of the institutional innovation developed in this thesis with a case study of anonymous sharing of the electricity in rural India.

*Rhythima Shinde*
*Delft, August 2017*

# Acknowledgements

When I took this thesis, I wanted to do an independent research, I challenged myself with something new and that is why everything I chose in the thesis: the domain, the field of theory, the modeling method was completely new to me. Then came those sleepless nights and migraine-filled weeks where I was on the verge of giving up the work. And now I am here writing the final section of my thesis. This was not possible, if there wouldn't have been a supporting squad of people with me. Cutting the chase, I would like to first thank my wonderful supervisor, Dr. Amineh Ghorbani. You have been the biggest inspiration for me to push myself through so many papers to find those creative ideas. You made me realise in every meeting that I could do it, helping me keep on track. I am also very thankful to my second supervisor, Dr. Martijn Warnier, who has been patient and kind through my very silly agent based modeling questions. Your support even in last days of writing was very helpful. My chair, Prof. Paulien Herder has been really helpful and understanding about my migraines, along with the whole committee and your critical reviews have helped me push boundaries. I would also like to thank Dr. Bert Enserink for supporting me in my endaevors.

I would also like to extend my thanks to all the interviewees from Gram Oorja, Gram Power, Simpa, Selco, Barefoot College, and Mera Gao Power, who in their busy schedules took time to help in my research. I am really grateful to Tejaram ji from Manthan for hosting me and my family for the visit and showing the project installments, and making my community based interviews possible. I am also very thankful to Rob de Jeu and Rural Spark team for answering my questions at any point in the day and helping validations. I would also like to thank researchers around Netherlands whose inputs were very valuable including Nishant Narayan from faculty of EWI (TU Delft), Abhigyan Singh from faculty of IO (TU Delft), Ankit Kumar from TU Eindhoven and researchers from India including Denise Fernandes from Clinton Fellowship and Abhishek Jain from CEEW.

Coming to my dear ones, my parents, you were not here physically, but my field visits have been possible and my motivation has remained strong to keep going, because of you both. Baba, you have always trusted in my every decision, right from changing my complete branch of engineering without any question asked and I can't thank you less for it. Aai, your innocent words make me keep smiling even through hardest times. Vinay, you were there for everything and even nothing, thanks for that. Kriti, Deepali, Purav, Saboo, you guys were always there for my late night messages, and it means a lot. Duygu, Bramka, Nadia, Anil and all EPA-mates, you guys made me go through two long years of EPA without giving up through the curriculum, and that's why I thank you all. Especially Duygu, you have been my biggest cheerleader and reality-checker, who made me switch to good food habits and loads of coffee. Finally my friends in Delft, Gaurav, Nilaya, Milan, Ameya, thank you for your presence and those random walks and talks which made Delft a third home.

*Rhythima Shinde*
*Delft, August 2017*

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# Executive Summary

There are more than 200 million people still without any form of electricity in India. Many of them are being approached with innumerable government schemes with the aim to achieve 100% electrification by year 2018.These schemes include, but are not limited to, Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY), a Ministry setup of New and Renewable Energy (MNRE), and other efforts from different private and non-governmental organizations. Most of these projects are focusing on the decentralized energy solutions specifically renewable, and mostly solar energy based solutions, because of the environment-friendliness, portability of solar house system, access and the abundance of sun in rural India. The DER or decentralized energy renewable sources prove to be very helpful provided the transmission loses to the distribution companies or DISCOMs, and the remote settlements in the large inconsistent and at times, harsh terrains of India.

Even though the DER solutions look to be appealing they have not been successful because of two reasons: First, there is an issue of upgrading with the increasing demand of the people. Second, the schemes of government have been focusing on electrifying a village and not the households, leaving around 90% of the households un-electrified even with a so-called "electrified" village. Thus the issues of access to all and the reliability of the solar house systems to upgrade have led to constant failures of the solar electrification projects. Additionally, the rural communities of India are very strong on their social norms and thus if a technological solution is not fitting as per their values or the informal institutions in the community, there is a high chance that it will be discarded.

There are three types of major solar electrification projects : Microgrid, Sharing and individual Solar Home Systems(SHS), based on the level of ownership. The first is owned by usually a private organisation with community and partially funded by the profits and the corporate, banks or government funds. These projects have a main source of energy usually centrally located and distribution lines are connected from this source to the households. Second is partially owned by community and partially by a private organisation or an energy providing firm, and completely funded by the profits. These projects have households as producers and consumers, with variety of products. Usually energy is produced a SHS on a house and the excess is sold to other households in form of electricity or charging batteries. The third is completely owned by the households and the energy providing companies act as external agents responsible for installation and repairs. All these societal level issues for the DERs are present for all the three types of projects, and have led to an overarching research question of the thesis *"Given the dynamics of rural communities of India, how can socio-technical systems of solar electrification be sustained?"*

## Community management of resources and innovation diffusion

Breaking down the research question, the first question is posed as *Which frameworks can help study the effects of all dynamic factors combined on the solar electrification systems in rural context?*. Usually for understanding such effects, literature considers the projects of rural electrification from the perspective of the energy providing firms or the households. But this thesis used a different approach and looked at the rural electrification from a community level. Here the community is considered to develop management rules (institutions) to sustain the resource, which is the electricity produced by solar energy. It is similar to the common pool resource management approach where the resource is limited, as first studied by Elinor Ostrom through various frameworks (Ostrom et al., 1994). The reason to use this approach is that this approach allows to understand the community attributes and their changes at once. By considering only energy provider's or households' perspective, one can understand supply and demand of the technology or the households, respectively. But, this restricts the freedom to look at the effects of the important societal-cultural effects and their impact on the rules in the community. This is brought by community management approach, as used in the thesis.

The Institutional Analysis and Development (IAD) framework combined with the Socio-Ecological System (SES) framework looks to be most appropriate for this case to answer to some extent the first part of the research question. This part would help understanding the effects of various combination of socio-cultural, technical and economic factors on these electrification projects. These socio-cultural, technical and economic factors will also be labeled as the "dynamic factors" throughout the research. IAD framework proposes adaptation of rules of use based on the outcomes of the patterns of interaction of the actors in the system based on their individual action, to adapt to these changing factors. SES theory helps in understanding the exact variables included in the considerations of socio-cultural, technical and economic factors. But, IAD and SES, together, fall short mainly in recognizing that the individuals adopt rules which are established around a technology, only if they agree to embrace the technology. This directed the research towards studying the dynamics of innovation diffusion.

Thus it was further decided to dive into depth of the innovation diffusion theories for this research. The word-of-mouth theory lists the conditions under which the neighbors accept an innovation and the economic theory helps setting a threshold to help households decide if they will accept an innovation or not. These two theories are adapted in this research due to their depiction to reality in the rural solar electrification case of India. Thus, answering to the first sub-research question, the answer can be summarised as the IAD, SES and innovation diffusion theories together, can help in understanding the effects of all dynamic factors on solar electrification systems in rural India context.

## Institutional Innovation Framework

Though these frameworks are useful, there is no clear direction on how to use them together and thus the next sub research question is posed: *"If there is no framework available, how can a new framework be developed to study the effects of all dynamic factors combined on the solar electrification systems in rural context?"* This question led to the development of an institutional innovation framework which would help understand effects of the dynamic community on such socio-technical infrastructure projects. Here, the action of an agent affected by innovation diffusion, followed by institutional diffusion and adaptation, lead to design of a new institution in the system, and this is called institutional innovation as shown in Figure 2 and explained in further paragraphs. This term was first coined by Vernon and Hayami (1984) and such a need of merge of approach was explained by Redmond (2003). The institutional adaptation and diffusion, fitting in institutional innovation was first pointed by Hargrave and Ven (2006).

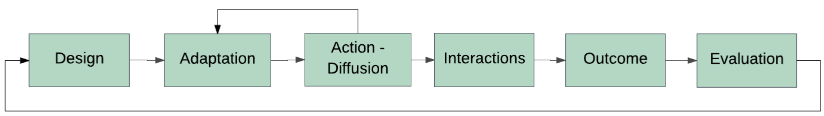



Figure 2: Proposed framework of institutional innovation

The proposed framework fills the gap of the IAD framework of understanding the impact of the individual decisions and development process of institutions based on these decisions. IAD misses out on understanding the exact process of development of institutions, where the process of institutional adaptation and diffusion goes on simultaneously. In case of socio-technical infrastructures as innovations, the adaptation of institutions occur at two levels: before the innovation is accepted by majority, and after the innovation is accepted by majority. The institutional adaptation before the innovation acceptance leads to top-down rules (institutions) usually applied by the authority controlling the resource or the community heads. The adaptation after innovation acceptance leads to development of usage rules. These usage rules are again of two types: decided by evaluation of individual utility, and resource/community utility. These rules are defined by an evolutionary process of rules variation, outcome and adaptation.

The institutional adaptation is simultaneous with institutional diffusion, where the institutions are passed on from one member to another in the community. This follows similar rules to innovation diffusion like word-of-mouth, where a new member adopts rules based on the benefits of the adapted rules. Note that here institutional design is restricted to the same definition of adapting a new institution by majority. These institutional rules are adapted at different levels of actors and individuals. Different properties of the resources and communities help develop individual components of the institutional innovation framework. A summary of this framework can be seen in Figure 3 and 4.

## Context study of rural solar electrification in India

Now that a framework is developed for answering the question, it needs to be applied to the given case. Thus, a further sub research question is posed: *"What are the existing effects of the different dynamic factors on*

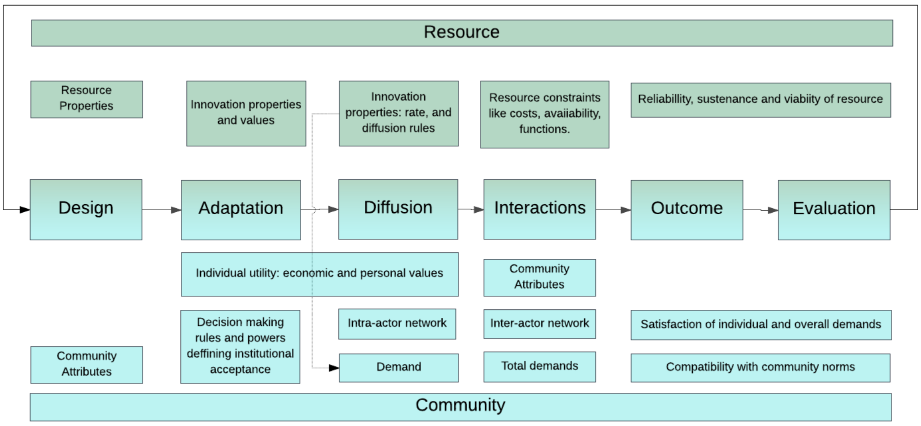



Figure 3: Resource and community attributes defining the institutional innovation framework

*the solar electrification in rural India?"* To understand the existing effects thoroughly, after a thorough context study based on literature, more than 20 interviews were conducted on-ground and online with energy provider and communities in presence of energy provider. The interviews developed a very clear insight into these aspects of the electrification project: technology, energy provider characteristics, community characteristics, actors properties and involvement, operations and maintenance, market settings and funding, institutions (Formal and Informal), success and sustainability parameters for the electrification project.

The main intervieweing organisations were: *Gram Power, Gram Oorja, Mera gao power, Selco, Manthan, Simpa, Piconergy, Rural Spark, SolShare*, where the first four are microgrids, the next three are SHS and the next two are sharing projects. The different actor charts gave these types based on roles and responsibilities: Energy provider firm, Manufacturer, Households, village committee, government and NGOs. The first three are considered to be the most critical actors due to the resources they govern, with local and national governments as a context setter. The analysis of these interviews to understand the process in the electrification projects, shows that the microgrid projects have higher number of collectives choices and other projects are very operational in nature. Collective choices are the decisions taken by the interaction of actors, where one common decision (choice) is chosen by all the actors. The collective choices are completely absent in the case of individual SHS and thus these projects will be kept out of the context of further analysis.

The above analysis of the actors and processes is aimed at understanding the effects of the dynamic factors on the rules of the communities. These rules further help to define the effects on the resource usage and the community, and thus help in defining the success and sustenance of the projects. This relation between the success parameters and the resource usage and community parameters need to be more explicit. Thus, further research is done on understanding the success parameters for such projects. A lot of research is already present in the field of the rural electrification domain on success factors, and following it, the major parameters of success came out to be affordability and accessibility for community, reliability and viability of technology, socio-cultural and political sustainability of the project with long term sustenance and profitability and positive environment impact of the project. Based on an analysis of these success parameters on statistical and visualization based result, it was seen that: (1) the success parameters stayed similar for the ownership basis i.e. there was not much difference for microgrids, sharing and SHS project, (2) but the results varied as per the involvement of the stakeholders e.g. profitability was important for a project where village committee was involved.

## Framework for comparison of projects

The next step is to define operational structure of developed framework to help find the effects of factors on the project. This leads to the next sub research question: *"Given the developed/ existing applicable framework, how can the effects of the combination of dynamic factors on the solar electrification be obtained?"* Based on the actor and process analysis, it is difficult to jump to finding the effects of the socio-cultural and institutional factors. Thus simulations in form of agent based model would be performed. But this first needs operationalization of the framework to develop this actor and process analysis into a system which can directly help check these effects. Such a system can be some form of model, and here as the focus is on the actions of the agent, an agent based model will be used. But even developing an agent based model would need a designing concept. Here, the MAIA (Modelling Agent systems based on Institutional Analysis) framework developed by Dr. Amineh Ghorbani was used which has a foundational (physical, collective and constitutional), operational and evaluative framework.

The foundational framework helps lay down the actor networks, the action sequences and the physical components with the different institutions. The operational structure lays down all the decision rules with the action situations. Finally, the evaluative framework helps define the success parameter variables which can be used to compare different models and performance of each model. Here, the institutional innovation framework comes into role for defining the rules after every action situation and this is defined in the operational framework with a proposed module: "rules-check". This is introduced after the action situations' design in the operational structure of MAIA. This helps to evaluate the gap between the individual utility and resource/community utility, to define the exact usage rule. Additional to the MAIA, as can be seen in the following Figure 4, the different methods followed in the research helps define the different components of the proposed institutional innovation framework.

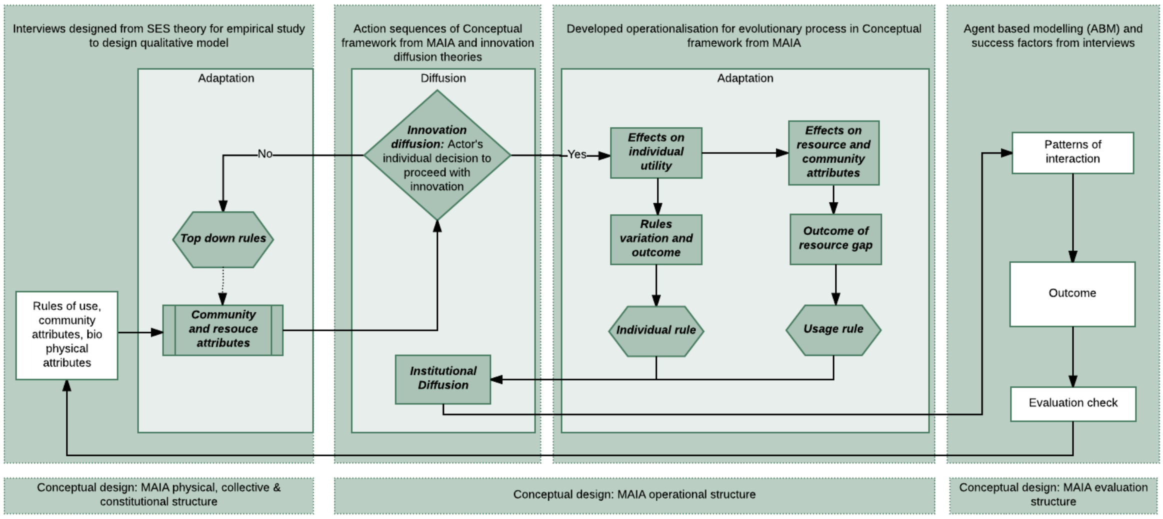



Figure 4: Theoretical framing with methodology

## Effects on projects

Finally, that the operational structure to find the results is framed as shown in the above figure and discussed in last section, the next sub research question is *"Given the developed framework, what are the effects of the combined dynamic factors on the solar electrification in rural India?"* Looking a the major effects of the sharing and microgrid projects, it can be seen that the sharing projects don't allow the income rise to be met with the increase in demand, while the microgrid project shows a lack of profits due to the payment skips in the project. Also, the demands based upgrading in more easier in a microgrid project but difficult to achieve due to lack of profits, while this is very difficult in sharing projects due to higher installment costs of the project upgrading. One of the solutions to this is to merge the two projects i.e. develop a hybrid project with the inclusion of microgrid to meet the higher demands at a lower cost (microgrid installments are lower). This also helps reducing the cheating behavior as in pure microgrid, because now people have incentives to be producers. As seen from the three models (i.e. microgrid, sharing and hybrid projects), the major insights in the effects/ behaviors of the models were as follows:

1. Laggards never get electrification: Laggards or the non-acceptors of the innovation get left out of the network of electrification. This is highly because of the demand-rise of the products and the income-rise of the early acceptors to a level that they become producer. So even if the laggards want to be the consumers later, there is no motivation for the producers to sell more kits to households and thus the market itself has saturated to provide any more transactions. The same case is with microgrid and sharing, with former missing out on consumers due to payment skips and sharing switching to stable market much faster than sharing project (demands are met faster now using microgrid).

2. Importance of connectivity: Connectivity of the agents with each other is more important for a household to decide to become a producer or not, especially in sharing and the hybrid project. This is even more important than affordability.

3. Rise and dip in the consumers/producers: Due to the replacement and operations & maintenance tasks, the reliability of the products become questionable, and less is the reliability more is the variation in the number of producers and consumers. Upgrade of income and connectivity helps bringing the rise to the market to a limited extent.

4. Microgrids' profits: The profit of microgrid is the biggest risk to the project because of the unaccountable behavior of the community accompanied by heavy operations tasks. There are many more reasons like the village committee changes, which keep the profit random and non-positive.

5. Hybrid project wins (significant differences based on statistical results): Comparison of the projects can be done on the following parameters which helps in showing that the hybrid projects is much better than the other two projects:

   (a) Afford and Access: In terms of affording, microgrid always turn to be much cheaper due to smaller payments, while in terms of access, the hybrid projects make a network which allows adding a new household much easier and beneficial for the network.
   (b) Operations and demand rise (Reliability): Operational issues are more frequent with sharing and hybrid, but more larger (due to large size of the source) with microgrid. But the hybrid projects are more complicated due to presence of both and thus the least convenient for operations. But at the same time, the hybrid projects are better at meeting high to low demands than the other two.
   (c) Consumers and Producers: The number of consumers is highest in the microgrid, and the number of producers will be highest in Sharing and Hybrid, leaving the sum to be almost the same.
   (d) Profits: The profits are highest in the hybrid due to management of losses in microgrid and the profits to the producers, while only one of each is present in the other two, with microgrid having losses.

## Policies and Recommendations

Now that the best project is known as the hybrid projects, the next sub research question is *"What new policies and rules can be developed which would help change these effects to improve sustenance of the solar electrification in dynamic context?"*. These policies and recommendations here are addressed to majorly two segments of stakeholders: one, the energy providing firms and especially those who are ready to accept innovations with time and are inclined towards a sharing project e.g. *SolShare* and *Rural Spark*, but even microgrid companies with more innovations in their side like *Gram Power*, with smart meters, can find the recommendations helpful. The SHS projects like *Manthan* can focus on the more adoption of the social level innovations, due to lack of funding support and extreme poverty in the end user segment they are catering to. Once, they are able to help everyone get minimum electricity, the more technically advanced solutions can be integrated in their project. Finally, the local governments cannot directly use these recommendations, but their involvement while such implementations smoothen the process of development of electrification projects.

- The recommendations for all the energy providing firms are as follows:

  1. **Switching to Hybrid projects is beneficial for both sharing and microgrids:** Especially for the microgrids, this is more beneficial, due to the presence of infrastructures. Sharing (and SHS) projects would face heavy investment initially, but more number of consumers would help in payoff and thus both projects should invest in it.
  2. **Introduction of grid has heavy impacts:** But reliable products and contracts with central grid can help here on introduction of grid. The latest possibilities of PPA (Power purchase agreements) by central government, can help arrange these contracts.
  3. **Laggards can be included using pay as service model and in-house manufacturing:** This would help solve the issues of affordability in poor rural areas. Lessons from *Barefoot college* for in-house manufacturing, incorporating community knowledge development, and women empowerment would be helpful here.

4. **Demand wise payment helps reduce demand-income gap:** Demand versus income gap can be reduced with demand wise payment and electrification i.e. microgrid can be only used when the demands are high enough to prevent cheating.
5. **Resource and individual utility gap is important to decide usage rules:** These usage rules are the compensation, prioritization (distribution) or constraint rule for usage of the resource in the community, increasing the profits and access of the resources.

- The recommendations specifically for the microgrid energy providing firms are:
  1. **Community energy system should be grown as economic hubs:** It is important to have a steady growth in these community energy systems - i.e. there constant development like a livelihood organisation/ economic hub is important to prevent decline in number of producers and consumers due to increasing demands or the replacement costs piling up.
  2. **Prioritization rules help get community back on ground:** In cases of emergency, distribution from community pool should be used in such cases. If these rules are not present, the community might lead to completely stop using the resource.
- The recommendations specifically for the sharing projects' energy providing firms are as follows:
  1. **Variety of the products should be experimented:** Energy variety doesn't have any effect on the number of producers, buyers, but the effect on profits might be different. For example, in the case of Rural spark, the more modular products have helped to cater to different amount of demands more easily.
  2. **Cashless payments:** They would have a heavy positive impact on the profits of the energy providing firms, because this would save a lot of hassle and investments in terms of time for the energy provision firms.
- The recommendations for the local governments (with collaboration of energy providing firms) are as follows:
  1. **Cooperative shops prevent discrimination:** Discrimination can be tackled with cooperative shops and anonymous sharing. The collection of the small sections of society as one entity makes look at the weaker/ smaller section of society with more status.
  2. **Policy impacts should be considered:** Policies can lead to generation of unanticipated demands, benefits and problems as well and it should be kept in mind. For example, policy of in-house manufacturing might lead to new community hub development and increased connectivity, and thus, such effects should be considered.
  3. **Delays in the processes need to be avoided:** Delays need to be avoided as the communities have a high rate of change with terms of demands, and delays lead to a loss in the trust of the service. Thus the processes of testing and registrations should be integrated with project deployment and design. This need a steady formal regulation from the governments.

## Recommendations for framework

Based on the above recommendations it can be seen that the institutional innovation framework has helped to develop policies which when applied for the case leads to better sustenance of the electrification projects. In the same way, the case study has also helped to contribute back to the institutional innovation framework.

1. **Institutional Adaptation at two level:** The institutional adaptation was developed considering before and after innovation effects. This was developed only after taking the inputs from the energy providing firms in the interviews, when it became apparent that the top-down rules and the usage rules are differently applied based on the action of the majority to adapt or reject an innovation.

2. **Institutional Adaptation to Diffusion connection:** The link between the institutional adaptation to institutional diffusion was developed when a gap of this link was seen in operationalization of the framework for the case study. This was done via understanding the evolutionary process of rule variation, rule outcome evaluation and rule adaptation.

3. **Exact effects of resource properties:** It is important to know what exact innovation was brought into and what resource properties were changed, for the usage rule to be adapted accordingly. The framework is developed further for the consumer producers based on the different cumulative effects which define the actor's choice and thus affects the innovation diffusion. Here the cumulative effects involve the different features, varieties and serial correlations in innovation of the product.

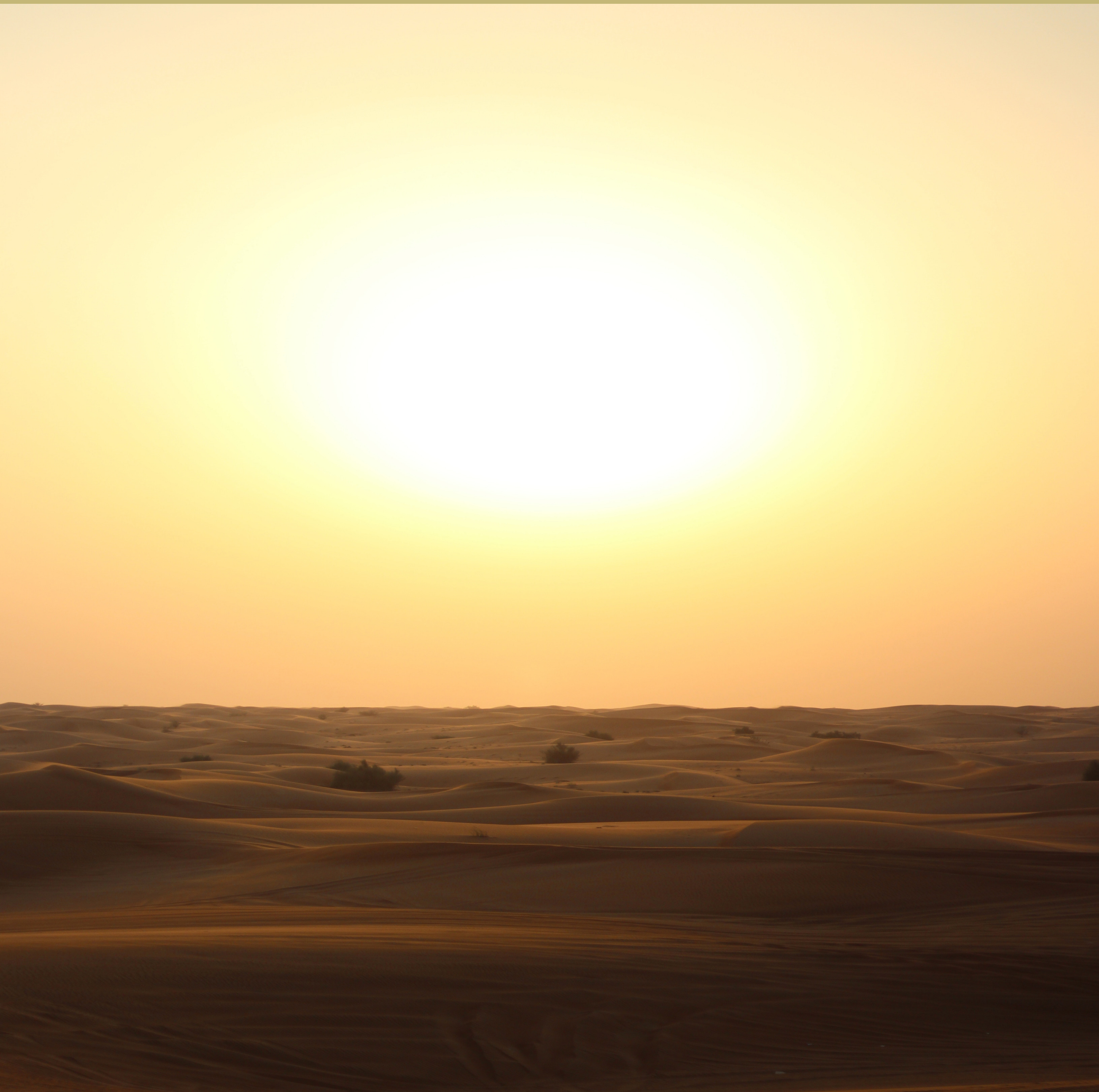
4. **Rules based on gap between resource and community:** The case study helped understand the different types of usage rules which would help the project in terms of profitability, increasing access, etc. They were developed and included in the framework based on the resource and individual utility gap (additionally, resource availability and community gap) as compensation, constraints, and prioritization/ distribution rules.

5. **Application beyond case study domain:** Based on the case study, it was also realized that the framework needs to be further adapted for similar domains, so that the framework can be applied more generally. Only considering the tp-down rules, this framework was adapted for the consumer products and the networked infrastructures. Here, the exact effect of the social, technical and economic changes in the community on the specific components of the framework was noted. For example, the technical changes happened for the varieties in the products, or performance of the product, which affected the actor's choice to adapt an innovation. This would thus affect the top down rule for the consumer products.

Additionally, studying the limitations of the thesis and the reflection on the research approach showed what could be further developed in the research. The reflection showed need of a more comprehensive approach in institutional designs by considering not just the collective actions, but also the collection of actions effect in changing institutions. In terms of tools, the usage of some other tools like Java instead of Netlogo, using system dynamics with agent based modeling, and more detailed interviews focusing on more quantitative data, was mainly noted. Furthermore, this research can be followed up with other researches to: (1) automate this institutional innovation framework and integrate in policy designing for energy distributions (or similar socio-technical infrastructures), (2) understanding co-existence of different types of socio-technical infrastructure systems like electricity and telecommunications, when all fields have continuous innovations, and finally (3) integrating the blockchain and smart contracts technology in infrastructure design for this specific case study to be realised on-ground.

# Part I: Define

Laying down problem definition and methodology



# I

# Thesis Definition

# 1

# Introduction

*Around 200 million people in rural India do not have any form of electrification. Decentralized renewable resources like solar energy allows electrification of these remote and rural habitats. Out of microgrid (MG), community-based energy sharing (Sharing) and individual solar house system (SHS) projects, the Sharing projects look to be the project which can be sustained and remain successful in longer term. But, the difficulty of sustenance of solar electrification projects due to socio-cultural, and technical hindering factors, with increasing demands of the consumers, poses questions on feasibility of the Sharing projects as introduced in Section 1.1. To answer these societal problems, a thorough context study of electrification domain especially solar at organizational and societal level inclusive of the context of rural India is done. The context study gives the insights and the research gaps emphasizing on need of a research framework for management of resources in the context of solar electrification as discussed in Section 1.2. The research gaps deliver the research questions, which are listed in Section 1.3. The final section 1.4 gives an overview to the upcoming chapters in the thesis. Methodology for the solutions to these research question is detailed out in Chapter 2.*

## 1.1. Societal Problem

Access to electricity brings agriculture development, increases literacy rates, reduces crimes and increases security, helping people get out of poverty and allowing development of rural areas (Khandker et al., 2012; Munasinghe, 1990). In spite of these known advantages, even today, around 200 million people in rural India live without electricity (Barnes, 2015; Lindeman, 2015). Considering the large demand, the first solution which seems perfect for rural electrification in India is distribution of electricity through central grids (based on large power plants: coal, hydro, nuclear). But, lack of infrastructures and unreliable institutional rules leads to major efficiency losses in distribution of the electricity from the central grid (General Knowledge Today, 2015). To overcome the issue of distribution, Government of India launched an electrification project: Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY), which is aimed at ensuring that *every village* gets electricity by connecting to the central grid or through off-grid electrification. Even if DDUGJY is successful by April 2018 [1], there is one more challenge ahead: which is electrifying *every household* in that village, once the grid has reached. The figure 1.1 below shows this issue that even though the "electrification" of villages has increased rapidly in past years, but the number of households getting this electricity has remained low (Patel; REC, 2016). The figure 1.2 [2] shows the (un)electrified number of houses and these includes around 160000 households below 50% electrification rate. Added to this, there are also issues of unreliable supply by the central grids caused due to power shortages of as long as 18 hours per day in many villages. This has made people switch from central grids to other sources like solar lanterns, even though the latter caters to much lower demands (Velayudhan, 2003).

As the central grid fails for rural electrification, an economically feasible solution for developing countries in tropical regions are off-grid solutions or decentralized energy resources(DER) like renewable energy, which

[1] The proposed deadline to achieve electrification under DDUGJY is April 2018, where a village is called to be electrified even if only 10% of houses get electrified.

[2] `https://garv.gov.in/garv2/dashboard`

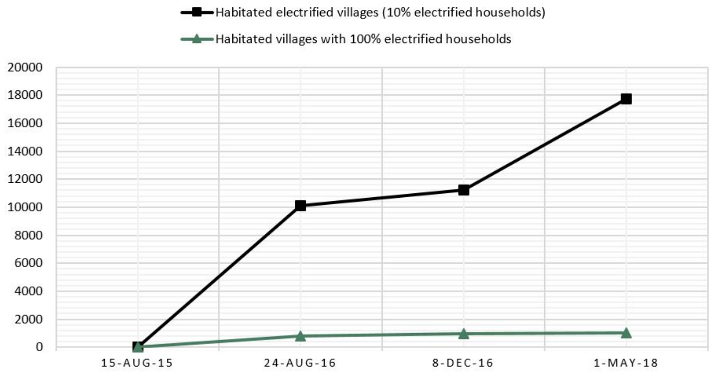



Figure 1.1: Recent trends and forecasts in rural electrification in India due to DDUGJY (Patel; REC (2016))

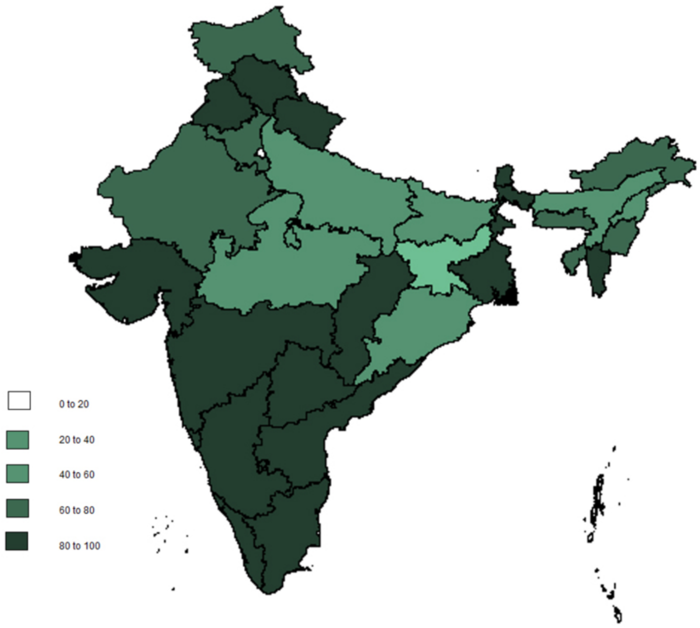



Figure 1.2: Percentage of households electrified as definition of electrification of DDUGJY (REC (2016))

are not dependent on the national grid distribution (Nguyen, 2007). In India, especially solar energy is widely available and also a feasible form of DER electrification as compared to other DER sources (Mahapatra and Dasappa, 2012; Ramachandra et al., 2011; Tripathi et al., 2016). Being an environmentally sustainable option too, many efforts by NGOs, industries and government of India in the last decade has tried to fulfill this demand of electrifying rural houses through solar energy incorporating technology and business innovations. The major types of projects installed till now are micr-girds and individual solar house systems (SHS). Micro or mini grids are owned by a village administrative body, a NGO, profit-based company, or government maintenance body (Camblong et al., 2009; Ramchandran et al., 2016). These allows energy from few sources (like solar, wind, or even diesel) produced locally, to be supplied to local households. Government of India has already invested in sixty different mini-grids in four different states in India, which impact over 13,000 people (Jay Giri, 2015). Individual solar house systems (SHS), owned by individual households are kits of a solar panel, few lamps, battery box and a charge controller. This is very common in remote places. Though the primary demand of these products is for lighting, these kits are also used in farms and for other livelihood solutions.There are also specific solutions to simple lighting like solar lanterns and they are owned by the individual households or different families in a household, but they are not in focus of this thesis as they cater to bare minimum demands of any society. The following figure 1.3 shows the physical infrastructural differences for all the four different types of projects.

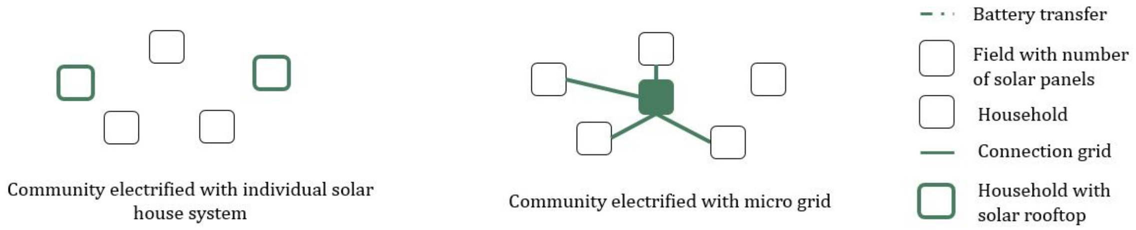



Figure 1.3: Microgrids and Individual SHS infrastructure setting

In spite of these different projects and innovations, there has not been 100% rural electrification, as the projects have not been successful in terms of implementation, continuation or scaling up of the projects. Especially the rural electrification projects are successful only if they sustain or scale up in long term (Kumar et al., 2009). Here, a project is said to be *sustained* for long term, if it at least exceeds the average time of technical failure for a given solar electrification project i.e. the project remains operational. There are other sustainability factors of economic, social and environment sustenance of a project, which comes into picture after a project is up and running, but it is not considered at this stage as the main aim is to first ensure an operational project. The reason for technical failure of these projects is due to the life of SHS components, especially the battery. The average time of batteries is not more than 5 years, though the solar panels are supposed to last much longer (around 25 years). For simplicity, based on battery life, the average lifetime of project is assumed to be at least two life-cycles of the batteries i.e. 10 years (after this households are reluctant to buy a new battery, or there are already major changes in the community discouraging continuation of the project- like introduction of the national grid in the village, lesser efficiency of the solar panels, etc.). Thus the sustenance of project here means 10 years operational solar electrification project.

There are many technical reasons due to which the individual solar house system (SHS) projects have failed e.g. the lack of maintenance of components like the solar panels. Within these technical factors, there is challenge in ensuring that the electricity remains available as per the users demand, due to limited SHS capacity. Also, there are major socio-cultural reasons like incompatibility of the solar energy product as per the social norms of the community (e.g. trading energy between different conflicting sections of community) which leads to failure of solar electrification projects. On the top of these socio-cultural and technical reasons, major reason of non-sustenance of these projects is that the demands of rural households are dynamic due to increasing populations, increasing dependence of households on technology (like mobile phones) and industry growth. These demands are very community-centric i.e. they are different for every community due to the various social, cultural, economic and institutional factors which affect the choices of the community (Singh, 2015; Trotter, 2016; Urmee and Md, 2016).

Summarizing based on the different socio-cultural and technical factors hindering electrification, the projects which needs to be brought in for solar based rural electrification needs to address two main questions for assuring a long term sustenance of the project: (1) how can every household be reached in spite of these factors, and (2) once every household is reached, how can the effects of dynamic demands of the communities be incorporated to prevent failure of the electrification project? So, first, to reach every household, there is need of connectivity of all households to the source of electricity. Not everyone can afford a SHS in a village, due to the socio-economic structure and prevailing poverty. Thus, solution of individual SHS does not fit here. Second, the source should be able to fulfill the dynamic demands of the community, building a flexible network. This requires to understand clearly that how communities adapt a given technology, and how the demands would thus change for a community. Micro-grids have external stakeholders (like NGOs, governments) for operation and maintenance of the grids and this makes it difficult for them to understand or communicate the changing demands of community. Also, the dependency is usually on 1-3 big sources of energy which decreases the reliability of the network because if one source fails, the network collapses. Also it should be noted that the "household choice in system sizes is often too restricted in donor-funded projects (Nieuwenhout et al., 2001)" like in micro-grids.

This brings us to the solution of the community-sharing projects, which provides a much higher flexible network due to choice to switch between the sources. Community-shared projects, with many producers in the community [3] allows households in the communities to share their individual SHS produced electricity with others. Here, the ownership is distributed based on different tasks like distribution, operations, etc. among the households, operating company, solar panel providing companies and villagers. Others may not own SHS and thus they can still get electricity via a network between the houses. These projects are of two types, which allows (1) grid and distribution lines based electricity sharing i.e. electricity can be shared through a grid laid between the houses or major hubs in the community. The other type is the one which allows (2) battery and device sharing, where electricity can be shared physically via the sharing of batteries or battery based devices which are charged from the solar panels on rooftop. The physical infrastructure setting of such projects can be checked in the following figure

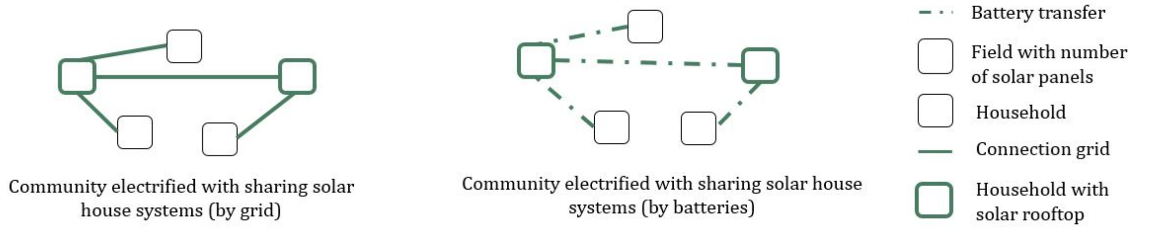



Figure 1.4: Community-based Solar-energy Sharing projects infrastructure setting

Additionally, community-sharing projects has producers and consumers as the community households themselves. This allows incorporating and understanding communities' demands much easily. Though the Community-based Solar-energy Sharing (Sharing) project look to be good solution here, they are not very common type of solar electrification project yet, as it fairly new solution with a peer to peer sharing market setting, and its installation depends on an existing infrastructure with communities having individual SHS. Thus, the hypothesis needs to be checked that whether these Sharing projects are actually feasible. Feasibility is important to be answered as Sharing projects are fairly new solutions and not tested in markets to a major extent. Also, it is important to understand if Sharing projects are a better solution or not than the micro-grid and individual solar house system, provided different socio-cultural and technical factors in electrification. If they are a better solutions, then it is important to understand what is their potential to accommodate future demands, and what would help their successful implementation and sustenance. If they are not a better solution, then it is important to understand how the microgrid and individual SHS can be sustained as electrification solution. This brings us to the societal problems and pressing questions to be answered in the course of this thesis:

1. Are sharing projects feasible electrification solution as far as the regulations and the demand for electrification are concerned?

2. Are sharing projects better electrification solution as far as catering to the socio-cultural and technical hindering factors for electrification in the community of rural India? If no, what other type of projects can provide electrification in long term?

3. What policies or rules can help these solutions be sustained for long time while catering to the dynamic demands of the community?

### Societal problems addressed in the thesis

- Questionable feasibility of the sharing projects
- No sustained and successful solar electrification projects
- Lack of policies and rules for sustenance of solar electrification

[3]Throughout the research, the definition of community is established as the Merriam-Webster dictionary - "a body of persons having a common history or common social, economic, and political interests"

## 1.2. Research Gaps

Based on the societal problems, and a detailed context study as laid out in Section 5.1 helped in giving some further insights into the solutions.

1. *Feasibility of Sharing projects:* The context study answers about the feasibility of the Sharing projects positively, as following:

   (a) *Organizational insight:* The problems in electrification in India can be traced to the distribution companies' failure and the policies of licensing, barring the market entry to new comers like the energy act of 2003. At the same time, due to the new policies and technologies by MNRE, opportunities like real time tracking of electrified villages, setting up of state level funds and local loans have opened up: facilitating entry to the new comers again. This has opened up a more innovative and competitive energy market. Acts like PPA are allowing more easier sharing and open transactions of solar energy.

   (b) *Demands of rural India:* It is far fetched to use solar energy for cooking purposes. But for the lighting purpose, it has shown a major demand rise in India, and households have shown interest in using solar energy for heavier demands like electronics devices.

   (c) *Rise of solar electrification:* Solar energy has shown to have lowered tariffs and highest potential in rural electrification sector, even for the future with potential of 41% of the renewable energy market of India. Thus, networked solar electrification projects like micro-grids appear to be technically more feasible option as compared to the individual SHS systems in rural India, to cater to higher demands and ensure sustenance of the project.

2. *Factors affecting and the definition of success of rural electrification projects:* The major categories of the factors affecting rural electrification are social, political, technical, market and institutional i.e. dealing with the socio-cultural and economic (labeled as "social" here) dynamics of the community, political and institutional dynamics of the actors involved at formal and informal level and finally the technical and market dynamics of the technology and the infrastructure. The major factors which allow measuring success of electrification project is based on Affordability, Viability, Reliability, Long term Sustenance, Profitability, Equal accessibility, Socio-cultural Sustainability, Political Sustainability, Environment Sustainability.

As seen in insights, there is no complete solution which could be found within the existing context literature. This has helped define the knowledge gap, which would be studied in detail in the upcoming chapters.

1. Some researches discuss about the changes in community with the introduction of electricity. But, there is no available research which studies that how the community demands evolve in rural India, with the onset of given Sharing project. Also, there is no research which talks about the time after which people start finding these electrification sources not fitting their demands, and discard them, leading to project failures and how this can be solved. Such approach is studied extensively for natural resource systems, essentially as developed by Ostrom et al. (1994). But, this type of understanding is not available at an extensive level except for few as by Künneke and Finger (2009) for socio-technical infrastructures.

2. Throughout the literature, there have been some comparisons of microgrid and individual SHS projects, but there is no comparison of those with the sharing project. In fact, there is no literature on sharing energy via Sharing projects in rural India contexts, especially considering the institutions, market and technical settings in rural India.

**Research gaps addressed in the thesis**

- Understanding effects of dynamic demand of the communities on sustenance of solar electrification (and similar projects of socio-tech infrastructures with constant innovation)
- Comparative study of different types of projects including Sharing projects

## 1.3. Research questions

The above sections highlight the context of the rural electrification emphasizing on the factors affecting rural electrification, and gives further insights delivering the research gap. This helps develop the relevant research question and the sub-research questions for this case. The main research question, broken down into further sub research question here, is: ***"Given the dynamics of rural communities of India, how can socio-technical systems of solar electrification be sustained?"***

- Which frameworks can help study the effects of all dynamic factors (i.e. socio-cultural, technical and economic factors) combined on the solar electrification systems in rural context?
- If there is no framework available, how can a new framework be developed to study the effects of all dynamic factors combined on the solar electrification systems in rural context?
- What are the existing effects of the different dynamic factors on the solar electrification in rural India?
- Given the developed/ existing applicable framework,
  - how can the the effects of the combination of dynamic factors on the solar electrification be obtained?
  - what are the effects of the combined dynamic factors on the solar electrification in rural India?
  - what new policies and rules can be developed which would help change these effects to improve sustenance of the solar electrification in dynamic context?

## 1.4. Storyline ahead

The aim of the thesis from here onwards would be to answer these research questions and it will be done in different phases of thesis. These phases or parts of the thesis are divided as defining, designing, applying, and re-designing and each part is further divided into further chapters. The following figure 1.5 gives an overview of the storyline of the thesis.

| Part | Part title | Chapter | Chapter title |
|---|---|---|---|
| I | Define: Thesis Definition | 1 | Introduction |
| | | 2 | Methodology |
| II | Design: Institutional Innovation | 3 | Literature review |
| | | 4 | The institutional innovation framework |
| III | Apply: Application to rural solar electrification | 5 | Context study and empirical analysis |
| | | 6 | Conceptualizing electrification projects |
| | | 7 | Simulation Models |
| | | 8 | Scenario and policy testing |
| IV | Re-design and learn: Conclusion and Reflection | 9 | Discussion |
| | | 10 | Conclusions and Recommendations |
| | | 11 | Reflection |

Figure 1.5: Thesis storyline

Based on the posed research question, the next step is to develop the methodologies which will help answering the questions. This is discussed in the next chapter 2, which lists down all the methods and the reasons why these methods are preferred. This summarizes Part I on definition, which goes from the societal problem to the context research, breaking it down to the research questions and the methodology.

Part II on design, develops theoretical framework which can be further used to apply the theory in next Parts of the thesis. The first chapter 3 in this part discusses the current frameworks in the literatures, which would help in finding the solutions to the posed research questions. As there is no clear framework available, a new theoretical framework is developed, as discussed in chapter 4.

The Part III on application, uses the theoretical framework developed to be adapted for the rural solar electrification case of India. To achieve this, the first stage is to gather the empirical data via interviews covered in chapter 5. The interviews help set up the qualitative and quantitative data to develop the conceptual and the simulation of the real case via an agent based model in Chapter 6 and Chapter 7, respectively. More simulations based on the scenarios and the policies is done in the following Chapter 8.

The Part IV on re-definition, not only synthesizes the results from the developed model and develops conclusions on the research questions with recommendations for the energy providing firms and the local governments, but also goes back to redefining the theories based on the application and results of the case study. Chapter 9 helps reflect back on the theory using results of case study and applying it to further domains. Chapter 10 reflects on all the research questions and shows the scientific and the social contribution of the thesis. It also discusses the limitations of the research and suggestions for future research. Finally, Chapter 11 reflects back on the whole journey of the author with focus on the research approach.

# 2

# Methodology

*Based on the research questions developed in last chapter 1, this chapter lays down the methodology to answer the research questions. The first step answering the first research question involves a literature review as laid out in the Section 2.1 to understand the given frameworks which studies the effects of different factors on solar rural electrification. The second research question needs understanding of the current context in more depth and thus involved empirical research via interviews as discussed in Section 2.2. This section helps finding the effects of actions of community and individuals on the electrification project. The third research question demands using the frameworks and the current context to be developed to a model as discussed in Section 2.3. Finally, Section 2.4 lays down the final detailed outline of the thesis.*

## 2.1. Literature Review

Based on the last chapter, every research question laid out is answered by a method. The relation of the research questions and the methodologies can be seen in the following Table 2.1.

Table 2.1: Methodology as per research questions

| **Research Question** | **Methodology** |
|---|---|
| Which frameworks can help study the effects of all dynamic factors combined on the solar electrification systems in rural context? | Literature Review |
| If there is no framework available, how can a new framework be developed to study the effects of all dynamic factors combined on the solar electrification systems in rural context? | Framework Development |
| What are the existing effects of the different dynamic factors on the solar electrification in rural India? | Interviews |
| Given the developed/ existing applicable framework, how can the effects of the combination of dynamic factors on the solar electrification be obtained? | Conceptualisation for simulation model |
| ..what are the effects of the combined dynamic factors on the solar electrification in rural India? | Simulations: Agent Based Modelling |
| ..what new policies and rules can be developed which would help change these effects to improve sustenance of the solar electrification in dynamic context? | Policy and Scenario testing: Agent based modelling |

The first research question "*Which frameworks can help study the effects of all dynamic factors combined on the solar electrification systems in rural context?*" is answered by a thorough literature review. This methodology helps to go through different frameworks adopted across literature and developed for understanding the effects of social, political, technical, market and institutional factors on the rural electrification in general. The initial context study as described in section 5.1 already covers the individual factor effects on the rural electrification projects. The aim here is to find the combined effects of all these factors on the sustenance of the project.

The focus keyword remains "rural electrification" here and not "developing countries" or "India" for context, or even the "solar" electrification. Only once these frameworks are found for rural electrification, the aim is to look for more focused contexts in literature for developing countries, India, and/ or solar electrification projects. The other possible depth is to look at possibility of using these frameworks for dynamic communities i.e. applicability of these frameworks when there are significant changes in these factors.

If such frameworks are not fulfilling the demand of understanding dynamic factors' effects, one of the ways is to look at technology as a resource which is owned by the community and consumed as per their changing demands/ other factors. The community management of resources developed for natural resources can help understanding such frameworks. Further attempts of adapting these frameworks for the socio-technical infrastructures can be studied in depth.

As these frameworks are not developed for technical systems, it is important to understand that how technical systems are consumed and adapted in a community, like those understood in the innovation diffusion theories. A combination of the innovation diffusion and the community management theories might help in developing a new framework which can be adopted for the specific rural solar electrification context of India.

