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Analysing Eco-Innovations: Applying and Extending the National Innovation System Framework for Specific Instances

Deepika Chandra Verma
Doctoral Student, Indian Institute of Management Calcutta
D. H. Road, Joka, P.O. Kolkata 700 104

Runa Sarkar
Professor, Indian Institute of Management Calcutta
D. H. Road, Joka, P.O. Kolkata 700 104
http://facultylive.iimcal.ac.in/workingpapers

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The National Innovation System (NIS) has been widely used to explain the role of institutions in the emergence and diffusion of new innovations. This paper contends that, when applied to specific innovation applications, the extant NIS scholarship is limited in explaining how the innovation is adopted, diffused and commercialised. With the objective of developing a more micro level understanding of the internal workings of eco-innovations, this paper proposes to adapt the NIS using the Institutional Analysis and Development framework (IAD) and a co-evolutionary approach. This framework combines the insights from NIS, co-evolution and IAD with a multilevel perspective (MLP) to explain how networks of institutions facilitate or impede the development of specific eco-innovations. This is then used to analyse the successful commercialisation of an eco-innovation, related to the generation and distribution of electricity, in rural India.

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Keywords- Co-evolutionary approach, eco-innovations, IAD, NIS, MLP

Track- Innovation

1. Introduction

This paper aims to study how institutions and their networks can facilitate or impede innovation activity at a micro-level, by developing a theoretical framework for analysing eco-innovations. Using elements of the NIS, MLP, co-evolutionary theory and the IAD, an analytical framework is arrived at, which is then applied to a specific case of commercialisation of an eco-innovation by a power generating and distributing company in rural India.

Innovations have been studied using a systemic approach since the last three decades (Watkins et al, 2015). A system consists of components which interact with each other to fulfil a certain function (Edquist, 2005). The systemic approach of innovations talks of *interconnecting network of institutions* [emphasis added] that *produce, modify and consume technological innovations* [emphasis added] (Freeman, 1995). The National Innovation System (NIS) studies the nation's innovation creation and sustainability capacity as well as indicates the crevices for improvement thereon (Groenewegen and Van der Steen, 2006). A systemic approach can be used to study eco-innovations as well (Rennings, 2000; Andersen, 2004). However, trying to extend the NIS framework to the study of specific eco-innovations can be problematic.

Eco-innovations are that sub-set of innovations, technical or otherwise, which aim at improvement in both environmental performance and economic wellbeing. Eco-innovations need not be segregated by regional, sectoral or technological divides. The approach of the NIS is to study the what, where, why, when and who of innovation, but it may not address the how of innovation.

Another macro level framework closely associated with sectoral and technological innovation systems is the multilevel perspective (MLP). However, this is also difficult to apply to stand-alone eco-innovations that are still evolving because the framework looks at an ex-post analysis of innovations with a long history. Eco-innovations in developing countries are immature, with neither a long history nor any large scale macro data. Further, it leads to benchmarking the ideal drivers and structures for eco-innovations from the experience of developed countries (Groenewegen and Van der Steen, 2006), instead of concentrating on what is happening on the ground.

Nevertheless, NIS and its different versions are important (Edquist, 2005) and can be adapted to provide a coherent analytical framework for studying eco-innovations (Andersen, 2004). A micro level rendering of the NIS and MLP frameworks which engages with the co-evolutionary approach could help understand discrete eco-innovations. Further, Ostrom's Institutional Analysis and Development framework (IAD) can be blended with these approaches to develop a framework that can be applied to understand the specific stages of diffusion, adoption and commercialisation of an eco-innovation.

This paper is organised as follows. Section two reviews the literature on NIS, MLP, co-evolution as applied to these and the IAD. This is followed by a description of the proposed framework and its constituents for understanding the roles of different agents and institutions in the development of an eco-innovation, through the stages of its diffusion, adoption and commercialisation. In order to demonstrate the applicability of this framework, it is applied to a specific case of commercialisation, which is described in section 4. In section five, the process of commercialization of the eco-innovation is analysed. Section six concludes, with a discussion on the possible contributions of this paper to the eco-innovation literature.

2. Literature Review

2.1. Versions of NIS and Related Co-evolutionary Engagement

Watkins et al. (2015) classify the NIS research into three shifts - early approaches, NIS dynamics and internationalisation of NIS. Evolutionary approaches like co-evolution, developed to open the black box of radical changes (Rennings, 2000), form a part of the second shift of the NIS, described as an analytical framework for analysis of the co-evolution of technology, institutions and organizations (Andersen, 2004). A co-evolutionary approach aims at studying the evolutionary process based on reciprocal responses and their feedback mechanisms between evolving systems and related sub-systems (Norgaard, 1984). Lundvall (2007) recognises the shift from linear to interactive theorisation of innovation as a positive development in innovation system research.

Adding a co-evolutionary focus to Watkins et al.s' classification, we can arrive at three stages of co-evolutionary NIS, namely, traditional (innovation system at the national level), intensive (innovation systems focusing on particular aspect of innovation systems- namely, regional innovation systems or RIS, social innovation systems or SIS and technical innovation systems or TIS) and interactive stage (co-evolutionary engagement of two sub-systems)[1]. Figure 1 shows the three stages. The trajectory of research has moved towards increasing co-evolutionary theoretical depth and a more micro approach towards analysing innovations. The black region is an unexplored zone thus far. This review focuses on examining the key characteristics of each stage in relation to its co-evolutionary complexity.

Please Insert Figure 1 about here

The traditional stage of NIS was headed by forerunners such as Freeman (2002), Lundvall (2007) and Nelson (2002). Despite certain differences in the extent of theoretical focus (Edquist, 2005), this stage was characterised by its emphasis on institutional structure, collective learning, path dependency (Watkins et al., 2015) and historical analysis (Freeman, 2002; Nelson, 2002; Lundvall, 2007). From the co-evolutionary viewpoint, the theoretical engagement was limited to classifying technological change as *variation* [emphasis added] that succeeded or failed due to the *selection* [emphasis added] criteria of the environment (Rennings, 2000). The understanding of the formation of a stable, supportive and competitive environment through interactions among institutions was largely absent in this stage (Watkins et al., 2015). Much of this was probably due to the macro level focus and the dominant emphasis on university-industry linkages and collective collaboration and feedback between firms (Ibid). The scepticism about the macro approach of NIS and its apolitical nature inspired the second stage, namely, the intensive stage.

The intensive stage emphasised narrower systems for analysis, such as technological (Carlsson and Stankiewicz, 1995 as cited in Watkins et al., 2015), sectoral (Malerba, 2002, 2005) and regional (Cooke et al., 1997; Cooke 2001; Asheim, 2007; Asheim and Gertler, 2005) innovation systems. The analysis of institutions in this stage included knowledge building and its transfer and exchange. Other areas of focus were processes, relations and dynamics between actors and co-evolution of the system (Geels, 2006; Watkins et al., 2015). The context of these studies shifted from OECD to emerging countries (Watkins et al., 2015) as well. At this stage, there was evidence of some co-evolutionary theoretical engagement, but the analysis was restricted to remain within geographical boundaries.

Figure 2 is a schematic of the increasing fusion of NIS models with the co-evolutionary approach. Figure 2(a) and 2(b) show little or no engagement of NIS with co-evolution in the

[1] Please note that the first and second stage are identical to Watkins et al.'s (2015) first two shifts in the NIS

first two stages of NIS. These two stages of NIS result in a framework where government and firms negotiate policies to influence the innovation process. Research institutes (government or privately owned) in addition to in-house corporate research departments innovate and financial institutions like venture capitalists or finance departments of large corporates facilitate the innovation process (Lerner, 2012; Watkins et al., 2015). The grand objective of NIS was to make the list of relevant institutions, enablers and disablers (Edquist, 2005), as comprehensive as possible so that ideal conditions for the conception, production and consumption of innovations could be introduced in an economy (Groenewgen and Van der Steen, 2006). Thus, it had a normative focus. This fascination of NIS scholars for such 'ideal conditions' made such frameworks theoretically weak (Ibid). The heterogeneous elements used to define and describe the innovation systems failed to establish the inter-linkages, adding to the weakness of the NIS (Geels, 2004). The need for better conceptualisation of the role of institutions in innovations and explanation of the emergence of new innovation systems was evident (Ibid). In addition, there was little attention to the demand side (an exception is Faber and Hoppe, 2013), leading to the third stage of NIS, the interactive stage.

Please Insert Figure 2 about here

In the third phase, the focus of research was on developing an understanding of how innovations took place. This was done through a deeper co-evolutionary engagement of two sub-systems- namely social and technical innovation systems (Geels, 2004, 2006). The micro level components were further extended to study the technological transition process using MLP (Geels, 2002, 2006), by explaining that "the different structural levels are continuously reproduced and enacted by actors in concrete" interactions (Geels, 2011). The changes at landscape level create pressure on the regime and its destabilisation. The regime's destabilisation creates windows of opportunity for niche innovations. Learning processes, support from networks built over time, price and performance improvements help niche innovations become disruptive innovations (Geels, 2007).