Focus keywords for literature review in SCOPUS, Web of Science and Google Scholar:

1. Rural AND Electrification AND Success Factors AND Framework OR Dynamic OR Social OR Cultural OR Economic OR Technical OR Feasibility OR Profitability OR Demands
2. Rural Electrification AND India AND Solar OR Developing countries OR Emerging countries
3. Community Management AND Common Pool Resources OR Infrastructures OR Networks
4. Community Management OR Institutions OR Energy Sharing OR Rural OR Electrification
5. Innovation Diffusion OR Institutions OR Energy Sharing OR Rural OR Electrification
6. Community AND Innovation Diffusion OR Institutions OR Energy Sharing OR Rural OR Electrification

## 2.2. Interview

After developing or finding a framework based on the literature review and/ or theoretical development, for adapting the framework for a new methodology, interviews with the experienced personnels in this domain is important. Most of the interviews are semi structured because the exact information to be gained or the answers to be obtained are not exactly known, and there might be some interesting insights from interviewees discussing their peculiar experience. This methodology is detailed out more in the chapter 5. The interviews are done in three stages: the first one is done with the community to answer the first societal gap and understand the feasibility of the solar energy sharing project: if the people are ready to share solar energy. These interviews are informal semi structured qualitative interviews. The second set of interviews are focused on on-ground experiences from the relevant (based on solar electrification) practitioners. These are semi structured qualitative interviews again, with some quantitative questions. Additional to getting more depth understanding of the social, technical, market factors and their influence, this helps understand the different institutions in the rural communities while dealing with electrification. The final interviews are done with few of the practitioners to validate the assumptions to design model. Here the assumptions are validated simply with a yes or no answer and if the assumption is incorrect, the practitioner correct the assumption.

### 2.2.1. Stakeholders

Interviewees from three micro-grids projects: “Gram-Oorja" based in Maharashtra, "Mera Gao Power" based in Uttar Pradesh, and “Gram Power" based in Uttar Pradesh, are involved in defining the institutions (formal and informal) and validating the hypothesis of the models around micro-grids including socio-economic, institutional, technical and environmental factors. Next, Stakeholders from community-sharing based projects:

*Rural Spark* based in Uttar Pradesh and *Sol Share* based in Bangladesh, help as above micro grid projects, and added to it, they are also involved in understanding community based assumptions (like trust in the community) around energy sharing rural electrification projects. Also, individual solar house system based projects: *Piconergy* based in Maharashtra (urban context) and *Barefoot College* & *Manthan* based in Rajasthan (rural context), Selco and Simpa (Northern India) give an added view to the difference in urban and rural electrification project settings. Finally, a Delhi-based think tank *CEEW, India* (Centre for energy, environment and water) is involved in validating the hypothesis and models, due to their experience in the working in rural electrification and Indian institutions' perspective. All of these practitioners are critically involved in checking the hypothesis and deliverables around the pricing mechanisms, community and consumers behavior.

### 2.2.2. Choice of Projects

The existing solar sharing projects in India are usually in the form of micro-grids with major one or few big sources of solar energy - generally in the form of PV solar panel arrays (the mentioned above will be used for the case study here). The case-study to develop the model of the microgrid is used from the interviews based with *Gram Oorja*, *Boond* and *Mera gao Power*. Other interesting sharing based innovative project is the one by company called *Rural spark*, which allows few shops/ houses to buy individual SHS. These shops charge some solar "cubes" which are basically small batteries and these cubes are rented to the people who cannot afford buying the entire SHS kit. The other type of sharing involved here along the cubes is the sharing of the devices which are charged by the solar panel. This is a non-physical type of solar energy sharing. The other type of sharing which is based very close to India is incorporated by *sol-share* which uses a "sol box" in every household with or without electricity and allows sharing of electricity based on a swarm optimization algorithm. The aims of these project being profitable business models is to expand and increase their networks, and become as optimized as possible catering to exact user demands. This ensures longer usage of their products. This project would be the main case-study of this thesis. These systems have an interesting element of pay-as-you-go model which allows paying remotely and only as per the amount of usage.

Interviewees and the interview stages:

1. First Round for understanding feasibility of sharing projects: Informal interviews with communities at Manthan (SHS), Rajasthan (Northern India)
2. Second Round for problem definition and research gaps: 4 Research Interviews based in CEEW (India), TU Eindhoven, and 2 with TU Delft researchers in DC (Direct Control) Systems and Anthropology
3. Third Round for empirical analysis: 2 sets of 9 interviews with projects leaders of Microgrids, Individual SHS, Sharing Projects
    - Microgrids: Gram Oorja in Maharashtra (Western India), Mera Gao Power and Gram Power in Uttar Pradesh (North-Western India)
    - SHS: Selco, Simpa, Piconergy, Manthan (All in North India)
    - Sharing: Rural Spark in Uttar Pradesh and SOLShare (Dhaka, Bangladesh)
4. Fourth Round for Model Validation: 2 sets of interviews with Sharing Projects (Rural Spark)

## 2.3. Agent Based modeling

After the interviews with the stakeholders to understand the existing institutions in the rural electrification in India, the qualitative data would be used to develop an agent based model. The agent based model or ABM, would be first conceptualized using the theoretical framework and the MAIA framework which would be explained in detail in chapter 6. MAIA framework as developed by Dr. Amineh Ghorbani is based on the IAD framework and allows to breakdown the socio-technical system to the parameters that we wish to define in a computer model. MAIA helps define physical, collective and constitutional structure for a model, followed by the operational and evaluative structure. The first three lay down the context of the case, while the operation lays down the exact actions of the actors as action sequences. The evaluative structures defines the evaluation of the model to compare the model with reality. After conceptualization the next step is to develop ABM. In ABM, major agents are the households and qualitative data would be incorporated in these models here. Here, the two main deliverables would be to understand the sustenance of the project.

### 2.3.1. Why agent based modeling

Agent based model is preferred here as it is the most flexible method to model the system (here energy system or electrification) from the perspectives of the involved stakeholders. Also, there are studies which have incorporated modeling markets (in this case, energy market) and rural systems, from perspectives of CPR theories which would be supportive here. Ghorbani, Amineh; Dijkema, Gerard; Schrauwen (2015). Major models that could be investigated were in the field of Agent based modeling(ABM) as it deals with more different households as the decision makers for a given community which can be modeled as agents in the model Schlüter and Pahl-Wostl; Verhoog et al. (2013). Also, the behavior of these households changes (the dynamic demand) and ABM facilitates such design of agent. Some of such models dealt with groundwater management. These models were prevalent to show the tragedy of commons issues and were focused on the resilience modeling for CPRs Bueno and Basurto (2009); Bueno (2009; 2014).It should be noted that the majority of the data that would fit in such models would be qualitative and thus needs to be handled differently Ghorbani, Amineh; Dijkema, Gerard; Schrauwen (2015). On-ground study based on the experience of practitioners can help here too via interviews. But as seen in the gap of the study and discussed in length in section, the innovation diffusion model would be combined with the institutional change perspective.

### 2.3.2. Model Designing

Here, the data would be gathered from the existing projects and the factors would be ordinal. For example, the factor of community cohesion, which is a cultural factor, can be given a scale on level of cohesion. Some of the factors can also be nominal like role of individuals in family or community. Majority of the data would still be numeric like the socio economic level of the people and it would come from census of India ORGI(Office of the Registrar General & census cmmissioner India) (2011), government rural electrification project websites REC (Rural Electrification Corporation Limited) (2015), data from the think tanks like CEEW Aklin et al. (2016) and world bank data Bank (2016). This data would also be supported by the interview results brought in by the communities and the other stakeholders. The interviews (preferably twice) would help in designing and validating the ABM model. The data would necessarily be used in validating the models created, especially the one with the intelligent framework for chosing project as per the different factors.

Due to major role of community in the decision for resource (Sharing based electricity or electricity) management, two models would be designed for comparison: Model 1: based on micro-grid and Model 2: based on community shared solar energy sharing. Due to more information available from the stakeholder of the battery and device based energy sharing model then simple energy sharing model, preference of modeling is given to the latter. The experiments and scenarios are developed for the models by varying the variables and introducing various future scenarios and different market mechanisms like pricing mechanisms. These experiments help in understanding based on various success parameters if a project is better than other and on what grounds. Different policies introduction can help understand which models work better and finally, if there is need of some new types of models.

Validation of the models and results with practitioners would follow based on interview. This is important, as agent based models are developed here with a limited perspective of the energy providers at an earlier time reference. The validation interviews help in checking on the model assumptions and the model behavior. It would be checked that how close it behaves with respect to the reality. The verification of the models would be done by dividing the models in smaller modules/functions and each function will be checked if it behaves as it should, irrespective of the other function. For example, the selling action of the energy would be developed as one function, and appointing producers would be another function. This would be detailed out in the Section 7.1.3 and 7.1.4.

## 2.4. Thesis Structure

All the methodologies and their results developed based on the research question requirements are shown in Figure 2.1. This reflects the flow of the thesis as well which helps reader understand the choices made by the author for going from one method to another to give the final set of solutions and recommendations.

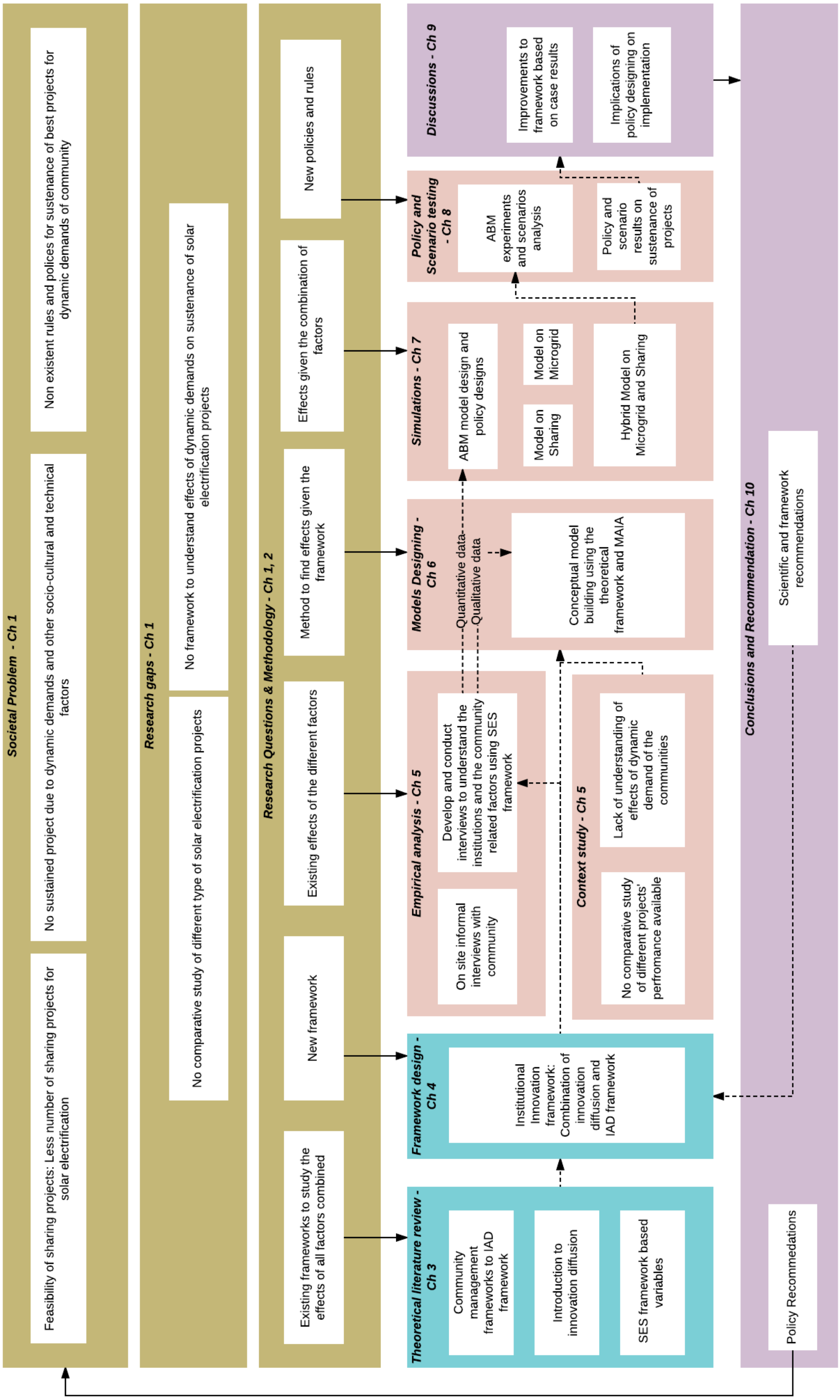



Figure 2.1: Thesis Structure

# Part II: Design

## Growing communities and innovation

# II

# Institutional Innovation

# 3
# Literature review

*As mentioned in chapter 2, a thorough literature review of different available frameworks to understand the effect of different socio-economic to technical factor is done. As no available framework could be found as a perfect fit which understands effect of different factors on technology, another approach of understanding the management of resources by community wold be studied. These studies are mostly done in the context of common pool resources and especially natural resources as discussed in Section 3.1.1, but research has been initiated in the direction of using the community-management theories for electricity market as explained in Section 3.1.2. It is important to specifically understand the community-management related factors in context of India and this is discussed in Section 3.1.3. From these different studies, Institutional Analysis and Development Framework developed by Elinor Ostrom and Socio-Ecological Systems Theory is chosen to be used to understand the changing community demands and individual actions as discussed in section 3.1.4.*

*As solar energy based electricity is an innovative technology, especially with the sharing projects, the role of innovation diffusion is strong on the individual actions as discussed in section 3.2.1 and concluded in section 3.2.2. Section 3.3 concludes the literature review with the final theories which can be used as framework for studying the effects of the different dynamic factors. The final framework uses these theories in combination and detailed out in Chapter 4.*

## 3.1. Towards community management

As factors affecting rural electrification are known, it is important to see that if and which frameworks have developed to determine a successful rural electrification project (Note that all these frameworks are not in context to India, but developing countries). The study by Urmee and Md (2016) develops a framework, based on the diffusion of innovation and the social, cultural and political(institutional) factors. It shows that how different segments of given consumers *accept* a new technology when introduced in rural electrification perspective, and how it can be speed-up by considering different consumer segments Urmee and Md (2016).

Another study shows a different perspective, conducted by Jain and Kattuman (2015) shows a "project planning and decision-making framework for decentralized rural electrification." This study takes in all the key determinants like physical characteristics of area, socio-cultural, socio-economic factors and assessment of resource potential and electricity needs, to deliver pricing, technology, operations and maintenance, scale of service and such strategic decisions for a project. This framework also considers financial, social, operational and environmental sustainability aspects.

Both these frameworks are insightful to see the effects of consumer adaptation based on different factors to the sustenance and success of projects. But none of the two or the available frameworks clearly reflects on how the changes in these factors e.g. dynamics of the societal structure changes would affect the project's sustenance and success and to what extent.

There is need of a more concrete approach to understanding the effects on the project due to the community demands. One of the ways is to look at the demands of communities as a whole and manage them. Existing policies and organizations work for resource management at higher level of governments i.e. at national grid distribution and generation. The local governments work at a district or a complete village level, but there is no organizational structure at community levels. Some of the resources talk about individual management of resources e.g. the operation and maintenance tasks and the choice of technologies in their given economic states, etc.

There is a major research gap that lies in understanding management of solar electrification projects from the perspective of communities. It is important to understand the effects of communities' demands at a closer level. Thus, the next step is to study the evolution of demands of the community for assuring the sustenance of Sharing projects i.e. how the changes in both the community and technology would affect each other. In other words, how do communities manage a given technology.

Solar electricity as common pool resource and managed by community:

- As Sharing based Electricity is also a technology which is a limited resource, and it is shared among community (though owned individually), it is a common pool resource.
- The existing research on community management of limited natural resources as developed by Ostrom et al. (1994) can give some insight into existing frameworks which try to manage these resource systems.
- This community management perspective is further extended by Künneke and Finger (2009) for managing non-natural resources as common pool resources.

### 3.1.1. Natural resources

The community management study of limited natural resources is exhaustively done by Ostrom et al. (1994). This study was done for the management of common pool resources with aim to prevent their depletion or excessive use. Common pool resources are non-excludable and subtractable i.e. people not paying cannot be excluded easily from using these resources, and the resource deplete with increase in number of users, respectively (Ostrom, 2015; Ostrom et al., 1994). It should be noted that Sharing based electricity is a type of socio-technical system because the technology can only succeed by understanding the household and community demands (Wolsink and Others, 2014). Now, to check that whether Sharing based electricity is common pool resource, its limited nature can be checked: "Access to the resource is limited, because of the spatial requirements linked to limited resource-rights and property (rooftops, land)" (Wolsink and Others, 2014). Additionally the battery packs have a discharging limit and the uncertain weather conditions may not guarantee full time availability of the resource, making the resource limited. If such a network of SHS is large enough, it becomes difficult to make it excludable.

The general characteristics of the common pool resources system fit well for the Sharing based electricity infrastructure here as (Ostrom, 2010): A large number of participants (here, the number of consumers and producers are the households themselves); Legal uncertainty (existing legislations are vulnerable to quick changes due to the developing markets and rapid industrial growth, changing the *rules* which would be discussed in next subsection); Asymmetric interests (changing authorities, conflicting consumers and citizens demands); Lack of fit between "problem" and governmental units (involved governing bodies are larger than the geographical area of the energy sharing community). As mentioned by Ostrom: "Citizens are an important co-producer. If they are treated as unimportant or irrelevant, they reduce their efforts substantially" (Ostrom, 2010), which reflects in this case clearly as households are producers and thus they get enough benefits or at least see themselves as an important part of the CPR.

All these CPR management discussions are primarily done in the field of natural resources like water management, fisheries, etc (del Mar Delgado-Serrano et al., 2016; Madani and Dinar, 2013). Here the objective is to use the resources cautiously yet satisfactorily for the community. Theoretical models are developed and tested for different types of institutional settings like non-cooperative institutions with ignorant and smart myopic management, where individual and community rationality are taken into account based on short term profits and considering heuristics.

**IAD framework:** Now that it is established that these resources are CPR, the next step is to understand the Common pool resources (CPR) management. Ostrom and her colleagues have developed the Institutional analysis and development framework [IAD] (Ostrom, 2011b; Polski and Ostrom, 1999) to carry out the

CPR management. This framework tries to identify different types of variables present in a given institutional arrangement. As explained by Vernon and Hayami (1984): "Institutions are the rules of a society or of organizations that facilitate coordination among people by helping them form expectations which each person can reasonably hold in dealing with others." This takes in account the biophysical conditions, the attributes of the community, the institutional (informal and formal) rules in use and generate some “action situations" which result from interaction in the communities, resulting in outcomes in terms of social and ecological performance measures.

The action situation discusses how and what outcome is achieved due to position of an actor in the given position. Here, the actors interact, exchange goods and services, solve problems, dominate and fight. Here, clusters are formed for variable based on what actors bring in to a situation, what valuation actors assign to states of world, way actors use for selection of particular course of action, and finally the way they acquire and retain the knowledge. This framework helps in evaluating and predicting outcome based on this interaction in terms of economic efficiency, accountability, conformance to values of local actors, equity, etc., as shown in figure 3.1

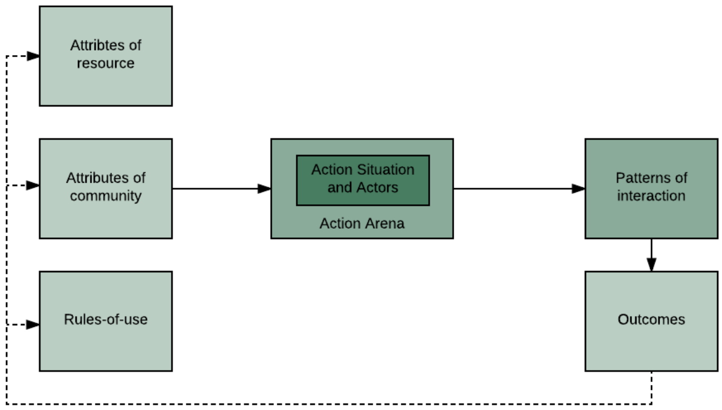



Figure 3.1: IAD framework

**SES framework:** The next study in the Socio-Ecological Systems is a modified version of the IAD framework which tries to identify the exact variables that "affect the likelihood of self-organization in efforts to achieve a sustainable SES" (Ostrom, 2007; 2009). In other words, it gives framework based on the given social settings for analyzing outcomes in SES. It introduces four main features which leads to community members to interact: Resource systems (e.g. water system, specified territory with forested area), Resource Units (e.g. Amount and flow of water, Trees in the area), Governance systems (e.g. the government or other organizations managing the resource system), and Users (e.g. individuals using the units). The governance systems interact with the users, and the resource systems interact with the resource units leading to the outcomes, which in turn affect these four components. There are sub units like sector, size, productivity of resource system, etc., as shown in 3.2.

Other similar frameworks for natural resources are given by Oakerson (1990) and Edwards and Steins (1998). Some specific framework developed in the context of particular fields of resource management are given by Tang (1992) and Grafton (1996). These and other theories are further discussed in the Section A.2.

### 3.1.2. Non-natural resources

CPR management researches have been done in the field of non-natural resources extensively too like digital commons (Van Laerhoven, 2007) and infrastructure services, where infrastructure service is referred as a CPR and the relevance and gaps to fit CPR management theories have been identified by Künneke and Finger (2009). Here Kunneke points out that the infrastructure is not completely fitting the IAD framework, but it is still highly relate-able to CPR due to the non-excludable and subtractable nature of energy. The CPR problems here as the congestion, investment, lack of robustness, etc. and the simple solutions like government ownerships never work because of many reasons like changing social expectations, technologies, etc. Thus, he proposes to use a “diagnostic approach" as proposed by Ostrom to identify synergy between subsystems like

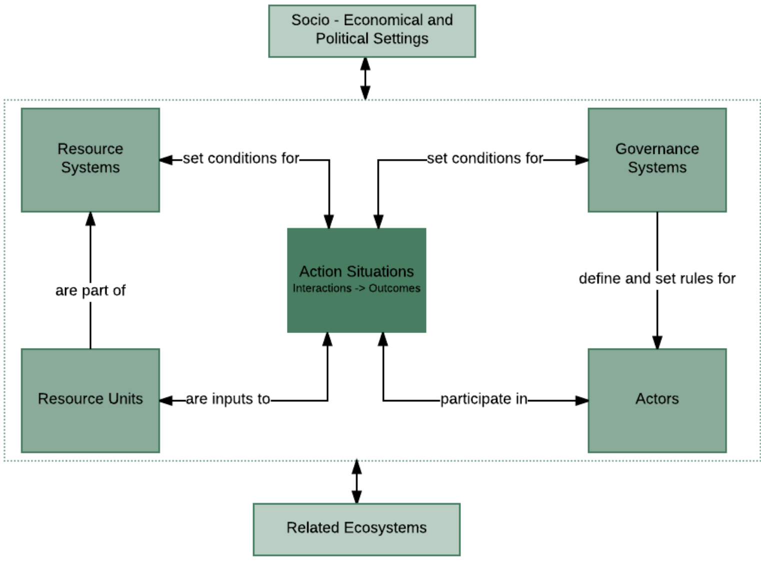



Figure 3.2: SES framework

the social, economic and political systems. Thus, though this framework raises good questions to understand CPR problems in electricity and other infrastructures, it still lacks in clearing out the definition of "resource units" and "resource systems". Also, definition of capacity management regimes for different infrastructures would not directly fit the CPR concepts and theories.

### 3.1.3. Indian context

Important factor close to Indian institutions is that the major decisions are taken by informal institutions and social norms rather than the formal organizations. This approach is also studied in various literature (Helmke and Levitsky, 2004; Madani and Dinar, 2013; McGinnis and Ostrom, 2014; Ostrom, 2009; 2011a). A diverse population set is the characteristic of Indian community and thus, how CPR would be managed by a heterogeneous population is of interest here (Gaspart and Platteau, 2007; Janssen, M. A.; Ostrom, 2006). At the verge of the research between the CPR management and the social and cultural factors, a major factor very aligned with India's social setting is about inequality. A lot of research has been done to understand that how inequality affects CPR management (Baland and Platteau, 1998; Bardhan et al., 2007; Jean-Marie Baland; Jean-Philippe Platteau, 2002; Justino, 2015).

This study can help understanding the impact of the caste systems in India on CPR management. Trust plays a major factor in a community and this is studies extensively for CPR management, especially using the micro-situational and broader contexts (Poteete et al., 2010). Here, the idea is that when few individuals initiate cooperation in repeated situation, others learn to trust them and willing to adopt reciprocity increasing the level for cooperation. Being trustworthy is gaining a reputation in this case and thus trust and reciprocity are mutually reinforcing, and decrease in one may lead to lack of cooperation.

**Peculiar Indian community parameters important for CPR management:**

- Trust within community members
- Heterogenity due to different divides
- Negative word of mouth by influential leaders

### 3.1.4. Final theory: IAD and SES

Now that different frameworks are known, the next step is to determine that which framework(s) suits the best to incorporate these dynamic demands. The best possible combination here looks to incorporate the study by Ostrom in IAD framework, and the SES framework. The combination allows to study the evolution of rules, technological innovation, and consider the different specific variables effecting the outcome for resource sustainability. The SES framework gives the variables which are important to be considered, while the IAD framework allows to see that which institutions and demands are affecting the actors' action and affecting the outcome, which are again leading to development of the institutions. This combination thus fits the CCSE resource, where the innovation is fast and the community demands are dynamic. This is the first step to understand the effects of dynamic demands due to a technology and vice versa as posed in the first research gap. As seen in the Table 3.1, the multi-use framework also looks to be a good fit for this case, but there is lack of implementation cases and thus the reliability of this theory for socio-technical or even socio-ecological fields. Also, there is no need of a theory here which would cater to multiple resources or multiple uses of resources as the focus here is only electrification and the next level usage of electricity is out of the scope of this study.

Table 3.1: Comparison of different CPR management frameworks

| | IAD | SES | Oerksen | Multi-Use Common | Tang | ITQ |
|---|---|---|---|---|---|---|
| Allows dynamic update of community rules | X | | X | X | X | X |
| Gives list of community variables to be included in the analysis | | X | | | | |
| Includes properties of the resource | X | X | X | X | | X |
| Allows using more than one specific type of resource | | | | X | | |
| Includes community properties - flexible | X | X | | X | X | X |
| Used for different case studies | X | X | | | | |
| Allows different resource actor relations | | | X | | | |
| Introduces specific mechanisms to prevent resource depletion | | | | | | X |

**Solar electricity as common pool resource and managed by community:**

Thus, the final theories for community management here include IAD and SES theories, where both fit well as per the dynamic community context, exhaustive inclusion of different community and resource properties, applicability to different cases and other such characteristics.

## 3.2. Innovation diffusion

As can be seen till the above section, the IAD and SES framework helps understanding the community management of resources. But this works when the demands of the community are fairly stable. When the individual demands change, which affect the total demands of the community, new institutions/ rules are required to manage the resource limit. This can only be done by understanding that how individual demand changes at the first place, which would further influence the demand of the community.

Urmee and Md (2016) discuss the innovation diffusion theory for the rural electrification market to show that how any innovation affects an individual's action in a community. They also show that how different sections of community based on their time of adoption (in ascending order - the innovators, early adopters, early majority, late majority and the laggards) accept an innovation differently and what are the parameters which influence their respective choice positively in case of rural electrification as shown in Figure 3.3.

Innovation diffusion here can help in answering that how long would it take for any villager to adopt the electrification solution and who will be the next adopter at a given point of time. Many theories have been developed for innovation diffusion and the following section discuss the existing theories before choosing the most suitable theory for this case.

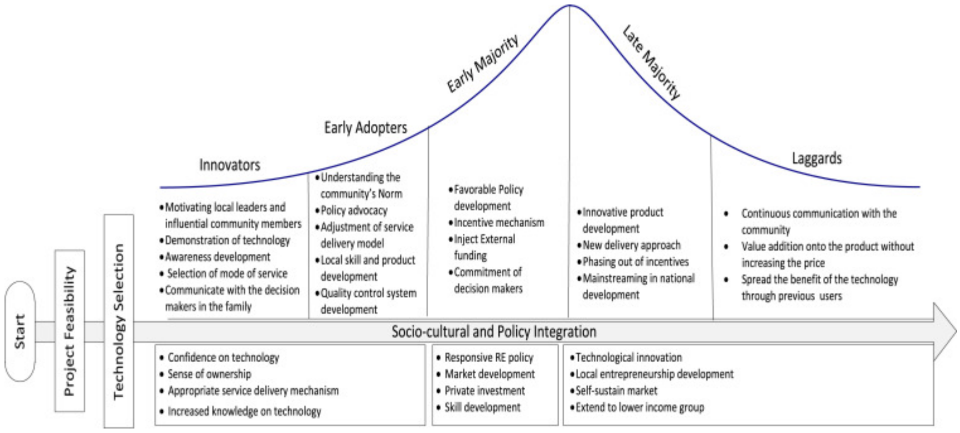



Figure 3.3: Diffusion of innovation parameters and affecting policies for rural electrification (Urmee and Md, 2016)

### 3.2.1. Overview of theories

Different theories from literature on innovation diffusion is studied and this section discuss the summary of the literature studied. A more detailed analysis of this literature can be checked in the appendix A.

***Word of mouth:*** Usually, there are two types of influences for innovation diffusion: internal and external - the internal one is generally the word-of-mouth based communication within community and the external one is the mass media or the external effect as the marketing campaigns or introduction by a political leader. These influences can be shown as an equation 3.1 below, where $N(t)$ is cumulated number of adopters at time $t$, $m$ is the potential number of adopters, $p$ is the influence that is independent of previous adoption, $q$ is the influence from the word of mouth (Bass, 1969). Bass model gives the S curve of innovation adoption which is applicable in various domains and shows that how the number of innovators first expand and then stabilize (Mahajan, 1985).

$$\frac{dN(t)}{dt} = p[m - N(t)] + \frac{q}{m}(N(t)[m - N(t)]) \tag{3.1}$$

***For the solar PV innovations:*** Zhang and Vorobeychik (2016) states that in the field of solar photovoltaics (PV) it is best to use one of the four following theories for innovation diffusion: heuristics, economic, theory of planned behavior (TPB) and machine learning (data driven).

- *Heuristics:* Not grounded in any theory but uses simple intuitive models. For e.g. Zhao et al. (2011) defines the desire for technology to be modeled as linear function of payback period, income, social influence, and advertising.
- *TPB:* Helps defining the intention of the people to buy the solar panels where the intention is the regression model of the subjective norms, attitude and perceived behavioral control.
- *Economic theory:* Allows utility maximization (like profits, personal utility, etc.) functions to help in determining the innovation diffusion, where different parameters determine the utility and a threshold is used to see if it is acceptable by an agent.
- *Machine Learning:* States that it is possible to successfully understand individual action by developing a model like an Agent based model, train the agents on their individual properties given the data and run as Data driven Agent based model (DDABM) (Zhang and Vorobeychik, 2015; 2016).

***Decision Rules:*** Additional to the above theories, it is important to have a decision rule which helps in determining if the innovation would be accepted or not.

- *Threshold:* Kiesling et al. (2012) stated various ways to define a decision rule like putting threshold on utility, i.e. only if the utility of a consumer is going to increase above a threshold/ consumer would be able to afford, the consumer would adopt the technology.
- *Percentage:* Other ways are that if a percentage of acquaintances start using the innovation, then the consumer adopts innovation. These leads to a state transition of the agent from non-adopter to adopter or partial-adopter (Goldenberg and Efroni, 2001).

**Interesting innovation diffusion factors for solar rural electrification context:**

1. Heterogeneity of sociodemographic parameters can be used for allocating the social and spatial groups and giving an indication of how each group would affect each other or internally (DUGUNDJI, 2008).

2. Negative word of mouth as done by the political leaders plays an important role, but can be handled fast if reacted upon immediately by the innovators (Richins, 1983).

### 3.2.2. Final theory: Word-of-mouth percentage and economic threshold

As seen in the table 3.2, internal WoM is important in the context of rural India, due to families and similar sections of society living close together in a community. Then, external WoM happens via marketing campaigns of energy providing companies, awareness about electrification from NGOs, and political leaders campaigns (which can be positive and negative, and generally negative as will be discussed in the next chapter and mentioned by interviewees). This makes the threshold on percentage of neighbors accepting the technology as a major decision rule as well. Also, A rural household is usually not economically well off and thus the income level and the added utility by the investment in technology of solar electrification is something which they consider significantly. The utility maximization and thus the threshold on this becomes a major decision rule.

Table 3.2: Relevance of innovation diffusion theories for this context (from very low to very high)

| | | |
|---|---|---|
| Theories | Internal- External Word of mouth | **high** |
| | Economic | **very high** |
| | Theory of planned behavior | low |
| Modeling methods | Heuristics | low |
| | Machine learning - data driven | low |
| Decision Rules | Threshold on utility | **very high** |
| | Threshold percentage of neighbors | **very high** |
| Other Effects | Social network effect | **high** |
| | Consumer behavior: Social and personal effects | low |
| | Satisfaction versus uncertainty level | low |
| | Position of innovator in network | **very high** |
| | Co-evolution and dependence | medium |
| | Heterogrnity of consumers | **high** |
| | Negative word of mouth | **very high** |
| | Risky versus non-risky | **high** |

Based on the relevance in this context, the final model has two types of major influences: Internal (word of mouth) and External (marketing). This is also affected by the percentage of acquaintances start using innovation. Economic theory for utility maximization (like profits, personal utility, etc.) decides threshold on the utility value and determine the diffusion of innovation. Finally negative word of mouth decides the negative rate of innovation diffusion and affect the rate of change of adoption equation as in 3.1. The adapted equation is described below as in equation 3.2. This equation is not used further, but it helps in showing different effects of the different innovation parameters, as in Figure C.1. Here, $r$ is the rate of decrease of the number of adopters, which would be very high due to the influence by leaders:

$$\frac{dN(t)}{dt} = s.(p[m - N(t)] + \frac{q}{m}(N(t)[m - N(t)]) - \frac{r}{m}(N(t)^2)[m - N(t)]) \tag{3.2}$$

Innovation diffusion relevance for this context:

1. Relevant final theories (important parameters for individual decisions and actions): Economic threshold (utility, profitability) and word of mouth (internal, external and negative)
2. Social network significance of the consumers in the community
3. Difference of risky and non-risky innovations are important to be noted.

## 3.3. Conclusion

The literature review of the various frameworks have shown that the IAD framework, when studied together with SES, help in understanding the dynamic community demands, while including different factors together. These frameworks help include various variables influencing use of a resource in a community (SES variables) and the IAD framework helps to understand the development and design of institutions as the community attributes or the physical resource properties change. The major gap in both these theories is that they have not been used for socio-technical infrastructure projects like solar electrification especially in very dynamic communities like rural India. Adapting this framework every time as the technology develops or the community demand changes, to study the effects on te project's sustenance is not practical. Thus, it is important to understand that how institutions can be adapted with changing technologies and communities. This implies understanding of how socio-technical infrastructures are accepted in community, where the innovation diffusion theories can help. A literature review of innovation diffusion theories show that the economic and word of mouth based theories are very relevant in this context, with decision rules like threshold on utility and other effects like negative word of mouth. This mutual gap filling of IAD with innovation diffusion is explained in depth with introduction of institutional innovation framework in next chapter 4.

# 4

# The institutional innovation framework

*The literature review in the last chapter 3 shows that IAD framework and few theories of innovation diffusion together contribute in understanding the effects of various factors on solar electrification in rural India. IAD framework has some gaps in the theory (institutional diffusion and adaptation) which are introduced in the section 4.1.1. Similarly, the innovation diffusion theory also has its gaps, which is defined in Section 4.1.2. These gaps can be fulfilled with each other and this is discussed as the institutional diffusion and adaptation in the Section 4.3 and 4.2. All these combined make institutional innovation and the introduction to institutional innovation with the description of levels of agents and the co-evolution in this framework is discussed in Section 4.4. The final subsection 4.5 goes deeper into the innovation diffusion theories to explain operationalization of the institutional innovation. Before conclusion, it is briefly explained why and how this framework positions itself in the given literature in Section 4.6. The final conclusion of the chapter is presented with complete framework in Section 4.7.*

## 4.1. Gaps in theories

The major theories chosen in this thesis, innovation diffusion and the IAD theory both have gaps in them, which doesn't allow to answer the research question of the thesis and define a framework for sustaining resources for dynamic communities. But, at the same time these theories can be combined together and the gaps on each can be fulfilled by each other to develop a framework to develop the required framework.

### 4.1.1. Institutional Analysis and Development (IAD)

As described in the last chapter, IAD helps define the actions and interactions of the actors based on the designed institutions. The outcome and evaluation of these interactions helps in redesign of institutions. Thus, the IAD framework is more of an institutional design approach ("actions and roles individual actors undertake to create or change an institutional arrangement") and helps define collective action ("institutions emerge to facilitate or constrain social movements or technological innovations"). These definitions of the institutional design and collective action are given by Hargrave and Ven (2006). The steps of IAD framework can be seen in the figure 4.1.

Hargrave and Ven (2006) also mentioned that there are other domains which contribute to development of institutions as well and that includes institutional diffusion ("institutions reproduce, diffuse, or decline in a population") and institutional adaptation ("individual organizations adapt to their institutional environment"). These diffusion and adaptation domains of institutional development are missing from IAD and show the major gap in the theory. The innovation diffusion theories which focus on diffusion, acceptance and rejection of innovations by the community can contribute in understanding that how institutions diffuse. This will be discussed in depth in section 4.3, after the next section which explains that how institutional perspective can fill the gaps of innovation diffusion theories.

In summary, IAD frameworks defines roles and actions to change an institution based on outcome, but misses on showing ***how*** these institutions would be adapted and diffused within the community to sustain a resource.

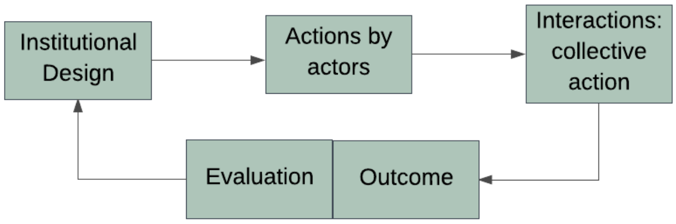



Figure 4.1: IAD framework stages

### 4.1.2. Innovation diffusion

Innovation diffusion has a rather idealistic view about how an innovation/ technology acceptance happens in a society, but it is not that simple in reality. As stated by Redmond (2003), the rational choice models of utility underlying the diffusion of innovation model makes sense for the instrumental innovations like hybrid corn, but they are not sufficient to explain consumer level innovation like adoption of sport vehicles among adults, which is not a necessary resource.

Additionally, in innovation diffusion, lack of communication is thought of as reason for delay in innovation acceptance. But traditions and social norms are also important factors in defining the delay, which are not considered in innovation diffusion. Taking the same perspective which underlies the norms and values of a society, the complete rejection of technological innovation is not impossible scenario. But if only innovation diffusion theories are considered, it is improbable scenario.

As stated by Redmond (2003), it is compatible to combine innovation diffusion with the institutional perspective. Combining these two balances individualistic and group concerns. The diffusion of innovation specifically focuses on the early adopters (who are indeed critical), but the focus on followers is lost, which is stressed by the institutional perspective as stated by Redmond (2003):

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> "The process of institutional change depends on the followers to spread new patterns of interaction, replacing old habits and customs with new."

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## 4.2. Institutional Adaptation

Institutional adaptation aims at adapting institutions as per the environment of the resource and the community. The environment comprises of the community individuals and the interaction of the majority with the resource in form of its acceptance and usage leads to adaptation. Here, the majority of individuals go through same process of innovation acceptance and innovation (resource) usage. The majority decisions can be seen as a result in form of collection of actions, which is also a form of actors' interaction. But unlike collective actions where decisions are taken together, collection of actions is simply all actions put together as a sum. For example, the collection of action of innovation acceptance would give how many individuals in the community accepted the innovation. Based on this acceptance of innovation, different rules can be implemented.

Based on whether the innovation was accepted or not, the institutional adaptation happens in both the cases differently. When an innovation is accepted by a majority, it can be called as an accepted innovation by the community. If the innovation is not accepted by community, then the rules are adapted to make the community accept the innovations. These rules can be top-down rules implemented by an actor or organisation holding the resource rather than the community. For example, the rule to give subsidy which is usually given by government to promote acceptance of a resource can be one rule here.

If the innovation is accepted, then the aim is to define the rules to sustain the resources for the community usage for as long as possible. To sustain the community demands and resource at the same time, it is important to understand the gap between the two (the community and the resource). This gap can be conceptualized by understanding the changes in the properties of the resources and the community which happened after the innovation. Once these changes in properties and the extent of these changes are known, the gap between the resource and the community demands can be estimated. This is usually a qualitative gap e.g. the gap would just specify whether the demand from community is too high as compared to the the supply from the resource. Based on this gap, there can would be different resource allocation rules as discussed below and shown in Figure 4.2:

1. For resources much higher than the community demand, there will be use of the resource and development of the resource. This can be followed with use of resource for further community development.
2. For resources higher than community demands, there will be usage and preservation of the resources.
3. For resources and community demand to be equal there will be a constrained use of the resources.
4. For resources lower than the community demands, there will be priority regulations for usage. The priority regulations are decided based on the most crucial demand of the community e.g. night demands would be given higher priority than day demands for electrification.
5. For resources much lower than demands, there will be fulfillment of only highest priority demands, and search for the preserved or alternate resources.

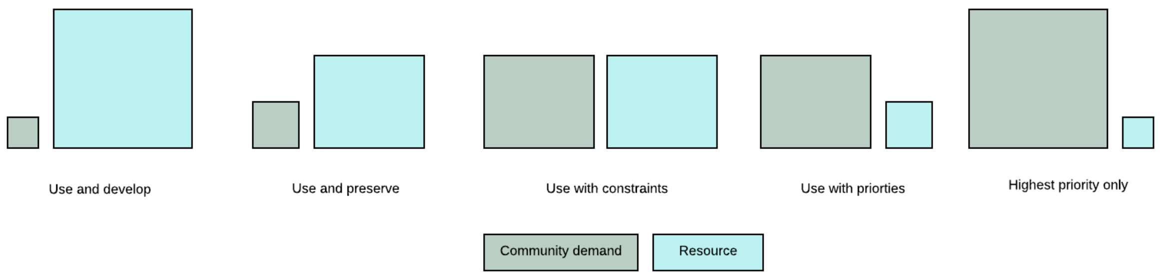


Figure 4.2: Rules decided by gap between community and resources

The decision makers for decisions on the development of the resource or community, preservation methods and regulations or roles allocation, constraints for the usage, highest priority, and the most crucial demand of the community will be done as per the position and authority rules (defined by Ostrom et al. (1994)) as laid by community.

Ostrom et al. (1994) discuss these rules to be of three types:

1. Property rights: The property rights are further divided into nature of goods (public, private, common property, etc.), rights-holder (Representational claims of entity claiming property rights:may be individual, private corporation, etc.), bundle of rights (authorized entrant, owner, etc.), access-to-alienation rules ("which actors have been authorized to carry out which actions with respect to a specified good or service"), and type of property rights systems (open-access, private, public, etc).
2. Formal rules: The rules written down e.g. in constitution, and legally followed are the formal rules. These rules would *not* be changed as these rules take long processes to be adapted due to the procedures involved and the innovation changes are comparatively faster changes.
3. Strategies and norms in the community as defined by the grammar of institutions ADICO (discussed in depth in the following chapters).

Amongst the property rights, rights-holder, type of property rights, and nature of good rules also take a long time to be decided and thus cannot change with every innovation. Finally, this holds the same for norms, though norms are informal in nature and thus more flexible to small changes. This leaves the strategies, bundle of rights, access-to-alienation rules, and norms which can be adapted after innovation acceptance.

## 4.3. Institutional Diffusion

Once the institutions are adapted, they diffuse with the actors to lead to further interaction. The institutional diffusion where the institutions diffuse, reproduce or decline is a frequent process when technological products are considered as resources e.g. solar electricity. This is so because such resources are exposed to innovations and this changes the properties of resources. This might further affect the demands of the communities, changing their properties. Also, in the context as rural India, these changes in the community are frequent as it is a context of a developing economy. Thus, to understand the institutional diffusion which is not answered by IAD, it is important to understand that how innovations are diffused, reproduced or declined in a community.

The innovation diffusion theories can help here as they answer that based on what properties of the communities, the innovations would be accepted. This diffusion would take form of actions of the community individuals, and thus the diffusion theories can be seen as their decision making rules of accepting or declining an innovation. The economic utility theory with the decision rule on the threshold to utility is an important diffusion theory to be considered here due to its context relevance (as also concluded in last chapter 3). Another important theory is the internal and external word of mouth theory with the decision rule on threshold on neighbors accepting an innovation. Innovation diffusion help understand the application of the decision rules for acceptance (diffusion and/or reproduction) or rejection (declination) of an innovation or a technological resource. These rules can be extended to institutions and help define institutional diffusion.

The institutions also diffuse, reproduce (pass over to community individuals) and/or decline. They can do so via evolutionary processes of variation, selection and retention (Hargrave and Ven, 2006). As the institutions here mostly develop with the innovations brought in the community, the diffusion, reproduction and declination of institutions can follow the same principles of economical and word of mouth theories of innovation diffusion, and threshold decision rules leading to the evolutionary process of the institutional diffusion. As the diffusion involves decision making actions of the individuals, it is done at two levels: action of acceptance of an innovation, followed by action of usage of a resource. It is so because these are technological resources, which are not necessity for living like water or food, and thus need to be first accepted by the individuals before bringing them in use.

Taking the context of this case of rural solar electrification, based on the economic utility (income level as indicator), it will be decided whether the institution will be applicable to an individual or not. For example, if the individual is poor household, then they would not be asked to minimize the use of heavier consumption products, as they would not be owning such products. The word of mouth is applicable usually for informal institutions/ norms, but even formal institutions are sometimes spread through word of mouth. The individuals start using a resource as per a specific institution mostly as they see the benefits or losses due to the institution in the community, usually through neighbors. For example, the light bulbs should be off when sleeping gives advantages for battery life and thus everyone in the neighborhood starts switching off bulb while sleeping.

## 4.4. Institutional innovation

Combination of institutional diffusion and adaptation leads to "institutional innovation" or the innovations of institutions. This was first described by Vernon and Hayami (1984) in their discussion paper on institutional innovation. Vernon and Hayami (1984) states that

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> "Anticipation of the latent gains to be realized by overcoming the disequilibria resulting from changes in factor endowments, product demand, and technical change represents powerful inducements to institutional innovation."

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What they emphasize is that though institutions are important to remain stable to provide necessary *assurance* for actions of others, they also need to change with developing technologies and demands. This

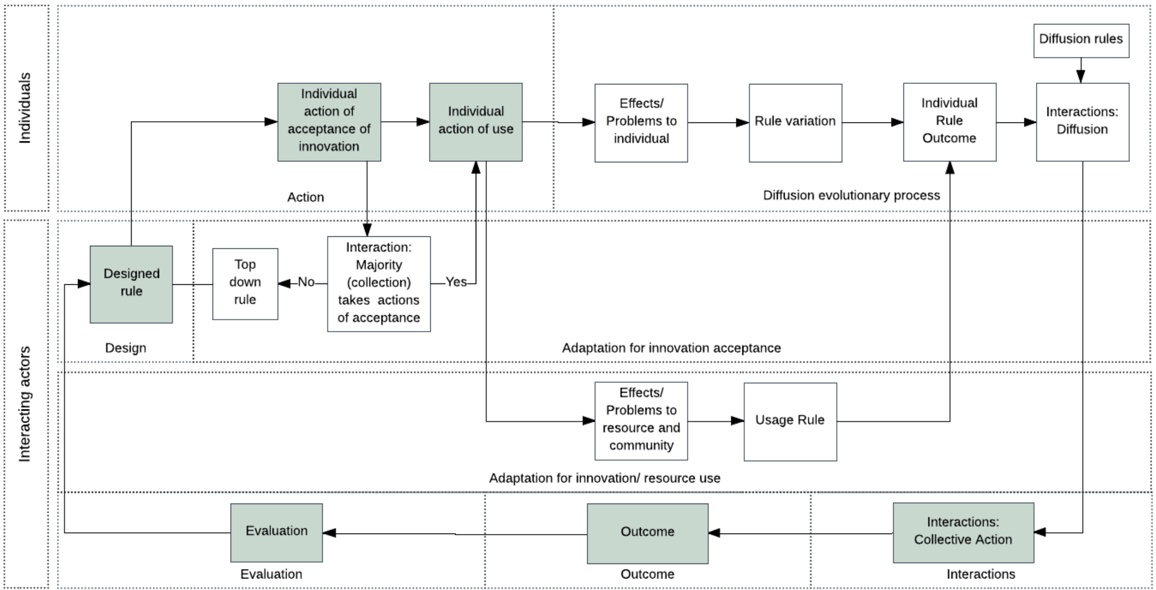



Figure 4.3: Proposed framework of Institutional Diffusion and Adaptation in institutional development

supports the argument of merging institutional designs using IAD framework with understanding technological development and the demands of people, which innovation diffusion helps understand. They also support the use of evolutionary processes for institutional adaptation as they propose "In some cases the demand for institutional innovation can be satisfied ... even by evolutionary changes arising out of direct contracting by individuals at the level of the community or the firm. In other cases, where externalities are involved, substantial political resources may have to be brought ... ."

The eight stages in the Figure 4.3 of design, action, adaptation for innovation acceptance, adaptation for usage, diffusion, interactions, outcome and evaluation, reflect the complete structure of institutional innovation framework. Figure 4.4 shows these steps of institutional innovation. Figure 4.5 shows the institutional innovation framework conceptually with more details. The action in the IAD framework is extended here with the diffusion. The adaptation is also incorporated with the interactions of the actors. Another important thing that the figure shows is that institutional innovation breaks the agents in two main sections of the individual actors and the interaction of actors. The individual actors can be divided further into segments of individuals and thus the interaction can be seen further divided into collection of all actions and collective action. This shows the need of collection of actions of individual actors versus collective action taken by interacting actors. These figures from 4.3-4.6 reflects on how the institutional innovation contributes and adds on to the IAD framework, and also allows to look at innovation diffusion theories from an institutional perspective.

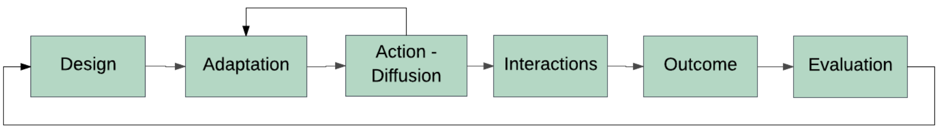



Figure 4.4: Proposed framework of Institutional Innovation

Now, it is important to understand that how all of these components of innovation diffusion theories will be developed. As the institutional development (even in IAD) is done with the community attributes and the resources properties, this framework is also supported by the resources and the community attributes, but there will be additional elements of the resources and communities used in the framework to define the components. In other words, this framework shows the co-evolution of the non-natural resources and the communities, as shown in the following figure 4.6.

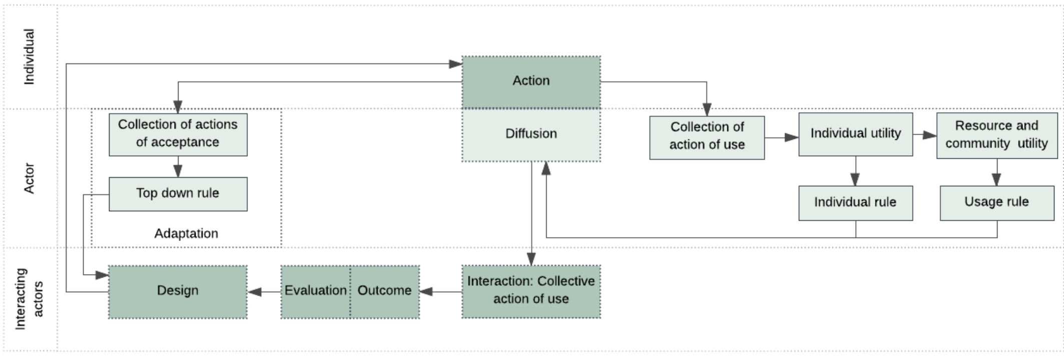



Figure 4.5: Proposed framework of Institutional Innovation with details

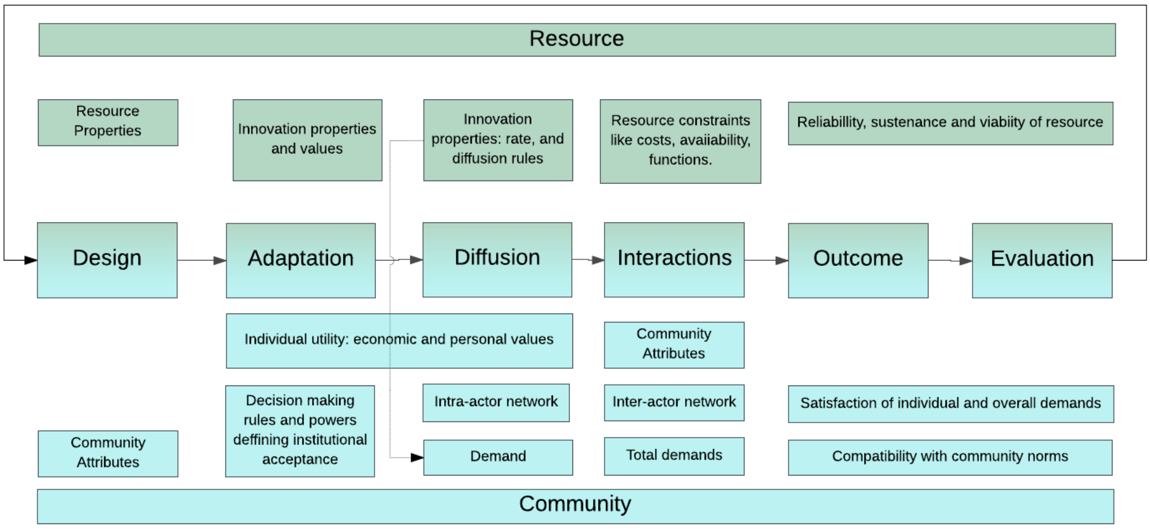



Figure 4.6: Co-evolution of resources and community in institutional innovation proposed framework

The resources and community properties as-is help lay down the current rules of use or the institutions. These institutions then diffuse among the actors based on the existing individual network of actors. The properties and the rate of innovation with the way diffusion happens (e.g. word of mouth or economic utility rules, etc.) define the action of the diffusion of the actor. This further helps define the diffusion of the institutions followed by evolution process of variation and retention, leading to institutional adaptation. The adaptation is rather affected by the individual decision rules and the resource constraints like costs, functions, etc. The final outcome and evaluation of the institutions is defined by the community norms compatibility (socio-economic sustenance), reliability and sustenance of resources, and satisfaction of original and overall community demands.

## 4.5. Operationalization

The operationalization of the institutional innovation framework involves combination of various concepts to be combined and fit together as depicted in the figure 4.7. The first stage of gathering the rules of use, the community and bio-physical attributes is done by gathering the SES variables via interviews. The top down rules which are laid by the actors in case of no acceptance of innovation by the majority or the collection of actors' action is also given by an insight in the community via the interviews. The action sequences from the MAIA framework can incorporate the actor's decision to accept innovation or not. Finally, the agent based model helps define the patterns of interaction and the outcomes in the form of gap on resources and community demands, followed by evaluation structure laid by MAIA. The results of evaluation based on the gap of the resource and community demands would come in form of the different rules as defined in Figure 4.2.

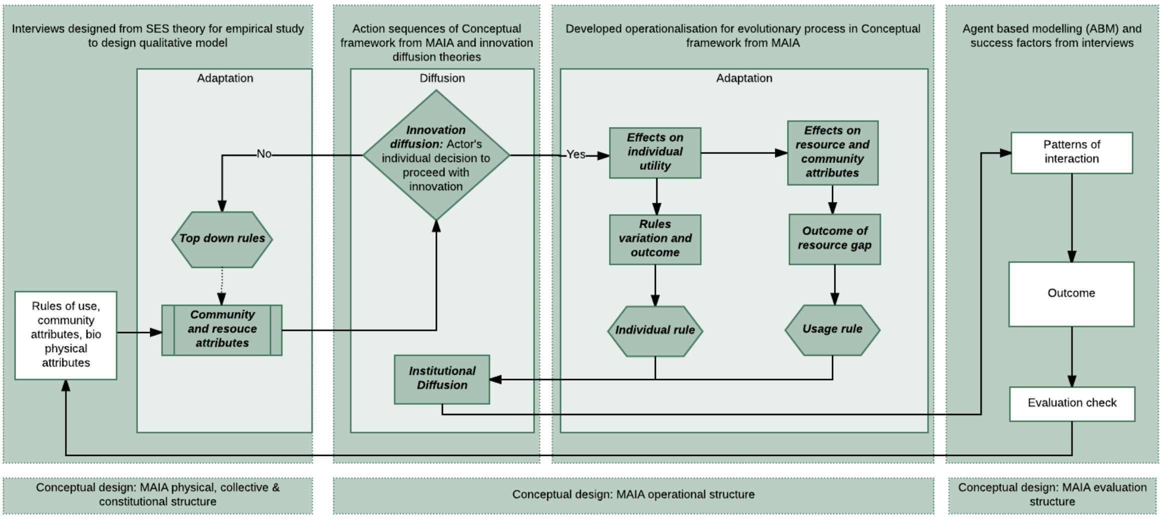



Figure 4.7: Proposed operationalization of institutional innovation

Before the agent based modeling is done, it is important to lay out the evolutionary process of diffusion in the conceptual framework and this is done with integration in the operational structure of MAIA. The effects of the actions are taken as different results and impacts on the resources and the communities. It is checked individually that whether the effects leads to loses on individual utility. If this is the case, then the rules are varied and if the variation helps the resource and the community, then the rule is decided to be passed to the community. This whole process can be called as the rule-check, followed by the action sequence and is shown in the following figure 4.8.

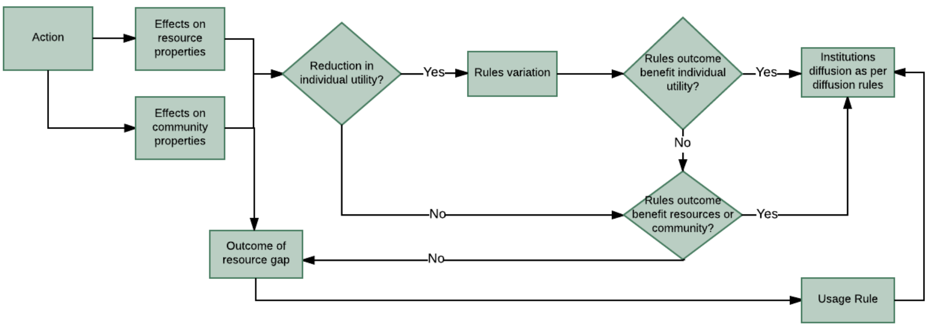



Figure 4.8: Operationalization of rule-check for diffusion and adaptation

## 4.6. Position in literature

Redmond (2003) and Vernon and Hayami (1984) indicated the need of the combination of innovation diffusion and institutional perspectives, where the latter gave the definition of the institutional innovation. Hargrave and Ven (2006) shows that institutional innovation can be actually seen as institutional diffusion, institutional adaptation and institutional design. Also, Hargrave and Ven (2006) defines an evolutionary process for defining institutional adaptation. All these researches are considered while adapting the institutional innovation framework developed here. The additional perspective that this research brings on to these frameworks is that this research:

1. Operationalize and conceptualize the institutional innovation by combing the diffusion and adaptation processes, using agent based modeling.
2. Shows that institutional diffusion and adaptation are not different processes, but goes simultaneously and complete the institutional innovation framework.

3. Defines the institutional innovation to be of different types; happening before and after the acceptance of innovation by majority of the community.
4. Incorporates both the individual and the community perspectives (choices) towards technological innovations.
5. The collective action and the collections of actions of the community, both play important role in decision making behavior of the individuals here.

## 4.7. Conclusion

Based on the gaps of the IAD and the innovation diffusion theories, it can be seen that how the institutional diffusion and adaptation are missing and can be filled by innovation diffusion theories. The complete framework which is resulted from this can be called as the institutional innovation framework and it helps in defining the actions and interactions of the IAD framework in depth with inclusion of individuals, set of actor, and different actors separately. The evolutionary process helps in adaptation of the institution, based on the specific variation in the property of the resource or the community. The adaptation process is a two way process which happens not just for the innovation acceptance but also for the innovation usage. The evolutionary process becomes significant for the latter. The operationalization of the institutional innovation framework is developed by introducing a new step of rule-check in MAIA operational structure, to incorporate the evolutionary process of the diffusion and adaptation.

# Part III: Apply

## Verifying the framework with case study

# III

# Application to rural solar electrification

# 5

# Context study and empirical analysis

*As laid out in chapter 4 conclusion, based on the institutional innovation framework developed, the first step to answering the research question is to understand the context via a context study and conduct interviews. The context study is done and the main findings are discussed in the section 5.1. The interviews helps to develop the knowledge of existing formal and informal institutions, socio-cultural, market and technical factors affecting solar electrification in Rural India. Out of a long list of solar electrification projects, it is first important to select few representatives and this selection process of interviewees for conducting the followed up research is discussed in the Section 5.2.1. These interviewees need to be communicated with clear questions: SES framework and other supporting domain literature lay out various variables to develop these questions. This is also discussed in Section 5.2.2. This is followed by laying a final structure of interview and the questionnaire. For conducting the interview there is a protocol/ methodology and it is kept consistent throughout interviews and discussed in Section 5.2.3. Other significant details of the interview can be seen in Appendix B. It should be noted that this interview is a follow-up for some interviews after the on-ground interviews conducted for understanding operations of the projects and community opinions on the projects and discussed in B.4.*

*Before moving to the analysis of the interviews, it is important to understand the reliability of the results and prepare the data for analysis which is done in section 5.2.4. Based on the conducted interviews, a thorough analysis of actor networks and processes in electrification project is discussed in Section 5.3. The next analysis is done on evaluating the success of projects and this is laid out in form of visualisations and statistical results are discussed in Section 5.5. The results of the interviews serve to fill the qualitative data to lay foundation of a conceptual model discussed in Chapter 6.*

## 5.1. Context of rural electrification

To answer the societal problem questions, first it is important to understand how a electrification project is marked "better" or more successful than other. Also, it is important to understand what are the different socio-cultural and technical hindering factors for electrification. For suggesting different policies and rules, it is also important to know the existing policies and rules around such projects and around electricity market in general in India. This can be explained by a thorough literature review in these domains.

As discussed in the section 1.1, aim of this section is to understand what leads to success or failure of a given rural electrification project. Various socio-economic, organizational or political, and environmental factors associated to a community affect the success of such rural electrification projects. Certain frameworks have been established to measure the dependency of these factors on success of projects. As any electrification project's success parameters depend on the efficient supply and demand fulfillment which is governed by the pricing mechanisms (price and tariff rates) and output of services (and technologies), a study of the pricing mechanisms is done.

Existing rules and policies are studied with the organizational (formal: behaviors of governments or organizations in charge of policy and decision making, informal: existing patterns of behaviors of the community like the social norms, trust, etc.) structure which give an overview and shape the present rural electrification scenario in India especially for rural regions in renewable. The organizations and policies structure at generation, transmission and distribution for all energies in India are studied first. The energy sources and the technologies available in rural India are considered next. To incorporate the demands of community, the technical aspects and the related bottlenecks of these projects especially for individual SHS are also reflected upon.

### 5.1.1. Affecting factors

After understanding the institutional and technical challenges and existing structures, the next step is to understand the exact factors which affect success of a typical rural electrification project. For the same, it should be clear what is meant by the “success" of a typical rural electrification project as mentioned in various sources (Camblong et al., 2009; Cecelski and Asia Alternative Energy Unit, 2000; Nygaard and Dafrallah, 2016; Trotter, 2016; Urmee and Md, 2016; Waddle, 2012): Affordability for the defined consumer segment, Equal accessibility for defined consumers, Viability and reliability of technology, Profitability for the supplier, Long term sustainability of the project, Socio-cultural and environmental sustainability, Political and institutional compatibility.

Literatures have discussed the reasons of failures to be the technical factors like major operation and maintenance (O&M) issues and proposed efficient models to manage the O&M issues (Kirubi et al., 2009; Ubilla et al., 2014). The solutions involved the ability to charge and enforce cost-reflective tariffs based on operation costs, to communicate operation issues within the global and local management level. Above these O&M issues, some of them have rightly pointed that even after availability of right available facilities, these projects have failed (Palit, 2011). The reason in such cases can be seen as the different social, economic, cultural and governance factors around these communities where the renewable technologies are brought in (Hirmer and Guthrie, 2016; Nygaard and Dafrallah, 2016; Singh, 2015; Trotter, 2016; Urmee and Md, 2016).

**The social and cultural factors affecting solar electrification:**

1. The careful choice of target users, identification and appointment of a local leader who people trust for, and who is usual decision maker in a community.
2. Community participation right from the installation of the projects has shown to affect the choice of people to trust in the technology or not(Urmee and Md, 2016).
3. The institutional factors like the presence and absence of democracy showed to make a major difference in deciding success of rural electrification projects(Trotter, 2016).
4. Some institutional framework changes like engaging consumers and municipalities while considering the low paying capacity of rural dwellers at national level, proved to be helpful in some cases like Morocco (Nygaard and Dafrallah, 2016).
5. Study based in Uganda showed that how identifying the right needs of a community based on their values helps in success of these projects (Hirmer and Guthrie, 2016).

A major analysis on the factors leading to success and failure of these rural electrification projects in Indian context is done (Bhattacharyya, 2006; Chaurey and Kandpal, 2010; Cust et al., 2007; Palit, 2011) which talks about the presence of economic barriers as one of the major causes of the energy affordability. Some studies have shown that how the factors like trust in community change the complete mechanism of “sharing" of electricity in villages (Singh, 2015). Few institutional perspectives have been brought into this field of energy and renewable, and they have talked about how co-benefits approach, priority to different economic sections of society and multi criteria analysis would help in figuring out more efficient off-grid, solar lights distribution policies (Deshmukh et al., 2010; Navroz K Dubash, D Raghunandan, Girish Sant, 2013).

Now that the factors affecting rural electrification are known, it is important to see that if these factors can be incorporated into some form of framework, to determine a successful rural electrification project (Note that all these frameworks are not in context to India, but developing countries). The study conducted by Jain et al. shows a “project planning and decision-making framework for decentralized rural electrification (Jain and Kattuman, 2015)." This study takes in all the key determinants like physical characteristics of area, socio-cultural, socio-economic factors and assessment of resource potential and electricity needs, to deliver pricing, technology, operations and maintenance, scale of service and such strategic decisions for a project. This framework also considers financial, social, operational and environmental sustainability aspects. Though it mentions about the principles like transparency, and sustainability, it doesn't show the direct effects. The complete figure of this study can be seen in Section A.1.

### 5.1.2. Price mechanisms

As seen in the above sections, these different factors in different contexts and different framework settings have a wide impact on the rural electrification projects. The major measurable impacts always come in terms of how much profits the project incur and in what time. This demand understanding the way the profits or the revenue is collected at the first place. Also, the price mechanisms involved here are controlled by the community in the rural India settings, as there are major affordability issues in such rural context. The price mechanisms vary specifically in perspective to rural areas in India, because of the diversity of economic standards of the people. Due to irregular daily wages, or jobs like farming, the pricing mechanisms need to be adjusted. This is done to ensure no loss to the supplying (or maintenance) organization and full satisfaction of the consumer.

A complete picture of different types of pricing mechanisms in China and India are laid out by Liming Liming (2009).The financing channels and instruments are laid out here with also the inclusion of innovative financing mechanisms. The comparison, where the major interest for this paper is in Indian sector, shows that the Indian renewable rural market is expanding with the domestic financing, and with special domestic funds like IREDA (India Renewable Energy Development Agency). This is helping involve local commercial banks too, facilitating easy loans for small and medium entrepreneurs.

Research in this field discusses the benefits of feed-in tariff and disadvantages of fixed upfront cost in rural settings Girish Sant and Shantanu Dixit (1996); Ramchandran et al. (2016). Non-India specific developing countries studies in the same domain has also shown similar results Camblong et al. (2009); Nygaard and Dafrallah (2016); Urmee and Md (2016). In general, it can be seen that different settings demand different pricing mechanisms, e.g. urban slums can pay regularly in spite of having low wages than farmers in rural settings. It is so because farmers do not have any income in the non-harvest seasons, and an unpredictable weather change might affect their savings. It is not so for a daily wage worker in urban setting.

Deshmukh et al. discuss the existing pricing schemes and how they can be modified in context of Indian solar PV markets Deshmukh et al. (2010). This study shows the effect of change in pricing policies (e.g. rise in the CERC(Central Electricity Regulatory Commission) tariffs for solar PV) on the competition and market entry in rural electrification domain. This study majorly deals with the large solar plants, but it is effective to understand the effect of feed in tariffs and competitive bidding (the latter is preferred by authors with a ceiling tariff), with the compatibility of national policies.

### 5.1.3. Energy organizations and policies in India

Ministry of Power is the central body created in 1992, meant to regulate the energy sector which enacts electrification policies in India at three different levels: generation, transmission and distribution. Reflecting on the public-private ownerships, as of the data obtained from Central Electricity Authority (CEA), 32% of the energy generation is owned by private firms and the rest by public (37% central and 31% state) (CEA (Central Electricity Authority), 2016; Hunink, 2016). The transmission is owned almost completely by the national and state transmission corporations (POWERGRID, the national corporation with 50% coverage). Similarly, distribution network (by distribution companies or DISCOMs) is owned by public owners as well.

**Reasons DISCOMs are facing heavy debt**

1. Very low cost and almost no profit-margin (as compared to the generation cost) at which they are providing electricity.
2. 22% of the energy is lost due to losses like power theft, non-billing, incorrect billing, leakage in lines and broken devices (Press Information Bureau Government of India, 2016).

Heading towards the rural electrification institutions and policies, they were first set in 2006, ensuring access to electricity of all households by 2009 where the State governments have to set up the plan to speed up the rural electrification. Recently many programs, like Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) have been set by ministry of energy and ministry of renewable energy to speed up the rural electrification, especially using micro-grids and off-grid electrification projects. In spite of this, the micro-grids have not been successful in the villages. because of the energy act of 2003, which doesn't ask the private organizations to have any license to start micro-grid projects, but it also doesn't give them security of intrusion from the central grids (Shukla and Thampy, 2011). But at the brighter side, recent technologies like SCADA control systems for the real time monitoring of electrical networks is also deployed and the results are shown on "GARV" board, where the MNRE keeps track of the number of villages that are electrified, and this has helped even private companies to understand the government's plan of electrification (REC (Rural Electrification Corporation Limited), 2015).

Recently, additional innovative measures allowing sharing of energy have been passed by Indian Power sector. One of them is PPA (purchase power Agreement), defined as an agreement or legal contract between a generator and purchaser, which is especially made avaialble for solar energy. The PPA is also being introduced for small rural projects like micro-grids, especially solar projects [1].

### 5.1.4. Renewable energies in India

For renewable energies, Ministry of New and Renewable energy (MNRE) implements national policies. As recently mentioned by the national head of the ministry, the solar tariffs were noted below the thermal power costs, confirming a profitable nation-wide investment in solar energy in future. Few projects based on renewable (even as hybrids or combination of different renewable energies) have shown to be successful for rural remote areas (Gupta et al., 2007). The assessment and comparison of different DER sources have shown that the solar energy is not economically feasible option when connected to grid, and in such cases the hybrid of the Photo-voltaic(PV)[2]-Wind Diesel is more profitable. Though, for remote areas, PV has proved to be successful and it has the lowest initial cost of installation as compared to other DER like bio-gas and wind power (Banerjee, 2006). The future studies of renewable energy usage in India has shown that the PV based electrification is sensitive to changes in the employment rates and population, still promising 41% of renewable energy market to be governed by PV and 55% by wind energy (Suganthi and Williams, 2000). The projection of the renewable energy potential in India is shown in Figure 5.1.


Figure 5.1: Small community based productions, projected by the Planning Commission of India (Tripathi et al., 2016)

### 5.1.5. Energies and demands at rural level

In rural India, the major requirement of energy is for cooking and lighting. Around 139 million households in India relied on traditional energies for their cooking needs in 2001 and these sources to be their sources of lighting solutions too (ORGI, 2001). Even in 2010 (like 2001), these sources were firewood (76.3%), crop-residue, cow-dung cake and coal in the descending order of number of households using them. Almost all of these are prevalent in rural areas. The more modern sources of energy in use are LPG, Kerosene and biogas (again in descending order) (Office, 2012; ORGI, 2001). Electricity is almost nowhere to be seen as a source of cooking in India. It seems that in spite of a decade long efforts to change the traditional cooking sources of rural households, the higher costs of the alternates have not led them replace the traditional sources (Kanagawa and Nakata, 2007). Solar energy in form of solar cookers and solar heater is very scarce due to initial cost investment which majority of households are reluctant in doing, and due to the social norm of reluctance to box-based cooking (Pohekar et al., 2005).

For lighting, kerosene and electricity (usually from the central grid), is the major source, where the former is more prevalent in rural India (due to ease of access and government subsidies). One other major use of

[1] https://cleantechnica.com/2017/04/21/power-purchase-agreement-signed-indias-cheapest-solar-project/

[2] the solar panels are based on photo-voltaic which converts the solar energy into electricity using semiconductors

electricity in rural areas is for irrigation and water pumping, but due to the huge subsidies, excessive demand and non-payment of dues and irregular supply, this has not been prominent anymore (Bhattacharyya, 2006). Looking at the end user appliances that the households demand in rural areas, electronics like TV are a socially preferred demand, followed by demands of hot water stoves and refrigeration demands (it should be noted that though demand might be low by the household, but the energy requirement for different needs varies. Thus it is not proportional to the number of households e.g. refrigeration needs more energy as compared to electronics, but the latter are in demand as per the total number of households). Considering these demands, the future scenario(2030) based study for different energy sources show renewable energy based rural electrification (especially solar) to be more profitable than other options (Urban et al., 2009).

### 5.1.6. Aspects and bottlenecks of solar energy in rural India

As discussed in section 1, there are three major types of solar electrification based on ownership level (micro-grid, community-shared, individual SHS). Added to them, there are small projects like solar lanterns, but they are out of scope of this thesis as they cater to demands of lighting only. Focusing on the three type of projects, and especially community shared, the SHS system has primarily four components which bring in the challenges: PV system, storage device, inverter and the power distribution network (PDN). The cost of a PV system is the first barrier when considered by an average household in rural India. Though the efficiency has developed in the recent years and the cost has reduced, it is still not an economically feasible option if more than 180 households are not using it as a micro-grid. The next issue is theft and deep discharge of batteries when considering individual SHS. This issue doesn't exist for a connected system of the SHS like micro-grid. But for a micro-gird, the issue lies in requirement of the area of land e.g. 40.000 $m^2$ is required for 1 MW capacity of electricity production. The increase in temperature also reduces efficiency of the system (Raman et al., 2012).

The lead acid batteries provide large current for short interval of time and thus fits for the micro-grids, and they are lower in cost and more efficient, but the lifetime of these batteries is low, with low specific energy. These batteries allow running motors and water pumps and the problem of their discharge is taken care through BMS system, which is not always possible to be used for individual SHS, but common for micro-grids. Similar to BMS, the advantage of inverter and PDN (in a networked system - consists of service lines, internal wiring and appliances to individual households) is more feasible for networks like micro-grid where there is major distribution generation unit, and not for individual SHS (Jossen et al., 2004; Tonkoski and Lopes, 2011; Venkataramanan and Illindala, 2002).

The insights from these contexts have helped develop the research gaps and laid down the research questions for the thesis as discussed in Chapter 1. The methodology has indicated the need of further empirical analysis via interviews to get the complete context picture of rural electrification, and it is done in the following sections with interviews.

**Insights in context through literature study:**

1. Based on an developing organizations for accepting sharing projects, increasing demands of rural India, and rise of solar electrification, the sharing projects look feasible for rural India.
2. Definition of success of rural electrification projects lies in Affordability, Viability, Reliability, Long term Sustenance, Profitability, Equal accessibility, Socio-cultural Sustainability, Political Sustainability, and Environment Sustainability of projects.

## 5.2. Interview designing

For interview design, first it is to understand the interviewee and their role with the community so that the biases of the interviewee and the assumptions of the final model are clear. Next, Interview design for this specific case of solar electrification from community-based management perspective demands defining variables. The variables can be found from different literatures available, especially SES as it discusses these variables. This understanding from SES leads to development of a structure and further reading on qualitative interview conduct helps develop interview protocol as shown in the following subsections.

### 5.2.1. Interviewees

The introduction to projects and interviewees is also given in the Section 2.2, previously. A list of different projects is developed and it can be seen in Section B.1 and out of these interviewees few representatives are finalized considering the time limitations of the thesis. A specific method for categorization of projects for selecting interviewees is done, which is described from here onward and shown in Table 5.1. A major condition is that all of the projects should be at least 5-6 years old as they are established as successful projects in the SHS (sustained for 1 life-cycle of the batteries at least). An exception can be made if the project has a completely new form of solar electrification with community sharing possible. These companies will be called as *Energy providing companies/firms* from here onwards in the thesis. The parameters for categorizing and finally choosing the energy providing firms is enlisted below and all the projects combined should have all of these properties. Based on this selection process, the finally chosen projects are: *Mera Gao Power, Simpa, Gram Power* and *Gram oorja* among microgrids. *SolShare* and *Rural Spark* among Sharing projects are chosen. *Manthan, Piconergy* and *Selco* among the individual Solar house system projects are chosen.

Table 5.1: Comparison properties of different projects of solar electrification

| ***Domain*** | ***Different properties*** |
|---|---|
| Level of community ownership | Micro grid, Sharing of energy among households, Individual SHS |
| Customer community as per the electrification level | No electrification - caters to mostly off grid systems with tribal communities, 5-10 hours of electricity from the grid - bigger villages, Community with partially connected to grid and partially not |
| Technology | Smart meters GP and other advanced remote sensing, Productive use energy, presence or absence of grid |
| Community characteristics | Presence of the patriarchy, caste divides, other sections of the community, trust and cohesion. conflicts |
| Physical location characteristics | Very close communities to highly scattered community |
| Community ill-attitude | Cheating, stealing |
| Regulations | Government strict regulations and support schemes |
| Community sharing Characteristics | Energy or other resources |
| Financing mechanism | Pay as you go, Fixed upfront |

### 5.2.2. SES theory based variables

SES or Socio-Ecological Systems theory as defined in section 3.1.1 and Figure 3.2 consists of seven major parts and all of them are further broken down into number of variables to understand the picture of community management of resources and actions and outcomes due to actors' interactions. These variables lay down framework to develop interview questions as the exact variables are captured here. Based on the SES Theory's variables, the relevant question domains can be developed for the specific case of solar electrification in rural India and it is shown in Tables B.1 and B.2. Further variables are listed to break down the parameters for simplifying communication and it can be seen in B.3 and B.4. As can be seen in these Tables, there are some variables which are not very relevant to the case and these can be discarded e.g. the human-constructed facilities for the resource is actually everything for this resource as this is not a typical ecological resource. Additional to the SES theory, the qualitative interviews bias is important to be considered here which can be understood from the literature of the qualitative interviews and how to by-pass or reduces the biases in a qualitative and semi-structured interview. These learnings are explained in depth in Section B.2.2. Based on the parameters of the table B.3 and B.4, the questionnaire is developed and it is given in the appendix section B.3. For clear analysis these questions are divided into relevant topics as shown in following Figure 5.2.


Figure 5.2: Major topics for interview (on properties of community and project)

### 5.2.3. Interview protocol and steps

A protocol of interviewee is must even if the questionnaire is ready to make sure that the interview doesn't deliver wrong results due to mis-management or mis-communication. Here, protocol means: 1) understanding what questions should be asked and in what order, 2) what should be the steps/ back-up questions, based on different types of answers, 3) how to introduce and conclude the interview formally. Based on the mentioned three steps, the first step involved writing down the relevant questions, as per the interviewee's background and interest. This involved reading up about the interviewee and the work they have been doing in the field of SHS and microgrids. This helped prepare the right questions as it gave more insight into their experience. Finally, browsing through the website of energy providing firm itself helped in understanding his present work and thus making the questions more relevant to what and how he could help in for the thesis project. A thorough interview protocol and the experience and learnings from one of the interview is developed as a report and can be produced to reader of the thesis on request.

For conducting the interviews, first the questionnaire is mailed to the interview in advance of a day and a Skype call is made. The interview goes for 1-1.5 hour with almost half of the content covered and then a follow-up call is scheduled which takes equally same amount. This means total 18 (9*2) interviews are done. Based on the answers in every interview, the questionnaire is cut down to smaller version as some questions are redundant and repetitive. This process of iterating through questionnaire stopped after 3 interviews (out of 9 different interviews). This interview is recorded after the consent of the interviewee which led to the development of the final analysis (Some of the answers are shown in section B.4). A small questionnaire where the interviewee can answer the questions on sustainability of the project is sent separately and it records quantitative answers. It should be noted that before this interview, as set of informal interview is done with 5 energy providing firms on field (*Manthan, Piconergy, Barefoot College* and *Rural Spark*) and discussion meeting with 3 research firms/ personnels *CEEW*[3], an *anthropologist/designer* and *postdoctoral researcher* on energy systems, and this is discussed in Section B.4. The steps followed to conduct interview with some details is given as summary in Figure 5.3.

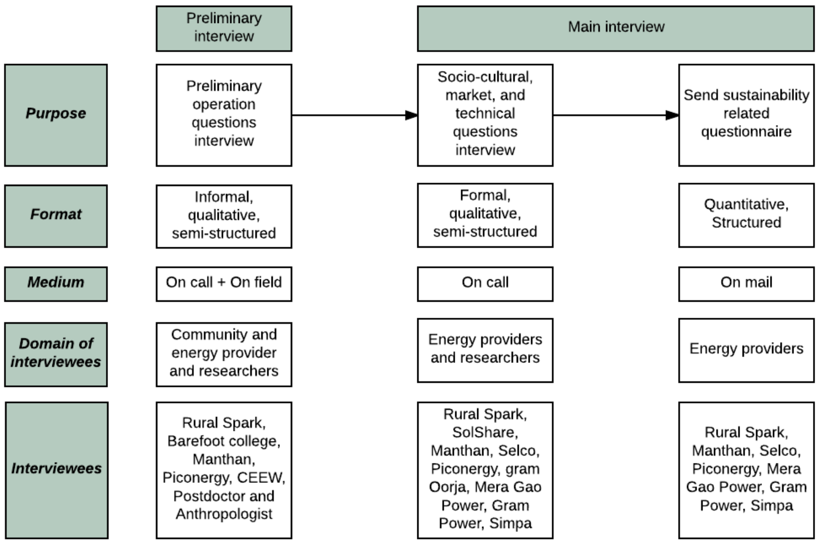



Figure 5.3: Interviews steps and details

### 5.2.4. Data development

As the interviews are conducted the next step is to make sense of the plethora of unstructured information (as it is qualitative). This first needs understanding of how these results are "averaged" out to be developed in a model further and how reliable these results are. After conducting main interviews and recording the videos, transcripts are written as answers to every question in an excel sheet. Thus, 9 main excel sheets with answers to each interview are developed and then a common spreadsheet combining all these answers is developed. All these answers are further broken down from descriptions to simple "yes"/"no" answers or 3-5 categories

[3]Center for Energy, Environment and Water - `http://ceew.in/`

in an answer. For e.g. "what are the supportive technologies you use?" is broken down as "Do you use Smart meters" and "Do you use automatic day and night control?", etc. This is done based on the answers received. This helps converting the answers into nominal factors as listed in the Table B.5. Note that some answers like regulations are peculiar and are kept as-is.

The interviewees are limited in number, but these interviewees are also the problem owner. General inferences from their viewpoints are made and their statements are considered to be reliable source of information because they have huge stakes and the information they give is something considered to be analysed, as they think of this information as important. If they don't have this information correct, e.g. about their consumers, they are losing a lot of money and their assets, which is not the case. Thus, the information both qualitative and quantitative which is provided by them is considered to be reliable.

The quantitative data will be used to populate the model (partially gathered from interviews and partially from online resources discussed in chapter 7). The qualitative data will be used to make the model concepts and foundation. But the qualitative data at the same time is sensitive to validity of the model and we can't play around that much with the variables here. To improve the reliability of such data it is always good to have census and policies type of data to make it more reliable, which will be done in the following chapters.

## 5.3. Interview analysis

Once this common framework across all answers is developed and the reliability of the results is taken into account, the next step is to develop a general analysis and insight into the common trends across different projects. The main trends can be seen in the actor networks and the process of development/ installation, operations, and handover stage of the projects. Thus the actor and process diagrams are developed and trends noted across different projects. The actors are connected via the flow of: Money/ Financial support, Energy/ Technology products and Policies/ Rules. Energy Provider is the main stakeholder for this project. The other actors are: Manufacturer, NGOs (Non-governmental organizations), Village committee (or individuals comprising of operator, Fees collector, community head), Villagers/ households, Banks/ Private industry , and Government.

As seen, the central actors in the community are village committee and households. The energy providing firm connects the manufacturers via products to the community. The NGOs are responsible for awareness and education of the community about electrification and creating more opportunities for general education. Banks and governments bring in funding and policies to support the electrification. The government can be further divided as local, state and national government and their policies differently impact the electrification project, but this will be discussed in next chapter. Thus, NGOs, and banks have very specific role and can be considered as external actors. We have five main actors: *energy provider, manufacturers, households, village committee* (existent as individual roles or operator fees collector and community head for Sharing project) and *government*. The actor network is bit different for different projects - SHS, Sharing and Microgrid as shown in the diagrams below, where Figure 5.4 show the microgrid and SHS project actor network.

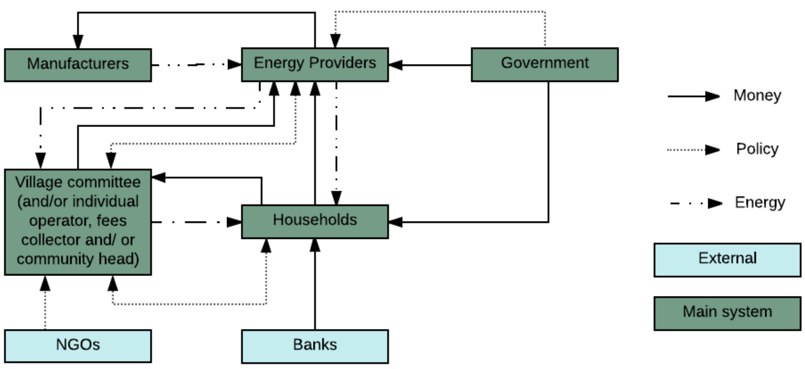



Figure 5.4: Actors network for Microgrid and SHS project

The actor network for Sharing projects is shown in 5.5. Note that these diagrams are simplified as the details are redundant for the actor network and will be dealt while developing the conceptual model and final model in later chapters. For e.g. the difference of the household between the microgrid project and the SHS project is that they are both consumers but they have different payment schemes, which doesn't affect the flows in the actor diagram. These typical differences are shown in the Figures B.6a, B.6b and B.7.A more detailed analysis for the processes is shown in the Figures B.8 and B.9.

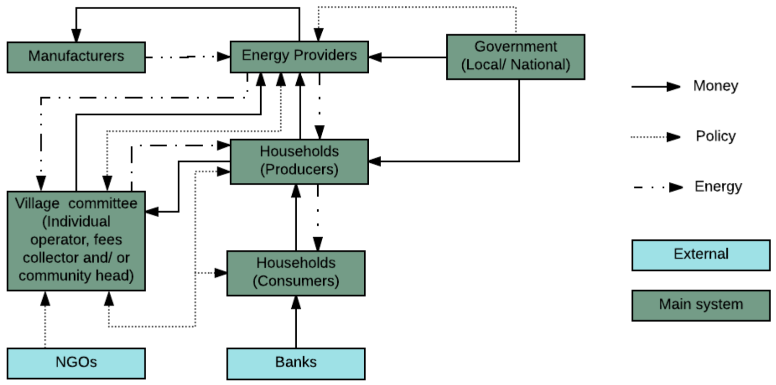



Figure 5.5: Actors network for Sharing project

Note that these processes are based on three stages of project: initiation, operation, and exit/ handover as shown in the figure 5.6 involving collective, constitutional and operational choices as defined by Ostrom et al. (1994). The actors are mentioned in the processes (E: Energy provider, H: Households, N: NGO, V:Village committee, G: Government, M: manufacturer, B: Banks). These processes turns to define the rules and choices as discussed in next chapter 6. The flow through arrows show the flow of the decisions of the actors.

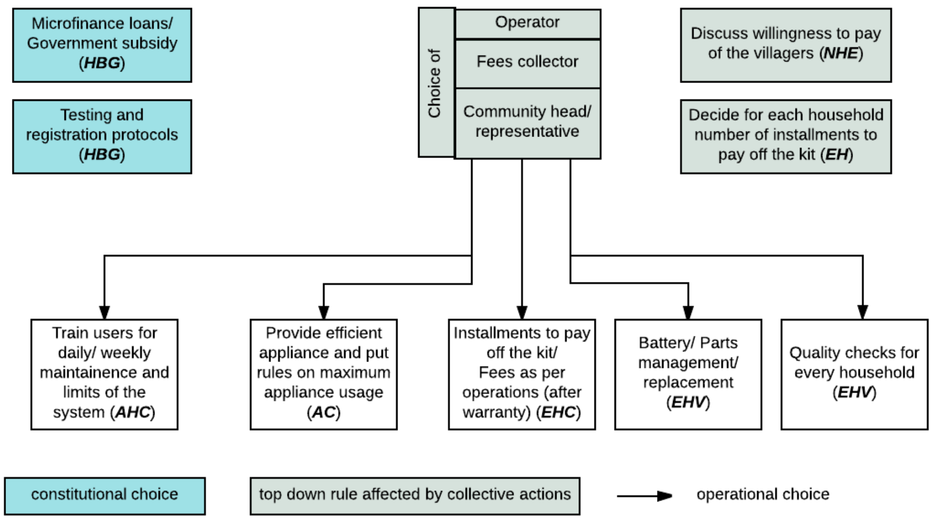



Figure 5.6: Decision flow network for microgrid

The decision flow for SHS and sharing projects do not have collective actions but influence of choices of community put together. It is an emergent decision making process (decisions are adapted and emerge) which will be discussed in depth in the next chapters where the action sequences for these projects are defined using the theoretical framing. A general overview of this is given in Figure 5.7.

## 5.4. Final Results

Based on the actor-process diagrams evaluation, the results focus on understanding the similarities among organizations based on the operations, social characteristics, different policies, and top-down rules imple-

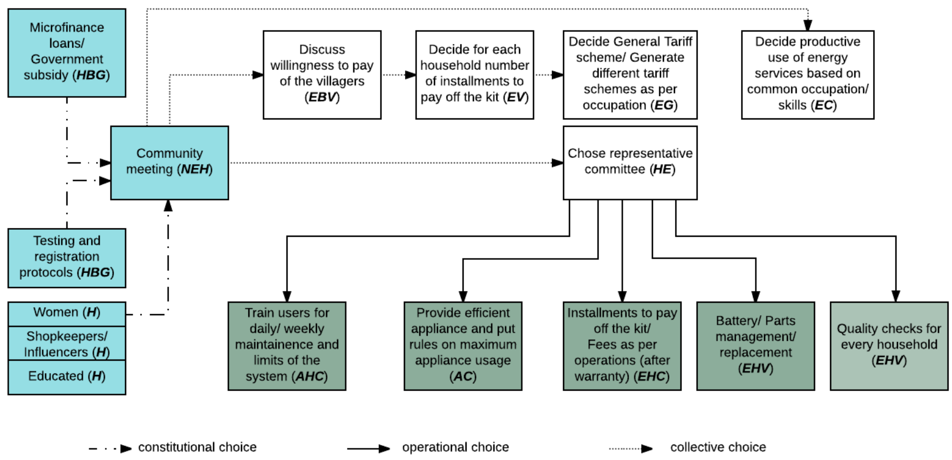



Figure 5.7: Decision flow network for microgrid

mented by energy-provider. These results will be further discussed in the following sub-sections.

### 5.4.1. Actors and Processes

Based on operations, there are certain similarities among the organizations. First of all there are some general similarities, for e.g. all the energy providing firms are buyer of the components and assembly maker. None of them is a component maker and they are dependent on different manufacturers for different components. Also, there are high number of contractors/ middle men involved in the process of distribution of products and money, but this is simplified in the processes defined in the figures above. This is compensated by using additional costs and delays for the flows wherever there are additional middle-men. Then, warranty period is generally given for 6 months to 3 year for individual SHS projects. Finally. role of external agents is always the same and they are involved to always the same extent.

Next, there are some community specific parameters which are similar to different organizations. Major employment has always been farmers, forestry or laborers. The type of employment decides the type of project chosen: farmers go for higher one time installments, labors and forestry workers for smaller spread-out installments. There are around 6 people in each household. Also, the young people, especially women, from the age group of 25-35 are more interested to get the SHS kits as they have families to take care of. Willingness to pay is high even if the capability to pay is low, as the customers understand the need of electricity (especially in forests - for protection).

Communities are not educated enough to understand the high margin of increase of cost for increase in demands (e.g. a TV set addition would need a bigger battery and more panels which the people cannot understand) and thus their willingness to pay in case of higher demands decrease. There are significant caste divides within community. The transition from customer to non-customer also happens and this happens as willingness to pay reduces with increasing demands as the marginal cost of technology increases and/ or if there is decreasing reliability of technology. The social norms like the castes/ religion plays significant role as caste divide restricts technology flow inter-caste, but strengthens intra-caste technology flow. Interestingly, in spite of patriarchy, women are major customers. Stealing & cheating by community is common to happen in micro-grids, especially when the projects are government subsidized.

Finally, the policies among the different organizations have similar roles e.g. kerosene is a competitor for all of these projects due to government subsidy on the kerosene. National solar mission incorporation 2009 has made possible subsidy within loan for higher afford-ability of SHS. In 2016, testing standard rules and fewer testing centers have lead to issues of delayed delivery for bigger SHS projects. Competitions from kerosene due to the subsidy to kerosene leads to lesser acceptance of SHS. Political leaders have been spreading negative word of mouth during elections to falsely promise extension of grid to get votes in their favor.

### 5.4.2. Rules and Decisions

The differences among organizations, mostly come out in the form of the rules which are applied to different types of projects. These differences and there reasons are listed below.

- General rules:
    1. More the market size, more the revenue for sharing and SHS
    2. Actors and Process networks are the same for SHS and sharing - but they have different roles/ they get their income from someone else
    3. Sharing models have B2B models, and the direct connection to and/or involvement of community is rare.
- Top-down Rules by energy providing firms:
    1. In sharing projects, payoff rules condition are affected by:
        (a) How many houses are connected
        (b) What is the quantum of energy traded
        (c) The cost of grid is not the only cost but there are other costs as well
        (d) "Different costs to different users could lead to conflicts" - statement by SolShare
    2. Operational rules
        (a) Training of users is common as soon as the households are handed with solar house kits
        (b) Quality checks and battery replacement is frequent but there is an operation fee for the same and there is warranty time to take care of early operations on all projects.
    3. Constitutional rules
        (a) The testing and registration protocols vary for strictness based on the size of company: larger company has stricter regulations for registration and testing.
        (b) The government subsidy/ micro finance loans are abide in the contract for larger SHS projects, like the case of Selco and Simpa.
- Usage Rules in place in the community
    1. An upper cap on the usage of number of devices is put to make sure that the usage of the SHS is optimum.
    2. In night, the households keep the lights on, because of fear of reptiles and thefts. This leads to loss of battery life.
    3. Maintenance of the solar panel is not a common practice among the households.
- Decisions taken by individuals for acceptance and usage:
    1. Acceptance of the innovation or not.
    2. Amount of resource usage i.e. the duration of the time the devices should be put on.
    3. Number of devices to be plugged in at a time for using electricity.
    4. Replacement and/or maintenance of the components.

## 5.5. Success of project

As per the rankings given by the interviewed practitioners based on the quantitative rankings to the success factors, out of all the success parameters defined: Affordability, Accessibility, viability, Reliability, Profitability, Socio-cultural, Political, Long-term and environment, the most relevant and important ones for energy providing firms (based on the mean score) come out to be: Affordability, Viability, Reliability, Long term Profitability, Equal accessibility. These will be the main focus of the analysis and the performance measurements of the electrification projects from here onwards. Affordability defines if the service is affordable for the customer, and Viability is defined as the efficiency of technology as perceived by the customers – e.g. if it says it will deliver the demand of running TV, it is capable of it. Reliability of technology lies in trust on technology of the customers. Long term means long term sustenance of the project i.e. at least 10 years of the 2 life-cycles of the project, the service should stay. Profitability relates to the profitability of the energy providing firms. Equal accessibility is important for the equal access to all the users irrespective of their socio-cultural or economical background.

An ANOVA analysis is done on this sample to see the effect of these factors on the success of projects. The data is divided such that the answers can just be a yes or no and thus converted into numeric variables as 1 or 0. Some of the answers are not clear yes or no, and based on every question it is decided whether they are given value of 1 or 0. For example, ownership transfer in microgrids happen simply for the community, but in individual SHS, people pay off their kits and get the ownership. The latter case is no pure ownership transfer, but still it has im pact on the way people define success of the project, and thus it is given the value 1. Similarly other answers are converted into categorical values for facilitating regression/ other statistical analysis. The complete conversion list of the variables is in the appendix in table B.5. The significant results of the ANOVA ($p<0.05$) are given below in the textbox.

Significant relations of community or project characteristics and success of projects:

- Long term sustenance of project was important if it was a Business-to-Consumer type of firm (directly interacting with consumers)
- Profitability of project was important if a village committee or manufacturers were involved
- Reliability of technology was important if banks were involved, and there would be an ownership transfer for the project

Based on an interactive visualization (developed in tableau [4]), the results show that irrespective of the type of projects in terms of ownership (i.e. microgrid, sharing or SHS) the valuation for success factors is very similar for the projects. This justifiess to use the same type of success parameters to compare different projects.

## 5.6. Conclusion

After a thoroughly developed main interview, taking the adoptions from preliminary interview, data preprocessing and reliability analysis is done for the interview results and the flow of this is shown in 5.3 involving on-ground and off-ground interviews. The major focus of the parameters to be checked in the interview are Technology, Energy provider characteristics, Community characteristics, Actors properties and involved, Operations and Maintenance of the project, Market settings and funding for the project, Institutions (Formal and Informal), and success and sustainability parameters for the electrification project.

The analysis is done for interviews on three levels, understanding the interview major points, actors network (involving energy, money and policy flow) and decision flow network as shown in Figure 5.4 to 5.6. The collective decisions are absent in the sharing projects, but major decisions are taken by the collection of the decisions of the individuals. The collective decisions are strong and present in the microgrid projects. The actor networks are not very different except for some difference of roles. The different rules in the form of top-down rules, usage rules and the decisions of the community are also narrowed down as the result of the interviews, which help in facilitating the institutional innovation framework.

The success of projects is compared and analyzed for different projects based on interview inputs using visualizations and statistical results. The visualization show that there is not major difference between the evaluation of success factors by the micro-grid, sharing and SHS projects. Thus these same success parameters can be used for three of them comparison ahead. Statistical results showed that different actors involvement (manufacturers and village committee) affects the profitability of the project to be a more relevant factor. Also, reliability becomes important with banks involvement and long term sustenance of project becomes important for projects with direct contact of providers and consumers. This helps in developing the conceptual model's foundation as shown in chapter 6 by laying out the rules, agents, and their properties for an agent based model to be discussed in chapter 7.

[4] `https://public.tableau.com/profile/publish/Interviewanalysis/Dashboard1/publish-confirm`

# 6

# Conceptualizing electrification projects

*Discussion in the chapter 5 showed the actors, process/ decisions/ rules and the success factors important for the project. Based on this, this chapter discusses the choice to define the conceptual models in Section 6.1. As the model cannot exactly depict the real world, there are some assumptions made to develop the model which are listed in Section 6.2.1 and then verified again with the energy providers as listed in Section 6.2.2. These assumptions also help in defining data for model to some extent, especially catering to the social characteristics. The model's three components (physical, collective & constitutional; operational and evaluative) taken from the MAIA conceptual framework are introduced in Section 6.3*

*The physical, collective and constitutional structure is discussed with all the components in the Sections 6.4.1 to 6.4.8. The operational structure listing the action sequences and the inclusion of theoretical framing happens in Sections 6.5.1 to 6.5.2. Finally, the evaluation of the model to check its outcomes happens in Section 6.6 which also helps the validation and verification of the final model. The final model initialization with the required variables and setup is discussed in Section 6.7, which is continued to final model building in chapter 7.*

## 6.1. Choice of models

Out of all the existing different type of electrification projects: Microgrid, SHS and sharing, the decision is made only to model the existing the sharing and the microgrid projects. Only these two models have been chosen because the institutional emergence at a community level is non existent in the individual SHS systems due to absence of collective choices. Also, it should be noted that sharing is of two types: box based (sharing/ renting-out of batteries/ devices) and grid based (direct transfer of energy across houses via grid). Out of the sharing models, the box based sharing is chosen here for developing the conceptual model development. The only difference between the two occurs in having a physical link via grid or not between the buyer and seller of electricity or battery (energy forms). This is not important for defining the conceptual model and as listed in the next chapter the model is adapted to develop a grid based sharing as well in sharing projects model.

## 6.2. Assumptions in model

All the interview analysis based results cannot be included in the final model as it makes model too large to handle and impractical, thus there are many assumptions made to develop the model. These are also verified with a round of interview with the energy providing firms (*Rural Spark* and *Mera Gao Power* for sharing and microgrid model, respectively).

### 6.2.1. Assumptions

Some important decisions and assumptions were made as shown below and then the assumptions were reverified with the energy provider stakeholders, specifically for the sharing model. These assumptions are divided into three levels: manufacturing of the energy kits; distribution and operations of the energy kits; and finally, the social scenarios of the community.

1. Manufacturing
   (a) The manufacturer makes the components as per the kits i.e. if 5 components are required for one kit, then the components will always be made 5 each, such that no component will be left in excess than others.
   (b) The energy provider do not take a cost based decision (first time fee doesn't exist) to buy the components from the manufacturer (everything is affordable).
   (c) The manufacturer is ready to sell the components to any customer that comes to them i.e. the energy provider.
   (d) The energy provider is not ready to buy the components from more than one manufacturer on a demand.
   (e) Time for component manufacturing is similar irrespective of the type of component.
2. Distribution and operations
   (a) A producer would not become a full consumer (i.e. not sell any energy) in Sharing projects, because their main motivation to be a producer is to make more income by selling energy.
   (b) There is no middle-men or an energy distributor company in between the energy providing firm and the producer
   (c) The distribution lines as a physical component are very important, but they are not included as physical components costing the energy providing company.
   (d) Different products bought by the producers are not considered here.
3. Social characteristics
   (a) In reality, there are shops, farms and other economic activities in the community. Except for shops, all other activities are neglected while calculating the potential of households to become shopkeepers. Households take the role of shops due to their higher connectivity and higher economic value.
   (b) Connectivity of every household includes all the people in the caste. Shops have a higher connectivity even outside caste, based on the number of unique products they can sell. Here the characteristics of the castes are used to define affordability and thus connectivity (described in detail in model setup and specification)
   (c) Electrification of the village from other sources is non-existent or completely unreliable, which makes the village almost completely non-electrified. all of these non-electrified households basically have kerosene as their source of electricity.
   (d) The caste ratios of every village are approximated as national average and as given in sachar committee report (2004-2005) and national survey [1] and national surveys [2]
   (e) There are only three types of "castes", which are low, medium and highest. In reality this picture is much more complicated based on religions, etc.
   (f) The considered jobs are of four types: big farmers, shopkeepers, small farmers and daily wage laborers, and finally forestry workers. A government job holder is considered to be highest payee here, but those are not suitable customers here. They are more of a extreme case scenario in the model - thus left out.
   (g) The complete income is taken into account for comparing with the installment, due to the savings and people's opinion to look at this as an investment and not an expenditure
   (h) If there is a subsidy, it will always help in allowing a household to have income more than the installment.
   (i) No consumers have the income as low as to not able to buy battery as the costs of battery in sharing is very low.