Figure 2(c) shows a much greater co-evolutionary engagement in the third stage with its ability to throw light into how innovations occur. However, a complete merger of NIS models with co-evolutionary approach (as figure 2(d) projects) is not seen in the literature yet.

Table 1 summarises the developments in the NIS literature as it has evolved, in the context of studying how institutions and their networks can facilitate or impede innovation activity at a micro-level.

Please Insert Table 1 about here

2.2. Multilevel Perspective

The MLP is a middle-range theory (Geels, 2011). A middle range theory consolidates "segregated hypotheses" and empirics (Merton, 1957 as cited in Boudon, 1991, p.520). MLP provides a conceptual framework that provides a plot to study transitions through heuristic devices (Geels, 2011). The central aim of MLP is "to identify principles that enable an integrated level of understanding of phenomena that unfolds across levels" (Kozlowski and Klein, 2000). It is centred on the axiom that systems are multilevel (Kozlowski and Klein, 2000). Multi-level frameworks refer to all such frameworks that have more than one level of conceptualization and analysis. Multi-level models address bottom-up emergence i.e., they describe phenomena that have theoretical origin at a lower level but have emergent properties at higher levels. The goal of MLP can be realized only with adoption of interdisciplinary approaches to research (Rousseau, 1985). In the innovation literature, MLP has been used by several scholars, as discussed in Geels (2002, 2005, 2006).

Geels's (2005) MLP of socio-technologies involves three analytical levels to understand system innovations. The micro-level is composed of technological niches, where learning and social networking take place. The meso-level is composed of socio-technical regimes, which are relatively stable configurations of institutions, techniques, artefacts that determine development and use of technologies (Smith et al., 2005). The macro-level is composed of the sociotechnical landscape (aspects of the wider exogenous environment). The dynamics at multiple levels brings about system innovations through several phases of transition- technological niche to market niche to disruptive innovation competing and replacing incumbents and old regimes. The replacement of the old regime is accompanied by changes on wider dimensions of the socio-technical regime (Geels, 2005). Engaging with different sub-systems and their interactions using MLP will answer how the micro interactions bring changes within and across sub-systems and systems in a much less deterministic way. Some adjustments, however, are needed in the MLP framework to study innovations rather than the transition of innovation regimes. This is summarised in Table 2

Please Insert Table 2 about here

2.3. Institutional Analysis and Development Framework

IAD (Ostrom, 2005) examines socio-economic system interactions by delving into the feedback mechanisms of behavioural and institutional sub-systems. The focal unit of analysis of IAD is an action-situation. The structure of all of action situations are described and analysed by using a set of variables. Table 3 summarises the IAD framework and its components.

Please Insert Figure 3 about here

Figure 3 is the schematic of Ostrom's IAD framework. It shows the relationship between the several components of her framework, which are outlined and discussed in brief in table 3. The action arena is composed of action situations in which the participants, who can take different actions, interact with each other and their interaction is affected by some exogenous factors over which they do not have any control, like institutions, environment etc. Their choice is a function of several factors. These include the extent of their control and possible outcomes (hence power they wield). Further, the costs and benefits of their action, available information and levels of uncertainty affect their choices. Evaluative criteria help evaluate the outcome as well as the actions that helped bring in the outcome.

Please Insert Table 3 about here

Analysts usually assume incomplete information for less formally set up action situations with a full set of actions available to participants, the full set of outcomes, and the action-outcome linkages. Incomplete information either implies "assumptions made about the limitations of human cognitive abilities in a model of the individual" or "relates to the complexity of the action situation being modelled" (Ostrom, 2005, p.51).

3. Framework

Rather than base our framework on innovation systems as the NIS warrants, we propose to situate our framework to understand eco-innovations at the intersection of ecological, economic and social systems. This is primarily because eco-innovations, by definition, seek to maximise three kinds of well-being, environmental, economic and social, making the objective function multi-dimensional. In contrast, an innovation system would only seek to maximise wellbeing, broadly understood as economic wellbeing, and the focus would be on the functionality of the system to come up with effective innovations (as observed and studied under NIS).

Using a co-evolutionary lens, Norgaard, (1991) suggest interactions between five sub-systems (as indicated by), environmental, institutional, behavioural, knowledge and technological within the ecological, economic and social dimensions. Figure 4 is a schematic representation of how these sub-systemic components of the three systems interact.

Please Insert Figure 4 about here

The environmental sub-system consists of different abiotic and biotic resources, and their interrelations. Often, this sub-system is considered to be the source to lower grade resources to which value is added through economic activity "rather than a complex system" transformed by those activities (Norgaard, 2006, p. 29). Norgaard (1991) talks of organization and values instead of institutions. We interpret the institution sub-system as rules, following Geels (2004). Rules are inclusive of values (Faber and Hoppe, 2015) but not organizations which are actors and hence another analytical dimension altogether (Geels, 2004). Rules are categorised as- regulative, normative and cognitive. Regulative rules refers to explicit, formal rules that regulate behaviour and interactions and imply legal punitive action in default. The best example is government regulations. Normative rules regulate social behaviour based on the society's values, norms, role expectations, duties, rights, responsibilities. Default of normative rules implies social punitive action. Cognitive rules constitute the frames that help in meaning making (Geels, 2004).

The behavioural sub-system is a joint revelation of institutions (values) and actors' agency. The knowledge sub-system is a product of knowledge generation and exploitation. It is based on the interplay and transformation of tacit and codified knowledge through interaction of knowledge carriers, i.e., the agents (Asheim, 2007). This sub-system is composed of three kinds of learning- analytical (scientific knowledge based on deductive processes and formal models), synthetic (applied, problem-related knowledge) and symbolic (recombination of existing knowledge in new ways). The technological sub-system is the manifestation of extant knowledge sub-system in the physical world dependent on routines, practice and thought.

Each sub-system is composed of diverse ways of valuing, understanding, organizing, and practicing (Norgaard, 2006). They are interlinked and respond to the changes occurring in the other(s) through the agents. It is not necessary for all new ways (value, understand, organize, practice) to sustain. However, the ones that do are very likely to bring cyclic unrest across sub-systems. The combination of all the subsystem dynamics would lead to system level dynamics in the ecology-economic-social (EES) space, and eventually lock-in at the sub-systemic level.

An example of such a lock-in through a change in the knowledge sub-system is the learning to tap fossil fuels for energy. The benefit of access to energy for agriculture and to the quality of life was reinforced by advances in mining and power production technology. This affected the way things are produced and consumed, and thus technology and behaviour (Norgaard, 2006, p.40) that influenced rational thought, planning and action, and institutionalized it. It is this institutionalization that resists changes at the level of the socio-economic systemic space (for example private versus social costs and benefits) on one hand, and all economic activities degrading environment in the ecological space on the other.

At the micro-level, the actors have the agency given the structural or systemic and sub-systemic constraints. These agents are individuals, communities or organizations (Ostrom, 2005). They not only carry, reproduce (Geels, 2004) and modify institutions but also behaviour, knowledge, technology. In the very long run, their choices affect the environment as well.

Several innovation 'systems' exist in this co-evolving EES space and specific innovations can be understood by identifying certain micro games and sub-systemic interactions. The outcomes of the games and the games themselves when arranged in a sequence will help understand the following

- Who participated in the games, i.e., who were the agents? Who innovated? Who commercialized the innovations? Who adopted the innovation? Who diffused the innovation?
- What actions did each actor take? What was the nature of the innovation?
- Where did each action situation occur?
- When were these games played?
- Why were certain actions (strategies) chosen over others?
    - What was happening at the sub-systemic level?
    - How were the perturbations in one sub-system leading to changes in other sub-systems?
- How did the artefact (invention) and innovation (commercialization, adoption and diffusion) come about?

The micro-level interactions reproduce and modify sub-system level interactions which in turn cause system level dynamics. At the same time, these system level dynamics also spiral sub-systemic interactions and new micro-level games. This multi-level perspective is represented in Figure 5. Each interaction is an action situation where participants interact, and the IAD framework can be applied to each of these situations. The outcomes could be status-quo or some change could have taken place. The nature of the outcome and an ex-post analysis of the strategies (both available and played in the game) leads to formation of new knowledge which in turn leads to innovations at the technical, social, business and policy level and several other changes.

Please Insert Figure 5 about here

Examples of some changes are listed in table 4. As is evident from the table, as we move from technology to environmental sub-systems, the changes in the subs-systems become progressively more subtle to identify.

Please Insert Table 4 about here

The micro-level games make changes at the system and sub-systemic level. These games are continuous and can be represented through a honeycomb of sub-systemic interactions, as demonstrated in Figure 6. The sub-systematic level interactions are represented through a honeycomb of the five dimensions, namely- knowledge, technology, behaviour, institutions and environment, adapted from the co-evolutionary interpretation of the NIS. A honeycomb in geometry is closely packed arrangement of polyhedral or higher-dimensional cells, so that there are no gaps (Olshevsky, 2007). In the arrangement in figure 6, the five dimensional sub-systems are connected to a closely knitted chain of sub-systems. This is the meso-level depiction of the continuous micro games. The reason for studying micro games and not sub-systemic interactions directly is that sub-systems interact with the help of the actors who take the decisions at the micro-level and are in turn influenced by the sub-systemic state.