[1] http://www.teindia.nic.in/Files/Reports/CCR/Sachar%20Committee%20Report.pdf

[2] http://mospi.gov.in/

### 6.2.2. Verification

Even though assumptions help in making models more practical to be developed, they might lead to losing on some important points in the real system. The impact of some of the "wrong" assumptions can cost the model's results and thus, these assumptions were verified with the energy providing firms (*Rural Spark* and *Mera gao power*) as shown in the C.1. The final model assumptions based on the verifications are listed below (only the modifications are mentioned below, the assumptions which remain same are not re-mentioned):

1. Manufacturing and rules
   (a) Registration is significantly time consuming process and happens repeatedly
   (b) There is more than one manufacturer
   (c) No government restriction for even testing - but the companies would do it, and want manufacturers - for reliability
   (d) Significant delays caused due to manufacturers availability
2. Distribution and Operations
   (a) Not only batteries but also lamps are sold in Sharing projects.
   (b) Closest shops are more preferred over the sects based choices of shops and this is dominant in bigger villages with at least households more than 100.
   (c) Appointment process of producer do exist but it can be neglected here because it is mainly based on the locality and the income - which both are included in the model designing of voluntary involvement of appointment of producer.
   (d) For sharing projects, there is no involvement of community head.
   (e) If everyone becomes producer, Energy provider leaves the community
   (f) Penalty fee for damages is less than the selling cost of the product
   (g) Allowed margin flexibility exists
   (h) Kerosene is NOT a major competition - in fact people buy in spite of that.
   (i) Demand rise is accelerating and more than one product choice exists (people would like to be producers for more than 3-4 lamps)
   (j) There is maximum wattage limit on the devices and thus even if farmers buy for farm, he/she would not use it for high capacity appliances.

## 6.3. Introduction to MAIA

Before developing the agent based conceptual model, there is need of a framework which can help develop such a qualitative model into agent based actions, roles and properties and MAIA (Modeling Agent systems based on Institutional Analysis) (Ghorbani, 2013). It helps in laying out a modeling structure to define a complex social phenomenon using the IAD framework. This framework is adapted while defining the action sequences for the model and these developments are discussed in more depth in the Section 6.5. There are three components to MAIA framework: constitutional,physical and collective, followed by an operational and a final evaluative structure. Constitutional structure helps understand and model the information on roles, institutions, groups and dependencies between roles and groups. The physical structure helps define the material flows in the model where resources with their properties are included in this structure. The collective structure helps to define the agents and their properties and the social network. The next structure, which is the operational structure defines the actors' interactions. Finally, the evaluation structure helps understand the output of the model and defines criteria to which the model results should comply. The following figure 6.1 shows this complete framework by showing the flow in the structures.

## 6.4. Physical, constitutional and collective structure

### 6.4.1. Roles

Every agent who is involved in the system takes up different roles and these roles have objectives, institutions, institutional capabilities, entry conditions, physical components ownership, and information owner-

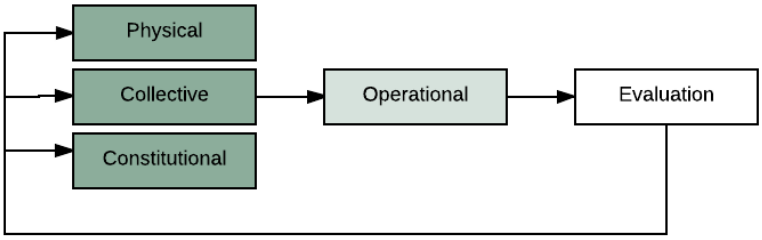



Figure 6.1: MAIA framework

ship. The Table C.3 gives the roles of the agents in this system and the major one among them are manufacturers, energy providers, producer, consumer, governments, operator, fees collector, community head / local legislator. The role of producer and consumer is given to household in case of Sharing projects, but for the microgrid, role of producer comes to energy providing firms. Also, the roles of operator, fees collector and the community head gets combined in the microgrid with the village committee, but it is given to households in the Sharing projects (who might not be producer/ consumer).

### 6.4.2. Institution

The institutions are formulated following the ADICO rules as listed by Crawford and Ostrom. (1995). Here A: Attributes, D: Deonic Type, I: aIm, C: Condition and O:Or else, gives the set of formal and informal rules or institutions which lay down the ground rules of the energy sharing and microgrids systems of rural India. The associated agents are shown in the table C.3 above as well. The Table C.4 gives the institutions, formal and informal which are present in the system of solar electrification of rural India. The major institutions can be categorized in the social characteristics of the community (relating to the inter and intra caste rules, patriarchy, and other community divides) which leads to the heterogeneity and homogeneity of the community and constitute of informal rules. The second set of formal rules pertaining to the formation of *village committee* for the microgrid project includes formal and informal institutions related to the choice of the members of the village committee. Then, there are formal regulations by the government and the company about the regulations, registrations and the tests for the energy provision. Additional to these formal regulations, local governments are more involve with the community leading to some informal regulation like local political discrimination, negative word of mouth to obtain votes from people and the choice of *energy providers* to not opt for subsidy or any government support to stay out of bureaucracy and politics.Finally, there are formal operational institutions which are placed by the *energy provision firms* for efficient use of technology to make sure it can be sustained for a long time. There are many exceptions to the institutions listed in the table C.4 and the component *Or Else* in ADICO lists such exceptions.

### 6.4.3. Groups

The Table C.5 shows the groups of the agents which can act together as single agent or as a single entity in the model for the given case, following the same institutions and having access to similar physical components. It is important to identify such groups to simplify the models where considering the same properties of the agents migth lead to more computational time and lead to redundancy. The main identified groups for the microgrid models are *ProducerGroup* and *VillageCommitteGroup*. The former constitutes of the energy provider who takes the role of distribution and provision of energy via an array of solar panels. The latter constitutes of fees collector, operator and community head who form a representative group of the consumers, chosen by the villagers. The groups in the sharing model comprise of *Allinoneprovider*, where energy providing firm also takes up the work of energy provision and operation (roles of operator and fees collector). The operator and fees collector here are appointed and employed by the *energy providing firm* and thus become a part of the energy provider. Depending on the purpose and scenarios of the model, these can be considered as the roles of agent *households*. Finally, the group Local legislation mostly common to the sharing projects comprise of the government and community head as the part of the local government and working as an external agent group.

### 6.4.4. Dependencies

The dependency diagram is an adapted actors chart as shown in the 5.4 and 5.5, with clear flow of the physical components and money. The figure 6.2 makes the dependencies clear for the sharing system of energy. For the microgrid, the difference is:

1. The producer and energy provider are the same (*ProducerGroup*)
2. The energy provider appoint the operator and fees collector and they remain as part of the village households (while in sharing they might be external employee not associated to the households)
3. The operator takes care of the components and the kit regularly and not only on demand
4. The fees collector collects money from the consumer (rather than the producer)
5. Electricity is sold instead of batteries (flow energy/ versus stored energy - through grids for former)

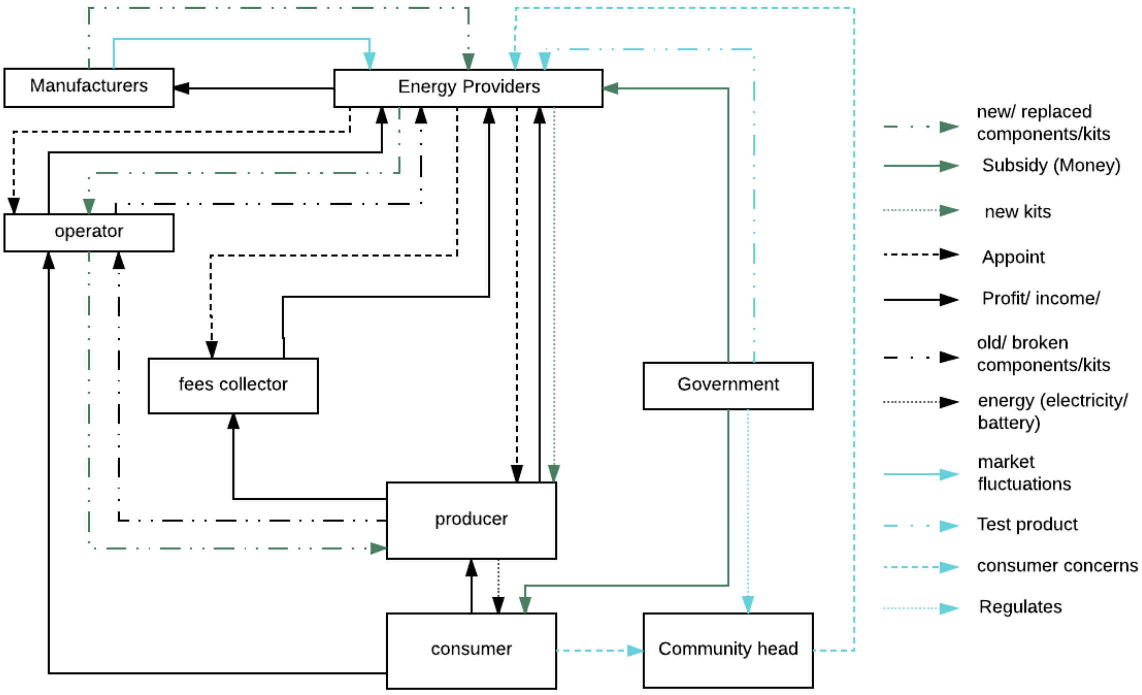



Figure 6.2: Dependency diagram

### 6.4.5. Physical components

As much as the agents are important in the model, it is also important to consider the physical components in the agent based models, because these are the resources which flow in the model. The physical components are owned by agents at different point of time and every physical component has different associated properties. The table C.6 shows the physical components properties, type and behaviors. The major components are the energy kits, energy itself (electricity/ batteries), and other appliances. These components are further divided into the new/replaced and old/broken components. The following Figure 6.3 also shows how different components are linked together for this case. This composition helps in understanding the hierarchies of the physical components and make it easier to associate them to the agents.

### 6.4.6. Social Network Diagram and role enactment

Based on the agents in the system, they are connected to each other in a network like a Social Network. This is shown in the form of connection table derived based on the dependency diagram and can be found in the

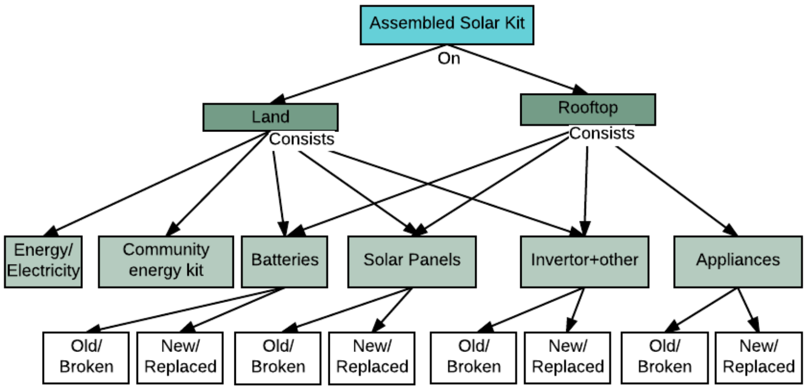



Figure 6.3: Physical composition diagram

table C.8. This table accompanies the role enactment as well for the agents i.e. how the agents take the roles and the actions and what are the associated physical component during these actions. These help in defining the following action situations, and the connection between the agents (sender and receiver) involved in the action with the constituting physical component, as conceptualized in figure 6.4. The main action situations defined through this table C.8 are Selling-buying of components between manufacturers, energy providers, producers and consumers. Appointment of the producers and village committee by the energy providing firms is also one of the action situations generated here.

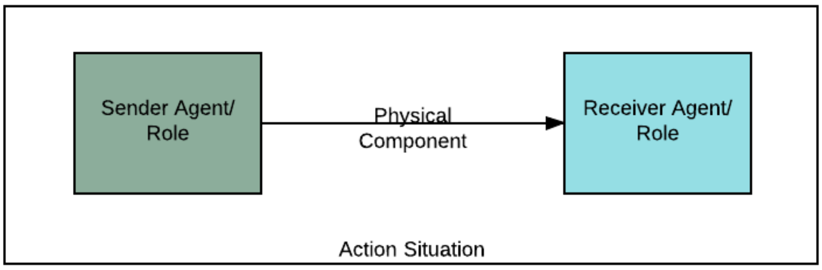



Figure 6.4: Social Network Diagram and role enactment concept

### 6.4.7. Agent

Till now, the agents have been defined at different levels as per their roles, properties and the different institutions and other agents they are associated to. Now, the next step is to put all this together to understand the capabilities and the information owned by the agents This can help in understanding that what are the decisions that the agents can make which will help in developing the operational structure of model easily. The agents used in the model with their related model, properties, actions and decisions they take and their intrinsic capabilities can be seen in the table C.7. The agents, especially households are seen to be taking the maximum number of decisions as they are the focus of the model and the decisions are governed by the community and also their own economic and other utility concerns/ choices.

### 6.4.8. Action Situations

The action situations as developed in the Social Network Diagram and Role enactment concept in Table C.8 and there further details are shown in the table C.9. This lists the associated actions and the institutions of the action situations. The flow of the action situations or action sequences is developed for both micro-grids and sharing and shown in Figure 6.5 and 6.6

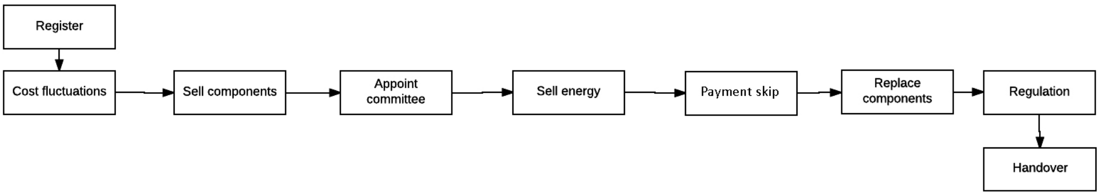



Figure 6.5: Action sequence microgrid

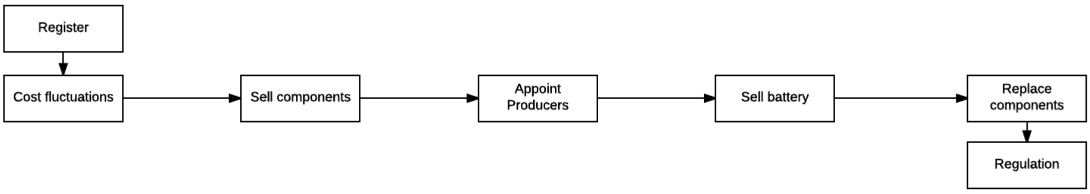



Figure 6.6: Action sequence sharing

# 6.5. Operational structure

Based on the physical, collective and constitutional structure, the final action situations and the action sequences are developed. To execute these action sequences it is important to define the exact decisions taken by the agents during these actions. The theoretical framework developed in the Chapter 4 and depicted in the Figure 4.7 can be used here. Additional to the action sequences, the evolutionary process of the diffusion and adaptation is also included in the operational structure of the conceptual model and this structure is detailed out in the figure 4.8. The operational structure of the institutional innovation framework which will be used here is shown in the Figure 6.7 below.

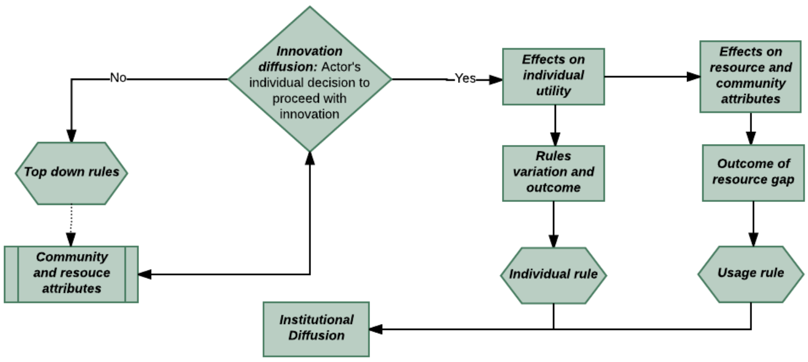



Figure 6.7: Operational structure from theoretical framing

**Innovation Diffusion:** As depicted in the Figure, the next step is to know the decisions that the actors take for considering an innovation. These decisions are adapted from different economic and word of mouth theories as concluded in Section 3.2.2 and the decisions chart is shown in Figure C.1. This figure shows the flow of decisions of an individual household to chose to adopt innovation or not (or even upgrade to next innovation/ better product). This decision chart helps to understand the inclusion of both the (economic and word of mouth) diffusion theories together. Note that this is only to understand the action of innovation acceptance of an individual. The examples of these can be seen in the action sequences of the households.

**Top-down Rule for acceptance:** Once the individual households take a decision, based on the combination of these decisions, the energy providing firms adapt the rules to try fitting maximum of the households as the consumers. But this decision cannot be taken without understanding the energy providing firm's profits. These adaption or the adapted rules of use can be seen as top down rules, followed by combination of decisions of people. This combination of decision is not the exact sum of the individual rational decisions though, as it is affected by the different policies (schemes by governments) and as mentioned the profit of the energy providing firm as well. These leads to development of more flexible rules like the "allowed margin" as seen in Figure C.4 by the energy provider, where they allow the people to be relaxed with a large installment if they have a low income (by reducing the amount of installment per month and increasing the number of installments). At the same time, though such flexibility exists partially, it is not fully practiced because it would lead to a loss for the energy provider and thus strict regulations are used many times using technologies of smart meter, where the customer is simply cutoff from the service as in case of Micro grids.

**Community Attributes:** There is a significant impact of community attributes in actions of the innovation acceptors and that can be seen in the figure below C.2. Such effect from the community attribute is seen in calculation of the connectivity of the households. The connectivity of a household is highly related to their caste and the employment they have. For e.g. a shopkeeper is much easily connected in a village than a farmer. This connectivity also defines if being a producer would eventually be profitable for the household (i.e. the household would be able to pay off the kit within a year by gaining enough income from selling the energy). After the setting of the connectivity, this connectivity also upgrades as the innovation is introduced in the community. For example, for connectivity, it increases with time because a consumer affects the neighbor and thus the neighbor gets connected to the producer as well. Like connectivity, a payable income which can allow helping you to pay the installment of the solar electrification project is also dependent on the social attribute of a person. This is shown in the Figure C.5. For income, as the producer makes profit after settling for all the investments, the income of the producer rises as an accumulation of the profits, which upgrades the income of the producer. Also, as a consumer gets continuous supply of energy, it starts affecting its daily activities, giving more productive time and thus increasing the income of the households.

**Effects on individual utility, rules variation and outcome:** Once an innovation is accepted as an action by an individual, the first effect it leads to is the effect on the individuals themselves. This leads to evaluation of the individual utility in terms of economic or social benefits or losses to the individual. The economic effects can be monetary or asset losses, and the social effects can be in terms of the connections of the community. The type of effect i.e. a loss or a benefit decide how the rule would be varied. Once the effect is known, the rules are varied based on the losses or the benefits to the individual utility to help increase it.

**Effects on resource and community utility, and usage rules:** The final section on the effects on resources and community attributes, Usage rules and Institutional Diffusion is discussed in depth in the section 4.3 and Section 4.4. An example of this can help show the rules laid down and choices based on the outcomes for the resource gap for the maximum power availability and need of the community. The general choice, variation and outcome for the rules for the individual and the usage rules can be facilitated by the combination of the individual, resource and community utility. This is shown in the following Table 6.1, depicting the rules choice based on the evolutionary diffusion and adaptation process. These rules facilitate maintenance of a higher utility of the individual, resource and community simultaneously.

Table 6.1: Rules variation and choice for different individual, resource and community utility

| | | Resource and community utility | |
|---|---|---|---|
| | | Low | High |
| Individual utility | Low | Constrained usage and innovation propogation for resource development and preservation: Variation of usage by individual and variation in community pool | Distribution to individuals: Variation of the community pool |
| | High | Compensation rule by individual: Variation of the usage of the individual | Preservation and development |

### 6.5.1. Sharing project

As per every action situation, the actors talk/ negotiate/ sell and buy physical components with other actors and this is reflected in the action situation diagrams C.4 and C.6 to C.8 (in the order of the action sequence). One of the examples of the action situation to appoint producer is shown in the Figure C.4. As shown in the flow charts these action sequences have decisions at every stage which get influenced by other actors thus helping form a pattern of interaction between the different agents.

### 6.5.2. Microgrid

Similar to the action situations and the action sequences of the microgrid, the decision making behaviors have inspired the action situation diagrams. Some of the action situations here are same as the sharing projects. One major difference here is how the energy provider gets profit and gets affected by the stealing and cheating by the consumers or simply the payment skipping by the consumers. This is shown in the figure C.3. Another important and different action from sharing project is appointment of the village committee and one of the example is shown in the Figure C.9.

## 6.6. Evaluation structure

Now that the model is set up to its very detail an evaluation structure needs to be set up to check the effects of the model on the performance indicators and the different parameters values set up in the model. First, the most important things which need to be calculated in this model as the parameters are listed down which can also help in defining the success parameters of the model as defined in the literature and followed up in interview (Affordability, Accessibility, viability, Reliability, Profitability and Long-term). The relation between these success parameters and general parameters is shown in 6.2.

Table 6.2: The parameters used for evaluation based on the success parameters

| ***Success parameter*** | ***Parameter of model*** | ***Description*** |
|---|---|---|
| ***Affordability*** | Afford-kits | Number of people able to pay the first installment of the solar kit/ energy |
| | Consumers | Number of households chose to be a consumer |
| ***Accessibility*** | Access-kits | Number of households having at least one consumer in closest neighbor circle |
| | Producers: | Number of households who chose to be a producer |
| ***Viability, Reliability*** | Battery stock time: | Time for which the battery stock last with a shopkeeper/ household |
| | Delay sell battery: | The delay between sold batteries |
| | Operation time: | Number of times the operator is asked for maintenance |
| | Meet-demand-rise: | Number of times the provider is meeting energy demand |
| ***Profitability*** | Profit | Profit the shopkeeper is able to make once he/ she has become a producer? |
| ***Socio-cultural*** | Allowed margin: | Number of times an allowed margin is given |

Additional to the parameters which needs to be looked at to understand the behavior of the model, let us also look at the scope matrix, which shows the effect of the action situations on the parameters. This is shown in Table 6.3 where it can be seen that whether an action situation affects one of the above given parameters, and if yes, then does it do it directly ('d') or indirectly ('i'). This will be referred back again in the verification section in 7.1.3.

## 6.7. Model Setup

Now that the complete structure for the model building is set up, the next step is to setup the model practically in Netlogo [3] software. This needs to define variables which would be used in the model and it is done in the table C.10. The values of these variables come from different sources and especially the community parameters are set up after a thorough research. These parameters are same throughout both the microgrid and Sharing model.

**Setup of community:** The community is different in terms of the number of households, their proximity

[3] `https://ccl.northwestern.edu/netlogo/`

Table 6.3: Scope Matrix

| ***Action situation/ Parameters*** | ***Afford -kits*** | ***Consumers*** | ***Access -kits*** | ***Producers:*** | ***Battery stock time:*** | ***Delay sell battery:*** | ***Operation time:*** | ***Profit*** | ***Allowed margin:*** |
|---|---|---|---|---|---|---|---|---|---|
| sell components / kit | | i | | | d | d | | d | |
| Sell energy/ battery | | d | | | d | d | | d | |
| Replace components/ kit | | i | | | i | | d | | |
| TestProducts | | | | i | | | | | |
| CostFluctuation | i | i | | | | | | | d |
| Appoint committee | | | | | | | | | i |
| Appoint shopkeepers | | i | | d | | | | | i |
| Regulation | | | | i | | | | i | |
| Subsidise | d | | | i | | | | i | i |
| Handover | | d | | | | | d | | |
| Register | | | | i | | | | | |

and other community characteristics as obtained from the interview and that need to be stored in the initial setup of the model. The characteristics include, but are not limited to total number of households in the community, followed by the number of castes in the community: low, middle, upper (SC-ST, OBC, general). The number of households in every caste are considered in the ratio of 28.2:41:30.8 percentages or 3:4:3 for simplification. The shops are distributed similar as the population ratio (3:4:3) and they are an important source of employment and points of connections of community. A simplified distribution of employment and the castes is done in the model based on the poverty indices and surveys present [4]. Income is shown as the affordability to pay the first installment or not based on the job.

### Model setup for employment characteristics

- Based on three castes and 4 types of employments, there are 12 types of income groups and the rules are (also shown in figure C.5) that the income for high caste big farmers and shopkeepers is high enough to pay the kit in one time.
- The income for middle caste shopkeepers is enough to pay installment.
- The income for high caste, low caste or middle caste small farmers/ daily wage laborers has 50-50 chances to be payed or not (done at random in the model).
- The forestry workers of any caste cannot pay the installment without subsidies.

The connectivity of the households, come from the different characteristics as below and the numbers are given in the figure C.10 and the final method of connectivity value calculation is shown in the figure C.2. For connectivity, all the households in the same caste are connected to all the other households. Also,a specific percentage of houses are not connected with one of its closest neighbor due to "conflict" (take this as one percentage for simplified model). A specific percentage of houses (3 percent, here) are shops which have higher connectivity than just their own caste. The shops in the highest caste are connected to every specific percentage of houses (5 percent here) in the middle caste which is higher than the houses in the lowest caste (1 percent here). The shops in the middle caste are connected to specific percentage (3 percent) of the lowest caste population. Note that the household itself can be a consumer and thus it is connected to itself as well and thus the connectivity of a household is not the total population-1, but total population itself.

**Setup of externalities:** As the model progresses, the community and other parameters change in the model, which would happen irrespective of the introduction of the such electrification projects. There is an increase in income of everyone as per changing inflation, but this varies for every caste/ economic level (because of their jobs) and the highest benefits come to the big farmers, followed by the shopkeepers, then the daily wage laborers or small farmers and finally the forestry workers. Also, there is an inflation drop or rise every year.

[4]`http://www.livemint.com/Politics/ino3tfMYVsd6VVGUdWXB8H/The-many-shades-of-caste-inequality-in-India`

**Setup for difference in projects:** Difference between different projects of electrification i.e microgrid and the sharing are based on not just the different action situations but some differences in the initial setup, whic hare the number and size of energy source(s), number and installment costs of billing cycle(s), and the operation costs. Number of energy source(s) is only one in the microgrid, and located in the center of the model. For Sharing, all the producers are the energy sources. Size of Energy source(s) for micro-grid is usually much larger than the size of one energy source of the Sharing Projects. This size is slightly more than the requirements of all households combined. Number of billing cycle(s) for the Microgrid is continuous as the payment for operation for the whole energy source is paid for. While in Sharing projects, the billing is as per the number of installments agreed upon till the kit is paid off. Installment cost(s) per billing cycle for the microgrid is much lower than one installment cost for Sharing, because the aim of the latter is to pay off the whole kit fastest. Operation cost(s) for the Sharing projects is handled as an extra fee to the energy provider every time there is need of maintenance except for the warranty period.

## 6.8. Conclusion

This chapter lays down the complete framework of the model to be developed in Chapter 7,based on the empirical analysis done in the Chapter 5. The assumptions in the model are crucial to be considered and verified with the energy providers again. Majority of the assumptions can be taken ahead, but one of the major assumptions to be modified were the competition with kerosene, which is reducing with the increasing awareness about its hazards. There are three main parts of the model: physical, collective & constitutional; operational; and evaluative. The first part/ structure of the model lists the major agents, roles, their connections, actions and the institutions around them. The most important product of this is the dependency diagram which shows how different actors are connected via forms of energy, policy and money as shown in Figure 6.2. The role enactment and social network diagram helps in laying out final action situations with the included physical component, where major action situations are buying-selling and appointment of producers and village committee.

This is followed up with the operational structure which uses the concept of the theoretical framework combining innovation diffusion to implementing the institutional innovation in the examples of action sequences.The different innovation diffusion decisions as taken by agents are combined and put in one decision chart as shown in figure C.1. The difference of institutional innovation leading to an adapted rule of use from a simple ADICO rule with emphasis on *Or-Else* is discussed here, where the former helps in adapting the rule every time in the model based on the community attributes. The community attributes related to the specific project are derived as shown in the figure C.2. All the action situations are developed in depth here as seen from Figure C.4 to C.3.

The evaluative framework finally lays out the validation and verification framework for the model using the success parameters and breaking them into the model parameters as shown in Table 6.2 to 6.3. This is followed by defining a setup of the model which would help defining the community characteristics, the externalities in the model which would arise as model proceeds and the different types of the model (Microgrid and Sharing).

# 7

# Simulation Models

*As per the defined conceptual models in Chapter 6, the next step is to build the models and perform analysis to answer the final research question. As per the action situations defined in the last models with the final decision making behaviors, the models' functions/ procedures are created and they are listed and described briefly with an example in detail in Section 7.1. Note that this initialization is different for the Sharing project and the Micro Grid project and this is explained separately in the sections 7.1.1 and 7.1.2. The models need to be verified and validated with a robustness check before the experiments are performed and this is done in Sections 7.1.3 to 7.1.5. The analysis of gaps in both these models shows the need of a hybrid model as described in Section 7.2. This model is also checked for sensitivity and the results are shown in the same section. All the three models results are checked and insights are generated with comparisons from Section 7.3.1 to 7.3.2. Based on the results, the best model is chosen to be the hybrid model. The final results and analysis based on all the policies are discussed in Section 7.4*

## 7.1. Sharing and Microgrid models

Based on the action situations in the conceptual model defined above, the following procedures are developed for different models. Note that the model is not very different for the both cases in terms of the procedures, but the setup is different as discussed in last chapter Section 6.7. Some of the action situations are skipped in defining the final model and they are the cost fluctuation, appoint committee, and handover. The cost fluctuations are kept as an external event and not considered right now in the model due to the less number of such occurrences happing in real world. The appoint committee, regulation and the handover activities do not add a lot specifically to the model in terms of the selling-buying activities in the community (except for income and status adjustments) for microgrid projects.These action situations will be considered for final analysis while developing policies and scenarios. The sell components is also combined with the sell batteries as the focus of the model is the transactions between the consumer and the producer, and not the provider and the manufacturer. The test and register actions are combined as the major effect they have on community is a delay in the reach of the product to the consumer.

### 7.1.1. Microgrid model initialization

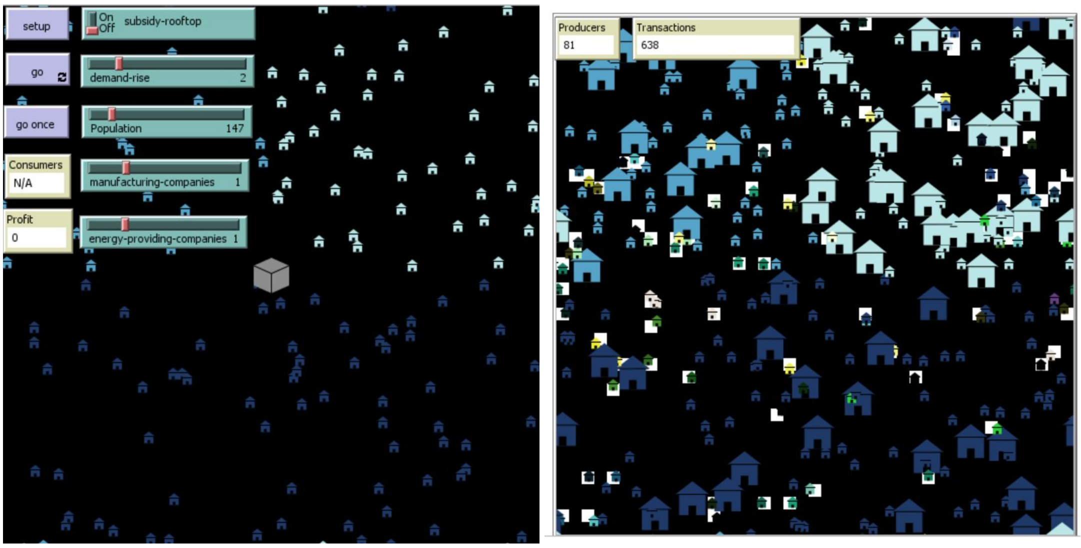
For microgrid, there is a central energy provider and this gets connected to the households which become consumer through a physical grid. There are two steps in a model, to setup the model using "setup" procedure, and then make the selling and buying actions for energy to happen through a "go" procedure. The *setup* procedure has further procedures in it: *setup-houses* sets up the community characteristics by settling different castes in different regions (the upper caste has highest area share) as shown in the Figure 7.1a. The employment of the households is also setup by a *setup-employment* procedure, by allocating the distribution of employments as discussed in Section 6.7 (para: community characteristics). The microgrid is setup followed by an initial connectivity and income setup, as followed from the Figures C.2 and C.5. The connectivity also helps in setting up profitability of producer followed from the same conceptual diagram in Figure C.2.

The *Go* procedure sets the selling and buying of the energy by following the action sequence diagram as in Figure 6.5. The first step is to *sell energy*. Selling energy demands looking at a potential consumer (based on their needs, e.g. if the household has a child and if the household is able to afford the first installment. As the number of consumers increase, the *profit* of the producer/ energy provider changes, and this is introduced in the procedure of selling energy. The next step is to *upgrade connectivity* based on the neighbor effect. The income of the consumers indirectly increases due to the electrification and this is a very slow process, introduced by the *upgrade-income* procedure.

As the electrification continues, some products might fail or get damaged due to use and they need to be replaced and this incurs a cost ou of profit to the energy provider, but is compensated by the installment fee paid by the consumer and this is implemented by the procedure *replace-components*. Finally based on the cheating act by the user or skipping the payment, the households are directly cut off from the system, after checking if there is *allowed margin* or not. There is also a switch of *subsidy* which helps becoming everyone a consumer by allowing them to pay first installment.

### 7.1.2. Sharing model initialization

Additional to the procedures in the micro-grid model, the procedures to be included in the Sharing project model are *appoint-producer* and *test-register-product*. The appointment of producers happen based on the income and the demands, very much like the consumer appointment of the Microgrid. But there is a significant role of connectivity which plays a role in deciding the profit of the project here. Unlike the micro-grid project, which are one time installation, the Sharing projects involve many producers, and regular upgrading of the products. This requires number of tests and registrations for the project, causing delay in the product and energy supply. The *sell-energy* function is also different here. It is heavily dependent on, where the one who produces more (due to more connections) get major profit. Here the caste dynamics are important decision makers. An example of the sharing project model after the go procedure is shown in the Figure 7.1b.




(a) Setup of the microgrid model showing different castes as different colors and variables setup

(b) Go procedure of sharing model (white patch are producers, large households are consumers)

Figure 7.1: Models initialization

### 7.1.3. Verification of models

Before experiments are performed on the model, it is important to understand that if the model is working correctly as what happens in reality and this is done via verification and validation process. For verification, the best method to do is the Unit testing method. This method as listed by Wilensky and Rand (2015), focuses on developing iterative model with every small iteration to be tested as a module. For the same, here these modules take form of different functions of the model and each of them is tested in stages as also listed in the following textbox.

### Stages of model development:

1. First, there is *model setup* module, where the setup procedure is implemented with all the community characteristics.
2. Next, the appoint producers and sell-energy (appoint-producer is only for the Sharing Projects) procedure is introduced.
3. This is followed by upgrade income, upgrade connectivity, allow-margin, replace components and test-register procedures.
4. The respective modules for these are *model go-once-appoint, model go-upgrade-income, model go-upgrade-connectivity, model go-allow, model go-replace, model go-test* (only for Sharing).
5. The subsidy on and off switch doesn't have a procedure of itself, but is still a module.

The model setup shows that the employments, castes, number of families with children, patriarchy prevalent and other such community characteristics are comparable to the real patterns (the distribution is even as it is in the communities). The connectivity setup also functions as per expectations, and it is checked by picking a random household and checking its connectivity. For the microgrids, the next module of model *go-once-appoint* shows that there are some consumers appointed and inspecting them shows that they have income and community parameters as expected i.e. there are no consumers which had no children, and no affordable income. The module *upgrade-income* shows that the demand of the houses who became consumers start increasing after a point of time once they became consumers. The *upgrade-connectivity* module doesn't show any difference till a long time because it only leads to the passing the information to the neighbor, but not increasing their income till the electrification continues for a long time, developing the state of the community.

For checking model *go-allow*, the effects can be seen clearly as well that if the number of consumers are less than half of the population, only then some of the consumers get some margins to become the consumers (also the profit is not negative then). For the module *go-replace*, it can be seen that the profit of the microgrid provider starts getting negative as soon as there is a replacement request. Due to the present cheating and reducing consumers module this profit never gets positive and everyone in the system never becomes a consumer. Finally, the subsidy module makes everyone consumer but the profit is still less than zero. Also, the subsidy in real world doesn't remain forever, which would lead to the stealing and cheating behaviors again.

For the Sharing projects, the same modules are followed. The first module of setup is exactly the same (as it is the same community) and thus works the same as microgrid model. The module *go-once-appoint* helps setup few producers and accordingly some consumers in the community (very few in number due to condition of profitability). Module *go-upgrade-income* leads to increase of all the consumers to a limit and they all become producer. There are no more transactions, as the others couldn't increase their income. Module *go-upgrade-connectivity* helps to involve more consumers because new consumers are born due to the connections (word of mouth). Module *check-margin* leads to higher number of producers, as expected in reality. Finally, with the module *go-replacement* there is a dip and rise in the number of producers, because the damage and replacement of products lead to decrease in the number of the producers (they don't find service as reliable). The rise happens because of the allowed margin. The module *go-test* delays the model by some ticks whenever there are tests. The module of *subsidy* doesn't show any difference but it is so because the subsidy only makes the kit affordable but doesn't increase the connectivity or profitability of the household (both are important to become producer).

For the results obtained, based on the evaluative structure developed in last chapter, the Table 6.3 delivers that which parameters should be affected by which procedure. Dividing the procedures into their respective modules, the following table shows that if the model behaves as expected during the evaluation structure design, as can be seen in the following table 7.1. "T"/ "F" in the table represents if it is "True"/ "False" that there is a relation or not, as defined in Table 6.3. Surprisingly, it can be seen that some relations which were not expected (during the evaluation structure design). This is discussed in detail in section 7.3. Those which are not marked with a "T" or "F" are not checked at this stage. For the allowed margin there is a new procedure and that is why the parameter's effect is not included for verification.

Table 7.1: Scope matrix to verification

| ***Parameters/ Procedures*** | ***Sell energy/ battery*** | ***Replace components/ kit*** | ***Test Products*** | ***Appoint shopkeepers*** | ***Subsidise*** | ***Register*** |
|---|---|---|---|---|---|---|
| Afford-kits | | | | | d - T | |
| Consumers | d - T | i - T | | i -T | | |
| Access-kits | T | | | | | |
| Producers: | T | T for Sharing | i - T | d - T | i - T | i - T |
| Stock time: | d | i | | | | |
| Delay: | d - T | | | | | |
| Operation time: | | d - T | | | | |
| Demand Rise: | d - T | d - T | | d - T | | |
| Profit | d - T | | | | i - T | |
| Allowed margin: | | | | i | i | |

### 7.1.4. Validation of models

As stated by Wilensky and Rand (2015), there are four types of major validation steps: micro-validation, macro-validation, face-validation and empirical-validation. Micro-validation helps understanding if there is similarity between the behaviors and mechanisms of agents as per the real agents in the world. Macro-validation is the process to ensure that the aggregate and the emergent properties as depicted in the model correspond to actual aggregate properties in the real world. Face validation checks the difference (similarity) between the mechanisms and properties of the model and the real world i.e. the action sequences in the model. Empirical validation makes sure that the data generated by the model corresponds to similar patterns of data in the real world.

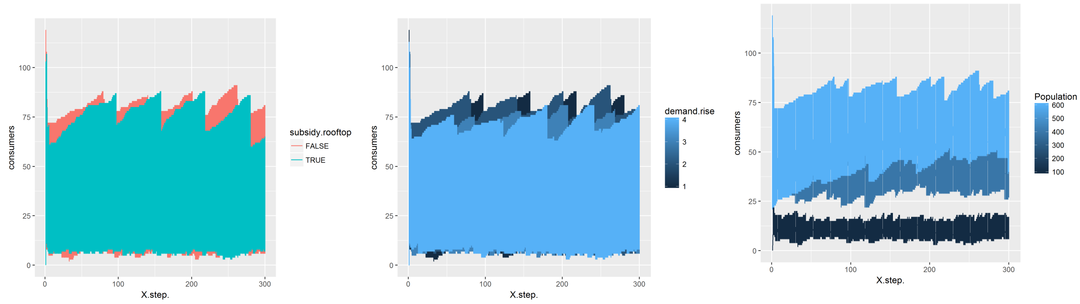
Empirical validation is followed up from the results obtained in the following robustness check behaviors from Figure 7.2 to 7.5. The micro, macro and the face validation is already done while doing the assumptions check part in the section 6.2.2. Also the behaviors of the agents and the model are developed as per the empirical research based on the interview. Some of the behaviors are also verified in section 7.1.3. For empirical validation, as seen the value of the profits goes often below zero (losses) for the microgrid project due to the cheat-steal behavior and the regular replacements. The number of producers and consumers never reach the total population which is also true as majority of the Sharing or the microgrid projects have failed to electrify the households to 100%.

### 7.1.5. Robustness Check

The model needs to be verified for its robustness and this is done by performing sensitivity analysis. The variables used for testing the sensitivity of the model here are: population, subsidy switch, and demand rise. Basically, these variables are varied and their effects are seen on the dependent variables. The dependent variables which are studied will be the number of producers and consumers in the case of sharing projects, and the profit and consumers in the case of microgrid.

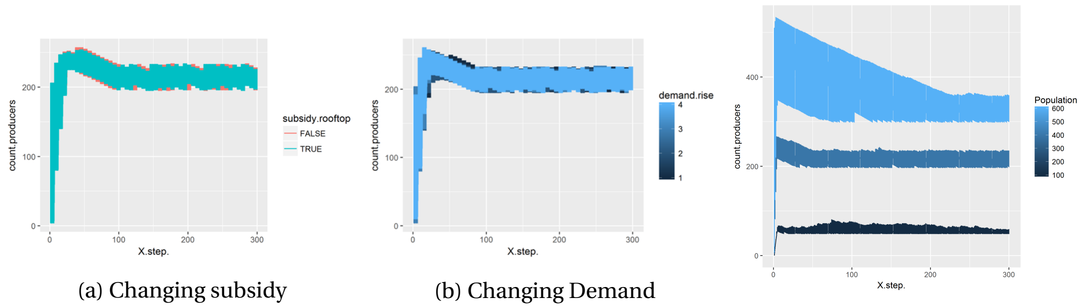
The dependent variables are chosen so because as shown in table 6.2, the "profit" variable help measuring the profitability of the project, which is crucial to be measured for the microgrid projects due to their losses. The number of producers help measuring accessibility of the project in the case of sharing projects and the number of consumers help measuring accessibility and affordability of both the projects.

The results of robustness for 20 replications (20 replications are enough as the path dependence due to setup of experiment does not play an important role to change the behavior of model here) for each experiment for 300 ticks, can be seen in the Figures 7.2-7.5. The first results in the figure 7.2a and 7.2b depict effect of changes in the subsidy and changing demands (demand increase per step) for sharing projects on the number of transactions. These results show that whether the subsidy is present or not, the number of the transactions remain similar. The same is true for the changes in demands. Looking at the changes in population a steady growth can be seen in the number of transactions with the increase in the population as in figure 7.2c. The results as seen in Figure 7.3a - 7.3c show a similar pattern for the producers for sharing project with no significant effects due to the subsidy and the demand, and a steadily increasing number of producers with the same pattern.




(a) Changing subsidy (b) Changing Demand (c) Changing population (without upgrading consumers to producers)

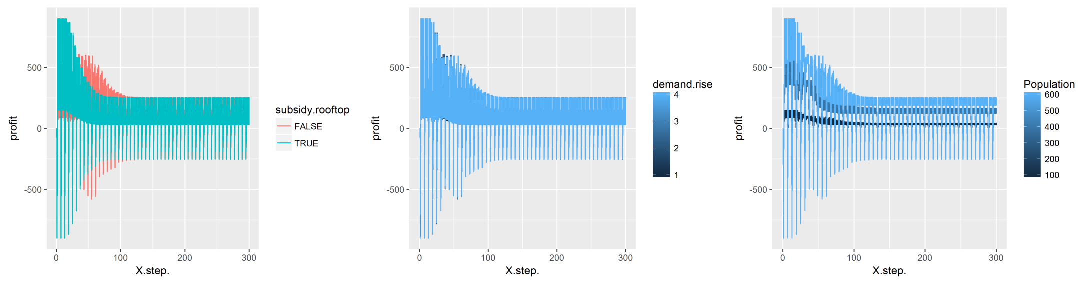
Figure 7.2: Sharing Projects' consumers




(a) Changing subsidy (b) Changing Demand (c) Changing population

Figure 7.3: Sharing projects' producers

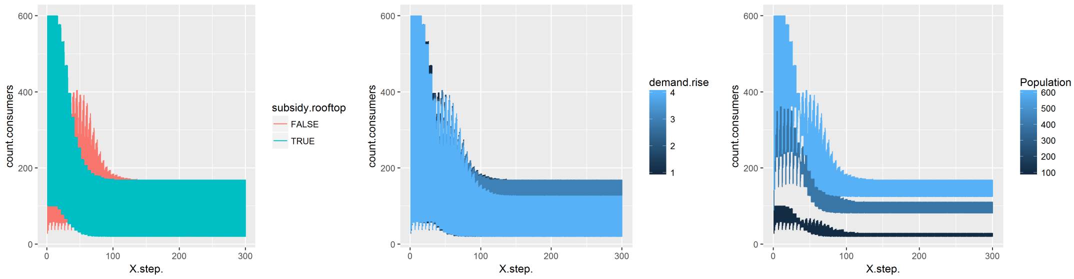
The results as seen in Figure 7.4a, 7.4b, and 7.4c show profits with similar patterns for changing subsidy, demand and population for the microgrid projects. The profit first increases slightly due to the customers, but drops again due to the replacements costs based on the number of consumers. This pattern finally leads to a stability, and this pattern is same across subsidy, population and demand changes, with heavier differences in profit for higher population. The profit is lesser for the microgrids without subsidy, due to less number of consumers who are able to afford the microgrids.




(a) Profit with subsidy (b) Changing demand (c) Changing population

Figure 7.4: Microgrid's profits

The results in Figure 7.5a to 7.5c show that the number of consumers decrease with time. This happens because many people become consumer but eventually, the cheating-stealing behavior or the decreasing reliability of the products, and lack of upgrading leads to declination in the number of consumers. People accept the innovation slowly with innovation diffusion (word of mouth, etc.), and after a point the same reasons of cheating, etc. lead to declination. The effect of demands is similar. The different trends here are further discussed in the section 7.3.




(a) Subsidy Changes (b) Demand Changes (c) Population Changes

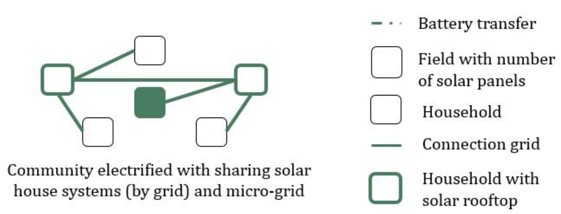
Figure 7.5: Microgid's consumers

## 7.2. Hybrid model

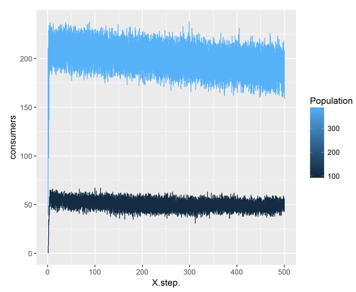
From the earlier section results, microgrid model showed that project very rarely becomes profitable even when there is a complete absence of cheating. Also, everyone never becomes consumer because of cheating and regular operations and installments. But microgrid projects are buffered, i.e. they can provide to the needs of all in the times of demand rise and affordability to pay for the demands rise. Now, this cheating is absent in the Sharing projects, but there is another issue for Sharing projects as seen in the above results. Here, everyone never becomes a producer even if model runs very long. It is so because the rate at which their income increases due to electrification is not as fast as their increase in demand - so these people remain "dissatisfied" consumers who cannot afford a complete kit upgrade. But what they can afford is very smaller payments to the system which is also catering to their demand. This can be a microgrid system. This makes a hybrid project combining the microgrid and the sharing projects. The people can switch to microgrid as their demand increases.

This hybrid project not just solves the problem of income versus demand gap, but also solves the issue of cheating. It does so, because the people cannot be part of microgrid till they have a high demand, and this an incentive for them to already become a producer and thus get into the innovation faster. This is explained in depth while discussing institutions in the section 8.3. Here there can be also different institutions (like the households can take the role of an operator on turns allowing everyone to have small additional income / formal regulation like a subsidy from the government) which can help at least everyone to be a producer and remain less "dis-satisfied".

The hybrid project is developed with similar setups and procedures with an extra procedure to setup-microgrid as the demand of an household increases beyond a threshold of the energy kit and beyond affordability. The following figure 7.6a shows the diagram of physical infrastructure in such a model. After a verification of the model (no validation possible, as such projects do not exist/ not widely known as implemented projects), a similar sensitivity analysis is performed, as shown in the figures 7.6b. This shows similar trend of increase in consumers with population. The demand and subsidy changes has no effect on the patterns of the consumers




(a) Hybrid model infrastructure setting




(b) Population change effect on consumers in hybrid project

Figure 7.6: Hybrid model settings and results

## 7.3. Results and Analysis

Based on the results in the section 7.1.5 and 7.2, the general trends and important results are discussed in the following sections to generate initial insights from the model. Then, the results are compared for different types of projects to chose the most sustained project (in terms of the success parameters and as mentioned in the Table 6.2) for further scenarios and policy testing.

### 7.3.1. Insights

**Laggards never get electrification:** First looking at the general insights throughout all the models, the households who never became a part of the network or accepted the innovations or the laggards are the most poorest and belonging to lower sections of community with least connections. Even subsidies do not make technology very attractive for them. They chose to be consumers, but they cannot be producers in a sharing model. After a point all of these consumers gain enough energy to become a producer due to rise in income and thus they do not want to sell of their kits further and thus the market reaches stability with no transactions as shown in fig 7.2a,7.2b, 7.3a, 7.3b. When the consumers do not upgrade to producers, there are least number of producers and continued transactions with the same set of consumers, due to no increase in the income of the people as sen in Figure 7.2c and 7.3c.

Looking at microgrid, there are no strict patterns, but still there are few of the households who skip too much than others and thus lead to the decline of the total final consumers as shown in Figures 7.5 who stick for a long duration in the micro grid. Similarly, in a hybrid model, the patterns as seen in figure **??**-**??** are similar to the pattern of the sharing model except for a faster stability in the number of producers and consumers. This fast pace of stability shows that the demand rise is met faster in the community due to presence of microgrid allowing the consumers to become producers fast, when they can afford small microgrid payments. But it keeps the laggards stay in the model to be un-electrified.

**Importance of connectivity:** For sharing models, connectivity is the most important factor which played role for deciding the producer. This can be seen as majority of producers are from the mid-caste (higher connectivity due to highest population of middle caste), have the employment of shopkeepers and even if the total population is low, mid caste gets the first sets of producers and consumers. Transition of the consumers and producers generally happen from the mid caste with producers, then to the highest caste as last set of consumers to producers. Sharing of batteries: Sharing doesn't have effect of subsidy because it only increases income of people for one time payment, but what people check is profitability and if they are not connected to majority, the batteries sharing doesn't allow them to be connected anyways.

**Rise and dip in the consumers/producers:** As explained in above sections, ideally everybody should become producer but the system cannot upscale to meet all increasing demands with increasing income (demand rise > income rise), leading to dissatisfaction of consumer. This dissatisfaction is additional to the reliability of the products i.e. the products which decreases for some and lead to the producers to leave the service due to decreasing personal profits. The latter especially discourages producers to leave the network leading to a small dip. Due to a constant upgrading connectivity due to the word of mouth, these networks develop again giving to a small rise. The exact same shape of rise and dip in the model is due to the model parameters, but in real life though the pattern remains the same, the size of the rise and fall varies.

**Combined trends of producers and consumers:** As this is not simply an innovation diffusion case, but includes the institutional perspective as well, the number of consumers and producers do not follow the specific s-curve. This is also accounted for by the fact that the total "consumers" (as per definition of innovation diffusion) here comprise of both the producers and consumers, so the trend of innovation diffusion needs to be studied together for both producers and consumers.