However, studying all micro-games is infeasible, either because of the paucity of resources (data or time) or because of other limitations such as doing a post facto analysis of an eco-innovation. The schematic in Figure 6 represents some specific games that can be studied by the researcher, as represented by the circles on the honeycomb structure.

Please Insert Figure 6 about here

When the micro games are not visible ex-post, i.e., their participants and all the strategies available to those participants cannot be identified clearly, we are left with a sequence or sum of sequence of all the outputs of all the micro games. This set of outputs represents the context or the sub-systemic state. The changes at the sub-systemic level are visible but how those changes come about cannot always be explicitly explained through data.

Specific action situations need to be identified, and a few discrete within and between sub-systemic interactions can be focussed on to arrive at the dynamics at the systemic level, so as to understand how eco-innovations occur. The discrete interactions identified can then be studied effectively through action situations which are the basic units of analysis in Ostrom's IAD framework (please refer to figure 3). For each snap-shot (interaction at micro-level), the system dynamics (disintegrated into sub-systems) are given or considered exogenous. Each micro game can be either solved through stylized games designed for rational analysis or heuristics. The assumption for the former would be that the micro game is so reduced that full information is available. In repeated interactions, the outcomes would be revised due to new considerations. The summation of several such stylized games would make a full micro game. Alternately, heuristics could be applied after loosening the constraint of full information. In such instances, the outcomes lead to learning after each play. This itself can lead to two kinds of games. Firstly, the same game is adapted to revised information and strategies. Secondly, a new game could evolve with new participants, strategies, information, relative positions, and expected outcomes.

In developing our framework, we apply heuristics as the assumption of complete information is not applicable in a real-life eco-innovation situation. Since this is a post facto analysis, we have access to the actions, choices and strategies of the participants as well as the real outcomes. The participants are considered as composite actors. Therefore, individual players, day-to-day actions and attributes of the players are not considered. Some other parameters listed in table 3, elucidating the IAD framework, such as certainty and risk are not considered in this framework since full information is not a characteristic of eco-innovations in a practical scenario. We are using organizational linkages rather than multi-level linkages of the action arenas because the focus of the framework is to trace the case of an eco-innovating firm and understand the artefact's manufacturing process as well as its commercialization process.

Similarly, the systemic state and their interactions can themselves be identified but how the transition of innovations takes place at these levels requires the exploration of micro games that constitute the sub-systemic and systemic layers.

Thus, this framework proposes a multi-level tool to analyse discrete eco-innovations by combining the understandings from Co-evolutionary NIS and IAD. The framework models a world where systems are multi-level; the levels are negentropic; the relationship between actions and outcomes is uncertain; and there is incomplete information.

We zoom into action-situations using the co-evolutionary NIS and MLP approach, and analyse them using the modified IAD framework. Then we identify some sub-systemic interactions, and distil these further to arrive at system dynamics, which manifest themselves as outcomes in the EES dimensions. These outcomes are then, applied with the institutional context to develop a rounded understanding of the trajectory of an eco-innovation.

To demonstrate the application of this framework, we analyse the commercialisation process of an eco-innovation by Power Tech Company (PTEC)[2] in rural India. The next section briefly describes PTEC and its evolving business model and eco-innovations starting from biomass based renewable energy equipment to distributed generation of solar energy. This is followed by an analysis of PTEC, to develop a better understanding of the role of the institutional environment to the commercialization of the innovation applying this framework.

4. Case[3]

PTEC generates and distributes clean off-grid power in rural India. In its earlier avatar, PTEC was an NGO, the Triple-P Foundation (TPF)[4]. In 2008, it was registered as a private limited company. It started its journey in rural power generation and distribution by installing and operating rice-husk powered AC mini-grids.

It designed the world's lowest cost biomass based renewable energy equipment. It initially struggled with rice-husk because it was difficult to produce commercially viable producer gas. Also, the existing technology only worked on a dual fuel mode (a combination of producer gas with diesel). However, PTEC devised a rigorous cleaning and maintenance programme of the biomass char and developed a 35 kW compression-ignition engine that was able to run on pure producer gas. Its gasifier had the ability to use multiple types of feedstock. The gasifier replaced fossil fuels for generating power completely while using locally available material.

A single PTEC biomass plant supplied power to about 500 households and small businesses through a local electricity grid. The gasifiers were used in AC mini-grids extending 1.5 km and supply minimum six hours of power on a pay-as-you-go system. Each plant used 3 quintals of rice husk per quintal. PTEC's revenue target for each plant was about ₹ 40,000 per month in 2014. Users paid a minimum of ₹ 100 per month with a connection charge of ₹ 100. The plants were installed after a pre-installation energy audit of households to assess the demand, determining the community's paying capacity, and obtaining commitments from a minimum number of households for revenue guarantee. Each plant was a near replica with the same kind of gasifier and generator, and nearly the same layout on rented plots of 2000-6000 square foot. The standardized layout, low fixed cost and negligible expense of civil works allowed for economies of scale and easy relocation. The small-scale generation enabled the off-grid villages to access electricity for the first time. Families were able to replace smoky kerosene

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[2] Name changed for anonymity.

[3] This is only a rough sketch of the case. Details of the case have been used for the analysis in section 5, and the authors may be contacted to obtain a more detailed case description

[4] Name changed for anonymity.

lamps with brighter electric light, use phone chargers, radio and TV at home. New businesses in need of electric power to run machinery could be started, and existing businesses were able to extend their working hours with better light. In its operations, PTEC minimized its wastewater discharge by recycling water in the cooling plants.

Since 2012, PTEC also installed solar DC-micro grids extending 300 metres to reach remote locations with very low population. Off-grid solar DC micro-grids, powered by rooftop photovoltaic (PV) systems, worked well for electrifying remote locations. Each micro-grid served twenty households at a time for six hours per day. Each house connected was also metered via world's lowest cost smart pre-paid meter designed by PTEC to keep the cost of monitoring, against electricity theft, low because the solar micro-grid connected less affluent locations with low population density. The solar PVs were manufactured by the technical partners of PTEC. The solar DC micro-grids had several advantages over the biomass AC mini-grids- lower cost of operation, less labour and no need to manage waste. However, the capital expenditure of this system was relatively higher (more than twice) due to the high cost of deep cycle rechargeable batteries to store electricity for use in not so sunny weather. Around 2500 households were connected through the DC micro-grid.

PTEC kept revising its business model in the presence of disablers which possibly has led to its success which was evident from its expanding size. In 2015, PTEC successfully launched their first biomass and solar power hybrid plant, which made it one of the cheapest energy plants that effectively served rural low-income communities by producing electricity via solar grid during the day and biomass gasification at night. At 2015 year end, PTEC had 70 operational plants supplying power to 20000 households across 350 villages and employed 375 rural people in various capacities with 17 locals as its franchisee partners. PTEC had also started marketing its incense-sticks under the brand-name 'Jasmine'[5]. By working with its stakeholders and going beyond just being a power generation and distribution company PTEC continues to survive in an environment where many other well-meaning startups would have closed shop. An example is the failed attempt by Greenpeace in Dharnai, India (Vaidyanathan, 2015).

Please Insert Table 5 about here

Table 5 provides a snapshot of what PTEC does at a glance.

5. Application of the Framework to PTEC's Case

5.1. Systemic level: At the confluence of the EES space concerning energy poverty (zero access to electricity) in rural India (198 million in 2005), three level-shifts were important. The first was the launch of 'Power for all by 2012' program in 2003 to electrify all villages by 2007 and all households by 2012 (implying energy equity). The second was India's ratification of Kyoto Protocol in 2002 and its entry into force in 2005 (implying environmental accountability). The third shift was the decision to undertake the remote village electrification program through renewable sources in 2005 (implying energy equity with environmental accountability).

5.2. Sub-systemic level: At the macro-level, it is difficult to study all the contexts due to the lack of subtlety of certain sub-systemic perturbations. However, the level-shifts brought about

[5] Name masked for anonymity

changes at the institutional sub-systemic level that are easy to identify especially at the policy level, due to their immediate nature, within the institutional sub-system These are depicted in Figure 7.

Please Insert Figure 7 about here

5.3. **Micro level:** Based on the findings from the sub systemic analysis, specific sets of micro games regarding PTEC's journey to commercialise its eco-innovation and make its business sustainable are identified and analysed in as much detail as possible. The study of each action arena in Ostrom's nomenclature, represents a sequence of micro games that delve into the impact of the game on changes in the relevant sub-systemic context. This helps us better our understanding of the co-evolutionary innovation 'system' that exists in this space. These action arenas, taken together, focus on the organizational linkages of PTEC. Six such action arenas have been identified for PTEC, as shown in figure 8, the analysis of which follows.