An important point to note in the figure 7.2-7.3 is that there is a peak of the number of producers and consumers as the experiment starts for the sharing project. The same can be seen for the number of consumers for the microgrid project as seen in figures 7.5. This is close, but not exactly as what happens in reality as well. Only after people start using an innovation, they start facing some issues and thus decide to not use it further or switch to alternatives. But this peak doesn't stand as an outlier in reality, as this is usually a gradual decrease. The reason of this specific behavior here is the model artifact which is due to the initial setup of the model and allocation of the roles to fairly larger number of households and then sudden decrease due to the higher costs and profits playing role (after the first time step). Thus, this value at the peak is not considered for analysis and comparison of the different types of projects (sharing, microgrid and hybrid).

**Advantage of Hybrid Project:**

The trends of the producers and the consumers start showing same pattern. Basically, the producers demands are met now and thus the reduction in the number of producers take a long time. The number of consumers are much higher than sharing projects here and the connected agents are much higher to facilitate exchange of energy.

**Microgrids' profits:** For microgrid models, ideally everybody should become consumer but everybody never becomes a consumer because of cheating and the project never becomes profitable and vaires a lot as shown in figures 7.4. For micro-grids to get all consumers, there is a trade-off of profit versus number of consumers. The trends can be explained because of various reasons. For example, the households have to pay the replacement cost: replacement costs are very minimal from the villagers. These costs being minimal, do not help in paying off the large investment costs of the micro-grids. Also, people skip payments, steal the electricity or simply cheat the payments, and after allowing some relaxations/ margin, even if the households do not stop such a behavior, they are removed from the consumers segment. This does not affect the pattern and range of profit because removing defaulters with a decreased consumer segment brings the provider back in the similar profit range.

Then the other reason can be that the demand rise would not be catered to as people wont pay and project is not profitable, leading to dissatisfaction of consumer and tendency to switch fast to anything other option possible. Also, a lot of community management change happens too often as per the appointment of the village committee which adds on not direct but indirect costs like time in teaching new operators, handover responsibilities, etc. Finally, other reason can be that if there is no committee involved (due to the provider's decision or due to number of committee changes), it leads to deployment of provider's employees, leading to lose of connection and access to all community members.

### 7.3.2. Comparison

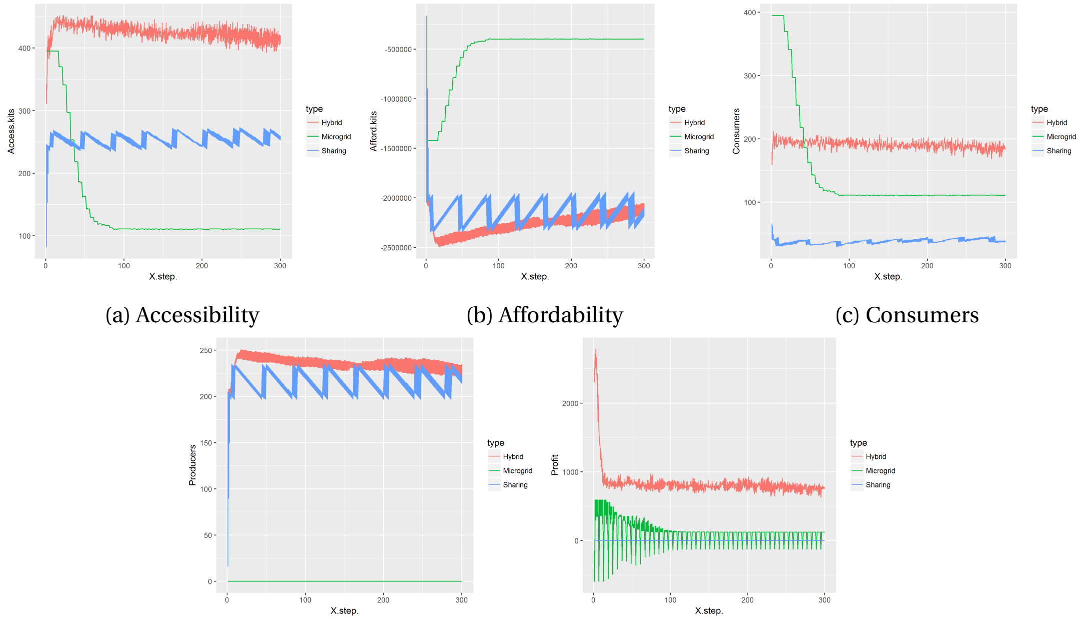
Based on the parameters generated in the Table 6.2, all the three projects (sharing, microgrid and hybrid) would be compared in this section. The success parameters to compare are: afford-kits, number of consumers, access-kits, number of producers, the operation time (the battery stock and the delay sell battery are less important parameters to measure the reliability of the technology and thus skipped for now), profits of the producers. As socio-cultural sustainability is not as important as other success parameters, the allowed-margin success parameter is skipped for now as well. The description of all these variables can be referred back in the table 6.2 and the results of the experiments can be referred in Table D.1. The experiments which are compared here are for a specific set of experiments: 395 as the population count and 1 as the demand rise. The Figures 7.7a to 7.7e show these comparisons clearly.

**Afford-kits:** The number of households which are ready to buy the electricity or are basically able to afford the installments are compared here. As the sharing and hybrid project involves selling of electricity, it helps increase income of the producers with time. Thus, it leads to an income upgrade faster than the micro-grid projects, improving the affordability for future payments. The installment costs of microgrids are lesser per consumer, while the installment cost per producer is higher for the sharing and hybrid projects. These installment costs with the number of respective consumers and producers give an idea of the affordability, additional to the surplus affordability of the producer due to their profit.

**Consumers:** The number of consumers can already be checked out in the figures 7.5, 7.6b and 7.3. The difference between the sharing and hybrid project is not major, except for the hybrid models having faster decline in the number of consumers, due to households shifting towards producers. The number of consumers in microgrid stabilizes to something much higher than the sharing project.

**Access-kits:** The number of households having neighbors as consumers or producers gives the value of accessibility. This is calculated by calculating the connected agentsets for producers here. Due to just one producer, this is minimum for microgrid. This value can be seen as the highest in the hybrid project because though the combined number of producers and consumers is almost the same in all the projects, the number of transactions are much higher in a hybrid project due to additional microgrid involvement.

**Producers:** The number of producers are only relevant for Sharing and Hybrid project, as microgrid has only one producer which is the provider. If the comparison is done as seen in the 7.5c and **??**, the only difference is that the number of producers reduces to a stable number faster in the Hybrid project. The number of




(a) Accessibility (b) Affordability (c) Consumers

(d) Accessibility/ Producers (e) Profitability

Figure 7.7: Comparisons

producers remain the same at stability given the same number of population. If compared to microgrid, the number of producers are obviously larger in the sharing and hybrid projects.

**Operation time:** The number of times replacements are done for the maintenance is not something developed from the model, but noted from empirical analysis It is so because as the maintenance request is made by the user, it is fulfilled by the provider. So, it is a matter of the technology used and the user/ operator's maintenance. For a microgrid, the operation happens every month and this is done by a trained personnel. For sharing and hybrid projects, the operation happens more distributed to number of users (producers and consumers), so it is done much more number of times but the operation tasks are smaller. Thus, it is difficult to compare the projects based on this parameter with the provided model and empirical analysis. With the given information, it can be assumed that the highest time is for the hybrid due to presence of two different systems (microgrid and sharing).

**Meet-Demand-rise:** The increasing demand of the households is met most easily in the hybrid model because as soon as the demand rises for the households, the microgrid enters with a much higher potential to meet large demands. This is also possible for the case of the sharing projects with possibility to upgrade energy much easily till the limit of the kit and a consumer can become a producer to fulfill maximum threshold demand. Finally, the demand rise compensation is possible in the microgrid but restricted by the consumer behavior and losses of the project.

**Profits:** The profits for the microgrid can be seen in the Figure 7.4. The profits are always many times less than 0 for the microgrid project. Putting all the profits together of the producers in the sharing project gives the final profit for the energy provider as well and this is much higher than the microgrid projects (because the operations also have costs). As the hybrid projects charge higher fees to the houses, the operations cost are covered and the profits for microgrid and the producers combined are highest than other projects.

**Statistical results:** Based on the above discussion, the parameters are calculated and the values are compared statistically (Independent sample t-test) and the results can be seen in the Table D.1. The results show that maximum results are significant except few of those for affordability and profitability and they are discussed below:

- Affordability is high for hybrids and microgrids projects. Hybrid projects (M=193.66, SD=5.799) have significantly high affordability in terms of consumers followed by microgrids(M=144.903, SD=80.294); t(598)=0.000. Microgrids and Hybrid projects have affordability for kits significantly more than sharing projects; t(598)=0.000.

- Accessibility is highest for hybrids, followed by sharing, with conditions of subsidy. Hybrids (M=229.393, SD=7.719) have significantly high accessibility in terms of producers than sharing projects (M=216.106, SD=11.541), t(598)= 0.000. In terms of access to kits, when the subsidy is not present, the Hybrid projects are more accessible than Sharing, else it is just the opposite.
- Reliability is comparable for hybrids with sharing and microgrids. Hybrid projects are most reliable for meeting demands, but take on average more operation time.
- Profitability is higher for hybrid projects. Hybrid projects(M=889.025, SD=244.660) have higher profits than microgrids(M=117.495, SD=155.390), but not significantly.

In conclusion for success and sustenance of projects, hybrid projects are better than others for maximum parameters, but they need to be more profitable and affordable. If the policies focus on these aspects to be developed with the additional insights discussed above in Section 7.3.1, then the hybrid projects can be adapted to be the most beneficial project.

## 7.4. Conclusion

This chapter dealt with designing two different agent based models based on the concepts defined in the chapter 6: one for the sharing project and other for the microgrid project. There are some basic model initialization differences in the two models of sharing and microgrid in terms of the number of energy sources, the size of the energy sources, the operation fees/ replacement costs associated, and the billing cycle for the consumers. This impacts the number of consumers in the models, as the word of mouth processes are different for both models. The model checks through verification and validation showed that the model performs well in terms of the relations to the success parameters. The robustness check has shown that how the models would remain robust enough even if the major variables, like population, demand rise, and subsidy changes. It can be seen after the robustness checks that the demand rise for households rises much more than the income rise leading to their dissatisfaction. Also, there are payment skips in the microgrid project, making it difficult to be profitable in long run. Thus, a new type of project called hybrid project is defined which combines the microgrid and the sharing project, such that the high demands are met by microgrid in a sharing project. This prevents the occurrence of cheating as well, as there are more incentives for a consumer in a microgrid system to make more income from becoming producer. The similar robustness checks show that the model is robust as well; subsidy changes does have a large impact on the hybrid project consumers though. This happens because subsidy gives initial support which leads to demand rise, but this doesn't help in increasing the income of the households, putting them out of the electrification network.

For performing experiments, a data analysis via Latin Hypercube Sampling is done, choosing 200 experiment points with the set of 18 variables. This is followed by the model analysis in two stages: gathering insights of the model and then comparing the three models at the success parameters to understand which model performs the best. The insights show that every model is incapable of involving laggards or the slowest adapters of electrification in innovation. Another insight on the importance of connectivity stresses that more than affordability in a sharing project, connectivity of the household is most important. Also, there is a pattern of rise and dip in the consumers/producers, especially the producers in the sharing and the consumers in the microgrid model(consumers here are also affected by the cheating/ stealing/ payment skips), and the reason is the reliability fo the technology. More is the reliability of the technology, less is the repair needed, and more are the consumers and producers, who stay in the market. Finally, the haphazard profits of microgrids with always being less than zero show the issue of the profitability of the microgrids due to five different possible causes including village committee composition instability and losses in terms of not just money, but time and expertise. The comparison of the models based on the affordability, accessibility, reach in the market with producers and consumers, reliability of the product with least operation inconvenience, meeting demand rise, and profitability of project showed that the hybrid project performs the best overall. This happens because of the last two factors where individual demands are met more easily and the project profitability is not a major concern. Still individual innovation affordability is low for these projects. Also, the access to the innovation here is very high due to more connections possible and value of the network increasing with higher number of people connected. The hybrid model is thus chosen for performing further scenario and policy tests.

# 8
# Scenario and policy testing

*In last chapter 7 different models were tested and analysis of results delivered hybrid model to be the best project which can sustain in long term. Now, it is important to understand that which policies will help these projects to be sustained further and what would be the effect of different scenarios. The first step to perform experiments for these scenarios and models is to know the parameters which will be varied across the model to define different experiments. This is done using Latin Hypercube sampling to pick the random experiment points across the behavior space. This is explained in Section 8.1. The developed scenarios are defined and the results are discussed in the Section 8.2. These results help in defining the policies for the model using the institutional innovation framework again as discussed in Section 8.3.1 to 8.3.2. These policies are divided into two sections, which focuses on institutional adaptation before and after resource usage. The final results and analysis based on all the policies are discussed in Section 8.4.*

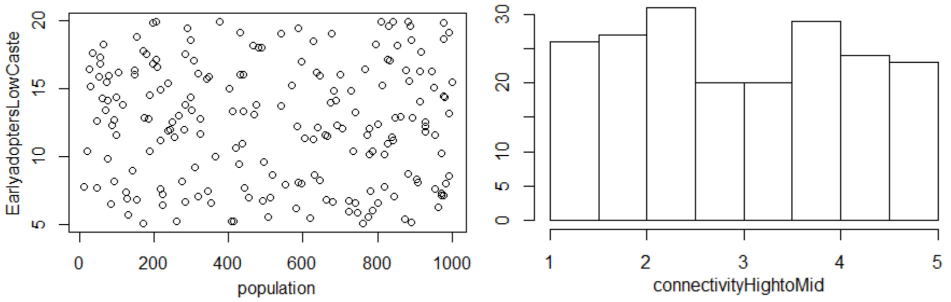
## 8.1. Data Sampling

For getting valid set of results for further experiments of policy development and the scenario testing, the model cannot be run for all combinations of parameters as listed in table 8.1 (as it will need a very high computational time), and thus a data sampling should be done to define the experiment set for the models. The behavior space of the model i.e. the space of the parameters range has population, demand-rise, subsidy presence, employment ratios (7 cases which decide 4 employments for 3 castes), percentage of people interested in product/ number of early adopters (for each caste), percentage of connections intercaste (for each caste-caste) and number of manufacturers. The table 8.1 shows the exact 19 parameters with their ranges. Performing a Latin hypercube sampling on this behavior space gives 200 points for the experiment runs and the distribution can be seen in the Figure 8.1a and 8.1b below. This Latin hypercube sampling is generated in *R* language (code shown in D.1) with some variables converted into numeric variables for generation of data (e.g. "on" and "off" for subsidy is converted into "1" and "2" as also shown in 8.1).

As also can be seen in the table 8.1 below that the cost parameters are not taken into account. It is because of two reasons. In sharing projects, the market reaches an equilibrium for the cost at which the producer sells the products to the consumers (this happens due to neighbors becoming shopkeepers as explained by Nash equilibrium in game theory). The second reason is that there is the *allowed margin*, which allows the cost to be reduced very subjectively depending on every household and this cannot be used for the setup of the model. Total number of generated experiments are 200 with 20 replications done per experiment for 300 ticks, which will be used for further analysis.

## 8.2. Scenario testing

Now that it is confirmed that the hybrid projects are most beneficial for the process, the next step is to introduce the model with number of scenarios which are possible in the real world. Based on the empirical study for this thesis and the literature review, some scenarios for the model are noted and they are broadly classified as the pricing mechanisms & market and the future scenarios. Here the number of transactions (be-




(a) Example distribution:continuous variables (b) Example distribution:discontinuous variable

Figure 8.1: Latin hypercube sampling based experiments data points

Table 8.1: Behavior Space

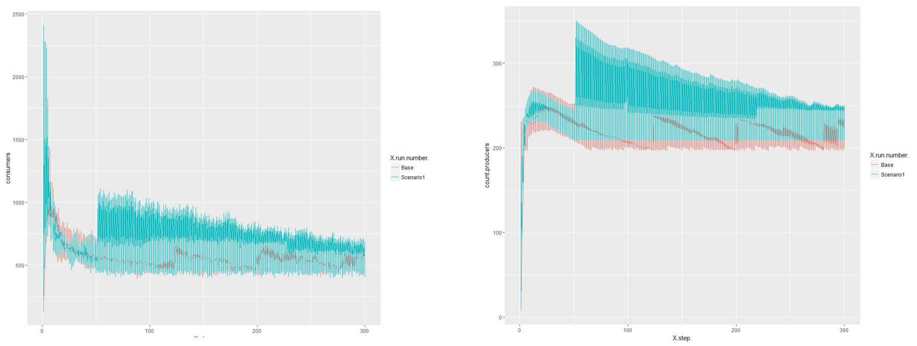
| | ***Parameter*** | ***Range*** |
|---|---|---|
| 1 | Population | 10 to 1000 |
| 2 | demand rise | 1,2,3,4 |
| 3 | Subsidy | 1(yes),2(no) |
| 4 | percentage of high caste conencted to mid caste | 1 to 5 |
| 5 | percentage of high caste conencted to low caste | 1 to 5 |
| 6 | percentage of mid caste conencted to low caste | 1 to 5 |
| 7 | Shopkeeper in low caste | 0 to 3 |
| 8 | Shopkeeper in mid caste | 2 to 5 |
| 9 | Shopkeeper in high caste | 2 to 5 |
| 10 | Big Farmers in low caste | 1 to 5 |
| 11 | Big Farmers in mid caste | 15 to 25 |
| 12 | Big Farmers in high caste | 70 to 90 |
| 13 | Small farmers/daily wage labor in low caste | 70 to 90 |
| 14 | Small farmers/daily wage labor in mid caste | 45 to 65 |
| 15 | Small farmers/daily wage labor in high caste | 1 to 5 |
| 16 | Early Adopters in low caste | 5 to 20 |
| 17 | Early Adopters in mid caste | 5 to 30 |
| 18 | Early Adopters in high caste | 5 to 40 |
| 19 | Number of manufacturers | 1,2,3,4 |

tween producer and consumer) and the number of producers are taken as the measures to check the impact of the policies. The number of transactions are considered here instead of number of consumers because the transactions help understanding that how the energy sharing is happening in the market, better than simply number of consumers.

**Scenario 1 - Community energy:** As discussed in the literature there are many pricing mechanisms, but if we cluster them they boil down to Pay-as-you-go payment systems, which have proven to be very successful and the upfront payments of the installments. Other types of payments are also done by some form of subsidies or loans by government, banks or other organisation (like corporates). This is already included in the government as a subsidy switch. Some other systems are those where the livelihood of the community is generated by producing community energy e.g. sewing machines in the community run on microgrid also support the livelihoods of the community. In the model the community energy gets introduced at the 50th tick.

The results of this scenario can be seen in the Figure 8.2. This result shows that the number of the producers increase after the community pool money is good enough to start a community energy system. This starts delivering a small regular income to family making them a producer. This is a limited business due to the size of the system and the choice of people for the given livelihood, and thus all the houses does not become producers. Also, they make new connections due to their involvement in a community energy system (a community activity) and thus being producer decision is taken as they consider this as a profitable service.

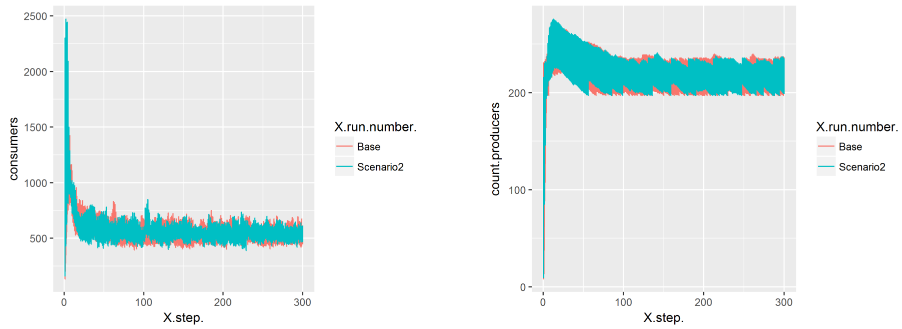
There is a steady decline in transactions and producers because the community energy system introduction happens one time in the model and then these people start leaving the service with time due to the replacement costs. This shows that just generating an income activity is not sufficient, but it needs to be sustained and grown with time.



(a) Number of transactions (b) Number of producers

Figure 8.2: Results of scenario 1:Community Energy

**Scenario 2 - Energy variety:** Other type of market systems include the selling and buying of devices rather than the energy itself and also buying energy in more varieties. This is also included in the model as the initial choice of the model allows the user to chose any size of the energy, but the upgrade always happens in a fixed value. This fixed value will be made variable in the second scenario. The results of this scenario can be seen in the Figure 8.3. There are not significant differences here from the base case and this is expected because the energy variety is not priority of the people in the rural villages, because they care more for presence or absence of electricity and the variety only becomes important when the demand and income are high enough.




(a) Number of transactions (b) Number of producers

Figure 8.3: Results of scenario 2:Energy Variety

**Scenario 3 - Introduction of grid:** The future predictions of the state of the market by the interviewed energy providers is clustered into major concern or the final scenario: introduction of grid in the community. This model is developed similar to the development of the hybrid model, where instead of microgrid, an extra grid as an energy provider is added with a much higher energy base. Now, as soon as this energy provider comes into the community, people want to switch to the grid provided they are not producer. If the grid doesn't seem to be reliable though, the consumers switch back to being no consumers. Though this grid reliability is a 50% chance, but a sequential lose of reliability of grid is considered which happens at the 100th tick. The results show that the number of producers do not increase even if the consumers remain high for a long time. Also, the consumers reduce after a point of time as can be seen in the Figure 8.4, because there is no growth of producers and the micro-grids cannot be used till the demand is enough, which would not happen provided low numbers of producers.

**Other scenarios: Cashless payment** Additional to the scenarios discussed here, the energy providers who were interviewed mentioned many more scenarios. A very interesting and impactful one of them was the cashless payments for the solar electrification projects. Though this is a far fetched scenario due to the tech-

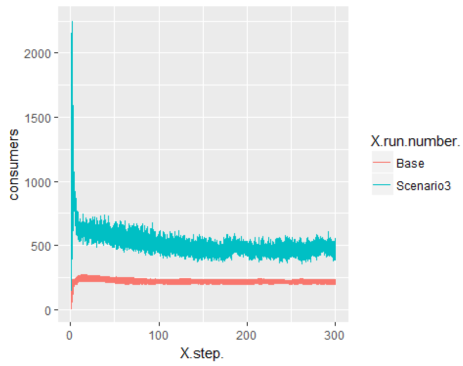



Figure 8.4: Results of scenario 3: Transactions after introduction of grid

nologies required prior to making this possible in rural areas, the Internet is coming into many rural areas much faster than electricity, making this scenario more possible. The cashless payments would mean a lower cost to the energy providing firms and much more efficiency with better focus on the electrification than the operations of the project. This would remove the job of fees collector, and this person can be employed at a more favorable job which directly helps electrification. The direct number of producers and consumers cannot be judged without a model to the scenario, but the scene looks more positive for the project' profits.

## 8.3. Institutional innovation: Improved policies

Because the hybrid model still doesn't achieve involvement of everyone in electrification/ make maximum producer or consumer, certain policies would be introduced using the existing theoretical framework which is developed in the thesis and mentioned in Chapter 4. Though the concept of institutional innovation is already embedded in the system of the regulations development by the energy providing firms to some extent (like the example of allowed margin), it is not used to adapt the needs/ demands of the community completely. Some policies can be defined to follow the institutional innovation rules as discussed in the following section. The operational structure for the policies are shown here similar to the operational structure in 6.7. These policies are divided into two groups: for institutional innovation before and after accepting innovation, where the latter focuses on institution for usage with usage rules, and the former focuses on institutional and innovation diffusion with top down rules.

### 8.3.1. Institutions for accepting innovation

Before accepting innovation, the institutions are adapted as top down rule and the following policies are such top down rules, which without going through institutional diffusion leads to interactions in the community. The institutional diffusion happens after the innovation adaptation and it is discussed in the next section.

**Policy 1: Pay as Service/ In-house manufacturing:**
The first adaptation to the rule as per the community attributes is to include the laggards via a "pay as service" scheme. What pay as service means is that the payment for the connection to electrification of the consumer who cannot pay or find becoming producer as profitable can offer service in operations of the microgrid in the system instead of paying cost. Thus the operator fees can be saved and the losses of the microgrid can be covered to some extent. As there are not only operations cost in terms of service but production, in-house manufacturing can be a good solution, where the consumers can develop and repair the product inside the community itself. This in-house manufacturing and repairing is a common practice in the campus of *Barefoot College*[1] in Rajasthan in India, where the villagers are involved in repairing and designing their own solar products. Introduction of this policy in the model is necessary when the laggards in the innovation remain unattended to, the following Figure 8.5 shows how institutional innovation helps deciding this policy. Finally, the results for this policy are shown in Figure 8.6. Here, an additional policy amendment in case of issues of in-house manufacturing can be to rotate the operator service, i.e. allow different laggards to pay as service on a rotation basis (Set of 10 laggards paying as service in first month, followed by set of other 10 in next month and so on)

[1] https://www.barefootcollege.org/approach/

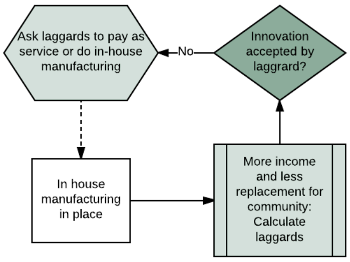
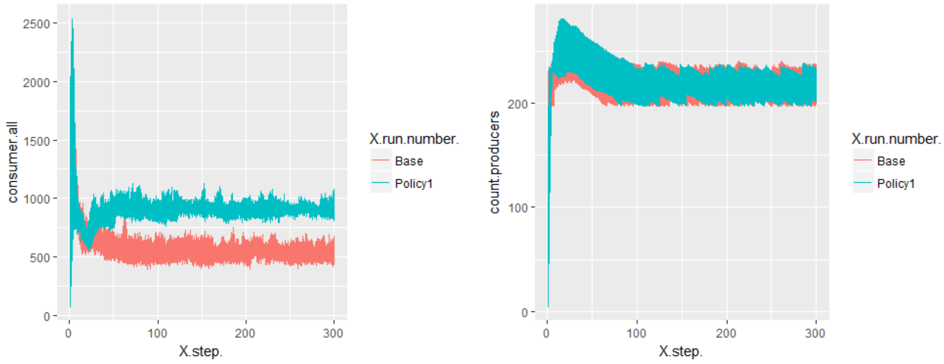



Figure 8.5: Theoretical framing for policy 1: Pay as service




(a) Number of transactions (b) Number of producers

Figure 8.6: Results of policy1

**Policy 2: Demand wise electrification and payment:**

This policy is partially implemented in the Hybrid model and emphasizes the hybrid model itself as a policy with some additions. Here, as the demand increases beyond a threshold the aim is to get catered by the micro grid. The operation fees is also adjusted additionally in this policy such that it is bit higher than the general micro-grid fees but still lesser than the installment of the Sharing projects. As the demands are raised by the houses with more demands, it makes sense to increase the micro-grid monthly fees more than the average. This would help in making the micro-grid profit non-negative. Once the profit of micro-grid is reached to sufficient positive value, then the microgrid can be opened for lower demands too. In case of stealing cases, the project would still not be stopped and the low demands consumer can still pay a lower cost as the higher demands would allow to take care of replacement costs. The following Figure 8.7 shows how institutional innovation helps deciding this policy. Finally, the results for this policy are shown in Figure 8.8. Profitability increases and more of them become producers faster.

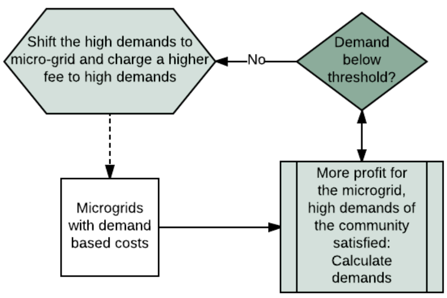
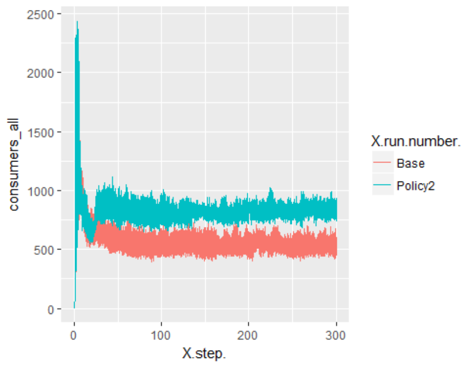


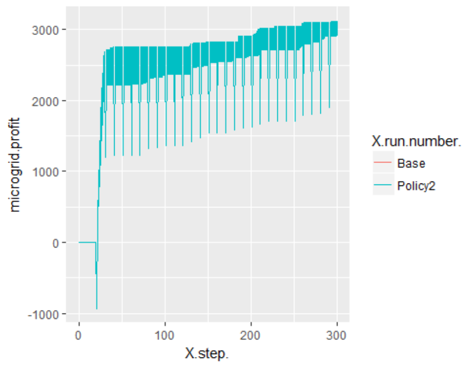

Figure 8.7: Operational structure for policy 2: Demand wise electrification/ payment

**Other Policies: Cooperative shops/ anonymous sharing:**

There are more policies which are possible following the same institutional innovation, e.g. if there is high discrimination or no easy upgrade of connection due to the regional or caste divides, one of the solutions is to anonymize the producer and the buyer, so that none of them know each other. Thus discrimination is not




(a) Number of transactions




(b) Profit

Figure 8.8: Results of policy2: Demand wise payment

possible. This can be done by clustering the production of small producers into one large cluster forming a pseudo-producer. A consumer from the higher section of community, then cannot identify the sellers and thus buy from anyone who is available in the market. This cannot be just done on a grid based sharing system, but also physical battery sharing, where a large coo-operative shop can be established for selling these batteries. Some discrimination is still possible in this case, but provided a large co-operative shop would have better services, there would be less chances of discrimination - in fact it can help reduce discrimination. The following figure 8.9 helps in showing that how institutional innovation inspires such a policy.

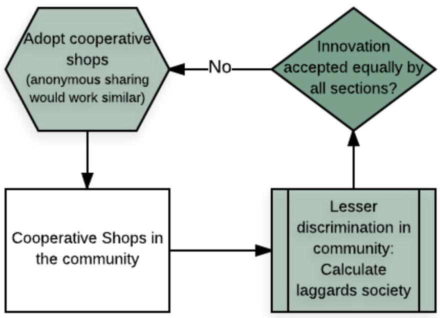



Figure 8.9: Operational structure for policy on cooperative shops/ anonymous sharing

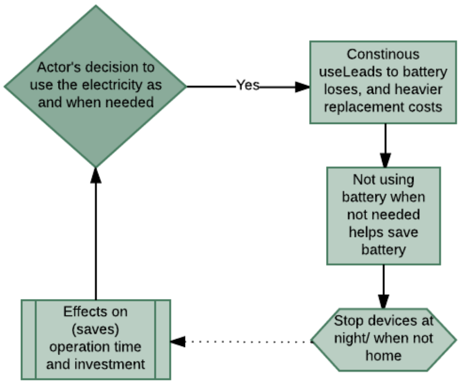
### 8.3.2. Institutions for resource usage

Additional to the above policy result, which signifies the institutional diffusion and adaptation when the innovation is not accepted by the community, it is important to understand the institutional innovation when the community has accepted the innovation. This would need evolutionary process of variation of the institutions based on the changed properties of the resources or communities. These policies would be the usage rules decided based on the individual, resource and community utility.

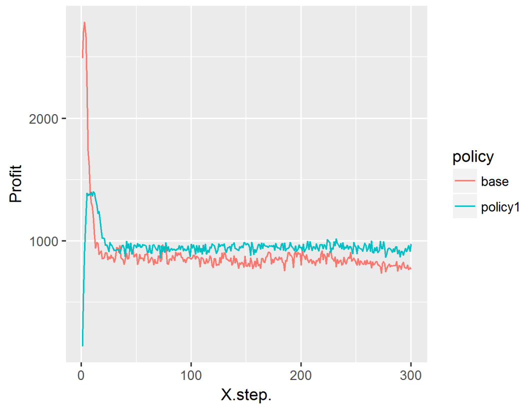
**Policy 1: Compensation by households for community**

Compensation policy means to reduce the individual utility to some extent to help the community and resource utility. One of the examples that will be used for modeling is the rule of reduction of usage during nights. As gathered in the empirical research, it was seen that due to no experience of using lights, and the fear of reptiles in the evening, households used light throughout the nights, leading to draining the batteries very fast. This in turn increases the operation and replacement costs, reducing the reliability of the product. Following the operational design as shown in 8.10a, the households vary the rule of usage by not using in night, see the benefit of battery saving and increased reliability and thus adapt it. These effects can be also seen in the model results as in Figure 8.10b in terms of the increased profits due to reduction in the operation costs.

**Policy 2: Distribution of community pool to individuals/ Prioritization**



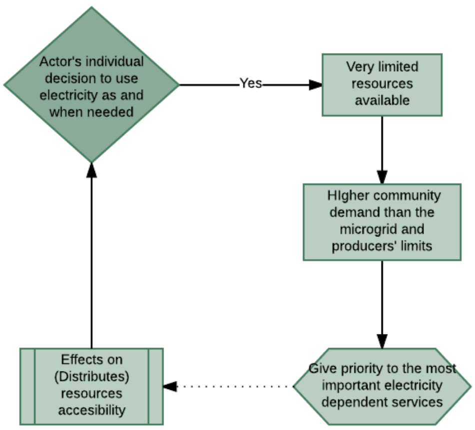

(a) Operational structure for policy on compensation



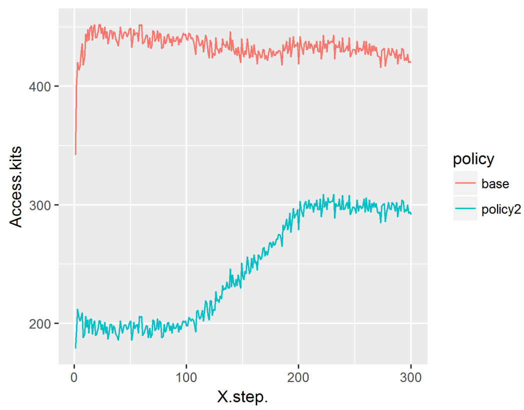

(b) Profits of the project

Figure 8.10: Results of policy 1:Compensation by individuals

The distribution rule allows to take the community surplus and helps it to distribute it to the individuals. One of the examples which is also modeled here is to distribute the microgrid surplus (community pool) and distribute it to demands based on priorities. The effect of this can be seen as an increase in the access to the households. The profits here for the complete community first decreases due to the investments for the community pool to the priority demands (which might not be paid for profits). After sometime, these profits start building again with increasing access because of the main priority demands being met, and normal trends would follow. Note that this would only happen if the community surplus is good enough to cover the main priority demands. This rule is applicable when the resource is limited (e.g. there might be a damage to the major producers in an area due to a calamity) leading to no or very less accessibility. Thus, base case is not a good comparison for policy effects here, and the results for accessibility can be seen in Figure 8.11b.




(a) Operational structure for policy on distribution from pool to priority demands




(b) Accessibility of the kits

Figure 8.11: Results of policy 2:Distribution to individuals and prioritization

**Other Policies: Constraints and Development & preservation**

Additional to the above two types of policies, the other policies or rules are either constraints on the usage or aim at development and preservation of the resource. The example of constraints are constraints on the usage of heavy power devices, which prevents pulling the energy of the whole network by just one household and prevention of power cuts. The usage regulations for the development and prevention of resources help suggest types of technological advancements and operational practices needed e.g. better batteries, and using the practice of cleaning of the panels, etc. All of these policies give the examples of the rules developed based on the individual, community and resource utility and can be seen in the Table 6.1. The model results show that these rules work for the better usage of the resources and meeting community's increasing and dynamic demands.

## 8.4. Results and conclusion

The three different scenarios are introducing community energy (livelihood of people built based on the electrification), energy variety (different products for electrification), and introduction of grid. The first scenario shows a rise in both the number of transactions and the number of producers in the market, as the ability of people to but increases due to an income upgrade, and being more involved in community related livelihood activity grows their connection. The second scenario doesn't show any difference because different energy products are already introduced at initial point in the model, and varied rise of product would not affect the buying and selling relations, till the assumption of equal availability of the different varieties hold. The third scenario shows a increase in number of consumers followed by a decrease (due to introduced reliability issues of the central grid), while a significant decline in the number of producers.

Finally, following the principles of the institutional innovation as introduced in the Chapter 4 and then embedded in operational structure in section 6.5, policies are developed for including laggards in the process of electrification and meeting the demand rise. For the first, the policy of "pay as service" and in-house manufacturing is introduced, which clearly shows higher number of consumers (significant) and some improvement in number of producers (not significant). The second problem is solved by doing a demand wise electrification and allowing different fees are per demands, which shows a significant positive impact on the profits of the project, especially the microgrid. It also shows rise in the number of consumers for the microgrid. A combination os both policies would achieve higher consumers, more profits and slightly more producers. More policies are possible to be developed using the same institutional innovation principle e.g. anonymous sharing of electricity or forming cooperative shops to form a bigger seller/ producer group to stop any discrimination on sharing of electricity and allowing more growth of connectivity of households (to prevent only one section of society to suffer as laggards).

Further usage policies are developed based on different types of effects on the individual, resource and community utilities due to the electricity innovation acceptance by the community. The first policy as the compensation done by individuals to save the resource clearly show the benefit in terms of the profit for the project. The second policy is for distribution of community surplus in case of emergency/ conditions where the resources are too low. It shows that the community can pool these resources and distribute it to priotized demands to help the accessibility get back to normal fastest. Other policies like constraints on resource usage and preservation & development of resources are also possible. All these model results show that the institutional innovation framework and the new policies & rules developed for such dynamic communities are very helpful to sustain the resources and make such socio-technical infrastructure projects of solar electrification successful.

# Part IV: Re-design and learn

## From case study learnings to framework, policies and recommendations

# IV

# Conclusion and Reflection

# 9
# Discussion

*Now that the results from the case are known and the framework is applied and tested, the next step is to understand the implications of the results, by understanding: (1) developments in the framework based on the case study, and (2) how the policies designed as part of the results would be implemented. This is done in Section 9.1.1. Followed by this, further analysis is done in the section 9.1.2 on understanding that how this framework can be used for other domains. To understand that how the designed policies will be implemented, it is important to discuss the actors involved in the implementation as discussed in Section 9.2.1, and the impacts of the implementation as discussed in Section 9.2.2.*

## 9.1. Implications on proposed framework

The results and the ease of framework to develop institutions conclude that the institutional innovation framework helps cater to dynamic demands of communities with the technological innovations of electrification projects. The institutional innovation framework could be successfully adapted to the case of rural solar electrification in India, to accommodate the dynamic communities and demands and maintain the success and sustenance of the projects. The results show an improvement in the accessibility, affordability, profitability and reliability of the projects as seen in Figures 8.6 to 8.11. The framework can also be successfully applied in different cases, e.g. a calamity or the sudden reduction in the resource availability, as it considers the resource and the community demand gap.

### 9.1.1. Case study inputs

The framework was developed at many stages based on the case study. Before the empirical analysis and the context study, the framework looked much less detailed and it was developed with the case study empirical analysis, the conceptual model design and the results as shown in the summary picture in the figure 9.1.

**Institutional Adaptation at two level:** The empirical analysis showed the need of the institutional adaptation in the institutional innovation framework at two levels: before the innovation acceptance and after the innovation acceptance. The interviews with the energy providing firms stressed the importance of the top-down rules which take place before the acceptance of institutions. These top down rules e.g. "allowable-margin" for payment in case of extreme poverty of the individual, already exist in rural India. This also stressed on the importance of the collection of actions in the system where innovations are accepted individually, but shared by the community. Thus, the proposed framework could be developed in two levels of institutional adaptation due to context study and empirical analysis of rural solar electrification sharing in India.

**Institutional Adaptation to Diffusion connection:** The operational structure of the proposed framework only consisted of the rules variation and adaptation of the usage rules. But only after applying this to the case, it was realized that based on the outcome and the followed benefits of the rule, the community starts adapting the rule through word-of-mouth (an innovation diffusion theory). This helped adapt the evolutionary structure of the institutional adaptation for the framework completely using the steps of rules variation, outcome and adaptation. Thus, the case study helped show the link from the institutional adaptation to the

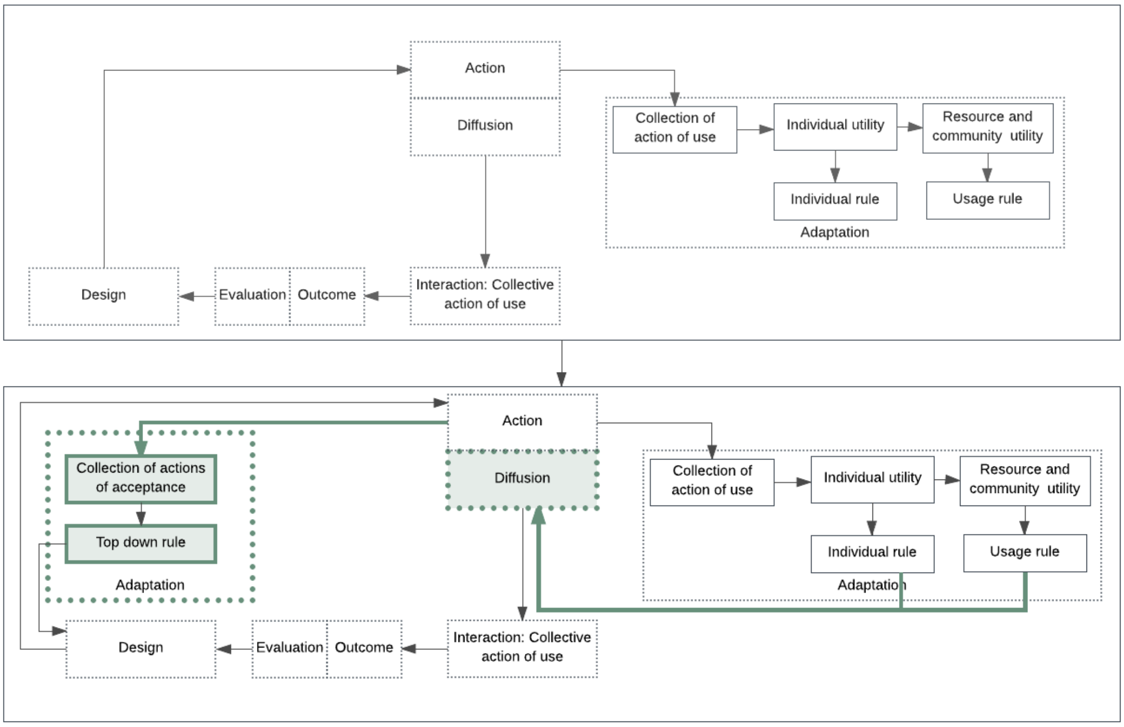



Figure 9.1: Development of old framework based on case study input

institutional diffusion clearly.

**Rules based on gap between resource and community:** The results of the institutions applied on the system via an agent based model showed that for applying usage rule, it is required to develop the institutional innovation framework in more depth. The basic results on accessibility and the profits can be seen to be effective through these institutions. The exact choice based on the resource and community gap can be seen with the five types of resource usage rules developed (later adapted to four types of rules with individual and community utility gap). These are developed based on the case study results e.g. to increase the profits, the compensation rule was developed. But, at the same time, the operational structure for exactly getting the resource and community demand gap is missing. This would need further empirical analysis to understand the measurable parameters to distinguish between the resource availability and community demands.

**Exact effects of resource properties:** The case study revolved around a consumer product, and the major gap here was in understanding the exact innovation type and the affecting properties of the community and resources for institutional diffusion and adaptation. For e.g. if there is an innovation which allows solar panel to produce electricity irrespective of the dust on surface, we would need changes in the usage rule of cleaning solar panel regularly. It is important to know what exact innovation was brought into for the usage rule to be adapted accordingly. The case study here was restricted to the innovation acceptance of electricity itself, but the products of solar house systems go through various innovations and based on that, the usage rules would further develop. The framework is developed further for the consumer producers based on the different cumulative effects which define the actor's choice and thus affects the innovation diffusion. This can be seen in the following figure 9.3, where the cumulative effects involve the different features, varieties and serial correlations in innovation of the product.

### 9.1.2. Adapting for other domains

Based on the case study, it was also realized that the framework needs to be further adapted for similar domains, so that the framework can be applied more generally. For different types of resources, the development of the framework is done differently. For example, the consumer products effects can partially be also seen in the figure 9.3. Here the social and political changes affect the rules of use, while the technical affects the variation of choices of the actors, and economical affects the innovation diffusion rules' threshold itself. Further domains are considered and discussed in the following section, e.g. the natural resources, etc. The detailed steps of development of the framework (based on literature) for all different domains can be found in this section. Note that it focuses on only the top down rule and not the usage rule adaptation.

**Natural and public resources:** For natural resources, the institutions developments were first listed by Crawford and Ostrom. (1995). They proposed a set of rules called ADICO, which are also used to list the first institutions in the conceptual model of the thesis. The example of the institutional innovation as cooperative shop rule shows an institutional adaptation at the community level which is relevant for any natural resource which can be merged together for better outcomes. This is the principle of voluntary contribution games. Here, the natural and the public goods (the first two segments on the horizontal axis of the *t-framework*) are merged as they overlap heavily. In Voluntary contribution games (VCG), every user possesses a monetary endowment and they may invest in the provision of the public good e.g. environmental goods like forests, rivers, etc. In VCG, only if all contribute to public good, the sum of external returns which one gets from contributing to the public good is higher than the internal return one gets from retaining their endowment. If we take the example of the agricultural land, combination of small lands usually owned by the lowest sections of the community (most discriminated against) could lead to much more rewards than small irrigated lands with very small or no rewards. This is a specific example of one policy of cooperative shops, but this shows that the inclusion of individual demands of the people to adapt the communities regulations, as simple as combining the resources: can help in making communities better off, even in the case of natural resources.

**Networked infrastructures:** The networked infrastructures similar to solar electrification (Sharing and microgrid projects) are the general electricity and telecommunication industries. As this research belongs to the same field, it is easier to look at the possibilities to adapt this research to such networked infrastructures. For example, the market of central grid electricity follows the same challenges of changing demand, but the difference is that of the capacity of the system, which is much more widely available than the solar electrification projects. But at the same time the resource in itself of solar electrification can be made abundantly available provided there are enough technologies for conversion to electricity. But this is not the case for the central grids based on coal, where the resource itself is getting much rarer and unsustainable for environment with time. This demands a wise use of the resource and again a community management approach can be helpful. A community management approach was explored by Künneke and Finger (2009), and the major flaws in adaption were to use the same stagnant rules by the government with changing technologies and societies and what he proposes is to find synergy between social, political and economic systems. A proposal from the developed research would be to adapt to the community demands here which get adapted from the innovation diffusion theories and thus the technology itself. It means there is a need to adapt as per the developing technology as well. Thus the approach by Künneke and Finger (2009) can be made more inclusive if there can be a study of the developing technology involved in the institutional innovation itself as can be seen in the Figure 9.2.

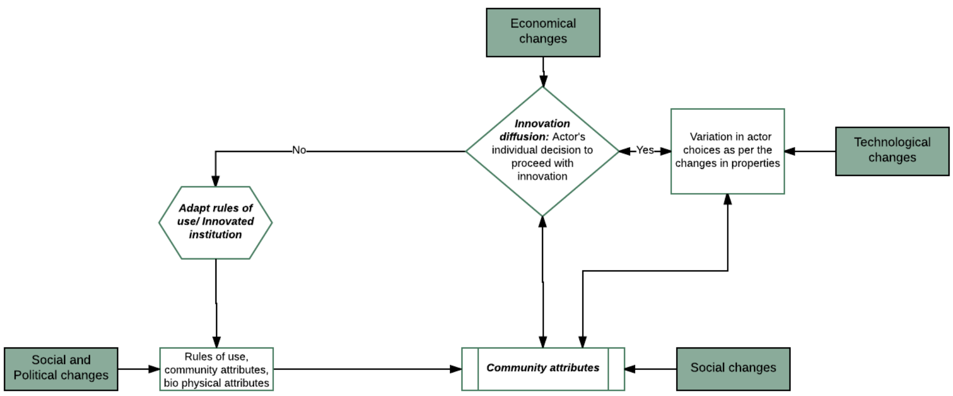



Figure 9.2: Development of proposed framework to fit for more networked infrastructure like electricity

**Consumer products:** Looking at the consumer products, the technology development part becomes very important. This means the link between the technology development to the impact on the individual choices need to be clear. This emphasizes on the link of the technological changes to the individual demand of a person. Researches on such links are very popular and the variety in product ranges, features of the technology (serial correlation among innovations: like an iPhone upgrade), etc. influence the choice of the people based on a technological change (de la Mathe and Edquist, 2006). Also, reducing performance gaps propagate innovations (explaining the fad and fashion of products, especially in organizationals) (Abrahamson, 1991; Abrahamson and Rosenkopf, 1993). These effects if included can help developing the institutions by the managerial organizations to fit this theory to the regulations used for developing products in different social, political (community) settings. This inclusion is shown in the following figure 9.3.

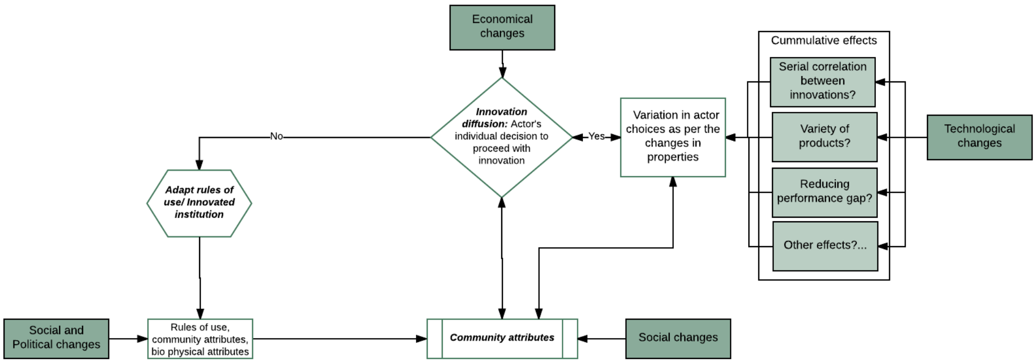



Figure 9.3: Development of proposed framework to fit for consumer products and managerial organizations

## 9.2. Implications of designed policies

The thesis was aimed at policy designing, and this section takes a further step to understand that how can these policies be implemented after design. Before implementing the developed policies, it is important to know the actors and their roles, to understand who would be in power and interests of the policies. Also, the effects of these policies are not limited to the model results, and these are discussed in the following sections. This helps in anticipating the challenges to be faced for implementation of the policies.

### 9.2.1. Actors involved

The policies affect actors based on their roles, powers and interests, and thus an understanding of the importance and level of involvement of the actors is crucial. This means it is important to have an understanding of the power relations of the actors here, with understanding of the most crucial actors. The actors gain power based on the resources they own and thus it is important to know that how much is they system dependent on the resource and if the resource is replaceable. The difference between crucial and non-crucial actors is done based on their dedication (i.e. involvement) and the supportive/ conflicting interests and objectives. Those with supporting objectives and dedication are critical as they have high potential and string allies e.g. the manufacturers and local/ national government.

Actors that do not have to be involved initially become non critical even if they have a supporting interest, e.g. the village committee in microgrid or NGOs. Also actors with high potential and conflicting opinions are critical e.g. the local politicians who spread negative word of mouth for the solar electrification projects to propagate their agenda in elections. The power/ interest matrix and the actor chart below in table 9.1 and 9.2 help explaining these power relations clearly in the given case study. It emphasis the role of energy providers, manufacturers and households, with context setter role of the local/ national government. These actors would take the lead of implementation of the policies ahead.

### 9.2.2. Policy output and impact

The developed policies need to be implemented with caution understanding the impact they might create, which is not considered in the research till now. This section discuss these different aspects of the policy impact.