Please Insert Figure 8 about here

Stage I - Invention: The founders of PTEC had always thought of working for the upliftment of the downtrodden in Indian villages. Around 2005-07, their ideas began taking shape and they started exploring feasible options for rural electrification. With the government policies and papers supporting renewable energy, the founders investigated into both bio-mass and solar power generation and distribution. Solar power equipment was too expensive. Their experiments with Jatropha seeds as biomass fuel (as indicated by government research and suggestions), were also unsuccessful. The founders got to know from a local gasifier salesman that several local rice millers were using biomass gasification to power their mills using rice husk on the 'dual-fuel' mode of operation. PTEC was able to manufacture this invention with the financial and technical support of MNRE.

The producer gas produced by the gasifiers was mixed with 35%–50% diesel to power the diesel engines. One of the founders' was trained as an engineer and had experience as a Senior Yield Enhancement Engineer in the Power Management Semiconductor industry. His prior experience of ensuring record yield levels at low cost helped PTEC reduce their operational expenses. He realized that he could make the gasification process commercially viable and use it to distribute electricity in the villages with ready supply of rice-husk.

In the action situation that PTEC faced in this action arena, PTEC had only partial control (low to medium range). However, with many possible outcome variables, and a wide range of outcomes for each of the variables (for instance, profits, recognition, carbon credits and customer base), it is apparent that PTEC enjoyed medium to high levels of power.

Co-evolution of Sub-systems in the making of the artefact (that is, the invention, or the gassifier equipment): Due to India's commitments to Kyoto Protocol and real environmental hazards, there was a perceived need to lower its carbon footprint, as is evident from governmental regulatory institutions.. Existing normative institutions inculcated the sense of duty that PTEC's founders felt towards their lesser well-off countrymen. Cognitive institutions pushed several stakeholders towards environmental well-being and social equity which was a key factor in Shell Foundation's interest in India and later its partnership with PTEC from 2008 onwards. The institutional sub-systemic changes led to reciprocal change in the behaviours of people who felt a warm glow from investment in environmental well-being leading to sustainability of business. This led to economic profits as well as an improvement in social and environmental wellbeing which were reaped later through carbon credits and awards that PTEC won in its first years of operation.

Stage II - Bio-mass plants: PTEC (then TPF), commercialized its biomass-gasification equipment in Hamlet A which did not have access to electricity as it was not connected to the national power grid. PTEC's position was dependent on its relationship with the locals. It had partial control. Analysis for this stage is represented in Figure 9, using the IAD framework presented in figure 3 in section 2.3.

Please Insert Figure 9 about here

The main potential outcome was the state of commercialization measured in the terms of profits that PTEC made. PTEC's operation quality served as the control variable which would lead to a change in customer base. At the culmination of these set of games, PTEC was able to earn a reasonable profit and decided to scale up the model to other similar areas. The evaluation of outcomes (inclusive of the outcomes in table 5), on the basis of the evaluative criteria (please see figure 10), indicated that PTEC's presence for Hamlet A ensured equity (ability to access energy), environmental efficiency (clean production and distribution of electricity) and the adaptability of PTEC to evolve from an inventor to a business entity. However, its status with respect to trust from the locals is unclear. Other potential outcomes of these games were PTEC's ability to scale up and fulfil its social and environmental agenda. The opportunity that presented itself to PTEC was the cumulative range of outcomes from commercialisation. PTEC's control of these action situations was partial as the rest of the control resided with the residents of Hamlet A. The power (product of control and opportunity) that PTEC wielded ranged from medium to high (authors' assessment).

PTEC's electricity generation and distribution in a rural area like Hamlet A provided the locals with a more equitable existence as compared to their counterparts in electrified villages and small towns. PTEC's operations were environmentally efficient because locally sourced raw materials like rice-husk and bamboo (for distributive infrastructure) were used and clean electricity produced.

Please Insert Table 6 about here

Table 6 categorises the evolution of different subsystems as a consequence of the series of outcomes represented by Stage II. Only those outcomes relevant to PTEC are considered. Table 5 enumerates the outcomes important to the residents, some of which are not considered here. There is incomplete information in the game as to how the locals may react to a given situation. Contracts with locals add the uncertainty (contracts are inherently incomplete and not all locals enter into contracts with PTEC). Note the reciprocity: to begin with, the sub-systems affect the micro level situations but at the end, these micro situations can impact the subsystems.

Stage III - Evacuation: By 2011, PTEC had scaled up to 50-60 biomass plants with the financial and technical support from its partners (like MNRE and Shell Foundation). However, its experience in Hamlet B was an eye-opener. Due to the introduction of door-to-door dehusking services in the area, the cost of husk increased. Further, the rice dehusking plant was not able to supply enough husk as it also started selling husk to rice bran oil makers. The plant was run by a local franchisee owner who was not able to manage the plant well. Franchisee rights changed hands thrice among locals within five years of operation without success. The operation quality was affected and the promised service of 6 hours of electricity a day was not met. The only locals involved in PTEC's operation in this location were the franchise owners, the owners of the land who had leased it to PTEC and the 4-5 employees required to run the daily operations of the plant. Eventually, Hamlet B got connected to the national power grid and PTEC had to move out of Hamlet B.

Please Insert Figure 10 about here

As is evident from Figure 10, PTEC had relatively lower opportunities to operate due to the low levels of trust of the locals towards PTEC. The operation quality was below expectation, and PTEC was not able to successfully commercialize its operation. The extension of the national grid to Hamlet B implies a rise in government accountability and its commitment towards equitable treatment. PTEC was impotent (no power) in these series of games because the control was distributed amongst local franchisee partners, the suppliers of raw material and government's grid extension to the site. The action arena was fraught with uncertainty and incomplete information. The co-evolution of sub-systems is summarised in Table 7.

Please Insert Table 7 about here

The learning from the last set of games played a role in the unfolding of the action arena. After the action arena produced concrete enresults, these outcomes and strategies led to new learnings, which led to slight sub-systemic perturbations, leading to Stage IV of the action arena.

Stage IV - More inventions: PTEC acted on its need to look for alternate locations not at all feasible for Grid Extension. Remote villages with very low population density were considered apt locations for commercialising a new solar DC micro-grid and smart meters that PTEC had already worked with in Africa through Shell Foundation. The focus of government policies and programmes on harnessing solar energy could have also influenced this choice.

Hamlet C was one such location connected to the DC micro-grid of PTEC. At this site, the micro-grid was set up by PTEC to meet very basic domestic demand for electricity. In this system, solar power panels were fixed on the roof of one house to provide power to adjoining 20 houses. All customers benefited from electrification. Households that rented out their roofs for putting up the solar panels obtained additional income. However, power storage was expensive, leading to erratic power supply. Also, investors and the government agencies failed to recognize the solar power panels as assets for PTEC as the panels that could be shifted from one location to another. Though profitable, scaling up this model was a challenge due to lack of committed finance.

Please Insert Figure 11 about here

The evaluation of outcomes (inclusive of the outcomes in table 5), on the basis of the evaluative criteria indicate (please see figure 11) that PTEC's presence in Hamlet C ensured equity (ability to access energy), environmental efficiency (clean production and distribution of electricity), and adaptability of PTEC, to learn from its experiences in Hamlet C and bring in new innovations to explore locations of a different profile. Due to no possible grid extension, PTEC enjoyed more control in this action arena. The opportunity was at a medium level due to the low incomes of the locals which lowers the range of the outcome variable, commercialization, measured as profit. This implies that PTEC had medium level of power to influence the situations.

Please Insert Table 8 about here

As illustrated in table 8, the changes in the sub-systems in the last set of games affected the exogenous variables that entered the choices made in the action arena. In turn, the outcomes from the interaction between participants in the action arena led to fresh changes in the sub-systems.

Stage V - Need for Business Model Innovations: Hamlet D, powered by PTEC, was the only village amongst adjoining villages not connected to the national grid. The residents felt forsaken by the government, without electricity and other amenities. They benchmarked PTEC's services with adjoining villages (24X7 service from the grid as compared to six-eight hours form PTEC). Thus they undervalued PTEC's services. Further, they did not like the subscription system, as nearly free electricity was supplied to reserved community households in grid electrified locations. There were cliques which either openly opposed PTEC (due to its small size, service quality, and employee wages) or supported it (due to PTEC's services and related gains).

Please Insert Figure 12 about here

The evaluation of outcomes, on the basis of the evaluative criteria raise questions regarding the equity of power access as Hamlet D was the only location without grid electricity in adjoining areas (please see figure 12). Also, due to clique formations, it was difficult to discern the extent of trust PTEC enjoys at Hamlet D. However, PTEC's presence ensured environmental efficiency (clean production and distribution of electricity). The residents' perception of PTEC's status as a power generating and distributing entity was low. Due to no grid extension, PTEC enjoyed more immediate control in this action arena but the stability of its operation at this location was uncertain due to the possibility of grid extension. The opportunity is at a medium level. This implies that PTEC had a medium level of power to influence the action arena. Its position was full of uncertainty.

Please Insert Table 9 about here

Table 9 shows how reciprocal changes in the sub-systems led to new understanding (knowledge) which was subsequently used by PTEC to move to stage VI, to a hybrid techno-commercial business model.