Table 9.1: Power interest matrix

| | | Level of Interest | |
|---|---|---|---|
| | | Low | High |
| Power | Low | Crowd: None | Subjects:<br>Village committee, NGO |
| | High | Context settings:<br>Local/ National Government | Key players:<br>Energy Provider, Manufacturer, Households |

Table 9.2: Actors chart

| Actor | Important resources | Replacable | Dependency limited, Average, high | Critical Actor |
|---|---|---|---|---|
| Local/ National Government | Land/ Regulations | No | Average | Yes |
| Energy Provider | Solar kits | No | High | Yes |
| Manufacturer | Components of kits | No | High | Yes |
| Households | Land | No | High (for microgrid) | Yes |
| Village committee | Community rights | Maybe | Average | No |
| NGO | Education | Maybe | Limited | No |

**Emerging policies:** As this study takes into account the emergent approach of institutions and policies, the outcomes are in form of an adaptive cycle as shown in the figure 9.4 and as first discussed by Holling (1986). What this figure signifies is that there is an existing resource and people start exploiting it which leads to the conservation rules on the system. This breaks the system and leads to a new form of organisation and re-exploitation. But the path which is taken now is not the same as what was taken in the earlier cycle (a form of hysteresis) as usually organisms learn from history. This leads to evolution of a new system. This exact policy cycle is something that the institutional innovation - not to the level of complete re-formation of a new resource, but those of community settings. This can be seen in the form of proposed policies: the first policy of the pay as service and in-house manufacturing leads to formation of new livelihood hubs in the community, with new development of connections.

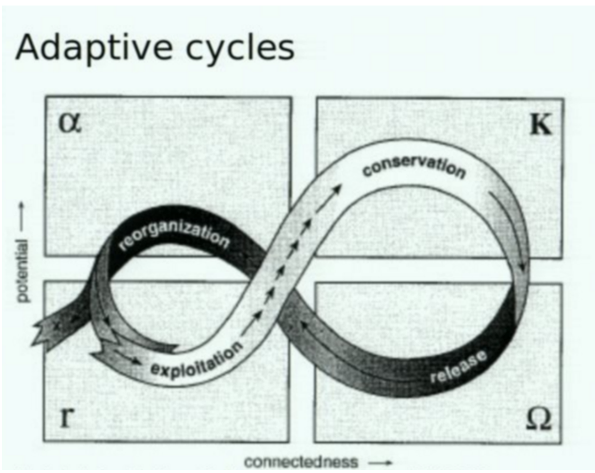



Figure 9.4: Adaptive evolutionary cycles of systems (Holling, 1986)

**Effects of policies on developing demands:** The second policy of demand wise electrification and payment to more satisfaction of the community demands leading to formation of new types of demands in the system of those whose demands are satisfied. This is a very common trend in any human society, that even if one demand gets fulfilled, people shift to new demands very fast. In a developing country like India, with so many demands left unfulfilled, this should be something totally expected. The final cooperative shops/

anonymous sharing leads to decrease in discrimination of community leading to new forms of identity differentiating mechanisms to be developed in the community (based on education or employments). Rural India especially being strong at its social norms and very vivid in different cultures, the identity structures are very strong and even if one discrimination is eliminated, many more still stay.

**Introduction of grid:** Considering the specific policy of the introduction of grid, it leads to sudden sway in the market, as people have trusted the central gird as the best form of electricity. in terms of reliability and because of no limits to usage of devices. The assumption made here is that people switch as soon as grid is introduced if they have payable incomes, and good demands. This reduces the scope of potential producers in the market. This is a threat to the energy provider market, but a solution to this is to have a very reliable product at source, so that there is no need of shifting the demand to the grid by the people. A PPA (Power purchase agreement) can be arranged with the central grid for collaborating such that people switch to grid only for higher demands.

**Alignment with current policies:** Theoretically speaking, there are a lot of takeaways for the thesis in the outer domains, but it is more important to understand if these cases are really implementable given the current policies in India and not just rural, but even urban context, and to stretch it further - to the context of developed countries like Netherlands. Considering the current policies, a recent PPA electricity act has clearly shown the value of hybrid projects. PPA allows and facilitates different organizations to trade electricity, even solar to make optimum use of the production. This is well implemented and analysed in the United States of America, and can be brought down to Indian context [1]. Similarly sharing projects can use these PPA acts, where the producers are large in energy source size.

**Implementation at Urban and developed contexts:** Beyond the rural context, the solar energy rooftops are a more viable and affordable option for urban areas, but less preferred due to the maintenance needed, and a more reliable source of central grid present. While talking to the CEO of Piconergy, an urban poor solar electrification SHS project, he mentioned that "urban poor settlers are migrants, and thus have a low level of trust to accept the Sharing projects, or even a stable life - a kerosene competition is still a big problem for implementation of my project." Looking at general urban population, who can afford as well and are not migrants, the community characteristics are much low in the urban areas - and for that matter even in developed countries, when people are more independent and satisfied in their needs. But at the same time, they are not geographically very distant: in fact in the metropolitans of developing countries like India, the density of settlements is too high. This increases the potential to develop a shared energy system. In urban context the social norms are very flexible and seldom followed, making the dynamism of the community a lower influencing factor as well. The storage of energy is also a smaller issue due to the fast possibilities of repair and maintenance. So, at a technological and more implementation level, with the presence of better infrastructure, it is easier to use the sharing and hybrid projects in urban and developed areas.

### Summarizing case study and policy implications

1. The framework has successfully helped to redesign the policies for the case study and the case study has also contributed back to the framework withing and beyond the domain.
2. Looking at the policy implementation cases, it can be seen that the proposed policy implementation is possible, but the effects of current policies and the presence of the grid should be considered as well.
3. The urban and developed contexts look feasible for adaptation of these sharing systems and the concerned policies, in terms of infrastructure, but lack on the collective decisions.
4. It should be taken into account during implementation, that these policies are emerging and lead to further effects which might not be considered already, including effect of further changing demands of the community.

[1] http://www.nrel.gov/docs/fy10osti/46668.pdf

# 10

# Conclusions and Recommendations

*The research question in chapter 1 with methodology in Chapter 2, research in chapter 3 to 8 lead to this chapter with final comments on the results and the conclusions of the thesis. The first step is to answer all the research questions of the thesis and concluding on the implications of the research on the case and vice versa as done in Section 10.1. Based on these results, it is important to zoom out and see how the thesis helped to contribute scientifically as discussed in Section 10.2. This is followed by understanding that how this thesis contributes to the major societal gaps laid out in the thesis and this is discussed in Section 10.3. Based on the results from the models, theory and the empirical analysis, the generated policies help developing recommendations for the energy providing firms and the government organizations. The final section of the thesis helps set ground for the follow-up research by setting the limitations of the scope and the future work directions as discussed in Section 10.4.*

## 10.1. Answering Research Questions

Though India has been able to grasp many innovations with its fastest economic development decade, it has failed to make possible everyone to be a part of these developments. Providing reliable and long-term energy and electricity to every household is one of the traits to achieve such a development. As any other developing nation, those who are left from adopting these developments are the poverty stricken: mostly the rural population. Recent schemes like DDUGJY, and setup of Ministry of New and Renewable energy resources have helped to fasten up the pace of electrification especially through decentralized energy resources, majorly the renewable ones. But even if the village seems to be electrified, all the households still fail to achieve maximum electrification i.e. 100 % household electrification. Even if a house adapts electrification through renewable resources like solar, it's demands increases very fast with time, making this electrification system to be not suited for more than a year.

Rural India also has strong informal institutions, which makes implementation of projects like sharing of solar energy a challenge in itself, when people end up in conflicts due to different sections of community. The interesting thing noted across all the literatures is that they study the rural electrification projects from an approach to understand a household and its needs, or tries to look form the perspective of the energy providing firms. Both the approaches are interesting to understand the system and help giving the reasons for failure to meet the demand of the households, or the failure due to lack of supply from energy providing organizations. But none of them is able to capture the trends across these failures by looking at the complete set of households together where the social norms of community comes into picture, as depicted in the figure 10.1. Thus, a community management of resource approach is applied here followed from Ostrom's literature. The following section tries to answer the research questions posed in this research.

There are several electrification projects, and for this research they are considered differently based on the ownership of the project: Microgrid, individual SHS and Sharing projects. All of them have shown similar sustenance issues of the project, with the Sharing projects considered to be the most innovative project, but limited by system capacity as well. Thus, the overall research question of this thesis is *"Given the dynamics of rural communities of India, how can socio-technical systems of solar electrification be sustained?"*. The figure 2.1 shows that how this research question originates from the research and the societal gaps.

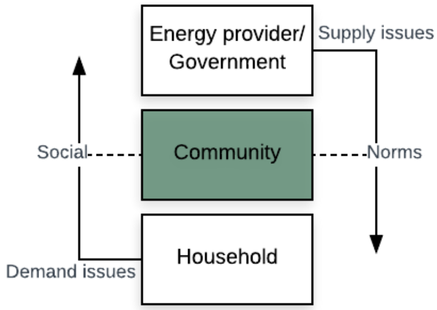



Figure 10.1: Community management fit for studying rural electrification

The research question posed above can be broken down into further questions to ease up the research and define a methodology.

### Which frameworks can help study the effects of all dynamic factors combined on the solar electrification systems in rural context?

For answering this, a thorough literature review of different community management frameworks like Institutional Analysis and Development Framework, Socio-Ecological Systems theory, etc. is done. Simultaneously, a literature review of the innovation diffusion theories is done to understand that how and when the innovations would be accepted by individuals in the community, which can help further community interactions. The conclusion of this literature review shows that the IAD and SES framework are most relevant here, but not sufficient individually. Also, the economic and word-of-mouth theories are most relevant for the innovation diffusion in this context. The next research question poses that

### If there is no framework available, how can a new framework be developed to study the effects of all dynamic factors combined on the solar electrification systems in rural context?

Looking at the results from the literature review it is clear that the innovation diffusion and institutional perspective is helpful here, but there is no framework which combines these two and thus they are combined in a new framework as the "institutional innovation framework." It is called so, because the institutions (rules) are adapted every time the community's (and/or resource's) demands and characteristics changes. The institutional innovation is divided into two main sections where different types of rules are adapted: top-down rule or usage rule based on majority of community's rejection or acceptance of innovation, respectively. The process is divided into stages of institutional diffusion and adaptation here . The top down rule is meant to make the communities accept innovations: e.g. allowing a margin on the cost of innovations for increasing affordability and number of consumers. For the usage rules, based on the community and resource properties and utility, the rules are varied slightly, the outcomes are evaluated and if they are beneficial, then the institutions are adapted and diffused. Thus, this framework helps in understanding the effects of the communities and resources changes. The framework also suggest the rules which can be used to help sustain these projects in spite of the dynamic communities.

### What are the existing effects of the different dynamic factors on the solar electrification in rural India?

For answering this, a context study is done via reading up further literature and recent news and development for rural electrification. To have a more depth understanding of these effects, interviews were conducted with the energy providing firms on-line, and on-ground (on-field) informal interviews were conducted with the community in the presence of energy providing company personnels. These two modes of interviews (iterated with time) gave a clear understanding of the settings of the actors in the network and the major institutions in the community. The interviews developed a very clear insight into these aspects of the electrification project: Technology, Energy provider characteristics, Community characteristics, Actors properties and involvement, Operations and Maintenance, Market settings and funding, Institution (Formal and

Informal), Success and sustainability parameters for the electrification project. This helped develop the actor and process charts showcasing clearly the actor networks and the collective, constitutional and operational actions in different projects as shown in Figures 5.4- 5.6.

From the literature context study, the success parameters for measuring the success of a solar rural electrification project were known. A lot of research has been developed in the field of the rural electrification domain on success factors, and following it, the major parameters of success came out to be affordability and accessibility for community, reliability and viability of technology, socio-cultural and political sustainability of the project with long term sustenance and profitability and positive environment impact of the project. Based on an analysis of these success parameters on statistical and visualization based result, it was seen that the success parameters stayed similar for the ownership basis, but varied as per the involvement of the stakeholders e.g. profitability was important for a village committee involved project. Based on this, the next research question posed that:

> Given the developed/ existing applicable framework, how can the the effects of the combination of dynamic factors on the solar electrification be obtained?

For going from the interview based research to an agent based model to study the effects, a design approach is needed - which is provided by the MAIA framework developed by Dr. Amineh Ghorbani. This conceptualization is done for two projects only (Sharing and micro-grid) due to the lack of the collective choices in the individual SHS projects. The MAIA framework helps lay down a conceptual framework in three structures: physical, collective & constitutional; operational; and evaluative. The operational structure here is adapted as per the institutional innovation framework to re-define the action sequences and introduce "rule-check" module in operational structure after action sequence. This module helps defining the type of rule to be chosen for the usage of the resource.

In MAIA, the first structure lays down different rules using ADICO, actor networks and action sequences. The second structure uses the institutional innovation theory to be integrated in the action situations of the actors. Note that this institutional innovation is not always there in the action situation, because sometimes, the actions of the agents are very straightforward and/or can be explained with a simple ADICO institution. The evaluative framework helps in defining the success variables from the success parameters to be exactly measured in the model. This conceptual framework shows clearly a significant impact of the informal institutions of the community on the solar electrification and the choices of the households. Based on this conceptualization and the followed up model designing, two models are developed with validation, verification and robustness check, where all the models look to be robust enough for proceeding further. The next research question lays down that:

> Given the developed/ existing applicable framework, what are the effects of the combined dynamic factors on the solar electrification in rural India?

To find the effects of these different factors on the project, it is decided to develop an agent based model, as this method allows to understand the evolution and emergence of institutions in a system by allowing to study the interaction patterns of the actors. Moving to the modeling, the model setups are different in terms of the number, size and locations of energy sources and frequency & payments of billing cycles. This helps in initializing the model with setting up if different institutions in different model. For e.g. the microgrid model has a high number of payment skips/ cheating/ stealing acts, and a significant role of village committee. At the same time, appointment of producers is very crucial action in the Sharing projects, which is completely absent in the microgrid projects.

Looking a the major effects of the sharing and microgrid projects, it can be seen that the sharing projects don't allow the income rise to be met with the increase in demand, while the microgrid project shows a lack of profits due to the payment skips in the project. Also, the demands based upgrading in more easier in a microgrid project but difficult to achieve due to lack of profits, while this is very difficult in sharing projects due to higher installment costs of the project upgrading. One of the solutions to this is to merge the two projects i.e. develop a hybrid project with the inclusion of microgrid to meet the higher demands at a lower cost (microgrid installments are lower). This also helps reducing the cheating behavior as in pure microgrid, because now people have incentives to be producers. As seen from the three models, the major insights in the effects/ behaviors of the models were as follows:

1. Laggards never get electrification: Laggards or the non-acceptors of the innovation because of delay in accepting innovations get left out of the network of electrification. This is highly because of the demand-rise of the products and the income-rise of the early acceptors to a level that they become producer. So even if the laggards want to be the consumers later, there is no motivation for the producers to sell more kits to households and thus the market itself has saturated to provide any more transactions. The same case is with microgrid and sharing, with former missing out on consumers due to payment skips and sharing switching to stable market much faster than sharing project (demands are met faster now using microgrid).

2. Importance of connectivity: Connectivity is more important than affordability for a household to decide to become a producer or not, especially in sharing and the hybrid project.

3. Rise and dip in the consumers/producers: Due to the replacement and operations & maintenance tasks, the reliability of the products become questionable, and less is the reliability more is the variation in the number of producers and consumers. Upgrade of income and connectivity helps bringing the rise to the market to a limited extent.

4. Microgrids' profits: The profit of microgrid is the biggest risk to the project because of the unaccountable behavior of the community accompanied by heavy operations tasks. There are many more reasons like the village committee changes, which keep the profit random and non-positive.

5. Hybrid project wins: Comparison of the projects can be done on the following parameters which helps in showing that the hybrid projects is much better than the other two projects (statistical results also show this comparison to be significantly better for hybrid in most cases):

   (a) Afford and Access: In terms of affording, microgrid always turn to be much cheaper due to smaller payments, while in terms of access, the hybrid projects make a network which allows adding a new household much easier and beneficial for the network.

   (b) Operations and demand rise (Reliability): Operational issues are more frequent with sharing and hybrid, but more larger (due to large size of the source) with microgrid. But the hybrid projects are more complicated due to presence of both and thus the least convenient for operations. But at the same time, the hybrid projects are better at meeting high to low demands than the other two.

   (c) Consumers and Producers: The number of consumers is highest in the microgrid, and the number of producers will be highest in Sharing and Hybrid, leaving the sum to be almost the same.

   (d) Profits: The profits are highest in the hybrid due to management of losses in microgrid and the profits to the producers, while only one of each is present in the other two, with microgrid's losses.

Now that the best research project is known, the next sub-research question asks

### What new policies and rules can be developed which would help change these effects to improve sustenance of the solar electrification in dynamic context?

For answering this research question, the first step was to understand that how can the effects of the changing demands and actions of the community be measured/ evaluated on the electrification project. Once this method is known, the next step was to understand the effects of the changing demands and actions of the community on the electrification project. The method is already answered using the ABM model and the conceptual framework. The next step is to find the new rules/ policies which can be introduced to sustain the projects. For doing this, the hybrid project is introduced with various scenarios and then different policies based on the institutional innovation principle.

The first scenario of introducing community energy livelihood options in the community shows an increase in the connections and the income of the households, leading to a higher number of producers and thus transactions. The second scenario shows no difference as energy varieties do not change the selling-buying relations in the community. The third scenario of the introduction of grid shows a high increase in number of transactions due to the shift of the community to grid, with a decline due to reliability issues of grid, and a significantly low number of producers. Other scenarios like cashless payment introduction in the community are discussed but not modeled, and such scenario promises to show a good impact on the profits of the project.

Finally, moving to the policies developed to improve laggards to include in electrification is done by introducing pay as service and in-house manufacturing policy. This policy shows a significant rise in the number of transactions and slight rise in the producers. The second policy on the demand wise electrification and payment to meet the demand versus income gap shows again a rise in the number of consumers and much higher and positive profits. The usage rules (policies) of compensation and distribution of the pool to the individuals with prioritization helps in increasing affordability (and reliability) and accessibility of the project, respectively. Other types of usage rules based on the difference between the individual, resource and community utility are also developed e.g. constraining the resource usage, and development and preservation rules for resources. These mostly help in developing the reliability of the resources. This brings us to answer the *main research question*:

> Given the dynamics of rural communities of India, how can socio-technical systems of solar electrification be sustained?

The answer to this lies in understanding the exact resource and community properties which change with the innovation. Once this is known, based on that institutions can be innovated (new rules can be introduced) by checking if the community majority has accepted the innovation or not. These rules help maintain the individual and resource & community utility gap, helping the projects to be sustained and become successful. Also, a combination of the sharing and microgrid project (hybrid project), tend to be most successful in such dynamic demands. In summary, top down rules before the community accepts innovation, and usage rules after community accepts innovation based on the institutional innovation framework, helps sustain the electrification project even with a dynamic community. The results show that the hybrid projects tend be more affordable, accessible, reliable and profitable with these institutions. Additionally, the informal rules in the context of such dynamic communities need to be adapted every time, and the existing grammar of institutions of ADICO, doesn't allow developing these rules every time there is a change. Thus, the institutional innovation framework helps accommodate such informal institutions easily for increasing the sustainability of the project. The framework is viable and implementable for further socio-technical systems as well, and the case study helps in developing this framework further as also discussed in Section 9.1.

## 10.2. Scientific Contribution

The case study has proven the viability of application of the institutional innovation framework, and now it would be discussed further that how this study has helped in scientific contributions by filling the research gaps. This is followed by understanding the recommendations at scientific level.

Two major research gaps were listed in the earlier chapters of the thesis: Understanding effects of dynamic demand of the communities, and no comparative study of different types of projects including Sharing projects. This has led to development of two major scientific contribution of the thesis: (1) Fitting community management of resources theories for technologically advanced systems, leading to the institutional innovation principle. (2) Comparative variables and methodology of conceptualization of model to develop different projects for the solar rural electrification projects. Both these contributions can be further broken down in more concrete contributions and they are discussed below:

1. **Adaptation of community management perspective for networked infrastructure in dynamic contexts:** In the existing literatures, very few electrification projects are looked at from a perspective of community management, but none of them have considered this perspective for a peer to peer (household to household) sharing. This thesis helps understand and adapt the framework to look at an individual owned resource in a networked system as a common pool community level resource.

2. **Modification of IAD framework with considerations of innovation diffusion:** The exact gaps in IAD and innovation diffusion theories are found out while developing the institutional innovation framework. These gaps can be filled by each other and thus a complete institutional innovation framework (Chapter 4) has allowed these theories to be used for understanding sustenance of projects involving technological innovations in dynamic communities.

   (a) IAD helps in developing the institutions based on the outcome and evaluation of the interactions based on the actions of the individuals. But it lacks in understanding that ***how*** exactly these institutions are adapted and diffused in the community. The perspective of institutional adaptation and diffusion is thus introduced here to fill these gaps. The institutional diffusion use the innovation diffusion decision principles here.

(b) Innovation diffusion focuses on only a specific perspective of how and when an innovation would be adapted as an individual, but with the framework, it gets an institutional perspective. Thus, the innovations are not just adapted based on specific decision rules, but other community and resource properties.

3. **Development of diffusion rules for institutions:** The thesis lays down which type of diffusion decision rules are actually also relevant for institutions diffusion. For example, word of mouth theory is actually helpful when an institution turns out to deliver benefits for individual utility.

4. **Development of institutional adaptation at different levels- three types of rules:** The thesis also lays down the institutional adaptation by explaining three different types of rules (institutions):

   (a) Top down rules are implemented when an innovation is not adapted by the majority of the community. These rules are called so as they are adapted by one of the actors controlling or operating the resource.

   (b) Individual rules are implemented after an innovation is accepted by the individuals to improve their own individual utility.

   (c) Usage rules are implemented for usage of resources based on the resource and community utility. Note that the individual and usage rules are sometimes decided together based on the gaps in the individual utility and the resource & community utility. These rules are developed based on the usage rules for different community demands and resource gaps. These lead to development of four types of rules: compensation rules, constraints, distribution of community pool to individuals (prioritization) and development & preservation rules.

5. **Definition of different levels of actors (Individuals/ community and Collections/collective) at different stages institutions development:** The thesis lays down that while considering technological innovations, it is important to looks at the individuals and community separately as well. The institutional diffusion happens at community and actor level, while the adaptation happens at individual level. Again the institutional design happens as a result of interaction at a community level. This also implies that as much as a collective action is important from a community as a result of interaction of actors, the collection of independent actions of individuals is also very important to evaluate the institutional choice and understanding community demands, when a technological innovation is considered.Additionally, studying the limitations of the thesis and the reflection on the research approach showed what could be further developed in the research. The reflection as discussed further in Chapter 11 showed need of a more comprehensive approach in institutional designs by considering not just the collective actions, but also the collection of actions effect in changing institutions.

6. **Defining co-evolution of resources and demands for institutions development:** The thesis has also laid out a structure which shows that which properties of resources and communities would be evolving within the institutional innovation stages. This will also hep define the institutional design, diffusion and adaptation parts of the framework.

7. **Development of operationalization and testing framework for institutional innovation:** The thesis not just ends at the conceptualization of the framework for institutional innovation, but also lays down its operational structure and this is finally implemented and tested successfully for the case of rural solar electrification. The operational framework is inclusive of integration and development of MAIA operational structure, with introduction of a new model after action sequence. This module allows to choose an institution based on the resource and community demand and utilities.

## 10.3. Societal Contribution

Three major societal gaps were raised in this thesis: Questionable feasibility of the Sharing Projects, No sustained and successful solar electrification projects, and Lack of policies and rules for sustenance of solar electrification. The research has help answer these questions in the same order.

The first question was answered by thorough literature review which showed that acts like energy act of 2003, PPA in renewables, are providing possibilities to develop more sharing projects. The increasing demands and adaptability of solar energy with its lowered tariffs and high potential of production shows the possibility to make sharing projects feasible.

The second societal gap is filled with the answer in form of a hybrid project of microgrid and sharing project, where the profitability issues of the microgrid are taken care by an incentive driven model to not cheat using sharing of energy. Similarly higher demands of the sharing projects are met by a lower fees of microgrid. Finally, the third gap is answered with the policies of pay as service/ in-house manufacturing, demand wise electrification and payment, and cooperative shops/ anonymous sharing help to sustain these projects with inclusion of maximum of the households and meeting the increasing demands. Additionally, the compensation, and constraints by individuals, with the prioritization policies by the community also helps sustain the resources in case of dynamic demands and innovations.

The recommendations here are addressed to majorly two segments of stakeholders: one, the energy providing firms and especially those who are ready to accept innovations with time and are inclined towards a sharing project e.g. *SolShare* and *Rural Spark*, but even microgrid companies with more innovations in their side like *Gram Power*, with smart meters, can find the recommendations helpful. The SHS projects like *Manthan* can focus on the more adoption of the social level innovations, due to lack of funding support and extreme poverty in the end user segment they are catering to. Once, they are able to help everyone get minimum electricity, the more technically advanced solutions can be integrated in their project. Finally, the local governments cannot directly use these recommendations, but their involvement while such implementations smoothen the process of development of electrification projects.

- The recommendations for all the energy providing firms are as follows:

  1. **Switching to Hybrid projects is beneficial:** A microgrid project should switch to sharing projects soon to prevent their losses, and incentivize consumer to be producers, gain income and stop payment skips. This is also not a very big challenge for a microgrid with the given amount of infrastructure already in place. This sharing is possible via grids. These grids need not be laid house to house but can be laid in hubs of the community (like major shops/ economic areas). A Sharing project would need more initial cost to setup the microgrid to switch to hybrid project, but it would increase the overall benefits of the project, as their will be higher sales of even the sharing based products and not just the microgrid service in a longer run. It will increase the satisfaction of the producers and help continue transactions with more consumers.
  2. **Introduction of grid has heavy impacts:** Grid has high impact, but reliable products and contracts with central grid can help: Introduction of grid leads to sudden sway in the market increasing the number of consumers. This reduces the scope of potential producers in the market. This is a threat to the energy provider market, but a solution to this is to have a very reliable product at source, so that there is no need of shifting the demand to the grid by the people. A PPA can be arranged with the central grid for collaborating such that people switch to grid only for higher demands.
  3. **Laggards can be included using pay as service model and in-house manufacturing:** Both these methods help in involving the operations fees in terms of the work itself: so rather than paying to an external agent/ another person, the laggards can do service for the microgrids or the producers in return to which they can get electricity This saves them fro the issue of affordability. In-house manufacturing can be developed as well established by *Barefoot College* in Rajasthan in rural areas. This helps in taking care of not just the services but also the product needs. This also incorporates community knowledge development and women empowerment, reducing discriminations.
  4. **Demand versus income gap can be reduced with demand wise payment and electrification:** The profitability of projects increase much more with a demand adjusted cost for electrification. Also, the demand based payment would only allow the microgrid to be used when the demands are high enough, and prevent cheating. The costs being a bit higher than the microgrid but much lower than the sharing project, compensates for the losses of microgrid and help meeting demands of all. Once the project is profitable, even lower demands can be included, allowing users to pay less, and even if there are some incidences of cheating, they would be compensated because of the profits of the microgrid.

5. **Resource and individual utility gap is important for usage rules:** Different types of rules are defined based on the resource/ community and individual utility gap. This helps define the compensation, prioritization (distribution) or constraint rule for usage of the resource in the community, increasing the profits and access of the resources.

- The recommendations specifically for the microgrid energy providing firms are:

  1. **Community energy system growth as economic hubs:** In case of community energy systems, it is good to sustain them as the community energy systems help develop community hubs where the connectivity and the income of the households increase. But it is also important to have a steady growth in these community energy systems - i.e. there constant development like a livelihood organisation/ economic hub is important , else they will achieve the growth for some time and then the number of producers and consumers will again reduce with either the reason of the increasing demands or the replacement costs piling up.
  2. **Prioritization rules help get community back on ground in cases of emergency:** The rules of prioritization of the energy resource to certain sections of the community based on the most important need in case of break down of services/ reduction in energy provision (quantity of resource), would help community. If these rules are not present, the community might lead to completely stop using the resource.

- The recommendations specifically for the sharing projects' energy providing firms are as follows:

  1. **Variety of the products should be experimented:** Energy variety doesn't have any effect on the number of producers, buyers, but the effect on profits might be different. Also, as noted in the technological products effect on innovation diffusion in the section 9.1.1, there are some possible effects due to more number of varieties in the products. For example, in the case of Rural spark, the more modular products have helped to cater to different amount of demands more easily, and as it doesn't have negative impact, more variety of products are recommended at least at the level of experiment in the market.
  2. **Cashless payments would have a positive impact on the profits:** Cashless payments would increase profits of the energy providing firms, because this would save a lot of hassle and investments in terms of time for the energy provision firms.

- The recommendations for the local governments (with collaboration of energy providing firms) are as follows:

  1. **Discrimination can be tackled with cooperative shops and anonymous sharing:** Discrimination based on castes, religion and gender is common in rural borders of India (varies heavily from region to region). These can be tackled using the cooperative shops to use the effects of a cumulation of all resources or as described in the discussion chapter as a voluntary contribution game. The collection of the small sections of society as one entity makes look at the weaker/ smaller section of society with more status. This can be done easily to develop anonymous sharing of the grid based system, where a large pseudo-producer is created by pooling the production of small producers (assumed to be belonging to smaller sections of community, who are discriminated against).
  2. **Policy impacts can lead to generation of new problems as well and it should be kept in mind:** All policies leads to evolution of the system, and this may lead to solving the old problem, but generating a new problem, e.g. solving an issue of one discrimination may already lead to development of new form of discrimination in community (discussed partially in chapter 11). This may or may not affect the system of electrification, but would play a role in community development. At the same type the policy of in-house manufacturing might lead to new community hub development and increased connectivity, which can be very beneficial for the project.
  3. **Delays in the processes need to be avoided:** The communities have a high rate of change with terms of demands, and if the project is not able to fulfill, it would lead to a loss in the trust and they would switch to something else soon, not coming back to the electrification service (something what happens with kerosene competition partially/ switch to grid because of affordability/ demand management). Thus the processes of testing and registrations are important, but should

be integrated with project deployment and design. This need a steady formal regulation from the governments, which can be followed rigorously/

## 10.4. Limitations and Future research

Due to the limitations of time, and the complexity of the system, there were many choices made during the course of the thesis. This led to limited depth in the research, but it also led to possibilities for further research. These limitations and possible topics of further research are discussed here:

1. **Co-evolution of systems:** The model developed here is considered to have no effects from the other communities which is not true, because as much as the electrification market affects the development of the community so does other services and technological products like the internet service and telecommunication. In this research, it could be seen that the laggards are a major issue i.e. the laggards remain left out from the system because the assumption is that they are not developing by adapting any other technology.

   This demands a new research where it can be studied that how different socio-technical infrastructure systems (e.g. electrification and telecommunication) affect each other (co-exist) when all of them goes through repeated innovations. Here the institutional innovation framework can be used with simulations to understand that how different domains' effects overlaps or conflicts with each other. The first step would be development of a model, followed by studying the interaction patterns, and generalizing it to a concept or framework for co-existence of socio-technical infrastructure systems.

2. **Data-Driven Approach:** Due to the unavailability of the data of communities and the impacts due to demands, a perspective which is missing in this research is to look at the research from a more data driven approach. The assumptions of the model are developed based on interviews and not solid data. The latter helps making robust models which are closer to reality.

   Such effects can be studied using a data driven agent based model, where the tools of machine learning can help in understanding the changing demands. The training on the compatible policies based on the given demands can help further. This can be then used for predicting the accurate policies for future, based on different demands.

3. **Smart contracts infrastructures:** The sharing of energy between households (who are producers) and microgrid needs very reliable technological solution. So though at a policy level this helps showing the hybrid and sharing project very lucrative, at a technical level they demand a system like a "smart contract", where the transactions between the microgrid and the sharing grids is changing constantly (because everybody's demands upscale or downscale at very different times).

   A framework comprising of incorporation of a new technology of block-chain can be studied as a separate research to understand the feasibility of such system. Block-chain based ethereum can help in this development of smart contracts, and a thorough analysis of actors involved would be required here.

4. **Automation of institutional innovation:** The institutional innovation framework shows that how an institution can be adapted with different innovations. But this needs to be done manually every time, and a better approach would be to automate such a system. This can involve just adapting such policy switches in the system for distribution of electricity, or developing more rigorous policy controls for enabling policy adaptation, like autonomous sharing. This can be an embedded system including the policy adaptations using soft-controls like "switches" with the hardwares used for distribution of electricity.

   For example, the policy of the anonymous sharing needs an automated system to be applied practically and function well as per every changing community and resource property. An automated switch can be applied based on whether a community actually has discrimination or not. There are actually some tribal un-electrified villages in India, where there is no form of discrimination and introducing such system would lead to break the high level of trust they have on community members (or on the energy providers), disrupting community values.

**Summarizing limitations and future steps:**

1. The key limitation was not using a more data intense methodology due to the lack of the data available, or more in-depth interviews to gather data from the energy provider.
2. In terms of tools, the usage of some other tools like Java instead of Netlogo, using system dynamics with agent based modeling, and more detailed interviews focusing on more quantitative data, was mainly noted.
3. The direction of a more data-driven agent based model where data helps in designing the behaviors of the agents would be interesting to explore.
4. An in-depth understanding of how other socio-technical infrastructures (like telecom industry) can co-exist, would be interesting research. This would deal with understanding continuous innovations which might lead to conflicts or additional benefits.
5. An equal attention of research on understanding the booming technologies like blockchain based smart-contracts for energy markets and their redesign, would be helpful here as well. The need of an autonomous system for such institutional innovation system is also realized.

# 11

# Reflection

*Now that the results are analyzed to give recommendations, it is important to step back and and understand the influences on research. This is done by reflecting on influence on the research approach due to personal choices and limitations of methodology as discussed in Section* 11.1*, followed by understanding the influence of research departments as in Section* 11.2 *and finally, influence of the existing research ideologies on collective actions* 11.3*.*

## 11.1. Alignment with personal motivation and method choices

The first set of reflections will be done on the methodologies used by the author in the research here. The motivation for these methods came from personal motivation to learn and understand new set of methods. Gaining knowledge of the context (rural solar electrification) motivated for in-depth interviews and on-ground interviews with the community. Also, the author wanted to learn the community interactions and thus the agent based modeling was best suited.

Different methods were chosen for this thesis and not just all these methods have their own limitations, the way of using these methods lead to some gaps in research and thus demand reflection. These methods are classified below using an indication of whether they were chosen as an inductive (generalize existing idea or goes from specific observation to general conclusion), deductive(narrow down existing choices or goes from general rule to specific conclusion) or abductive form of reasoning (goes from incomplete observation to best prediction) to develop solutions. Further, they are classified as an analysis at macro(collection of actors), meso (one actor) or micro(individual) level, and this is shown in following table 11.1. The classification of the methods at different levels and reasoning, helps critically reflect on the thought process of author has been for choosing different methodologies

Table 11.1: Methodology choice reflection: reasoning and level

| **Method / Analysis** | **Reasoning** | **Level** |
|---|---|---|
| Literature review to insights | Deductive | Macro and Meso |
| Framework Development | Deductive | Macro, Meso and Micro |
| Interviews to insights | Inductive | Meso and Micro |
| Conceptualisation for simulation model | Abductive | Macro, Meso and Micro |
| Simulation model: Agent Based modeling | Inductive | Meso and Micro |
| Policy formation and testing | Abductive | Macro and Meso |
| Back to framework from case | Inductive | Macro and Meso |

Finally, the learnings from these methods are discussed as the gap of the method, or the gap due to choice of author. These gaps also emphasizes the possibilities to make this research better and considerations for future research. these are discussed as follows:

1. Some of the modeling choices were made to keep the model simple. For e.g. The distribution network doesn't grow from house to house but rather from hub to hub (central points of communities, like shops

area, etc.), so the connectivity needs to be considered not from the proximity to number of houses, but proximity to hubs. This was not developed in the model accordingly. The distance of the connections needs to be included as well, provided there is significant cost of laying down the grid lines. These choices would significantly affect the model results, and should be considered ahead.

2. The interviews done verbally take much more time and being qualitative in nature lead to a lot of off track discussion. This can be avoided by either breaking down the qualitative questions into very specific questions, so that the answers are yes or no and can be filled by the energy provider on their own.

3. The biases of the interviews are not considered completely in this research, even if some emphasis was given on designing the questions to avoid these biases. As the institutions are gathered from the interviews with the energy providing companies and the community (in presence of the energy providing companies), some of the institutions imposed by energy providing firms are missed. For example, there might be corruption by the energy providers to influence governments and ease up on policies. This shows a need of further interviews without the presence of energy providing firms.

4. The effects of the innovation on the resource and community utility can be very well studied by a system dynamics approach, which is crucial for understanding the exact effects for the usage rules. Thus a combination of agent based modeling with the system dynamics approach would be really helpful for complete operationalization of the developed framework.

5. Net-logo in itself is a more restricted platform than Java or other languages due to its inability to define some very basic functions like updating an agent-set in one procedure and calling it from other procedure, and thus using other object oriented programing like Java would be much helpful for more complicated models.

## 11.2. Alignment with research departments

Additional to the personal choices, the maximum impact the research had was from the research department ideologies. The department of engineering systems and services (ESS) and department of multi-actor systems (MAS) were involved in this thesis. After an immense amount of learnings from these departments, it is important to reflect on how this study fit and contribute to these departments. ESS focuses on the individual actors and their actions' interactions on the system, while MAS focuses on the systemic level. This research is inclined towards ESS approach of understanding the effects of individual action on system, but reflects on the need of combining the interacting individual actors and systemic effects together.

Also, this combination allows using the research approach of one department to help answer the research target of another. For example, approach of institutional economics used in ESS helped in focusing on one of the research environment targets of MAS of "institutional voids", "where the rules and institutions lag behind the development of the systems which they were designed to serve, in effect leaving a governance gap[1]." Such institutional void has been present for management of networked infrastructures, partially owned by community, like in the case of solar electrification sharing projects, and this thesis helps develop these institutions with institutional economics (IAD and SES frameworks). The methodology of the agent based modeling had been commonly used in both the departments and thus the simulations, experimentations and data analysis would be compatible for both the departments.

ESS looks at the developments in system by understanding the effects of interactions of actions of different individuals and discuss the emergent behaviors of actors. This research complements in this approach by (1) showing that how new interactions happen systematically when technological innovations are brought into the system i.e. innovations lead to new behaviors among individuals, and (2) emphasizing that these innovations and changes in behaviors demand change in institutions to sustain the innovations which help transitioning towards better future (here, renewable energies).

MAS tries to answer that how in dynamic, uncertain and boundary-less environments, decision making and coordination happens. This research helps answer this by (1) developing individuals decision making with coordination of other individuals by looking at the community and resource utility, when innovation is brought into a developing economy, and (2) developing the systemic level evaluation framework for understanding development of technological networked infrastructures with dynamic communities.

[1] `https://www.tudelft.nl/en/tpm/about-the-faculty/departments/multi-actor-systems/research/`

Finally, this research tries to combine both these department approaches by reflecting on the need of looking at a problem at both a systemic (collection of actors) and individual level (individuals) as also discussed in the Section 11.3 above. Thus, this research tries to align with these research departments and successfully does so with contributing to the departments via developed perspectives and application of different research methods.

## 11.3. Alignment with existing researches

As briefly mentioned above in Section 11.1, the methodology demanded the author to look from micro, meso and macro level of the actors. This can also be seen in the final institutional framework developed and shown in Figure 4.5 that how different levels of actors are involved in the framework. This section tries to critically reflect on such an approach of researches where we are focused on using only either of the two sets; looking from individuals' interaction or looking at systemic level. It is important to look at some problems from a combined approach or in fact a middle level approach. For example, in this case, the individuals do some action individually, and this leads to interaction and the effects on the system at resource and community properties.

But at the same time, the collection of actions (without any form of interaction), leads to change in the system as well. For example, if the majority of the community choses an action i.e. a collection of the actions of not adopting an innovation, it still leads to a development of an institution and impact on the community. There has been so much of stress in literature on the collective actions, and the patterns and interactions of the actors, that this basic notion of collection of actions is forgotten. Collective choices are the decisions taken by the interaction of actors, where one common decision (choice) is chosen by all the actors. Though the interaction of actors is important to be understood in modeling, sometimes there is no need of modeling and the complex systems can be solved with simple solutions of just understanding the actions of majority! In fact most of the practitioners the author interviewed basically showed that the decisions they took on field were based on the response of majority, even if this majority was highly dispersed and not having any interactions.

Having said the importance of the collection of the actions of individuals, there is lack of interactions in the communities in these specific innovations. This might be one of the reasons leading to major failures of these electrification projects as the perspective to look at the energy in a network as a common pool resource. Also, the policy results show the collective rules to affect the project positively. Thus, it is important to consider the collection of actions and collective actions both to design institutions (though in this thesis, the collection of action is only used to decide the top down versus the usage rules, this can be extended further for institutional developments). A simple representation to compare these actions is shown in figure 11.1.

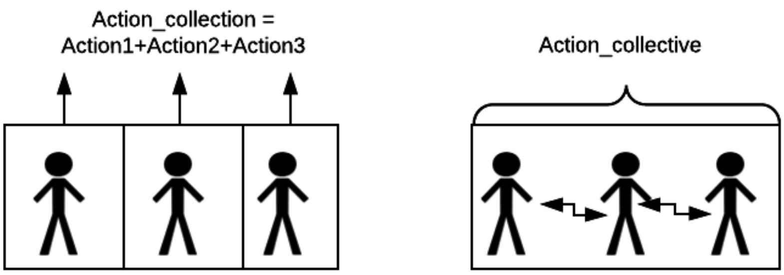



Figure 11.1: Collection of actions versus collective actions

Thus, the author's journey went from focus on collective actions due to the literature review, but shifted to the importance of collections of actions, due to the interviews. Then finally, based on the results from the simulations and policy testing (which showed benefits to institutional design by considering both, the collection, and collective action), it was realised that both the approaches are important and should be considered together for institutional design, as shown in figure 11.2.

Summarizing, the reflection emphasizes that the personal choices of the author, the work of the research departments, and the existing researches have helped set a direction for this research. But the personal ideologies were shaped further, impacting the research, by the field interviews and informal discussions with the energy providers. This has led to introduction of new ideologies in the research, e.g. understanding the

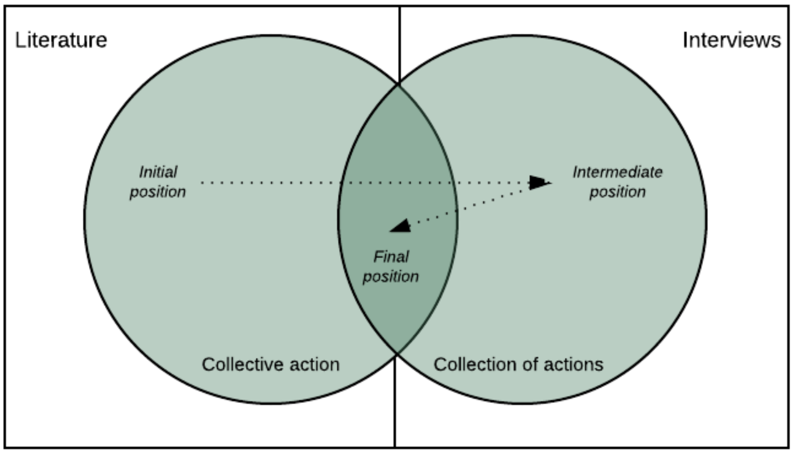



Figure 11.2: Viewpoint on Collection and collective actions

stress on the collective actions on the community in literatures, and importance of collection of actions and individual choices.

### Author's further steps on limitations of thesis:

- The thesis author is working on the smart contract research and project feasibility in Indian context as a side project with colleagues from TU Delft (`www.energybazaar.org`).
- Also, the autonomous and anonymous sharing concept will be followed up to develop an anonymization system/algorithm in a complete computer science research thesis.

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# A

# Theories and Literature Review

## A.1. Framework for affecting factor

Various frameworks were studied for understanding the effect of different factors on the sustenance of electrification, and the following framework as shown in figure A.1 was found to be most fit as proposed by Jain and Kattuman (2015). This framework can still not answer the research question posed in the research for incorporating dynamic communities and therefore it is not considered for further study.

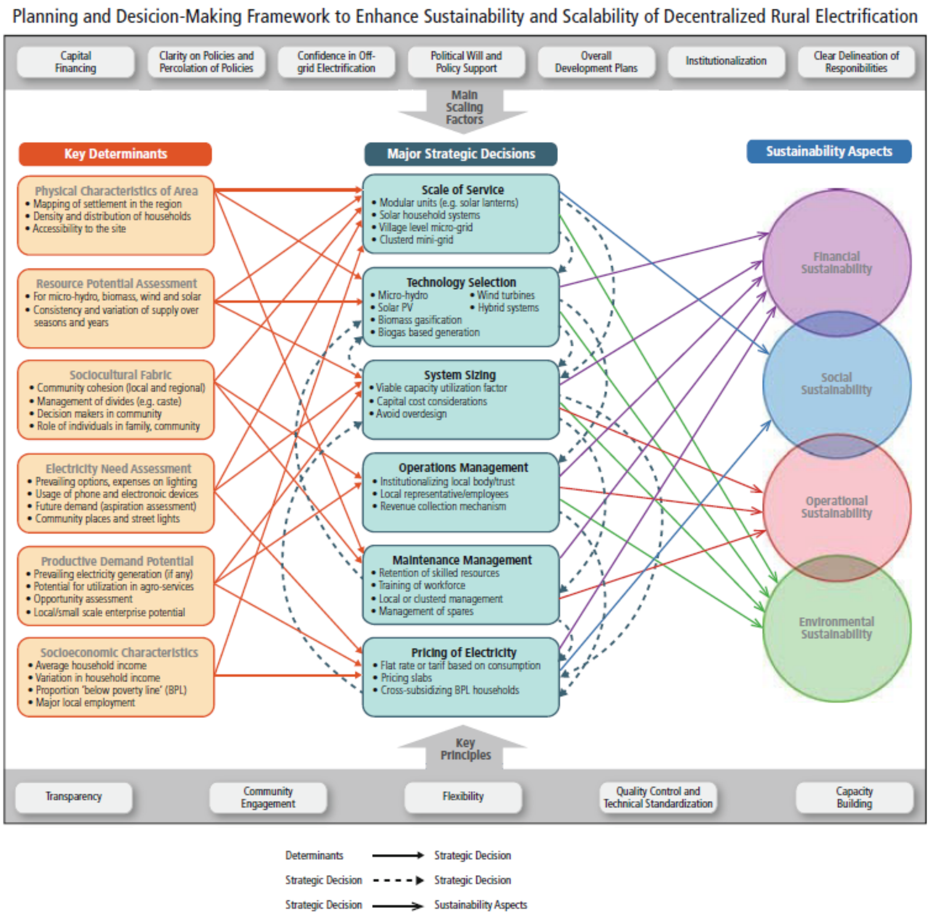



Figure A.1: Decision making framework for enhancing sustainability of rural electrification

## A.2. Community management theories(extended)

**Williamson's framework:** For understanding of the institution, the williamson's 4 layer model is used - informal institutional environment of socio-technological systems(norms, values, orientations, roles, codes, culture), formal institutional environment of socio-technological systems (formal rules, laws and regulations, constitutions), formal and informal arrangements (gentlemen agreements, covenants, contracts, alliances, joint-ventures, mergers, orientations, relations), actors and games (services, actors/agents, interactions aimed at creating and influencing provisions,outcomes).

**Oerkson framework:** Oakerson (1990) discusses physical and technical attributes of the resources, which is governed by conditions of how commons permits exclusion of individual users, capacity of resource base to support multiple users and determining physical boundaries of the commons. Oerkson also includes the principle of indivisibility of the resources, defining if the resource could be divided among private users and to what extent. The decision making arrangements are discussed here based on the operational rules (limitation on usage), rules establishing conditions of collective choice (e.g. entry and exit rules) and external arrangements (dependence on external legislation). Outcomes based on the interactions here given by the decision making arrangements and the physical-technical attributes, are based on inequity by checking Pareto-optimal solutions.

**Multiple use commons framework:** Edwards and Steins (1998) discusses the framework for resources, which are used for multiple purpose. They introduce the term amenity users or non-extractive users, who derive the use from resource system itself(e.g. recreational users, nature conservationists) and not the resource units necessarily. This framework includes the dependence of the subtractability of the resource on the given technological innovations. The context-bound factors (e.g. past experiences) make this framework widely applicable to more than one type of resource and incorporate the specificity of the particular resource or community. This framework also incorporates the links between different levels of decision making and their dependence on various rules (operational, constitutional, etc.) and defines how the rules evolution happens. Multiuse theory (Edwards and Steins, 1998) shows many potential advantages for this case, but as it was not the most suitable theory it was skipped. The following figure A.2 shows that how it could be fit in this case.

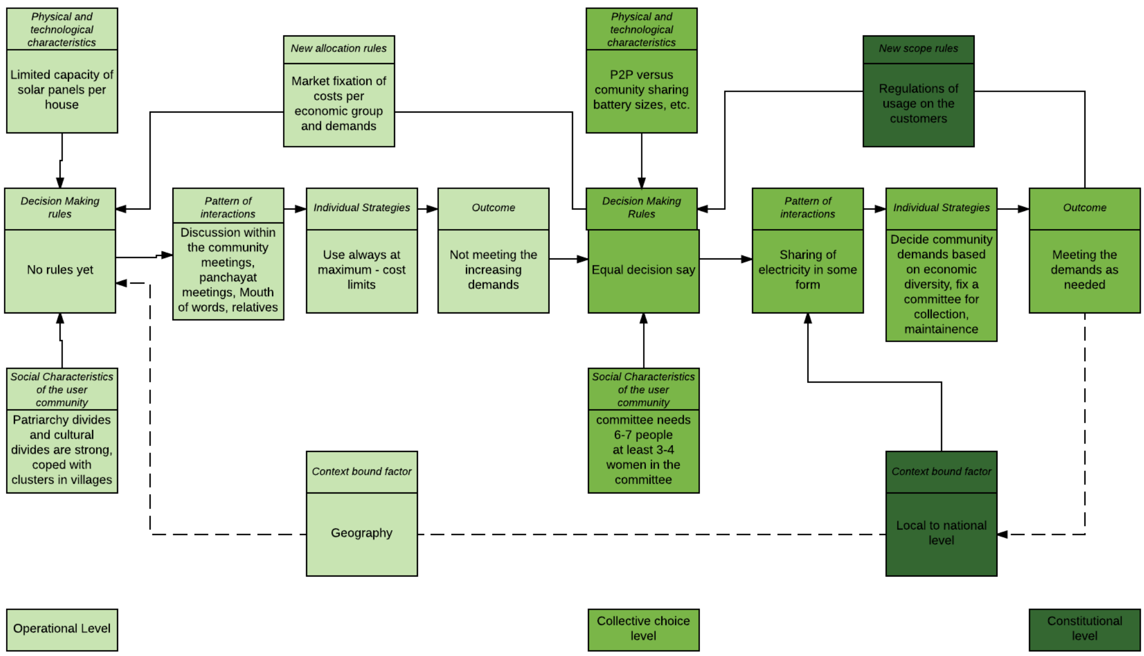



Figure A.2: Multiuse theory for the rural electrification case

**Tang framework:** Tang (1992) adds the social characteristics of the community to the Oerkson framework mostly for the irrigation systems, where the principle of bounded rationality and opportunism is introduced. This helps in understanding/ modeling individuals. The patterns of interaction here are studied in terms of transaction cost.

**ITQ framework:** "Individual Transfer Quotas(ITQ), in contrast to input controls (e.g. the restriction on fishing in certain season), operate on the principle that incentives (e.g. total allowable catch among fishers in the form of individual harvesting rights) rather than controls should be used to manage fishery" (Grafton, 1996). ITQs ensure that fishers pay price for harvesting an extra fish and this provides them with a long-term interest in the resource. This can help change fisher behavior and increase the net return from the fishery. In general this framework sets up a form of market where the selling and buying is done of resources to prevent resource overuse, and the evaluation factors here are very specific: economic efficiency, changes in employment, and cost recovery.

## A.3. Innovation Diffusion theories (extended)

The extended summary in section 3.2.1 of innovation diffusion theories and affecting factors which is used to develop the simulation model is discussed below:

1. Some initial parameters like the social network among the consumers affect the results of the innovation diffusion and should be kept in mind Janssen and Jager (2001).
2. Other consumer behaviors play crucial role as well. Conceptual model of consumer behavior where every agent can be modeled with set of opportunities, abilities, memory, needs, level of satisfaction, uncertainty and cognitive processing.
3. In such theories, it is seen that within a given time, if a product is able to satisfy the need of the market, else it gets replaced (which is defined by the needs of the consumer: both social and personal).
4. The additional consumer behavior based on the use of a product is defined on satisfaction versus uncertainty level (due to environment) leading to repetition, deliberation, imitation and social comparison.
5. The preference for a product changes in two ways: due to socialization or exposure, and the rate of preference change is decided accordingly.
6. These theories basically show co-evolution and dependence of different actors in the system: firms and consumers (Janssen and Jager, 2002).
7. Here the money which the market is inclined to spend on buying, the demand for the product, the price of the product and the refurbishment of the product is also used in the theory to define firms.
8. Also, the position of the innovator in the network decides the rate of diffusion of innovation.
9. Different types of innovations affect the emerging needs and leads to diffusion of innovation, modeled via two mechanisms: probabilities for spontaneous and Word-of-Mouth induced awareness (Goldenberg and Efroni, 2001).
10. The rule table, or the transition function or the interaction rule is determined for one cell using the neighborhood cells and following the rules of cellular automata[1].
11. The innovation which are less risky innovations take more time to spread if the central connected agents have a low threshold for adoption. When innovations are more risky, individuals who are less connected adopt product, reducing uncertainties and leading to followed-up diffusion (Valente, 1995).

[1] A basic rule where an agent takes an action based on the actions of its neighbors

# B

# Empirical Analysis: Interview

## B.1. Interviewee description

Before finalizing the interviews, the following projects were considered: Gram oorja[1], Boond [2], Manthan and Barefoot College [3], Piconergy [4], Rural Spark [5], Sol Share[6], Selco[7], Sankalp, Mera gao power[8], Simpa[9], Gram power, and Onergy. The research based interviewers were targeted from CEEW, anthopologist from Industrial Design Engineering department in TU Delft, Postdoctoral researcher in community studies from TU Eindhoven, Photovoltiacs researcher from DC systems research in electrical engineering in TU Delft. Other industries which were studied and not interviewed are as listed below. They were discarded as they are not from India, but still they had some interesting models to study.

1. IEEE smart village/ sunblazer - they have a portable set up (1 kWp with 80 battery packs) which is their USP. “The generator also accepts AC backup input from a wind turbine or small diesel generator and is configurable to other load options such as schools, churches, community centers, clinics, coolers, small businesses and Internet connectivity."

2. BBoxx - They have remote access like rural spark, but added to it they have very efficient devices like a 8W TV set.

3. OEEX - open energy exchange platform [10] “OEEX creates the base for a peer-to-peer-marketplace. In the future this will be a platform that allows energy suppliers, small producers and consumers to trade electricity effortlessly among each other."

## B.2. Interview designing

The interview development using different literatures and theory of SES is detailed out in the following subsections, as the final outcomes of this is explained in Section 5.2.

### B.2.1. SES theory to interview

The SES theory gives many variables and these variables can be fit for this case to develop questions as shown in the following tables B.1 and B.2.

[1] http://www.gramoorja.in/
[2] http://boond.net/
[3] https://www.barefootcollege.org/
[4] http://www.piconergy.com/
[5] http://www.ruralspark.com/
[6] https://www.me-solshare.com/
[7] http://www.selco-india.com/
[8] http://meragaopower.com/
[9] http://simpanetworks.com/
[10] http://www.oeex.org/en/

Table B.1: SES theory to interview parameters-1

| | |
|---|---|
| ***Social, economic, and political settings (S)*** | |
| S1 – Economic development | Income and employement |
| S2 – Demographic trends | Properties of the community individuals (age, sex, etc.) |
| S3 – Political stability | Political interference<br>Regulations for resource allocation |
| S4 – Other governance systems | Other affecting local governments,<br>external organisations |
| S5 – Markets | Market settings,<br>Payment mechanims,<br>Communities involvement in payments |
| S6 – Media organizations | Involvement of media organisations |
| S7 – Technology | Types of technology and components used |
| ***Resource systems (RS)*** | |
| RS1 – Sector (e.g., water, forests, pasture, fish) | Energy |
| RS2 – Clarity of system boundaries | Type of energy-provider |
| RS3 – Size of resource system | Size of the products/ services provided |
| RS4 – Human-constructed facilities | The resource (electricity) is completely technologically based and thus is a human based facility |
| RS4 – Natural facilities | Geographical factors affecting the electricity |
| RS5 – Productivity of system | efficiency of the solar panel |
| RS6 – Equilibrium properties | The decision for cost of selling of electricity<br>The cost of selling |
| RS7 – Predictability of system dynamics | Any tragedy of commons situation |
| RS8 – Storage characteristics | Storage solution |
| RS9 – Location | Location |
| ***Governance systems (GS)*** | |
| GS1 – Government organizations | Government organisations involvement |
| GS2 – Nongovernment organizations | NGOs involvemt |
| GS3 – Network structure | The flow of decisions within actors |
| GS4 – Property-rights systems | Property rights of lands and resources associated |
| GS5 – Operational-choice rules | Operational rules |
| GS6 – Collective-choice rules | Collective rules |
| GS7 – Constitutional-choice rules | Constitutional rules |
| GS8 – Monitoring and sanctioning rules | Registrations and regulations, Testing protocols |
| ***Resource units (RU)*** | |
| RU1 – Resource unit mobility | Electricity is mobile when shared |
| RU2 – Growth or replacement rate | Growth or replacement rate |
| RU3 – Interaction among resource units | Interaction among resource units |
| RU4 – Economic value | Income and employement |
| RU5 – Number of units | Number of units |
| RU6 – Distinctive characteristics | NA |
| RU7 – Spatial and temporal distribution | Spatial and temporal distribution of households |
| ***Actors (A)*** | |
| A1 – Number of relevant actors | Overall picture |
| A2 – Socioeconomic attributes | Socioeconomic attributes |
| A3 – History or past experiences | Electrification level (average hours)<br>Community shared resources |
| A4 – Location | Location |
| A5 – Leadership/entrepreneurship | Leadership/entrepreneurship |
| A6 – Norms (trust-reciprocity)/social capital | Trust in community |
| A7 – Knowledge of SES/mental models | NA |
| A8 – Importance of resource (dependence) | Importance of resource (dependence) |
| A9 – Technologies available | Technology |

Table B.2: SES theory to interview parameters-2

| | |
|---|---|
| ***Action situations: Interactions (I) to Outcomes (O) I1 – Harvesting*** | |
| I2 – Information sharing | Information sharing mechanisms |
| I3 – Deliberation processes | NA |
| I4 – Conflicts | Conflicts |
| I5 – Investment activities | Community sharing/ investments |
| I6 – Lobbying activities | |
| I7 – Self-organizing activities | |
| I8 – Networking activities | Networking activities |
| I9 – Monitoring activities | NA |
| I10 – Evaluative activities | NA |
| O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability) | Affordability, Viability, Reliability<br>Long term , Profitability, Equal accessibility<br>Socio-cultural, Political and institutional |
| O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability) | |
| O3 – Externalities to other SESs | Externalities to other SESs |
| ***Related ecosystems (ECO) ECO1 – Climate patterns*** | |
| ECO2 – Pollution patterns | Environment sustainability |

Table B.3: SES theory to detailed and communicable interview parameters-1

| | |
|---|---|
| ***Actors (A)*** | |
| A1 – Number of relevant actors | Overall analysis |
| A2 – Socioeconomic attributes | Caste / Sect prelevant? Religion divide? political divide?<br>Patriarchy, Sharing of property/ utilities in community?<br>Handling hierarchy/ difference in community methods<br>Reason for preferring microgrid /SHS /sharing? |
| A3 – History or past experiences | Electrification level (average hours)<br>Community shared resources |
| A4 – Location | Location |
| A5 – Leadership/entrepreneurship | Leadership/entrepreneurship |
| A6 – Norms (trust-reciprocity)/social capital | Trust in community |
| A7 – Knowledge of SES/mental models | None |
| A8 – Importance of resource (dependence) | Importance of resource (dependence) |
| A9 – Technologies available | Answered in S7 |
| ***Action situations: Interactions (I) to Outcomes (O)*** | |
| I2 – Information sharing | Information sharing |
| I3 – Deliberation processes | None |
| I4 – Conflicts | Conflicts |
| I5 – Investment activities | Community sharing/ investments |
| I6 – Lobbying activities | |
| I7 – Self-organizing activities | |
| I8 – Networking activities | Networking activities |
| I9 – Monitoring activities | None |
| I10 – Evaluative activities | None |
| O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability) | Affordability, Viability, Reliability, Long term<br>Profitability, Equal accessibility, Socio-cultural<br>Political and institutional |
| O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability) | |
| O3 – Externalities to other SESs | Externalities to other SESs |
| ***Related ecosystems (ECO) ECO1 – Climate patterns*** | |
| ECO2 – Pollution patterns | Environment sustainability |

Table B.4: SES theory to detailed and communicable interview parameters-2

| | |
|---|---|
| ***Social, economic, and political settings (S)*** | |
| S1 – Economic development | Maximum income, employment of consumers |
| S2 – Demographic trends | Customer age-group, type of community |
| S3 – Political stability | Involvement of government for asset allocation,<br>Government regulation for property rights |
| S4 – Other governance systems | Village committee, Committee composition, NGO involved,<br>Bank involved, Manufacturers involved, Government involved,<br>Local distributor company involved, Retailer involved,<br>Villagers voluntary assistance for installation |
| S5 – Markets | Funding of project, Payment, Community payee? Pay as you go,<br>Payment range (rupees) per month, Fixed payment available,<br>Prepaid recharge system, operation costs added to warranty?<br>Join liability groups for payment, Risk taker if no liability group,<br>Any form of community investments/ SHGs? |
| S6 – Media organizations | Involvement of media organisations |
| S7 – Technology | Meters, Smart meter, communicating meters, Data storage?<br>Theft detection, Remote control, appliances provided,<br>compatible with different loads and technology, App,<br>Upgradable, Customer written validation and SMS validation,<br>Type of upgrading, Automatic day and night control, |
| ***Resource systems (RS)*** | |
| RS1 – Sector (e.g., water, forests, pasture, fish) | Energy |
| RS2 – Clarity of system boundaries | Company, For profit?, Type ,B2B (1)/ B2C(0) |
| RS3 – Size of resource system | Size of the products/ services provided |
| RS4 – Human-constructed facilities | None |
| RS4 – Natural facilities | Geographical factors affecting the electricity |
| RS5 – Productivity of system | Efficiency of the solar panel |
| RS6 – Equilibrium properties | Preliminary survey for demand understanding<br>Survey based tariff decisions (no means fixed tariff for all)<br>Other financing questions as for S5 |
| RS7 – Predictability of system dynamics | Any tragedy of commons situation |
| RS8 – Storage characteristics | Storage solution |
| RS9 – Location | Location |
| ***Governance systems (GS)*** | |
| GS1 – Government organizations | Central/State Hindering/ supporting policies<br>Local hindering/ supporting policies |
| GS2 – Nongovernment organizations | As in S4 |
| GS3 – Network structure | The flow of decisions within actors |
| GS4 – Property-rights systems | Property rights of lands and resources associated |
| GS5 – Operational-choice rules | Survey based technology design and location decision?<br>Villagers voluntary assistance for installation<br>Local paid operator-trained personnel<br>Additional operation staff from company<br>Ownership transfer?<br>Allowed schemes to remove the project?<br>Importance for productive use of energy?<br>Geographical other conditions needed<br>Post survey for installation validation |
| GS6 – Collective-choice rules | Collective rules |
| GS7 – Constitutional-choice rules | Constitutional rules |
| GS8 – Monitoring and sanctioning rules | Registrations and regulations, testing protocols |
| ***Resource units (RU)*** | |
| RU1 – Resource unit mobility | Electricity is mobile when shared |
| RU2 – Growth or replacement rate | Growth or replacement rate |
| RU3 – Interaction among resource units | Interaction among resource units |
| RU4 – Economic value | Maximum income, employment of consumers |
| RU5 – Number of units | Number of units |
| RU6 – Distinctive characteristics | None |
| RU7 – Spatial and temporal distribution | Minimum number of households in community<br>Scattered communities?<br>Minimum distance in meters between households |

### B.2.2. Biases and qualitative interviewing

Following postulates were kept in mind - these are direct quotes from the available literature as they can be used as is for development of interview:

- "Less structured interviews are most appropriate for early stages of research because they allow interviewees to focus on what they think is most relevant to the question, providing the broadest set of perspectives."
- "More structured interviews ensure that interviewees all address the same questions, and thus that interviewee's responses can be compared. More structured interviews increase the likelihood that the findings of the research will be generalize-able and/or can be used to test specified hypotheses."
- "recent experiences are often easier for a respondent to recall accurately and in detail."
- Use probes for directing the interview in right direction "then what happened?"
- Personal acquaintance local/native language conversation helps.
- Order: Interviews should be structured like a conversation, with logical transitions between topics. It is typically best to start the interview with an easy and general question. E.g., a "tour" question such as "Could you tell me what you do here?" Save sensitive or controversial questions for the middle of the interview, once rapport has been established. End with a question allowing respondents to comment on any topic covered in the interview or on the interview itself
- Have a look at the flow of interview an time it well
- Do not share your hypotheses (if applicable).
- Do not use emotional, loaded or biased language and be careful about what your behavior conveys to participants (e.g., expressions of surprise, jumping to take notes)
- Make rapport (maybe praise, thank in between), be neutral to your reactions and attitude

## B.3. Interview questionnaire

The following interview questionnaire was sent out to the interviewee in advance and as discussed in the section 5.2.3, two interviews with the same interviewee are conducted to cover maximum questions. The brief of the interview questionnaire sent and covered during the interview is as follows: Hi, I am Rhythima doing my double masters in policy analysis and data science. I am doing my thesis on "community sharing of solar electricity in rural India" - This interview is aimed at understanding the factors which affect the success or failure of solar electrification projects in rural India:

1. Existing factors of technology, market, community, individual households and institutions
2. Changing factors of technology, market, community, individuals households and institutions
3. Definition of success or sustainability of the projects

1. Existing factors
   (a) Technology and operations
      i. Which technologies are more preferred in your range of services?
      ii. Who is responsible for the major maintenance activities? Why do you prefer such ownership of the maintenance activities?
      iii. How frequent are these maintenance activities required? (The list of activities can be asked if required for more clarity, but not necessary, as the frequency would be enough for the model, or what is the growth and replacement rate of the products of SHS?)
      iv. Are there operational costs every time there is damage/ are there warranty periods? Or is it like if a person buys off a kit, then that person owns all the remaining costs?

(b) Market Structure and costs

i. (Rural Spark, gram Oorja, mera gao power, Simpa:) If there is more than one organisation (i.e. except you) how do you decide the cost to the end-user? Do you aim at some profit margin for all?
ii. Pay as you go –fixed tariff – installments? What and why?
iii. (Micro-grids, Rural Spark and Sol Share) What is the exact selling cost from the local entrepreneurs/ local leaders/ sellers? How is it decided?
iv. (Only to companies with advanced tech like smart meters: )Is cashless payment feasible in rural context?
v. (In case of sharing and sol share:) What type of Payoff rules specify how benefits and costs are required, permitted, or forbidden to households?
vi. (Others :) if they share something else - what type of payoffs?
vii. Any investments together which communities do - Maybe Self Help Groups?

(c) Institutions (culture and norms)

i. Role of caste (other community hierarchy for Solshare) in the rural areas on affecting distribution on electricity or sharing? Any other type of divide or hierarchy?
ii. Which type of constitutional choice rules/ authority rules affect their choices of technology/ committee? (Who in the community should make decision - a policeman, sarpanch, or a house staying woman - role of patriarchy in community affects the choices for the product in any form?
iii. (Other version of the question) Tell about the local leaders'/ committee in-charge selection process – which of their characteristics are important?
iv. Any historical sharing of resources they did - like water - how did they carry it out? What was the cost and pricing in such scenario?
v. How the communities been able to solve some of their conflicts/ self-organize themselves in past efficiently?
vi. What type of historical things which stayed for long time with them - like living in a joint family - affect their choices to prefer specific service or product more?

(d) Institutions (formal structures and governance)

i. Did certain central/local/state level policies existing from generations like the existence of DISCOMs heavily hinder or help the project?
ii. At local level government (panchayat), is there a strong dependence of the type of party (or type of panchayat) on the success of project?
iii. Did certain central/local (Panchayat)/state level policies introduced more recently (or from previous governments-in rule) heavily hinder or help the project?
iv. (Specifically for micro grids with community ownership: ) Are there any Collective-choice rules for operations?
v. (Specifically for micro grids with community ownership: ) What type of property right related rule - if they do - play role?

(e) Institutions (actors)

i. What type of involvement of NGOs, Private sector (maybe in form of competition, alliance) affect the success of project?

(f) Individual

i. How much are the people willing to spend on electrification?
ii. How does the usage of phone and electronic devices affect the electrification proejct - if a community is already dependent on TVs, then, is this project implementable?
iii. What do the communities usuallly aspire from electrification - what do they think as an ideal scenario to achieve based on the given project (e.g. I should be able to use a rice cooker, a fan, a cooler, etc. or my children should be able to study throughout night, if needed, etc.?)

(g) Community (economic)

i. What is the Average household income?
ii. How much is the Variation in household income?
iii. What is the major employment e.g. labors, fishers, farmers (Does it affect your business choices - or pricing mechanisms – or energy affordability: Was there a specific choice of business model made based on the economic status of the target users?

(h) Community (social and cultural)

i. While choosing a village or a location of electrification, or in fact while choosing target users, were there any cultural aspects of the population (e.g. religious superstitions, etc.) that were taken into account?
ii. What is the extent of trust in community between each other - between households: Community cohesion (local and regional)?

(i) Community (region specific)

i. Anything important effect of the demographic of the population?
ii. What is the density and distribution of households?
iii. Number of members in household?
iv. Are there some factors which are very context-region specific which influenced the success of the project – like average temperature of the region?

2. Changing Factors

(a) Individual demand patterns: What changes in these individual demands lead to changes in demand of electrification?

i. Changing aspirations of the community
ii. Change in dependency on electronic devices
iii. More income level and ability/ willingness to spend

(b) Technology

i. How do communities change in demand affect different parts of technology? (Invertor, Battery, Charge controller, Panels, Connections)
ii. How do these technologies affect the demands of the customers?
A. Smart phones intervention
B. Introduction of grid
iii. What technology adaptations do you consider as threat or boon to your service - it might be in finance, technology purely, etc.?

(OPTIONAL SECTION – NOT ALL QUESTIONS HERE ARE RELEVANT TO EVERY STAKEHOLDER)

3. Market: What type of setting in market encourage or discourage users to use or leave the technology or the given electrification project?

(a) Price mechanism changes
(b) Mode of payment changes
(c) Cashless introduction?
(d) Pay off rules

4. Institutions: Which of these institutions changes and to what extent affect the electrification project and how?

(a) Caste system
(b) Government policies at local, state or central level
(c) Introduction of new party

5. Community: How do these aspects of community effects their demand?

(a) Demographics of the users – smaller households

(b) Authority rules?

The third part of the interview is handed over to the interviewee as another set of questionnaire which they can fill up and then send back.

Other industries which were studied and not interviewed are as listed below. Discarded as they are not from India - but had some interesting models to study.

1. IEEE smart village/ sunblazer - they have a portable set up (1 kWp with 80 battery packs) which is their USP. “The generator also accepts AC backup input from a wind turbine or small diesel generator and is configurable to other load options such as schools, churches, community centers, clinics, coolers, small businesses and Internet connectivity."
2. BBoxx - They have remote access like rural spark, but added to it they have very efficient devices like a 8W TV set.
3. OEEX - open energy exchange platform [11] “OEEX creates the base for a peer-to-peer-marketplace. In the future this will be a platform that allows energy suppliers, small producers and consumers to trade electricity effortlessly among each other."

## B.4. Preliminary interviews

Before the project started officially, to understand the solar electrification field in rural India from the perspective of the operations, the author of the thesis traveled to talk to the energy providing firms and the community members in 5 different locations: Rural Spark in Delhi, Barefoot College and Manthan in Rajasthan, Piconergy in Mumbai and CEEW in Delhi, anthropologist/designer based in Delft (originally from India, working on energy access) and postdoctoral researcher based in Eindhoven (originally from India, working on energy access).

### B.4.1. Rural Spark

Rural Spark is introduced already in the section 2.2 briefly which allows sharing of batteries and devices among different solar house kits on a rent basis. The discussion with them lasted for 2 hours and was focused on understanding the flow of the products, money and services among the network of the actors. The questions and the answers with Rural Spark are shown below.

- Questions:
    1. Power specifications of the box(s)?
    2. Advertisements show ease of usage of TV, so invertor within the boxes?
    3. Or are there issues due to cloudy days/ etc.?
    4. How do you chose villages?
    5. How do you provide maintenance – or make them do it? Like cleaning of the panels?
    6. What are the paying schemes?
    7. How do you keep records of payment? Is the data accessible?
    8. Are there any patterns noticed in payments?
    9. How do you make sure the entrepreneur won’t cheat?
    10. What are the trading energy costs? What is the rate at which boxes are sold?
    11. It was mentioned it was “designed to fit the rural context” – what does that mean – how was this measured?
    12. How is the SMS based interaction working out – any problems for customized support?
    13. What are the specific maintenance issues you heard from people?
    14. How difficult was it to convince villagers? How did you do it?

[11] http://www.oeex.org/en/

15. How do you plan to upgrade from village to village?
16. The rental format that exists at the core of the innovation of Rural Spark's business model, was recently piloted with two distinct variations:
    (a) In partnership with a strategic implementation partner with well-formed local, village level networks
    (b) Individual entrepreneurs with popular private trades (shops) at block level markets, acting as distributors
    (c) Which one is better model? Why?
17. No upfront payment – how is this sustainable business model
18. How the commission to entrepreneur is decided and again – how is this sustainable?
19. Cluster choices of villages – how many people are covered by one entrepreneur?

- Answers:

  1. Product and lifecycle- 1. Simpa energy sells the product to the entrepreneur 2. 12 lamps, 1 battery, 1 solar panel, 16 charging ports 3. TVs not in picture right now costly (need convertors): community TVs may be provided in the future 4. Future demand inclusion: more cubes, more entrepreneurs, need would determine the demand (like summers need fan) 5. AC to DC convertor provided already 6. Li-Fe-Po battery – more sustainable 7. Maintenance easy because entrepreneur has to sell so they take care of it 8. NPPT 9. Manuals present for entrepreneurs to maintain 10. Cubes work for 5 years – 2 years warranty 11. Rural Spark sells the kits to the wholesale seller, they reach the village entrepreneur 12. Water and dust resistant as a product
  2. Questions
     (a) How can we find the local energy suppliers? How to choose the entrepreneur? How to profile them? How to build the database? Clusters based entrepreneurs?: Check out the report of rural Spark
     (b) Trade of energy between the clusters – right now it is more isolated. Villages with other villages? Social Economic factors versus geographical factors to choose the clusters: Check out the article on RS website.
     (c) What the entrepreneurs should charge?
  3. Modeling- methodology
     (a) Bottom up approach (growing networks again) : ABM
     (b) User demands study can be supporting to the above questions, and not the research question in itself.
  4. User demands
     (a) Online database – mostly from entrepreneurs: Check out with Marcel for the cloud platform, check out with Shahzeb to get the right data(and the units)
     (b) Check out SonMoksha's user data extraction (Micro grid)
  5. Choice of villages:
     (a) Proving sustainability of RS or solar systems is the target of RS, and thus they are targeting on the villages with at least some form of presence of national grid connection
     (b) The partners decide based on the penetration possible in the village (based on the income of the village), reach possibility, need to increase their market, velocity of their market growth. The network development is shown in the Figure B.1
  6. Grid power role:
     (a) Grid power is a risk – like penalties – entry blockade for grids high in villages
     (b) Stealing guys understand that it is risky and they are ready to switch therefore to SHS
  7. Pricing mechanism
     (a) Let the entrepreneur decide what they need to charge : "Let the markets emerge" – thus it is more sustainable

(b) RS only tells them about the break-even point and the profits.
(c) Rural people are extremely street smart and thus they know better about how to run their business
(d) Ownership model and free flowing market needs to be intact for ensuring sustainability of the business, but at the same time investors would need to know the price (A paradox).
(e) Equilibrium reaches soon (game theory): Cartel forming
(f) Field agent of the partner (simpas) records the payment by entrepreneur on the online platform
(g) Initial model plays an important part – as they get used to that system
(h) Flexibility of price mechanism is important

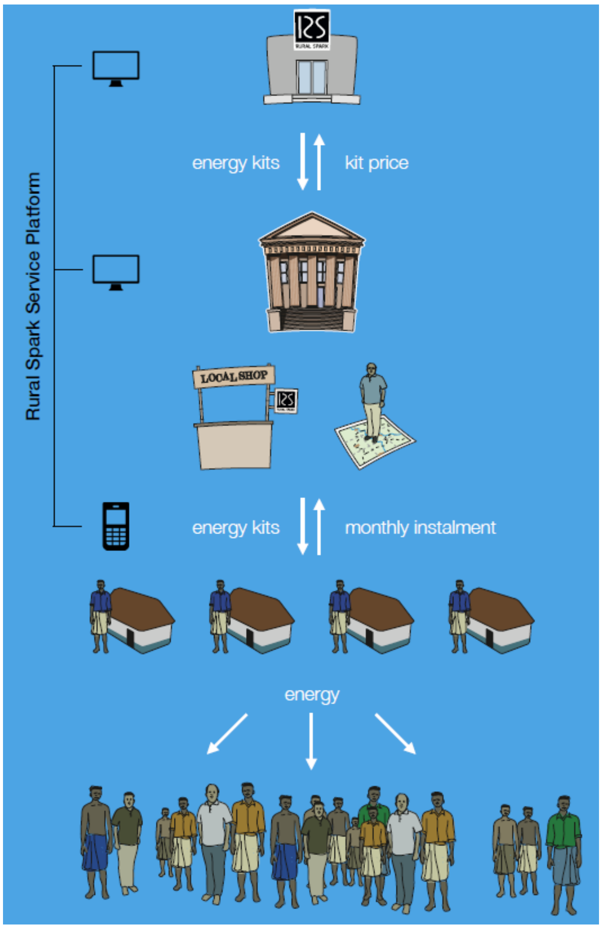



Figure B.1: Rural Spark network model of actors

## B.4.2. Barefoot College

From the two day stay at the Barefoot College campus, where 50 buildings get energy to an extent of 80% by solar electricity, the following notes were made on the whole community (the supply to other resources were also studied as this is a community with innovative approach to resource allocation and livelihood as shown in Figure B.2.) Some more images of the campus are also shown in the figures B.3a and B.3b.

- Solar electrification:
  1. Campus runs on solar
  2. 1988 -> 7 kW using solar (PV panels)
  3. 60 cents/ litre for water extraction as compared to 3 rupees/litre from government

4. Medical lighting
5. Night schools
6. 100 kW for the whole campus (5 arrays of panels) – runs complete place.
7. Payments: beneficiary + upfront + grants
8. Grid is present too in case of emergency (if battery runs out or not more than many appliances can be used)
9. Solar gave labor
10. 12v 10 W panel
11. 3 W solar lanterns
12. DC bulb to be directly connected to the panel
13. Panel and battery are directly bought components
14. Charge controllers, LEDs, and PCBs designed by the solar grandmas
15. Village community choses the ladies who are brought there for teaching
16. There are ground partners with ladies in the villages
17. 50 HH for 1 lady, and thus 100 HH village will have 2 grandmas
18. Maintenance of dry batteries, panel cleaning, cloudy weather carbonized batteries
19. Angel inclination like technical detailing to be thought of for different countries
20. Technology changes with time – CFL to LED, battery and wattage consumption changed
21. Retraining of candidates take place
22. 40, 75 W
23. MNRE (ministry of renewable energy) selects the candidate for the Indian houses and purely non-electrified houses are chosen only
24. Aluminum box, GI sheets, heat exchanger – for solar heaters
25. Technical practicalities for products like solar cookers taken into account

- Brownie points of the campus:
  1. Rain water exhausting
  2. Indigenous air conditioning (water coolant and exhaust)
  3. Cool air trapping on roofs using inverted earthen pots
  4. Social awareness programs – teaching about social norms
- Solar installations
  1. Solar cooker
  2. Battery systems
  3. Inverters
- Livelihood (puppet guys and handicraft) from Puppet shows in night schools and Cheap Sanitary pads production
- Healthcare (Dentist and general practitioner)
  1. Bare minimum products are present in the healthcare, but solar has never been the threshold for the needs to be suppressed.
  2. Solar and grid is not different as per the use, except the upfront cost.
- Water
  1. Neerjaal.org
  2. Online data feeding of the hardness of water of all the blocks nearby

3. RO plants by the government are installed (10/20 rupees per family charged)
4. Natural filtering of water like well within lake

- Radio: Transmitter at 90.4 MHz, 6 hrs for 30 km radius, Air Conditioning designed by using water coolants and exhausts and no specific Air conditioning system

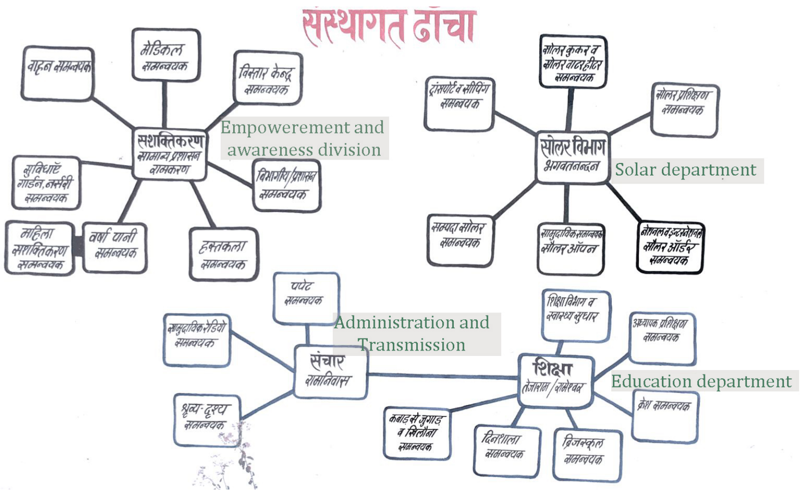



Figure B.2: Structure of the community run on solar electrification in Barefoot College

(a) Solar energy for cooking

(b) Solar electricity panels for community

Figure B.3: Barefoot College campus solar electrification

### B.4.3. Manthan

For the meeting with Manthan, the community was visited with discussions with the energy providing firm as well and the discussions are enlisted below. The communities visited were mainly nomadic or tribal and lived in very remote areas, and the implementation of solar electrification and the community's state can be seen in figures B.4a and B.4b.

- Funding of the project from the Coco cola foundation (Nandana) that is a corporate responsibility project.

- Community based management

  1. Contribution of one family to another to pay for the solar payment housing
  2. Families tend to stay together
  3. 7 people in one house on average
  4. Sleep even with the solar lamp
  5. Not ready to take grid as it would mean extra payment

6. Kerosene was used for lanterns and this was enough just for cooking.
7. "Even able to see insects"
8. 100-100 metre Dhani area
9. Maximum metre long connection
10. Charging point + 2 LEDs
11. For charging they used to give 5 rupees/charge
12. Houses made by govt. are being used for living.
13. NGOs start with installation of facilities (water, solar) not as per the requirement for the village, but as per their availability of resources.
14. Collaboration with sarpanch (govt. Presence necessary) for acts like BPL community need to be made. Else govt. would relocate these communities
15. Demands for more appliances will be increasing: need transition to grid again?
16. Sharing of water: 400/month - given by community - 10 houses.
17. Very common practice to do Len-den. Borrow lend from the houses in vicinity
18. They know all the houses and all members from the communities / Dhani

- Cooperative system:
  1. Requirement are different , leads to quarrel
  2. Women's community is a solution: Norms followed by women very well and Family needs priority. Also, no greediness and more open nature allows women to work without hidden motives Even schooling is issue issueas students are not sent to school (Teacher from other community they get higher salary) o The second community showed positivity for common grid, maintenance issues would be less as the engineer mentioned.
- Selection of the villages and miscellaneous
  1. Govt. gives some villages name as non-electrified, but even the 100% electrified villages are not in reality 100% electricity (they leave out the 25-30 HHs as they are too away from the main village: these are the focus of Manthan)
  2. Show potential use by allocating a leader (school teacher used it) -> grazers could see use when lanterns to be used in early morning when there is still dark
  3. Perception of people about community changed due to lights
  4. NREGA based labour workers in salt plant
  5. Water reservoir help in grazing, irrigation, diary setup
  6. Half way educated leaders are more of a threat than completely illiterate.
  7. Govt. Policy of cashless is not useful for the communities which are remote. They do not get daily wages.
  8. Some govt. Policies are so less thought of like container houses (in hot areas!! Duh!!) or putting handpumps in no borewell possiblity areas.
  9. Schemes don't reach the people in marginalized areas. E.g. labor card ( claims available for injuries), electrification schemes like if the Dhani is within 2 km, they can get connection of the grid.
  10. Village Panchayat is the main coordinator for these Dhanis.
  11. As these natural resources are decreasing or the institution setting (zamindari) is changing, their livelihood are ending (they were involved in security of the lands)
  12. Communities from main village not ready to be a part of them ("they are dirty, they are thrives"). Solution is to explain them that their village would only progress if everyone is included.
  13. "Bounded" IAS due to laws - how he/she will work if there is no flexibility in the laws?

14. Migratory population not ready to get involved back in the society (e.g. if a member of the family is outside working, it's difficult to get that person back to be a part of the community)
15. Jaisalmer side has tourism, so there is more attraction, so more investment, and thus a better local growth of facilities
16. Adhar card ration cards important identity to be taped for rights
17. Private organization don't provide maintenance and that's not community acceptable product (As use and throw models don't work)
18. For festival use of generators is common
19. Women are the technology graspers I'm a society - can be easily trained
20. RO power plant in the campus - 5 kW- 3-4 hrs
21. Panels maintenance weekly for dust (but in general for 35 years). Battery maintenance for 15 years
22. Involved political parties later. Not in the 1st meeting, mayb3rd and MLAs for 4th meeting (Only during the phase of approved projects and when no more discussion is needed).
23. Community involved by village meetings from start.
24. Migrant population now are no more nomads as due to lights they understand importance of having lands
25. Compactness of a village helps easier electrification.
26. First 50 houses electrified, then 25, then 10, then 1 in more remotes. Based all on the clusters of houses - 10 km radius needs 100 kW.
27. 1 time project and maintenance demands at least 50-60 houses.
28. Futuristic planning not available right now.

- Caste systems
  1. Inequality plays role in sharing of "touched" resources. Like common tap water is a problem, but common grid won't be. People don't deny to give facilities to all, they just won't accept themselves if it is consumable.
  2. The young generation doesn't accept untouchability issue, but due to the pressure of society, they tend up being a part of it (for acceptability in the family)
- Households 1st visit had 6 people in 1st house and the income was 250-300 rupees per day, with 10 days in winter off (seasonality of job is major factor for wages)
- Households 2nd visit had been using electricity for a year and had paid 1100 rupee upfront payment (total 3100 but 2000 rupees funding)
- Rebari community
  1. 3 phases installation : 2003, 2007, 2011-12
  2. Rain leads to more maintenance
  3. Duration of use/lighting usage regulations to be enforced
  4. Fuse issues in maintenance
  5. 8-10 Dhani, 30 HH/Dhani - 500 houses electrified - all under maintenance of one engineer (right now engineer being paid by the manthan, but later on the cost would be bare minimum and only for the products. )
  6. The basic livelihood of these people is pashu Palan, and farming
  7. Daily labor salt work -> 400 rupees/day (12 hrs work).
  8. In general, no issues from the families during installation
  9. Handpumps are common, but the houses have different tanks (individual)- due to location issues, money for installation issues

10. Houses are not taking grid anymore. Solar is enough for them. Power shortages in main grid and monthly cost payments is something they don't want.
11. Climate change have affected their rains and thus livelihood
12. No more need of kerosene (which took 1 day to be brought)
13. Government installed solar lamps, but they are not useful as they are not maintained
14. Community suggests other community to be electrified.

(a) Components of the solar electrification

(b) A typical solar electrified house in nomadic rural place

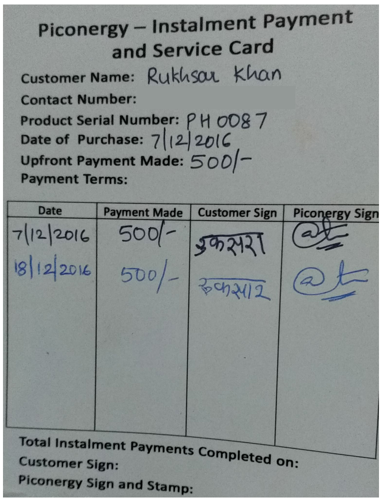
Figure B.4: Manthan provided solar electrification solutions

### B.4.4. Piconergy

Finally, not a rural but an urban poor community in the mumbai slums was visited, where electrification is done by Piconergy. The following points were noted and this discussion served as a nice benchmark to distinguish urban and rural communities when electrification is considered. The Figures B.5a and B.5b show the community and electrification state in urban poor areas in general, here case specific to Piconergy.

1. Behavioral change of the people needed to be studied: customer as well as the human behavior
   (a) People don't want to change from the kerosene to light bulb/ solar
   (b) Reasons of shabby maintenance also discourage them from changing or their own values as in the case of public toilets
   (c) Solution is to educate them – in non-technical language
   (d) Need to treat them as dignified customers
2. Families prefer these lights more than the bachelor migrants
3. Pico has minimum margin of cost here as easy payment structure is important
4. There are 3 main pillars of successful results:
   (a) Good technology
   (b) Good end user financing
   (c) Good distribution
5. Need to consider dynamics at community level -> Borivali and thane slum itself has vast distinction
6. "Poverty Penalty" is a big issue
7. Practical challenges of grid
   (a) Disputes between members would cost everyone
   (b) Modular design might help (Plug and play types)
   (c) Urban v/s rural – urban makes it easier due to cohesiveness of houses, but need to take care that customers re cohesive too

   (d) Environmental issues e.g. mangroves growth
   (e) Livelihood changes of the customers due to industrial/ Environmental change
8. Party-ruling over projects necessary but risky for innovations
9. If the institution involvement is needed, it might bring party disputes and play
10. Non-price factors like “bumping” factor like an occasion may necessitate the need and once shown the benefits, the customers won’t turn back
11. Organized crimes are an issue in slum and Involvement of sarpanch might be necessary. Also, community risks require mitigation by community
12. From Community and field visit:
   (a) 1250 fees upfront and then 250 rupees per 15 days to cover up in 3 months. This is the slowest rate at which one can pay for the whole system – 1 box, 1 solar panel, 3 lights
   (b) Stolen electricity – 500 rupees/ point of connection of device for a month
   (c) Diesel generators – 900 rupees/ month
   (d) Total 14 streets – 5 out of them connected by grid, rest stolen or by solar
   (e) Shops selling 40 W named bulbs solar ones, which are actually 20 W
   (f) Major population in the slum – migrants, low wage workers
   (g) Piconergy started using local leaders who takes care of the price installments, but they are not educated
   (h) Elections time motivate leaders to work more
   (i) 1 bulb – 16 hrs, 2 bulbs- 10-11 hours, 3 bulbs- 5-6 hrs, then it becomes dim, if already low power, then after 50% charging of the phone, it is disconnected – to use the charging only for the bulbs.


Piconergy – Instalment Payment and Service Card
Customer Name: Rukhsar Khan
Contact Number:
Product Serial Number: PH 0087
Date of Purchase: 7/12/2016
Upfront Payment Made: 500/-
Payment Terms:

| Date | Payment Made | Customer Sign | Piconergy Sign |
|---|---|---|---|
| 7/12/2016 | 500/- | रुकसरा | |
| 18/12/2016 | 500/- | रुकसार | |

Total Instalment Payments Completed on:
Customer Sign:
Piconergy Sign and Stamp:

(a) Payment installments for solar electrification

(b) A typical solar electrified house in urban poor community

Figure B.5: Piconergy provided solar electrification solutions in urban areas

### B.4.5. CEEW

For the interview with CEEW, the focus was on understanding modeling perspectives of rural electrification scenarios and the questions were mostly aimed at understanding how given two projects (SOLshare, Rural Spark) can be modeled as CPR: would help this model. The other questions were "what are different scenarios of institution settings (like governance, community setting)". Then, "Generalizing is difficult – but still the results should be relevant to more than one context in sharing perspective – how to do that?". "How to study over price mechanisms and after project support mechanisms – success measuring factors of the project". "How to consider future demands with limited technologies and incomes? As scenarios? System dynamics? What type of data is important from the community – to understand the payment - user data – models done?"

As an answer to the above discussion a framework for understanding the rural electrification factors, the following model as shown in Figure A.1 was suggested and discussions were done on the same.

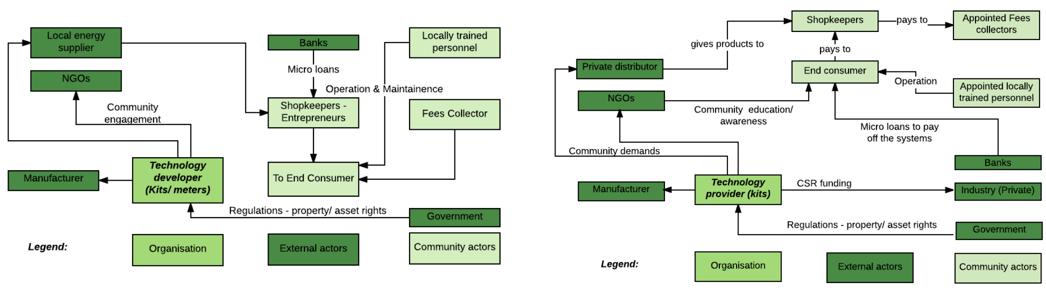
### B.4.6. Postdoctoral researcher and anthropologist

- Community should be studied socially and not geographically. No data available -> rural spark maybe, automatic bill generation, GARV app. No actual surveys by government -> they just offer position for transformers maybe
- Do not do more than 2 companies and be aware about BCs – and make it sensitive in your model -> do not aim for a very rigid model
- Pricing mechanisms to look for -
    1. Demand based priority, fixed rental (an issue as solar energy is exploited as you pay fixed thing
    2. kerosene competition is valid but not too well because economy of production of kerosene is different and Annual economy of people – like farmers – adaptable to people's economy
- Companies perspective – take private partners – where does energy project start and where does it end?

## B.5. Interview analysis

### B.5.1. Actors and Process Analysis

Additional to the given actor and process diagrams, there are more detailed description of the actor and process diagrams and they are given in the figures below. Here the "technology developer" is the energy providing company.




(a) SHS

(b) Sharing

Figure B.6: Detailed actors network in SHS and Sharing

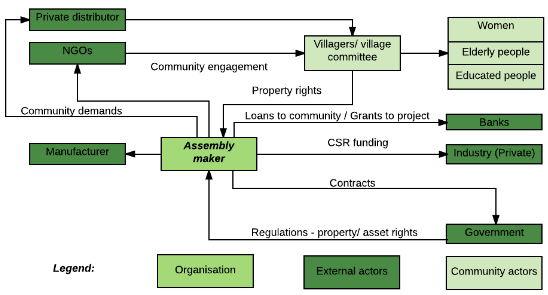



Figure B.7: Detailed actors network in Microgrid

### B.5.2. Statistical Analysis

Before developing the statistical results of the interview, it is important to preprocess the data so that the analysis through statistical tests can be conducted and it is shown in following table B.5 that which are the relevant variables and how are they converted.

Table B.5: Regression variables conversion

| ***Question*** | ***real value*** | ***numeric*** |
|---|---|---|
| | yes | 1 |
| | no | 0 |
| type of upgrading | Allows AC system; sizing anticipated with a buffer | 1 |
| | Battery upgrading/ changing | 2 |
| | Modularity: Additional components, battery and panels can be added to the SHS | 3 |
| type of community | Tribal Hamlet | 1 |
| | Protected zone hamlet | 2 |
| | urban slums | 3 |
| | rural comunities | 4 |
| employement of consumers | Farmers | 1 |
| | Forestry | 2 |
| | Daily wage (NREGA) | 3 |
| | farmers, shopkeepers, daily wage | 4 |
| Handling hierarchy/ difference in community methods | Cluster in villages | 1 |
| | NGO community awareness and involvement | 2 |
| | Different products | 3 |
| Geographical other conditions needed for technology implementation | Geographical proximity of houses | 1 |
| | Need 2g-3g connection | 2 |
| Funding of project | CSR | 1 |
| | Business profit | 2 |
| | Government contracts | 3 |
| | International organisations | 4 |
| | Banks | 5 |
| Type | Micro grid | 1 |
| | Individual SHS | 2 |
| | Community sharing | 3 |
| Prefererred model | 7 hours fan, 11 W lighting | 1 |
| | 2 bulbs, charging point | 2 |
| | Appliances and basic 1 cube kit | 3 |
| | Meter and boxes, 3 types - prosumers, consumers, producers | 4 |
| Payment | Monthly installments<br>Monthly installments or weekly<br>Monthly installments and then pay off for the kit | 1<br>2<br>3 |
| | monthly installments as per the sales | 4 |
| Risk takers | investors | 1 |
| | Household - connection is removed | 2 |
| | Government | 3 |
| | Company | 4 |

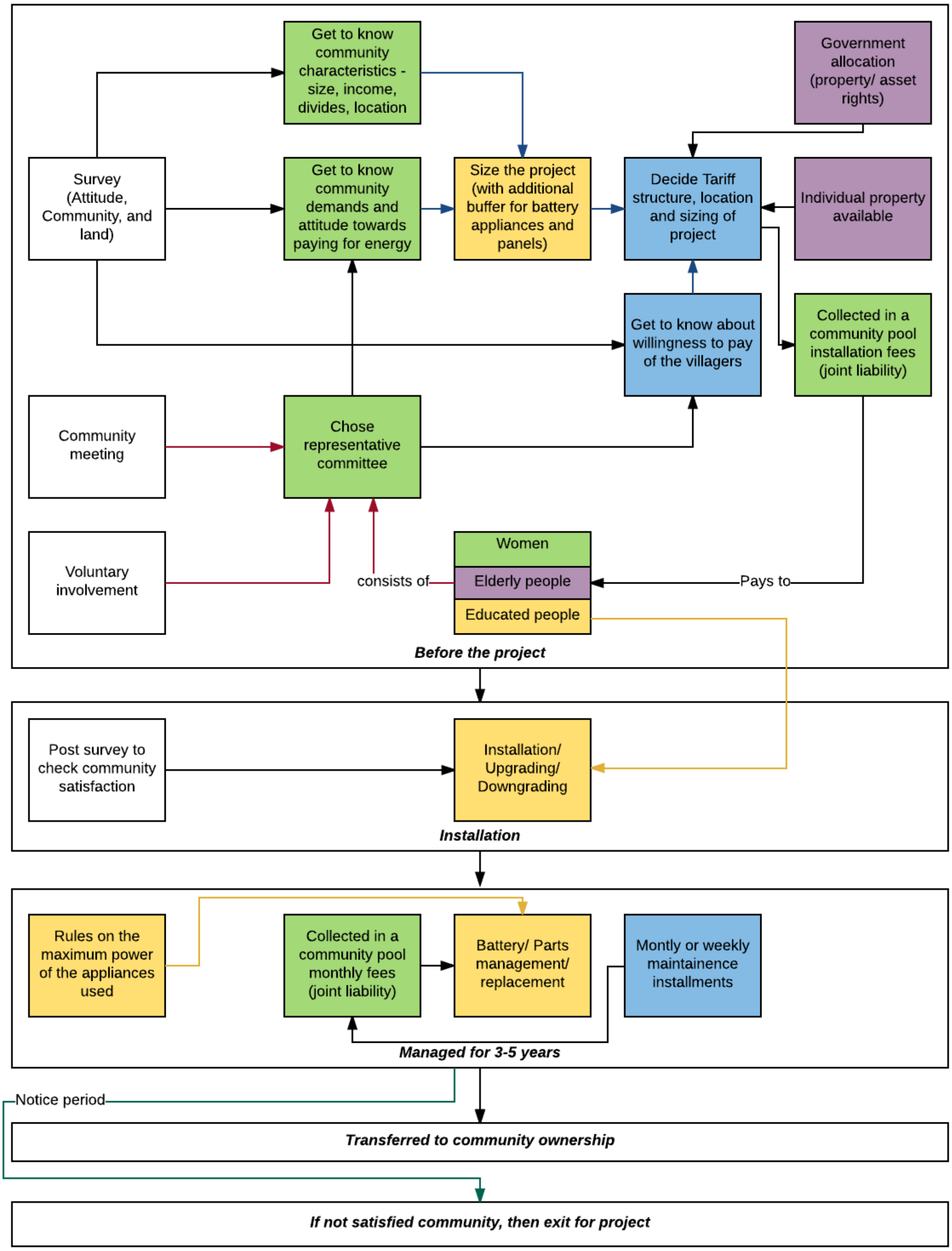



Figure B.8: Process chart for microgrid

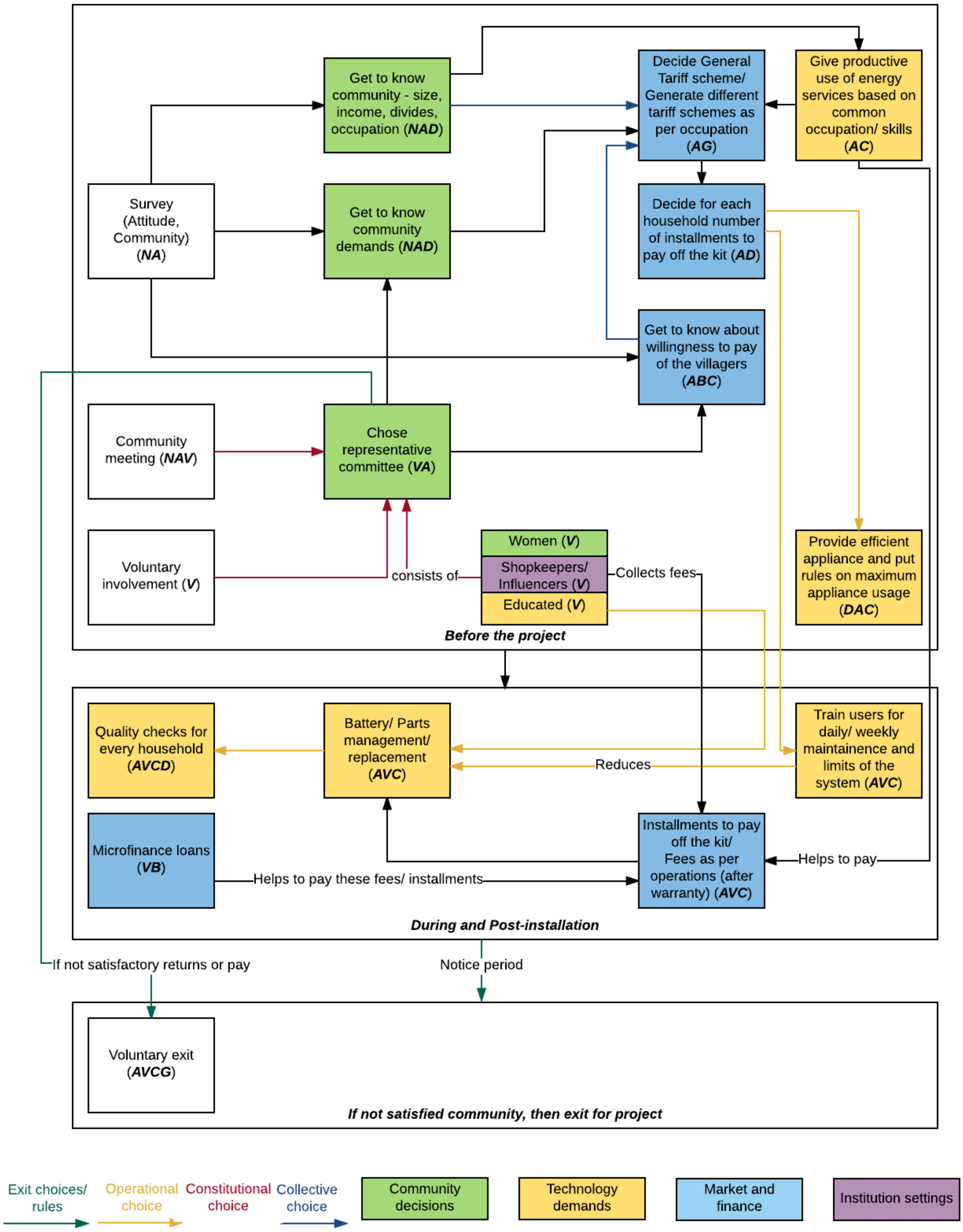



Figure B.9: Process chart for microgrid

# C Conceptualization

## C.1. Verification of assumptions

Table C.1: Verification of the assumptions from Rural Spark-1

| Assumption | T/PT/F | If False/ Partially True, what is true? |
|---|---|---|
| If someone skips the payment for a month/ installment, rural spark gives them a margin time on paying, or increases the number of installments while decreasing per installment cost. | PT | We relaxed this rule, and depending on the opinion of our local field executives we take appropriate action. We are more flexible. |
| Not only shopkeepers, but general households who are able to afford a kit becomes producer and sells cubes/ batteries. | T | |
| If everyone in the community becomes producer, Rural Spark's service remains to only operation and maintenance. | PT | But our implementing partner will take care of operations (including service) and maintenance. Though Rural Spark supports the partner with the service platform and customer care |
| Not only households, but even farmers buy this kit for their farms/ other occupations for sustaining other activities | T | However, they cannot run heavy appliances, so usage restricts itself to basic lighting rental, mobile phone charging and cube sharing |
| Kerosene is a heavy competition to persuade people to switch, and they would only switch to solar if they have children and they can afford this. | F | Electric light is cheaper. It is actually the selling point to convince people stop using kerosene. They save on kerosene spendings. |
| Every producer prefers one type of kit (for the model, there will be only type of kit – if it is highly untrue – please mention) | F | Recent findings found out that some LES want many lamps, or less lamps. Also additional products like fans and TV are demanded more and more. Kit configuration will be adjusted |
| No consumers have the income as low as to not able to buy battery/cubes as the costs of battery for one time use is low | T | |

## C.2. Physical, Collective and Constitutional Structure

The following tables C.3 to C.9 show the conceptualization for the microgrid and sharing solar electrification project models.