Stage VI - Hybrid Model: The hybrid model implemented by PTEC was a combination of the bio-mass and solar DC micro-grid technologies with bio-mass and solar powering houses and business at night and day respectively. This reduced the cost of batteries for storage in the solar micro-grid and provided stability to the system. PTEC's hybrid model was commercialized first at Hamlet E. Hamlet E, was already connected to a bio-mass plant and incense-stick manufacturing unit. Due to better service after the installation of the hybrid model (12-16 hours of power a day), locals got both domestic and business connections from PTEC. Upgrading their subscriptions helped them use appliances with more flexibility and reduced their dissatisfaction with the limited energy service provided by PTEC. The locals were impressed with the infrastructure changes done to start the hybrid model. Despite general satisfaction with the hybrid model, some people (generally older people who had worked in urban areas and returned) were unable to understand either the subscription system or its pre-paid nature. They failed to perceive why their electricity supply did not increase to 12 plus hours when they did not upgrade their subscription accordingly or how their recharge became nil before the end of the month, when they consumed electricity beyond their subscription.

With the economic success of the hybrid model at Hamlet E, PTEC decided to scale it up to all its existing and new locations.

Please Insert Figure 13 about here

PTEC's electricity generation and distribution in Hamlet E, provided the locals with a more equitable existence as compared to their counterparts in electrified villages. PTEC's electricity generation and distribution were environmentally efficient. Due to its profitability, ease of access and better service, the outcomes were economically efficient. This improved its perceived relative status amongst the residents. Transparency ensured increased accountability of PTEC to its customers. The accountability and adaptability of PTEC to make its services at par (nearly) with the grid led to an improvement in trust levels of the locals. Due to no grid extension, PTEC enjoyed more control in this action arena. The improvement in the service quality made customers more amenable towards PTEC. PTEC's opportunity ranged between a medium to high level due to the model's potential to attract more customers. PTEC also had a medium to high level of control due to lower uncertainty, both leading to a medium to high level of power to influence the action arena.

As evident from table 10, PTEC demonstrated its robustness[6] through its adaptability to local needs and institutional constraints. Institutions are resilient[7] but PTEC's potentially disruptive innovation of a hybrid power generation model made a chink in the cognitive institution that had inculcated the belief that the government was the main provider of services in rural areas. This belief was normatized and led to resistance from the locals. PTEC's dependence on subsidies was a subtler example of the same. Its break from this belief and efforts towards being its own committed source of finance led to the development of the hybrid model. The disruptive nature of this innovation has transformed the institutional sub-system.

Please Insert Table 10 about here

From the application of the framework to PTEC across several action arenas, some features of commercialization of eco-innovations become apparent. PTEC's existence as a clean power generating and distribution company was influenced by the broader context of policy. This included an emphasis on environmental protection and simultaneously extending energy access to all citizens in India. This shift immediately influenced power related policies in India, which affected PTEC's decision of which types of power generation activities to choose from and which innovations to make. PTEC's first invention was an application of analytical (gained through formal educational training) and generation of synthetic (invention through applied research) knowledge. PTEC gained and applied synthetic and symbolic knowledge through its

[6] "Robustness refers to the maintenance of a system's performance even when it is subject to external, unpredictable disturbances" (Ostrom, 2005, p.67).

[7] Resilience is the amount of disruption needed to transform a system from stability domain (characterized by a configuration of mutually reinforcing processes and structures) to another (Ostrom, 2005, p.67).

operation and interaction with CSOs like Shell Foundations, government departments at state and central levels, international bodies and other organizations engaged in renewable power sector. Its experiences vis-à-vis the locations at which it operated led to learning through experience. The need for having such living laboratories to experiment in is emphasized. PTEC's interactions with its consumers (who were also community members and sometimes employees) led it to develop an inclusive business model that included women who made incense sticks with the ash from the rice husk that fostered social equity. PTEC's operations led to environmental efficiency. A better understanding of consumer psyche led PTEC to introduce smart meters and a prepaid business model for power supply which built transparency, accountability and trust within the system. The adaptation of the analytical, synthetic and symbolic knowledge, thus generated, helped PTEC create more artefacts and business model innovations. These new inventions complemented PTEC's first invention to sustain its business that improved its economic efficiency and relative status amongst its customers and employees. Thus leading to the successful commercialisation of its eco-innovation and PTEC's identity as a successful renewable power generating and distribution entity in rural India.

6. Concluding Thoughts

As illustrated in section 5, the proposed framework, when applied to specific innovations, can shed light on how institutions and their networks can influence innovation activity, through its various stages of evolution. The analysis shows how a specific eco-innovation is commercialized. By linking macro-level changes in institutional frameworks to micro-level innovation through sub systemic interactions using a MLP, it clearly illustrates how these interactions produce reciprocal responses in other sub-systems as well as in the micro-level interactions. The adapted IAD framework explains the what, when, who and where of innovation and the whys are explained by the sub-systemic interactions. Taken together, the framework provides an insight into the hows of a specific innovation.

While our illustration of the application of this framework is to the commercialisation of an eco-innovation, the same may be applied to gain an insight into the various stages of innovation, whether it is conception, adoption, diffusion or commercialisation. Its main contribution is that it can study the evolution of an individual eco-innovation rather than a system of innovations, in the context of the larger institutional backdrop. Further, this paper tries to extend the understanding of innovations at the tri-systemic levels of environment, economy and society to study eco-innovations. The framework's basic unit of analysis is micro in nature and tries to reproduce and enact actions at the micro-level by studying actors engaged in concrete activities. Another contribution is the analysis of non-technical innovations like business model innovations. The objective of understanding how and why innovations come into existence in the EES space is served through the choice of environment, economy and society as systems, coupled with a co-evolutionary approach of interacting sub-systems. The multi-level analysis presented in this paper is neither top-down, nor bottom-up but circular in nature. Starting with using the systemic approach of the NIS, the paper adapts the NIS, bringing in elements of co-evolution, MLP and IAD to develop a coherent analytical framework. This framework could be useful as a standard tool to understand the process through which an idea in transformed to an eco-innovation, which in turn becomes a thriving business.

Being a first attempt at developing a suitable framework, there could be room for improvement in different parts of the framework. Some of the improvements could come about by applying this framework to other stages of innovation, namely adoption and diffusion. The analytical narrative of the commercialisation stage of an eco-innovation in the power generation and distribution business delivered by this framework is a humble beginning.

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Figures

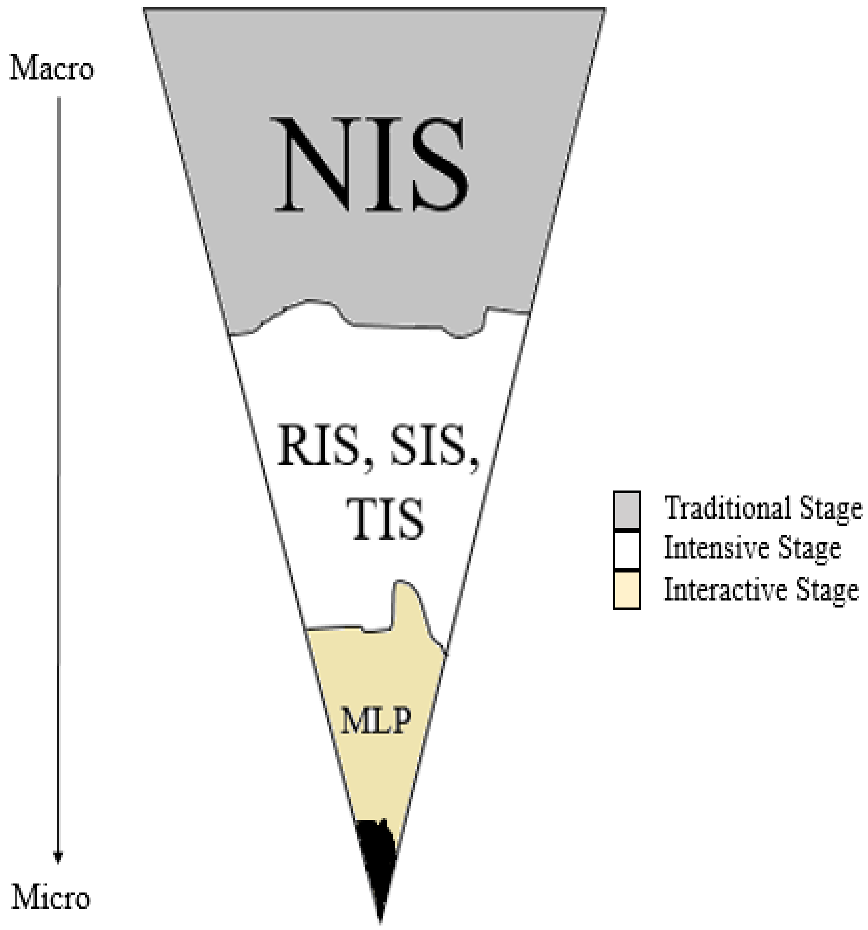

Figure 1: Stages of NIS
Source: Prepared by the authors

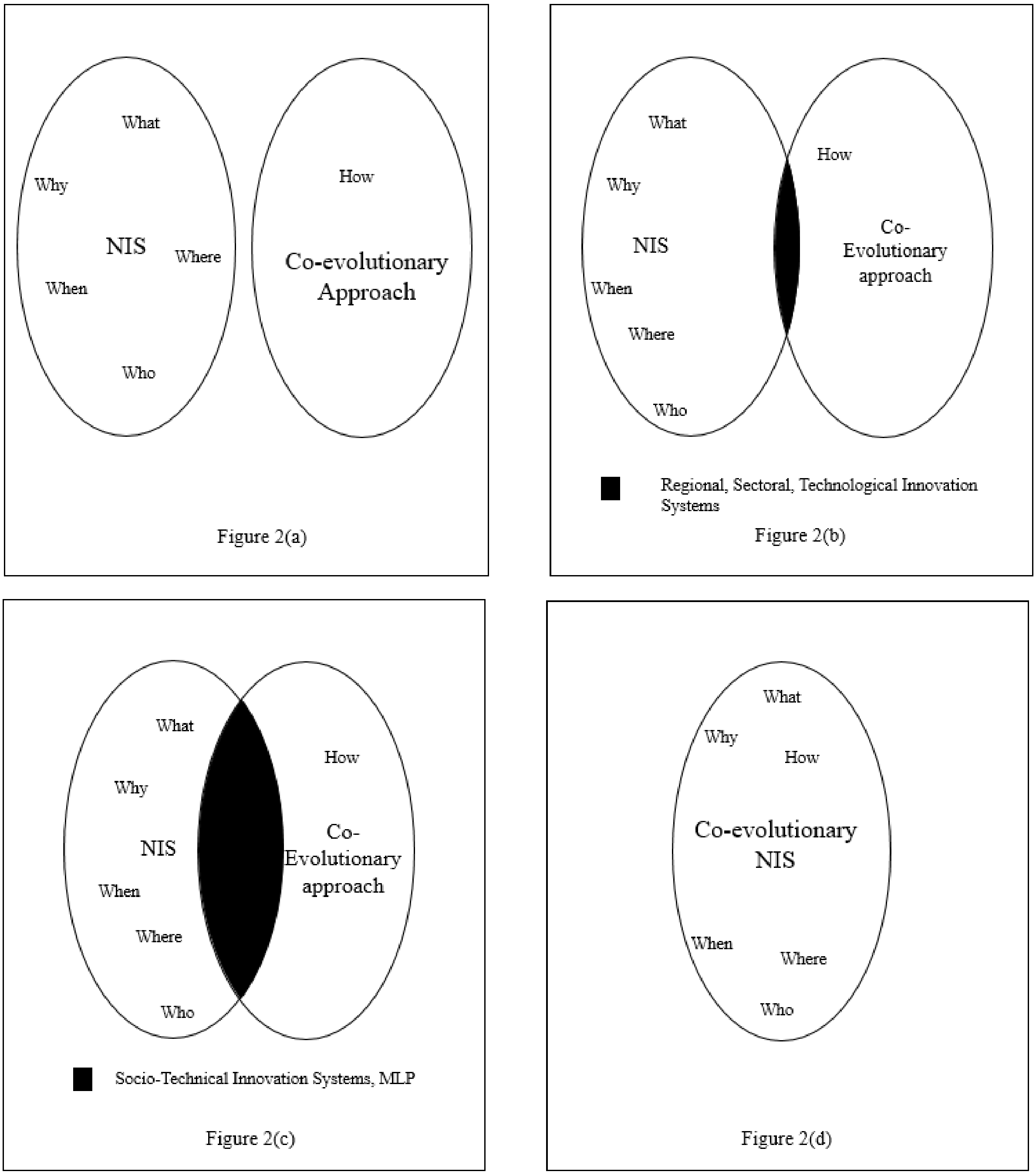

Figure 2: Objectives of Co-evolutionary NIS
Source: Prepared by the authors

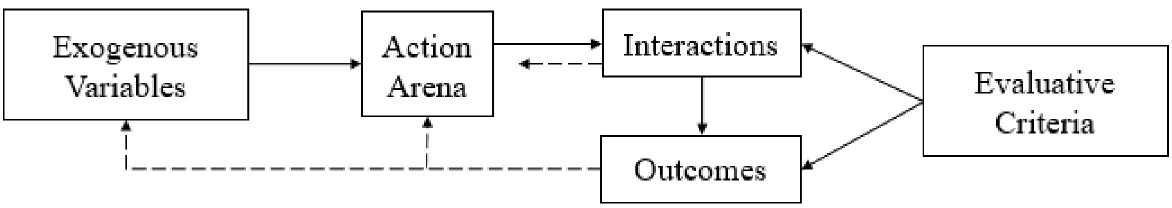

Figure 3: An Action Arena
Source: Ostrom (2005), p.13

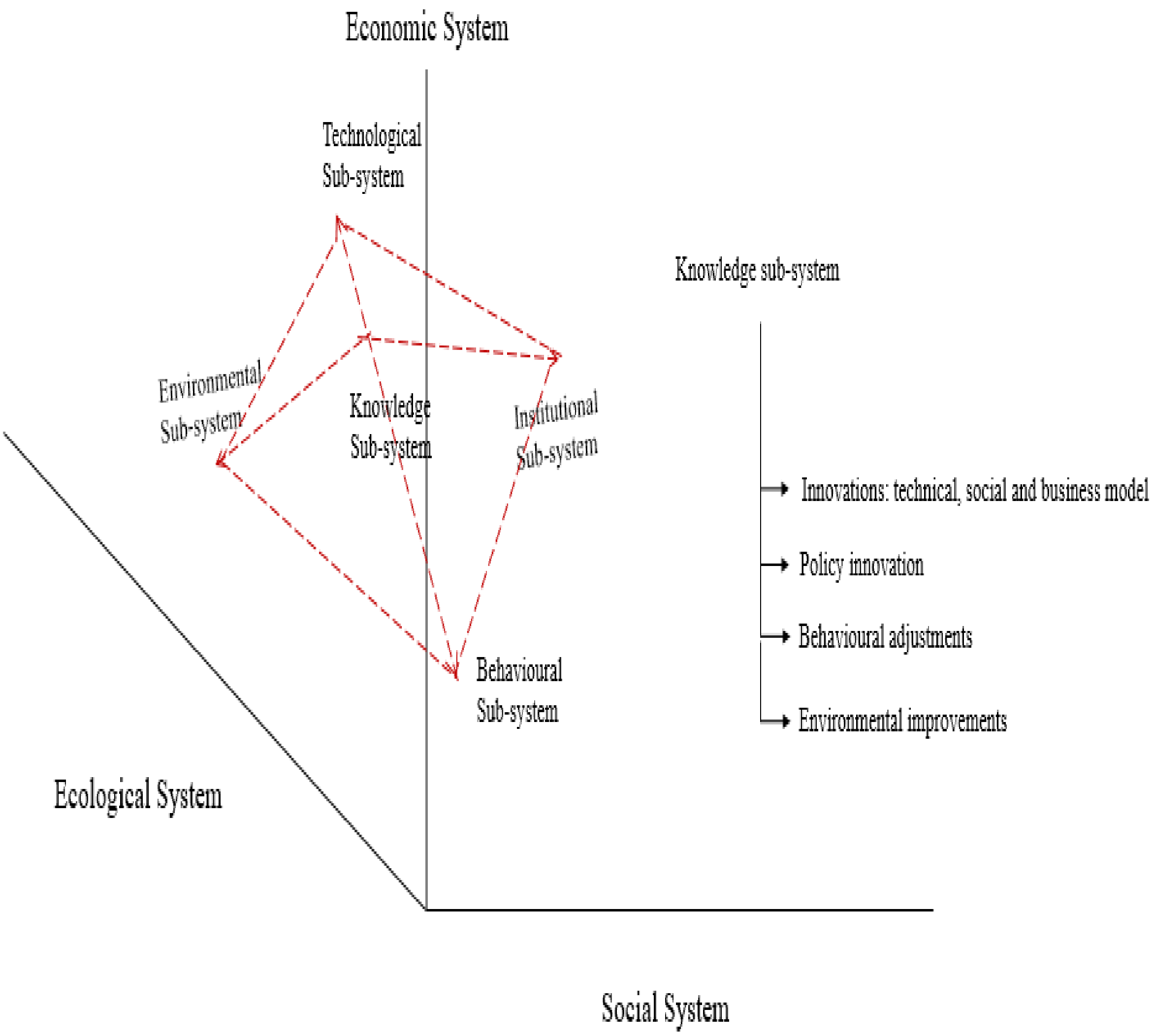