## C.3. Operational Structure

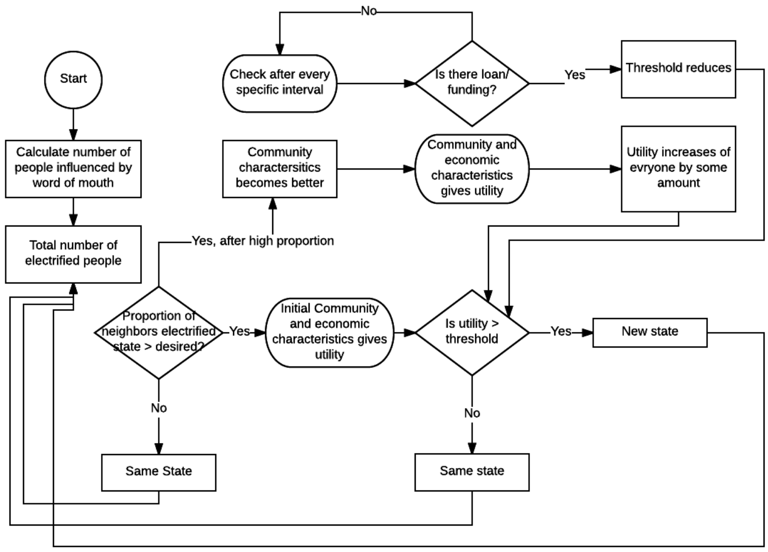



Figure C.1: Combination of different diffusion theories for an individual decision

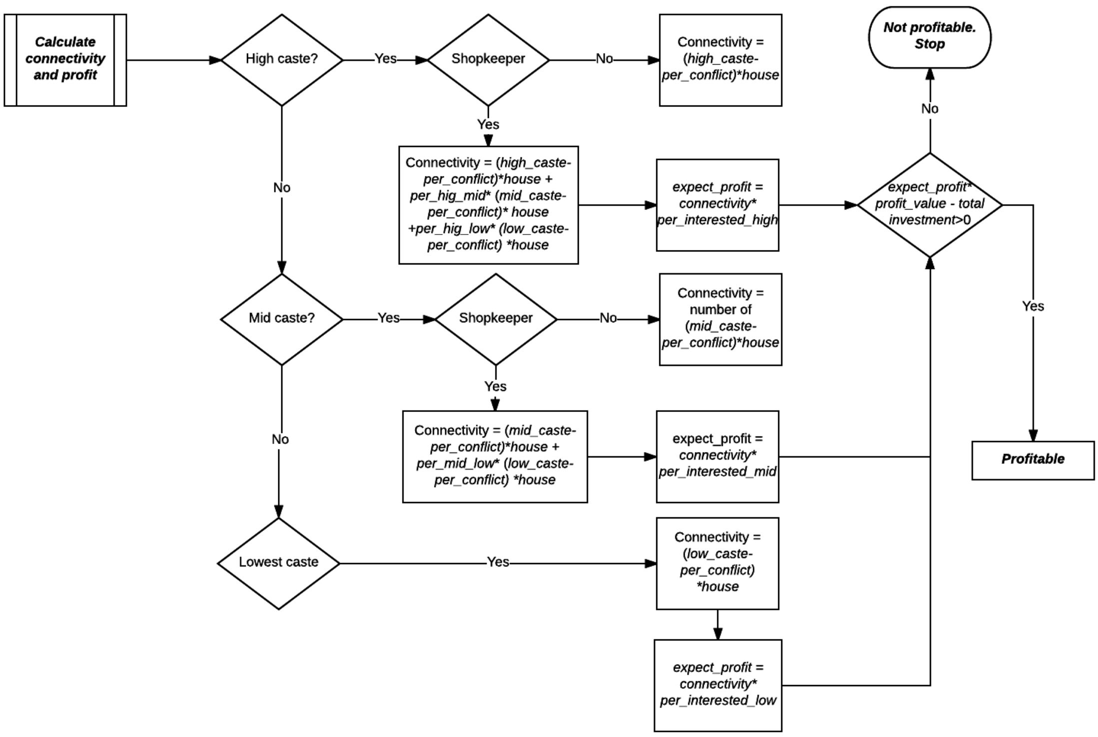



Figure C.2: Connectivity of the households

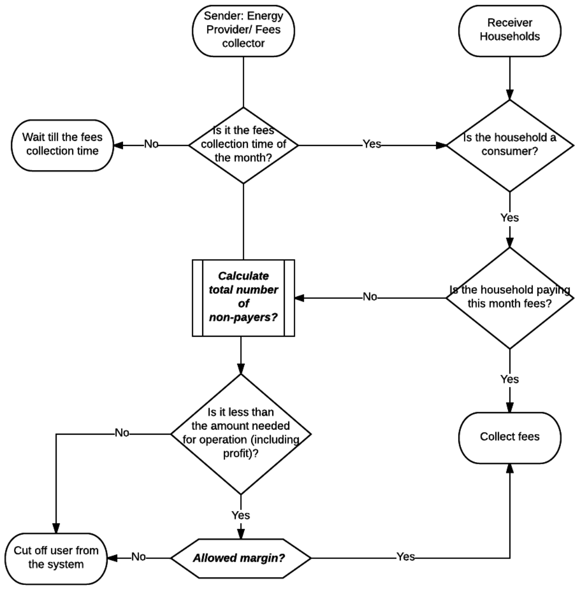



Figure C.3: Payment skipping in the Microgrids model

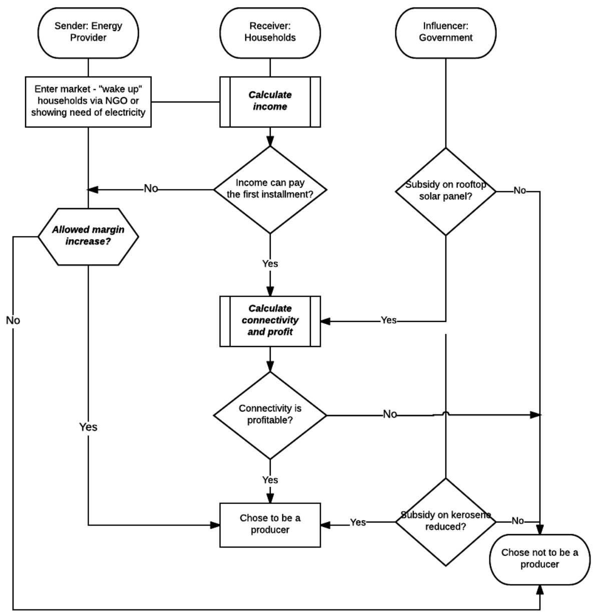



Figure C.4: Action situation to appoint producers (with the operational structure)

Table C.2: Verification of the assumptions from Rural Spark-2

| ***Assumption*** | ***T/PT/F*** | ***If False/ Partially True, what is true?*** |
|---|---|---|
| An end customer always buy the cubes/ batteries from the same shopkeepers every time until and unless there is a dispute. | T (True) | |
| An end customer always go to the closest shop in their own locality to buy the batteries (preferably from their own caste/ sect/ religion) | PT (Partially True) | I have seen a Muslim entrepreneur that rents out to Hindus. But it is true they go for the closest shop, often relatives neighbors or well-known friends |
| There might be one or more instances where the household will just buy off the whole kit for themselves and don't want to make money out of it. | F (False) | Never have seen this before. Price is too high to pay at once. |
| Any household chooses to be a producer based on their own voluntary decision (obviously, backed by their economic conditions). Basically, there Is no mechanism to "appoint" good shopkeepers by Rural Spark or LES. | PT | Though Rural Spark has an idea who is a potential LES and often target those. However, when someone who is not targeted tell us they want to become LES, we consider that and often this person becomes LES as well |
| There is a test to be passed before the rural spark kit is launched in market every time an innovation is brought into it. | T | We have quality assured checks (technical), and testing price points, selling price and usage (business model and operational) |
| The same tests apply for manufacturers' components and you check it every time before the components are bought. | T | |
| There is only one manufacturer Rural Spark buy all components from in a given time based demand. | F | We have different suppliers for batteries, electronic items, solar panels etc. |
| If the chosen manufacturer doesn't deliver the product to you on time because of tests, Rural Spark would wait and thus delay the consumer demands | T | |
| There is a limit to the maximum wattage of appliance that can be plugged in the batteries/cubes. | T | If it is true, can the specifications be given? cube give a max of 2A, so 10W. The cube will limit the current, so they can plug in whatever they want, however it will never give more than 10W |
| The registration process for selling the kits is done once with the government, and not repeated for every new community Rural Spark enters. | F | We still really really need to do this |
| There are no regulations by government on providing the technology to rural community except the testing procedure | PT | We have no testing procedure constraints from the government anyhow. So automatically we are not restricted by testing procedure |
| Village community head is involved in giving suggestions to improve service | F | Local Field Executives on the payroll of Rural Spark or our Partner are involved in this |
| There is a customer service feedback mechanism where you get general complaints from the operators / fees collector. | T | |
| If consumer damages a cube/ battery, he /she is accountable to pay the whole cost to the shopkeeper. Then the shopkeeper asks for a replacement to rural spark | PT | We follow a list of penalties that are not equal to the selling price. |

Table C.3: Roles of the agents(dark green:Sharing, light green: Micro-grid only)

| ***Role*** | ***Domain*** | ***manufacturers*** | ***energy providers*** | ***producer*** | ***consumer*** | ***governments*** | ***operator*** | ***fees collector*** | ***community head / local legislation*** |
|---|---|---|---|---|---|---|---|---|---|
| ***Objective*** | Energy | Efficient and/ or maximum production | Efficient electrification | Sustenance of electrification | | heed to community demands | | | |
| | Money | profit and/or income | profit and/or income | profit and/or income | minimum or no losses | minimum or no losses | profit and/or income | profit and/or income | |
| ***Institutions*** | | TestPass;Subsidy; NoGovernment Connection; Registration | TestPass;Subsidy; NoGovernment Connection; Registration | **Subsidy; Registration** | Politics Discrimination; Politics negativity; Intercaste; Intracaste; PayCost;LimitedUsage; PayCostDemand; ReliabilityCustomer; AgeCustomer; GenderCustomer; WageCustomer; EmployementCustomer; Subsidy | Politics discriminaiton; localpolitics discrimination | Village committee composition; Village committe eductation | Village committee composition | Village committee age; community headrole; Politics discriminaiton; local politics discrimination |
| ***Institutional capabilities*** | Energy / Policy | Make energy kits components | Assemble the energy kits components to make energy kit | **Assemble the energy kit at rooftop to make energy OR give access to LES to assemble** | | Make sure there is no discrimination based on caste, gender or religion for access to energy provision, or local regulations | replace/ upgrade the energy kit components from an old or outdated component to new component | | maximum access of energy to households |
| | | | **Distribute the energy kits to producer** | | | | | | |
| | | | **Distribute the energy to consumer, procure/buy the land from government/ consumers** | | **sell/give the land to energy provider/ government** | test the energy kits to be safe and launchable in market or not | | | |
| | Money | sell the energy kits components | buy the energy kits components | sell the batteries/ energy to a consumer | buy the batteries/ energy from a producer | subsidise the energy kits/ energy | sell service of operation | collect fees | hear everyone's need and communicate it to energy provider |
| | | | **sell the energy kit to producer** | | | **procure/ buy a land from the consumers** | subsidise the energy kits/ energy | | |
| ***Entry conditions*** | | Should be a registered manufacturer | Should be a registered energy provider | Should be a registered producer | | | Should be educated for operations tasks | | Should be >= 50, and/or well respected within the community as the chosen representative from vote |
| ***Physical components ownership*** | | | Assembled energy kit; New components of energy kit; | **Batteries of the kit** | | | | | |
| ***Information ownership*** | | | The community characteristics | The community characteristics ; the tariff regulations | | | The operation fees | The individual collection fees | The community characteristics ; the tariff regulations |

Table C.4: Institutions in the system

| ***Institution*** | ***Attributes*** | ***Deonic type*** | ***Aim*** | ***Condition*** | ***Or Else*** | ***Type*** | ***Content*** |
|---|---|---|---|---|---|---|---|
| TestPass | Energy provider; manufacturer | Obligation | Test products | All the five tests on safety, radiation, insulation, Earth test, etc. should be passed irrespective of the amount of the time the process takes | Develop the product and retest | Formal | Agents have to test their products before launching in the market |
| Registration | Energy provider; ; Producer; Manufacturer; Prosumer | Obligation | Register the agent as a reliable energy source | If the services/ products have to be sold by the agent | | Formal | Agents have to register themselve under their seller of the products / services if they are going to be selling their product/ service ahead, and if it is a new product in itself they have to be registered under government |
| **Subsidy** | Energy provider; ; Producer; Manufacturer; Consumer; Prosumer | Permission | Subsidise energy | "restricted to residential, government, social and institutional segments only and the subsidy supports total rooftop capacity" | | Formal | Agent with access to national policies for subsidy can ask for subsidy for their customers or their project |
| NoGovernment Connection | Energy provider; Producer; Manufacturer | Forbidden | Minimise or no government connection | If they fear corruption/ bureacratic image with customers | Collaborate for other advantages with government | Formal | Agents minimise government connections |
| Politics Discrimination | Communityhead; Government | Forbidden | No discrimination for energy provision or energy subsidy | The community head is not allowed any form of discrimination | Removed from the legislation position/ village committee | Formal | Agent is not allowed any form of discrimination |
| Localpolitics discrimination | | Forbidden | No discrimination for energy provision | This institution holds if the fear of being caught with discrimination is very low or non-existent or if there is no way of proof for the discrimination | The upper caste local authorities exploit the lower caste consumers by restricting policies in the favor of latter | Informal | |
| Politics negativity | Consumers | Permission | (False) Promise of central grid for votes | During election time | No central grid electricity | Informal | Agents can drop the solar electrification as the central grid energy would be brought to them |
| Intercaste | Consumers | Forbidden | Share resources | Different castes' clusters are living away from each other | Get "disowned" by caste or get into a "conflict" | Informal | Agents cannot share resources with different caste |
| Intracaste | Consumers; | Permission | | Same caste consumers are living close to each other | | Informal | Agents share resources with same caste at maximum |
| PayCost | Consumers; | Obligated | Payment of service | The cost for usage is affordable for the consumers | Cheat the payment or steal the energy - leading to cut off from the service or a heavy fine | Formal | Agents are obligated to pay a given cost towards usage of service |
| LimitedUsage | Consumers; | Forbidden | Limit the usage by the consumers to prevent overriding capacity of the system | 8 hours time limit or wattage limit | The energy provision kit fails | Formal | After a given period of time the agents cannot use the energy |
| PayCost Demand | Consumers; | Obligated | Pay the marginal increase of costs of energy with rise of demand | Till a limit of demand rise when the source of energy cannot take further load | | Informal | As the demand rises, the agents are supposed to pay extra costs |
| Reliability Customer | Consumers; | Permission | | Technology should meet minimum reliability condition | Customer leaves the service | Informal | Agent accepts technology till it is reliable and good service |
| AgeCustomer | Consumers; | Permission | | Age between 25 to 35 years AND/OR with a family | | Informal | Agents take initiative to get the energy |
| GenderCustomer | Consumers; | Permission | | If the customer is a female and a mother and is allowed by family leader (usually men) to buy the energy | Do not take the service or product of solar electrification | Informal | |
| WageCustomer | Consumers; | Permission | | Agents have at least minimum billing cycle based income to pay off the first installment | | Informal | Agents with lower income go for regular installments, and higher income go for larger installments |
| Employement Customer | Consumers; | Permission | | the agents are farmers and daily wage laborers and forestry workers | | Informal | |
| **Villagecommittee composition** | Fees collector, operator | Permission | | Must have at least one woman, educated youth, community head AND energy provider must trust the villagers to appoint a committee | no committee or re-election or re-appointments | Formal | Agents must be part of village committee which is nominated by people of the community and they have voluntary participated in election |
| **Villagecommitte education** | Operator | Obligation | | Higher education only | appoint a company personnel | Formal | Agent for operation tasks |
| community headrole | community head | Obligation | | Agent is not under the influence of caste, or gender discrimination | Agent prefers a specific section of community as per his/ her beliefs with discrimination | Formal | Agent would treat all households equally |
| **Villagecommittee age** | | Permission | | Age >= 50 | Appoint a local government personnel | Formal | Agent for final community decisions |

Table C.5: Groups of agents

| | *ProducerGroup* | *VillageCommitteeGroup* | *AllinoneProvider* | *LocalLegislation* |
|---|---|---|---|---|
| ***Case*** | Microgrid | Microgrid | Sharing energy provider without village committee | |
| ***Members*** | | Fees collector | Energy provider | community head |
| ***Producer/ Shopkeeper*** | community head | operator | government | |
| ***Energy provider*** | operator | fees collector | | |
| ***Institutions*** | TestPass;Subsidy; NoGovernmentConnection; Registration | Villagecommitteeage; communityheadrole; Politicsdiscriminaiton; localpoliticsdiscrimination | Politicsdiscriminaiton; localpoliticsdiscrimination | |
| ***Physical component access*** | Energy kits and components including new components | | | |

Table C.6: Physical Components

| **Physical component name** | ***Properties*** | ***Type(fenced/open)*** | ***Behaviors*** |
|---|---|---|---|
| *New/ Replaced Solar panel* | Power Output (W/ piece) Price (INR/piece) | Fenced | Power Output changes with age, Variable price (depends on externalities) |
| ***New/ Replaced Appliances*** | | Fenced | |
| ***New/ Replaced Batteries*** | Energy Storage (Ah/ Piece) Price (INR/piece) | Fenced | Energy Storage changes with age, Variable price (depends on externalities) |
| ***New/ Replaced Other components*** | Power unit Price (INR/piece) | Fenced | Variable price (depends on externalities) |
| ***New/ Replaced Assembled kit*** | Power Output (W/ piece) Price (INR/piece) | Fenced | |
| *Energy/ Electricity* | Voltage (V) Price(INR/piece) | Fenced | Variable price (depends on externalities) |
| *Community energy kit* | Power Output (W/ piece) Price (INR/piece) | Open | |
| *Land* | Size(meter^2) Price(INR/area) | Open | Variable price (depends on externalities) |
| ***Old/ Broken Solar panel*** | Power Output (W/ piece) Price (INR/piece) | Fenced | Power Output changes with age, Variable price (depends on externalities) |
| *Old/ Broken Appliances* | Power Consumption (kWh/ Piece) Price(INR/piece) | Fenced | |
| ***Old/ Broken Batteries*** | Energy Storage (Ah/ Piece) Price(INR/piece) | Fenced | Energy Storage changes with age, Variable price (depends on externalities) |
| ***Old/ Broken Other components*** | Power unit Price(INR/piece) | Fenced | Variable price (depends on externalities) |
| ***Old/ Broken Assembled kit*** | Power Output (W/ piece) Price(INR/piece) | Fenced | |

Table C.7: Details of the agents

| ***Agents*** | ***Manufacturers*** | ***energy providers*** | ***Households*** | ***Governments*** | ***VillageCommittee*** |
|---|---|---|---|---|---|
| ***Properties*** | Registered (y/n); Approved_test (y/n); number of components (comp_m) it makes; time for components manufacturing | Registered (y/n); Approved test(y/n); number of kits needed; number of producer; number of new producers | Specialisation (customer, producer); no. of household members; age of family head; young children in household (y/n); young mothers in household (y/n); gender of family head (m/f); income of the household; main occupation of the household; frequency of installments for paying off the kit; kit size owned; caste of the household (low/medium/ high); Cost of energy paying/ selling at; Registered (y/n); Size of shop (number of customers); Locality of shop (proximity to the customers); connectivity | level (state, national or local) | Specialisation (community head, fees collector, operator) |
| ***Personal values*** | Minimum repair of components | Minimum repair of kits | Maximum customers/ profit/ income, patriarchy in household (y/n); caste based discrimination in household (y/n) | Political discrimination and Local level discrimination is minimum, Testing regulations followed | |
| ***Information*** | Energy providers who are the customers | Local energy providers (List with their properties); Shopkeepers (List with their properties) | | Registered energy providers; Registered | Households information on their properties |
| ***Roles*** | Manufacturers | energy providers | consumer | Governments | |
| | **Operator, fees collector** | | | Operator, fees collector, community head | |
| | **producer** | | | | |
| ***Physical components*** | Components of kit | Kit | | | |
| ***Type (institutional/ external)*** | External | Institutional | Institutional | Institutional | Institutional |
| ***Intrinsic capabilities*** | | Able to understand the market potential - number of potential customers; Understand the government regulations, number of kits with every producer | Understand the capability of product - reliability within first few use and can disown before warranty time | | Understand the market potential and community regulations |
| ***Decision making behavior*** | which energy provider to chose; register with government; | which producer to chose; register with government; perform product tests | decision to buy the kit or not; decision for frequency of number of installments; decision to pay the installment fees; decision for size of kit; decision for caste based discrimination or not; decision to allow women's decision in family (if the head is man); decision of cost for selling the kit; decision to use community energy; decision to maintain the kit regularly; decision to call operator (inside or outside warranty time); decision to pay operation fees; decision to give back the kit if not satisfied; decision to replace the kit if broken/ unsatisfied; decision to upgrade the kit; decision to change the location of the kit; which customers to target; register with government; | fine for discrimination; perform tests for product | decision to change the location of the kit; decision to show dissatifaction with energy provider; decision to upgrade the kit; decision to increase, decrease or ask the operation fees; decision to increase/ decrease or ask the collection fees |

Table C.8: Social Networks and role enactment

| ***Sender Agent*** | | ***Sender role*** | ***Action situation*** | ***Final action situation*** | ***Physical components*** | ***Receiver Agent*** | | ***Receiverrole*** |
|---|---|---|---|---|---|---|---|---|
| Manufacturer | | Manufacturer | Sell new components | sell new components/kits | New Components | Energy Provider | | Energy Provider |
| **Households** | Energy Provider | Producer | sell energy or battery PC | sell energy | Energy/ New battery | Households | | Consumer |
| Manufacturer | | Manufacturer | **replace components** | | | Energy Provider | | Energy Provider |
| **Energy Provider** | | Energy Provider | | replace components/ kits | Replaced/New, Old/Broken components/kits | village committee | | Operator |
| **Village Committee** | Village committee | Operator | replace components/kit EO | | | Shopkeeper | Energy Provider | Producer |
| Government | | Government | test product | test product | New Assembled kit | Energy Provider | | Energy Provider |
| Manufacturer | | Manufacturer | Market fluctuation | Market fluctuation | X | | | Energy Provider |
| Energy Provider | | | Appoint/ Involve EO | | X | | | Operator |
| Energy Provider | | Energy Provider | Appoint/ Involve EF | Appoint committee | X | village committee | | Fees Collector |
| Households | | Consumer | Appoint/ Involve CCH | | X | | | Community head |
| | | | Regulates | Regulation | X | | | |
| Government | | Government | Subsidise GE | Subsidise | X | Energy Provider | | Energy Provider |
| | | | Subsidise GC | | X | Households | | Consumer |
| | Village Committee | Community head | **Handovers/ Sells land** | **Handover** | Land | | Government | Government |
| | Government | | | | | | Energy Provider | Energy Provider |
| | | | | | X | Manufacturer | | Manufacturer |
| Government | | Government | Registers | | X | Energy Provider | | Energy Provider |
| Energy Provider | | Energy Provider | | | X | **Households** | Energy Provider | Producer |

Table C.9: Action situations

| ***Action Situation*** | ***Actions*** | ***Institutions*** |
|---|---|---|
| sell new components | Become customer, Buy component, Check component | TestPass; Registration; Subsidy |
| **Appoint producers** | Check proximity, density, connectivity, Appoint | Registration; Subsidy; Intercaste; Intracaste; EmployementCustomer; KeroseneCompetition |
| Sell energy or battery | Become customer, Sell energy, Decide cost, Negotiate cost | Intercaste; Intracaste; PayCost; LimitedUsage; PayCostDemand; ReliabilityCustomer; AgeCustomer; GenderCustomer; |
| Replace components/ kit | Upgrade, Maintain, Check, Replace, Leave | |
| Cost Fluctuation | Fluctuate components rates randomly | |
| Increase demand | Pay as per the increase in demand | Intercaste; Intracaste; PayCost; LimitedUsage; PayCostDemand; ReliabilityCustomer; AgeCustomer; GenderCustomer; WageCustomer; EmployementCustomer; PayIncreasedemand |
| **Appoint committee** | Check eligibility, Appoint | Villagecommitteecomposition; Villagecommitteeductation; communityheadrole; Villagecommitteeage |
| **Complaints/ issues** | count number of complaints, elections | |
| Regulation | check discrimination - if yes, remove the head, else continue | PoliticsDiscrimination; Localpolitics discrimination; Politicsnegativity; communityheadrole; |
| Subsidise | Check need, ' subsidise as need | NoGovernmentConnection;Politics Discrimination; Politics negativity |
| **Handover** | Handover | |
| Register | Register; Add to list | Registration; Localpolitics discrimination; Politicsnegativity |

Table C.10: Variables used in the model

| ***Variable*** | ***Description*** | ***Global/local*** | ***Agent property*** | ***Information with*** | ***Value*** |
|---|---|---|---|---|---|
| comp_m | no. of components with manufacturers | Local | Manufacturer | | |
| kit_e | n. of kits asked by energy provider | Local | Energy Provider | | |
| kit_s | no. of kits with producer | Local | Household | Energy Provider, Household | |
| comp_kit | no. of components per kit | Global | X | X | 5 |
| pro | no. of producer | Local | Energy Provider | | |
| new_pro | no. of new producers | Local | | | |
| man | no. of manufacturers | Global | X | X | 5 |
| cust | no. of customers | Local | Energy Provider, Producer | Producer | |
| new_cust | no. of new customers | Local | | | |
| time_test_comp | time for testing of components | Global | Government | X | 20 days |
| time_test_kit | time for testing of kits | Global | Government | X | 30 days |
| time_tick | time of every tick | Global | X | X | 8 hours |
| time_comp_m | time for manufacturing each component | Local | Energy Provider, Manufacturer | | |
| house | no. of households | Global | X | X | 1000 |
| per_conflict | percentage of conflicts | Global | X | X | 1 |
| per_shops | percentage of shops per caste | Global | X | X | 3 |
| low_caste | percentage of people in low caste | Global | X | X | 30 |
| mid_caste | percentage of people in middle caste | Global | X | X | 40 |
| high_caste | percentage of people in highest caste | Global | X | X | 30 |
| per_hig_mid | percentage of population in middle caste connected to shop of high caste | Global | X | X | 5 |
| per_high_low | percentage of population in low caste connected to shop of middle caste | Global | X | X | 1 |
| per_mid_low | percentage of population in low caste connected to shop of middle caste | Global | X | X | 3 |
| high_BF | percentage of big farmers in high caste | Global | X | X | 90 |
| high_SF | percentage of small farmers and daily wage laborers in high caste | Global | X | X | 7 |
| high_For | percentage of forestry workers in high caste | Global | X | X | 0 |
| mid_BF | percentage of big farmers in mid caste | Global | X | X | 22 |
| mid_SF | percentage of small farmers and daily wage laborers in mid caste | Global | X | X | 75 |
| mid_For | percentage of forestry workers in mid caste | Global | X | X | 0 |
| low_BF | percentage of big farmers in low caste | Global | X | X | 2 |
| low_SF | percentage of small farmers and daily wage laborers in low caste | Global | X | X | 85 |
| low_For | percentage of forestry workers in low caste | Global | X | X | 10 |
| connectivity | total number of people the household is connected to | Local | Household | Household, energy provider | |
| expect_profit | expected profit by the household to become a producer | Local | X | X | |
| per_interested_high, mid, low | percentage interested people in product in high, middle, low caste | Global | X | X | 20, 40, 60 |
| profit_value | profit value per billing cycle | Household | Household | Household, energy provider | |
| total investment | total investment per billing cycle | Local | | | |
| household | type of household - producer or not a producer | Local | | | |
| Patriarchy | patriarchy present orabsent in family | Local | | Household | |

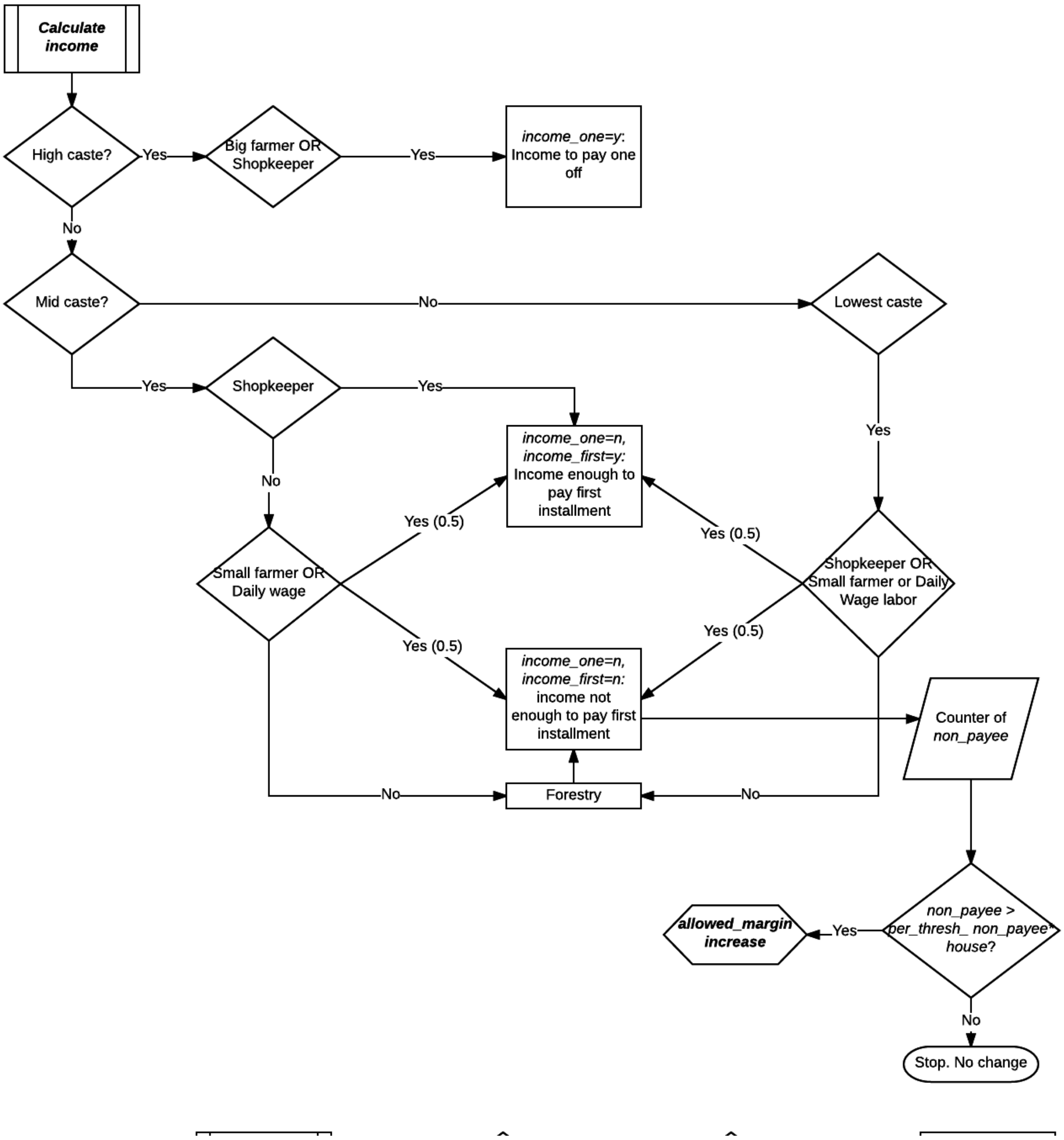



Figure C.5: Calculation of income

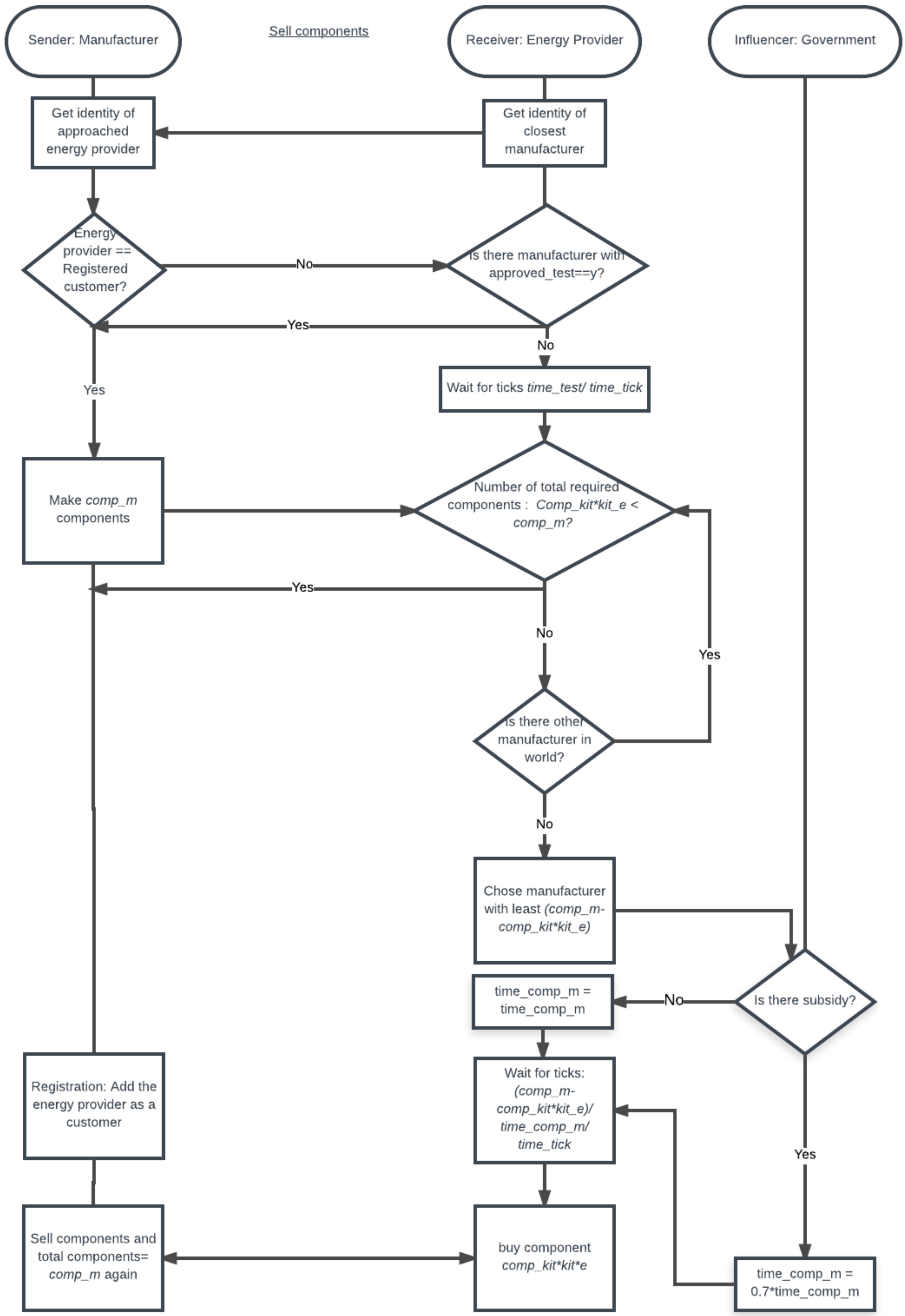



Figure C.6: Action sequence for selling components

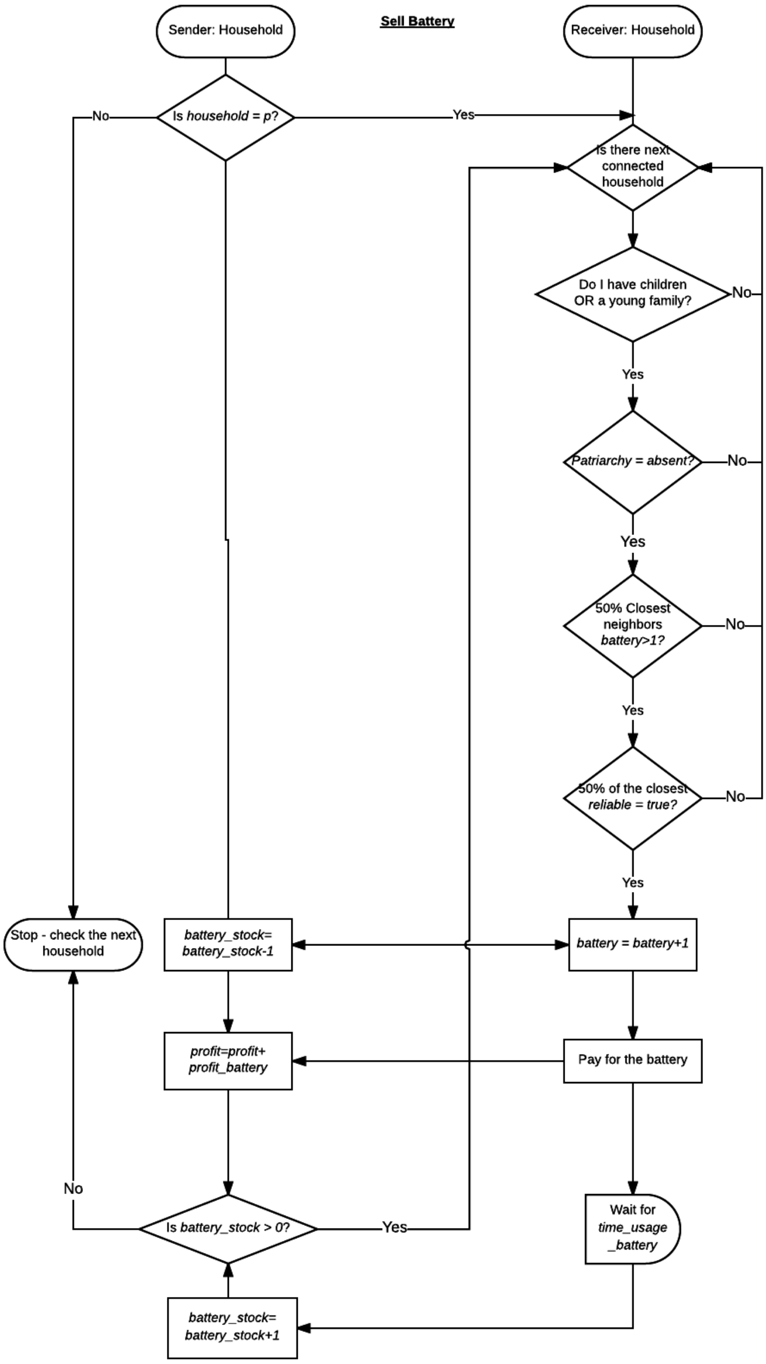



Figure C.7: Action sequence to sell battery

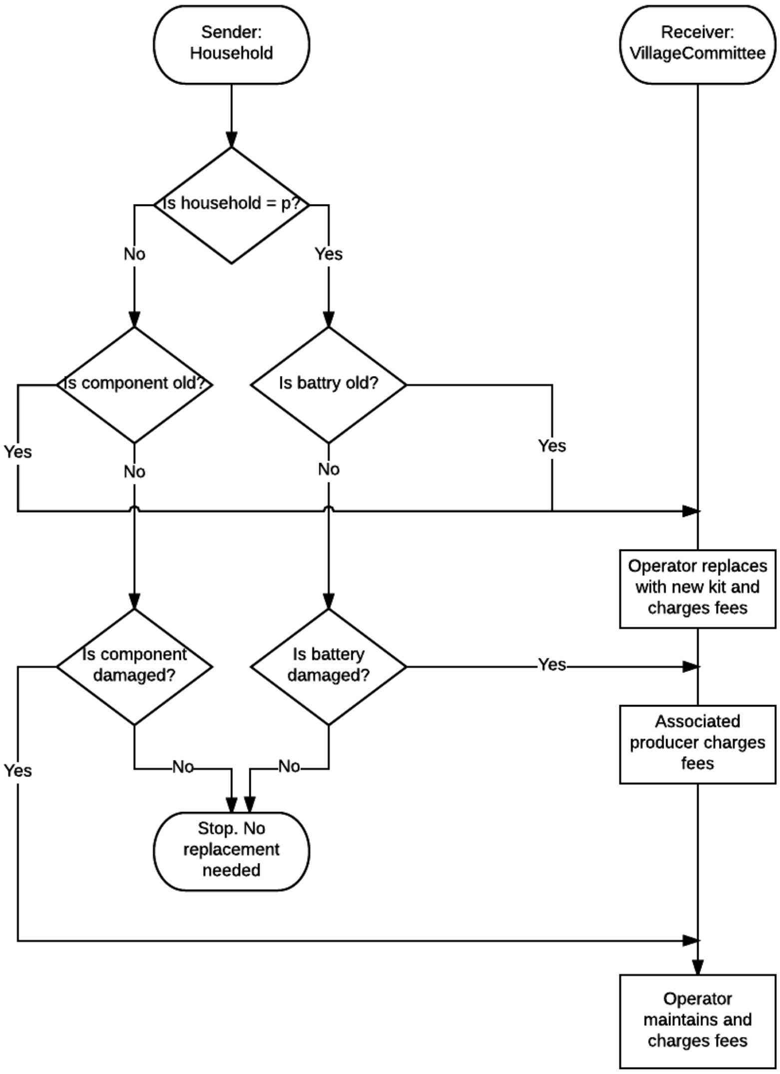



Figure C.8: Action sequence to replace battery

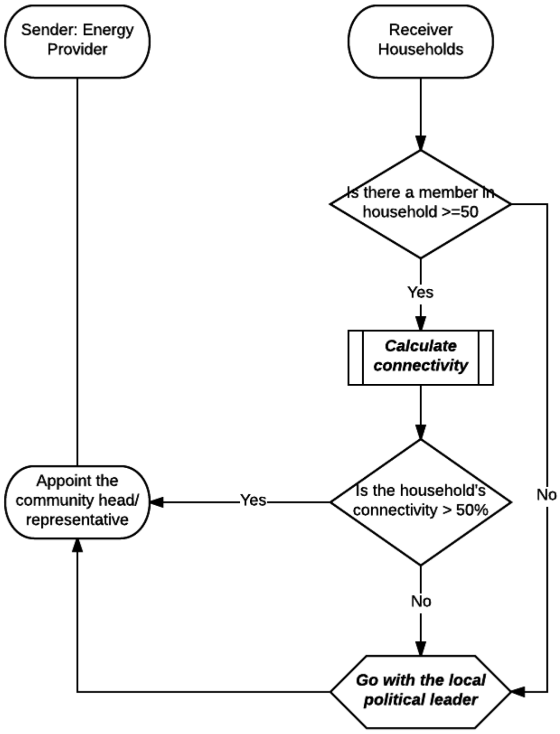



Figure C.9: Appointment of a community head for the village committee

# D Simulations

## D.1. Data Sampling

```
library(lhs)

X<-randomLHS(200,19)
plot(X)
Y <- matrix(0, nrow=200, ncol=19)
rdu<-function(n,k) sample(1:k,n,replace=T)

Y[,1]<- runif(X[,1],min = 10,max = 1000) #population
Y[,2]<- rdu(200,4) # demand of the user
Y[,3]<- rdu(200,2) # subsidy present or not
Y[,4]<- runif(X[,4],min = 1,max = 5) #high caste to mid caste connection
Y[,5]<- runif(X[,5],min = 1,max = 5) #high caste to low caste
Y[,6]<- runif(X[,6],min = 1,max = 5) #mid caste connected to low caste
Y[,7]<- runif(X[,7],min = 0,max = 3) #shopkeeper in low caste
Y[,8]<- runif(X[,8],min = 2,max = 5) #shopkeeper in mid caste
Y[,9]<- runif(X[,9],min = 2,max = 5) #shopkeeper in high caste
Y[,10]<- runif(X[,10],min = 1,max = 5) #BF in low caste
Y[,11]<- runif(X[,11],min = 15,max = 25) #BF in mid caste
Y[,12]<- runif(X[,12],min = 70,max = 90) #BF in high caste
Y[,13]<- runif(X[,13],min = 70,max = 90) #SF in low caste
Y[,14]<- runif(X[,14],min = 45,max = 65) #SF in mid caste
Y[,15]<- runif(X[,15],min = 1,max = 5) #SF in high caste
Y[,16]<- runif(X[,16],min = 5,max = 20) #Early Adopters in low caste
Y[,17]<- runif(X[,17],min = 5,max = 30) #Early Adopters in mid caste
Y[,18]<- runif(X[,18],min = 5,max = 40) #Early Adopters in high caste
Y[,19]<- rdu(200,4) #Number of manufacturers
population<-Y[,1]
EarlyadoptersLowCaste<-Y[,16]
connectivityHightoMid<-Y[,5]
write.csv2(Y,"finalexperiments")
plot(Y)
plot(population,EarlyadoptersLowCaste)
hist(connectivityHightoMid)
```

## D.2. Statistical Results

The table below shows the comparative results of the different types of projects.

Table D.1: Statistical comparison of the microgrid, sharing and hybrid projects' success parameters

| | Subsidy | Type | N | Mean | Std. Deviation | Std. error | F | Sig |
|---|---|---|---|---|---|---|---|---|
| Consumers | TRUE | **Microgrid** | 300 | 144.903 | 80.295 | 4.636 | | |
| | | Sharing | 300 | 38.473 | 3.130 | 0.181 | 222.150 | 0.000 |
| | FALSE | **Microgrid** | 300 | 144.903 | 80.295 | 4.636 | | |
| | | Sharing | 300 | 37.823 | 4.336 | 0.250 | 216.494 | 0.000 |
| | TRUE | **Hybrid** | 300 | 188.103 | 6.780 | 0.391 | | |
| | | Sharing | 300 | 38.473 | 3.130 | 0.181 | 115.353 | 0.000 |
| | FALSE | **Hybrid** | 300 | 193.660 | 5.800 | 0.335 | | |
| | | Sharing | 300 | 37.823 | 4.336 | 0.250 | 33.307 | 0.000 |
| | TRUE | Microgrid | 300 | 144.903 | 80.295 | 4.636 | | |
| | | **Hybrid** | 300 | 188.103 | 6.780 | 0.391 | 197.977 | 0.000 |
| | FALSE | Microgrid | 300 | 144.903 | 80.295 | 4.636 | | |
| | | **Hybrid** | 300 | 193.660 | 5.800 | 0.335 | 203.811 | 0.000 |
| Producers | TRUE | **Hybrid** | 300 | 229.393 | 7.719 | 0.446 | | |
| | | Sharing | 300 | 216.107 | 11.541 | 0.666 | 123.232 | 0.000 |
| | FALSE | **Hybrid** | 300 | 240.317 | 7.032 | 0.406 | | |
| | | Sharing | 300 | 215.193 | 18.083 | 1.044 | 66.664 | 0.000 |
| Profit | TRUE | Microgrid | 300 | 118.380 | 188.789 | 10.900 | | |
| | | **Hybrid** | 300 | 793.105 | 244.660 | 14.125 | 0.707 | 0.401 |
| | FALSE | Microgrid | 300 | 117.495 | 155.391 | 8.971 | | |
| | | **Hybrid** | 300 | 889.025 | 241.835 | 13.962 | 0.376 | 0.540 |
| Afford-kits | TRUE | Microgrid | 300 | -521534.505 | 289019.786 | 16686.565 | | |
| | | **Sharing** | 300 | -2208190.495 | 105419.341 | 6086.388 | 73.489 | 0.000 |
| | FALSE | Microgrid | 300 | -2143850.574 | 114514.604 | 6611.504 | | |
| | | **Sharing** | 300 | -2132526.896 | 179219.865 | 10347.264 | 1.151 | 0.284 |
| | TRUE | Hybrid | 300 | -521533.620 | 288980.371 | 16684.290 | | |
| | | **Sharing** | 300 | -2208190.495 | 105419.341 | 6086.388 | 73.482 | 0.000 |
| | FALSE | Hybrid | 300 | -2314483.639 | 93686.277 | 5408.980 | | |
| | | **Sharing** | 300 | -2132526.896 | 179219.865 | 10347.264 | 17.700 | 0.000 |
| | TRUE | Microgrid | 300 | -521534.505 | 289019.786 | 16686.565 | | |
| | | **Hybrid** | 300 | -521533.620 | 288980.371 | 16684.290 | 0.000 | 0.999 |
| | FALSE | Microgrid | 300 | -2143850.574 | 114514.604 | 6611.504 | | |
| | | **Hybrid** | 300 | -2314483.639 | 93686.277 | 5408.980 | 6.044 | 0.014 |
| Access-kits | TRUE | Microgrid | 300 | 144.903 | 80.295 | 4.636 | | |
| | | **Sharing** | 300 | 417.497 | 12.689 | 0.733 | 165.029 | 0.000 |
| | FALSE | Microgrid | 300 | 254.580 | 9.392 | 0.542 | | |
| | | **Sharing** | 300 | 253.017 | 15.299 | 0.883 | 2.427 | 0.120 |
| | TRUE | Hybrid | 300 | 144.903 | 80.295 | 4.636 | | |
| | | **Sharing** | 300 | 417.497 | 12.689 | 0.733 | 165.029 | 0.000 |
| | FALSE | **Hybrid** | 300 | 433.977 | 9.751 | 0.563 | | |
| | | Sharing | 300 | 253.017 | 15.299 | 0.883 | 8.511 | 0.004 |
| | TRUE | Microgrid | 300 | 144.903 | 80.295 | 4.636 | | |
| | | **Hybrid** | 300 | 144.903 | 80.295 | 4.636 | 0.000 | 1.000 |
| | FALSE | Microgrid | 300 | 254.580 | 9.392 | 0.542 | | |
| | | **Hybrid** | 300 | 433.977 | 9.751 | 0.563 | 34.752 | 0.000 |

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