Figure 4: Co-evolutionary Systemic Approach to Eco-Innovations
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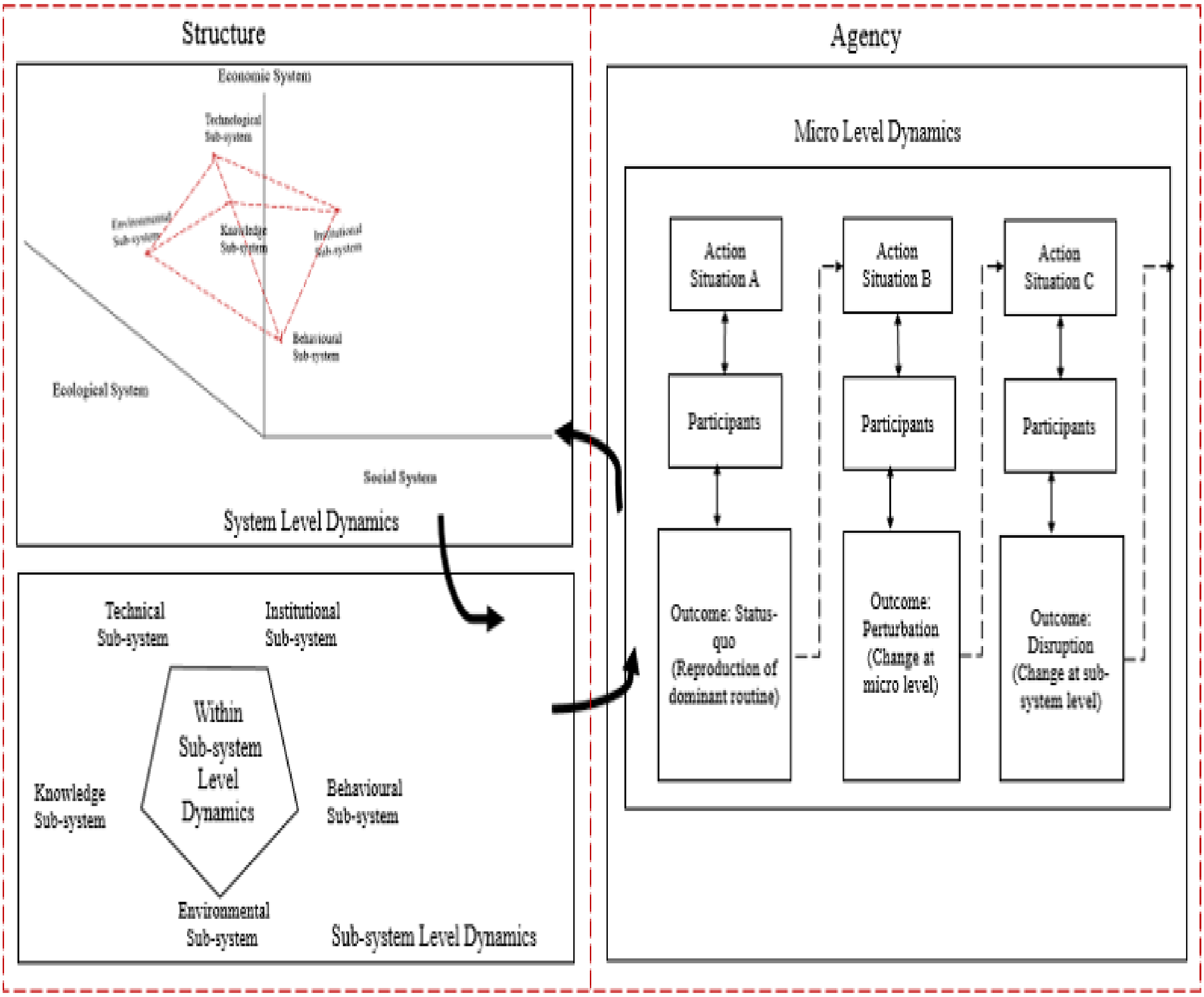

Figure 5: A Multilevel Framework for Analysing Eco-Innovations
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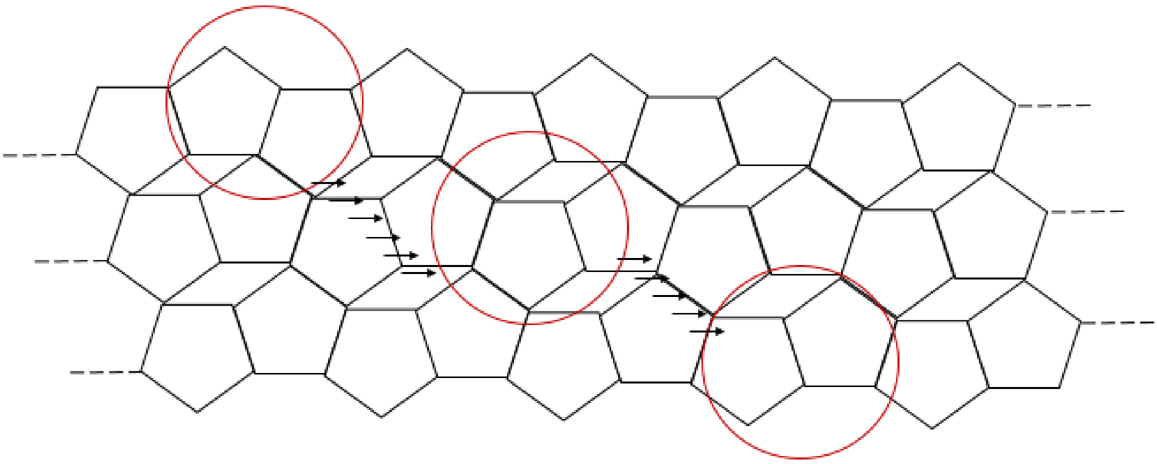

Figure 6: Discrete Within and Between Sub-systemic Interactions
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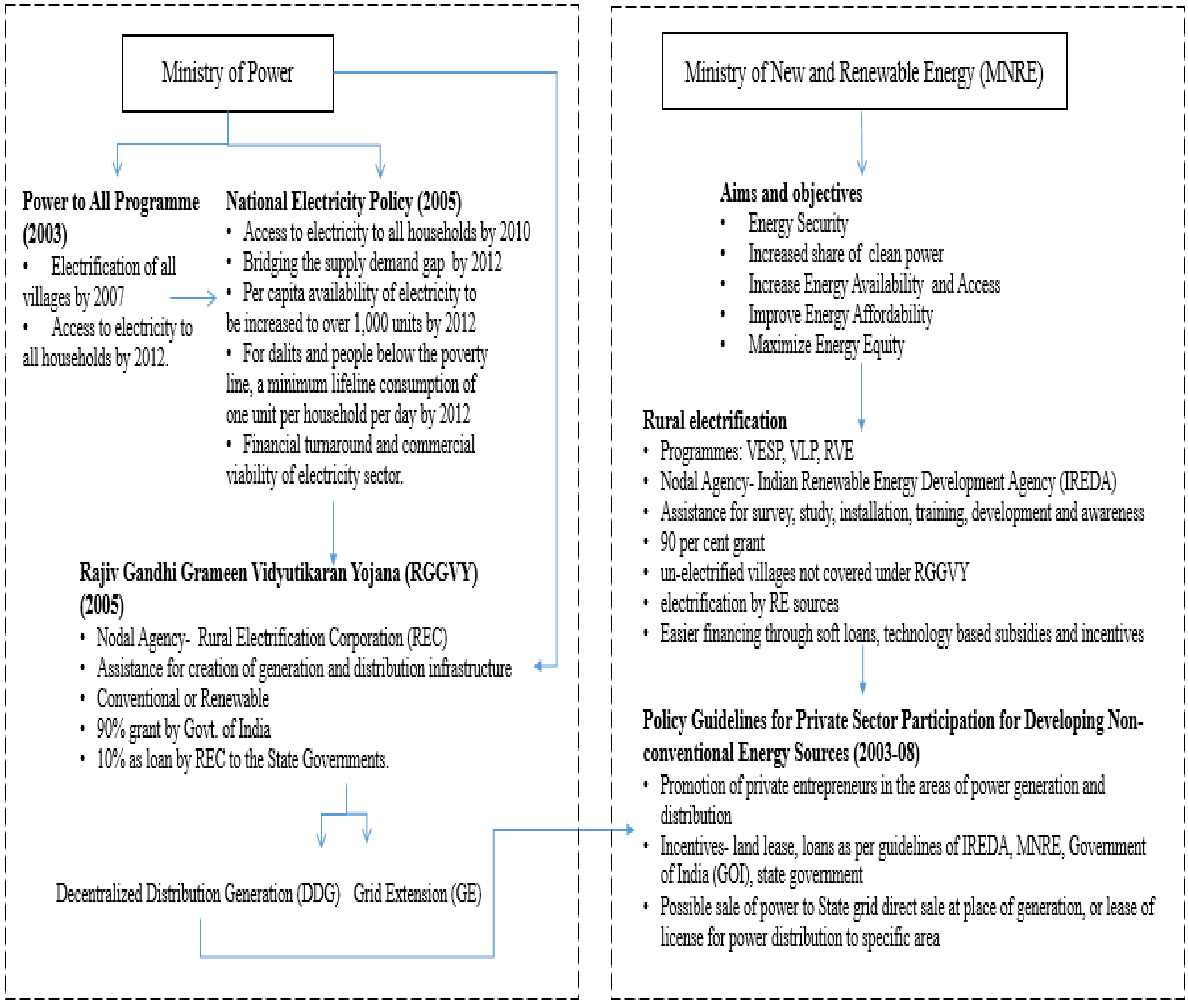

Figure 7: Institutional Sub-systemic States (2002-2007)
Source: Prepared by the authors

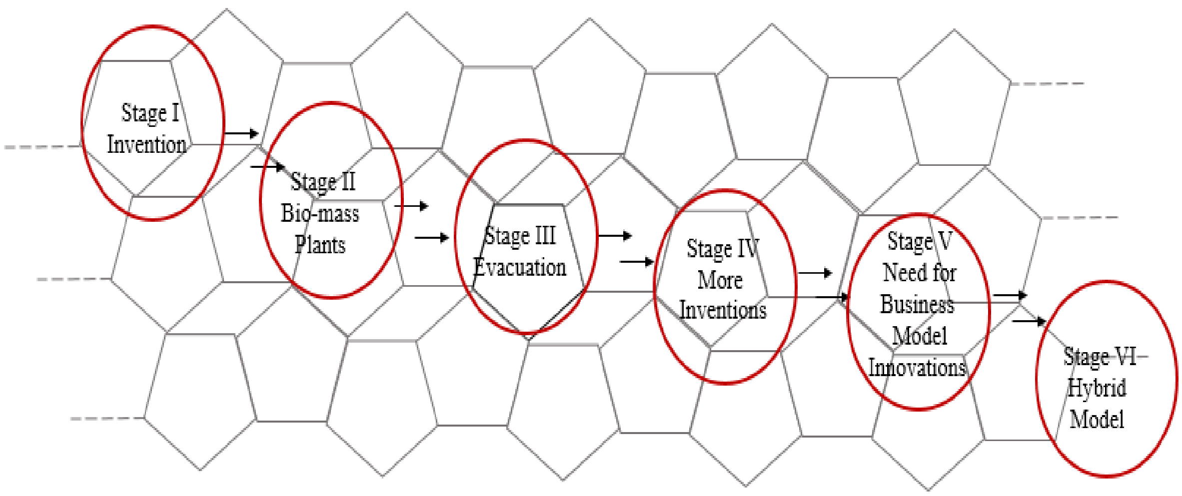

Figure 8: Discrete Action Arenas in sub-systemic space
Source: Prepared by the authors

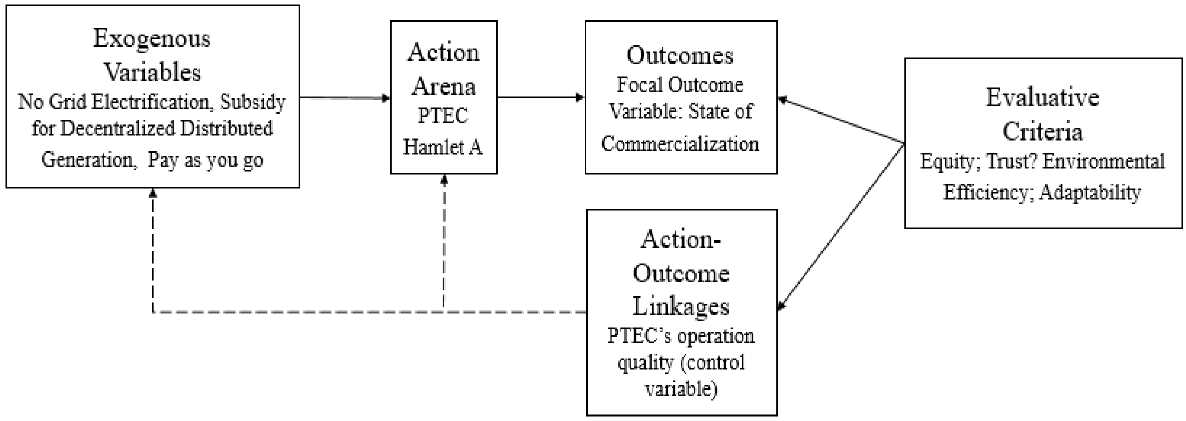

Figure 9
Stage II: Bio-mass Plants
Source: Adapted from Ostrom (2005)

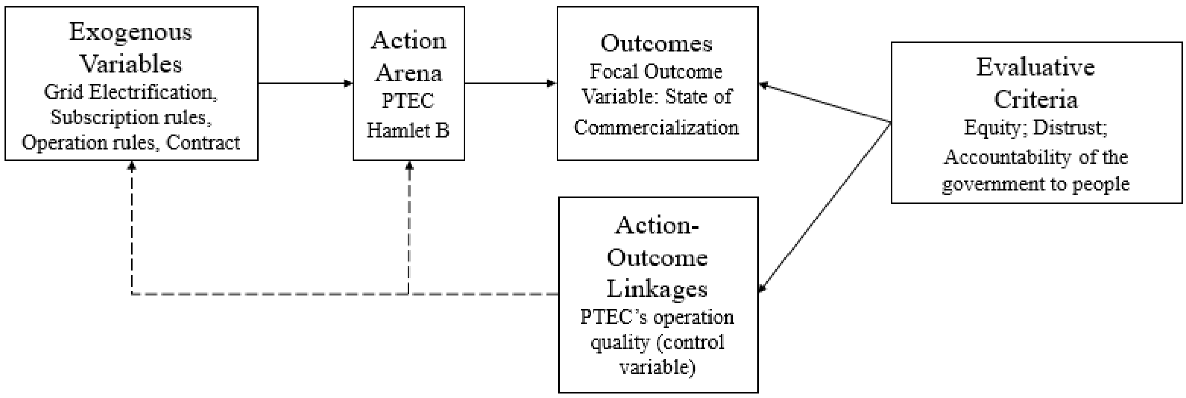

Figure 10
Stage III: Evacuation
Source: Adapted from Ostrom (2005)

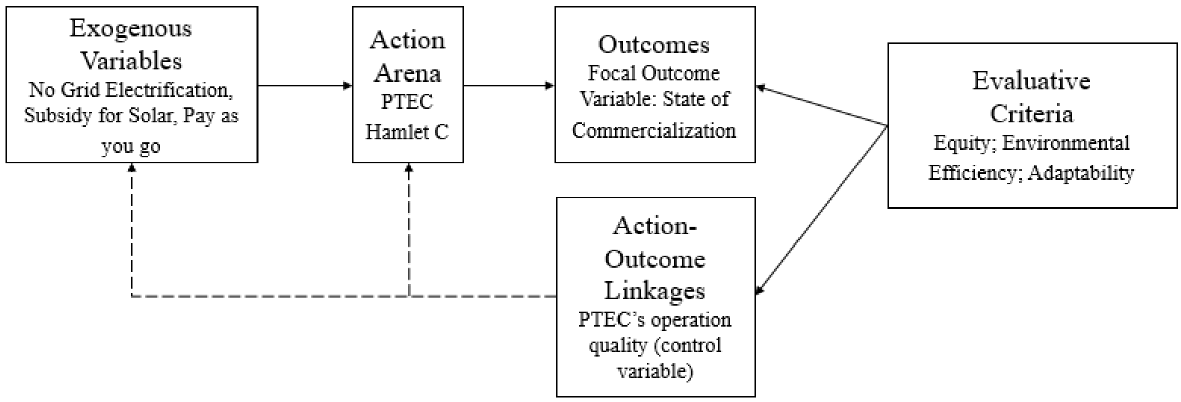

Figure 11
Stage IV: Solar Micro-grid + Smart Meter Invention
Source: Adapted from Ostrom (2005)

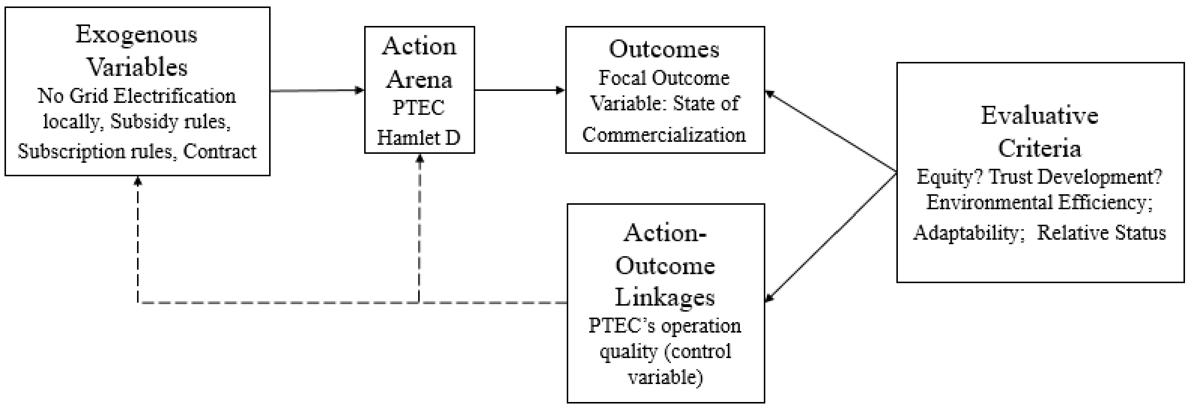

Figure 12
Stage V: Need for Business Model Innovations
Source: Adapted from Ostrom (2005)

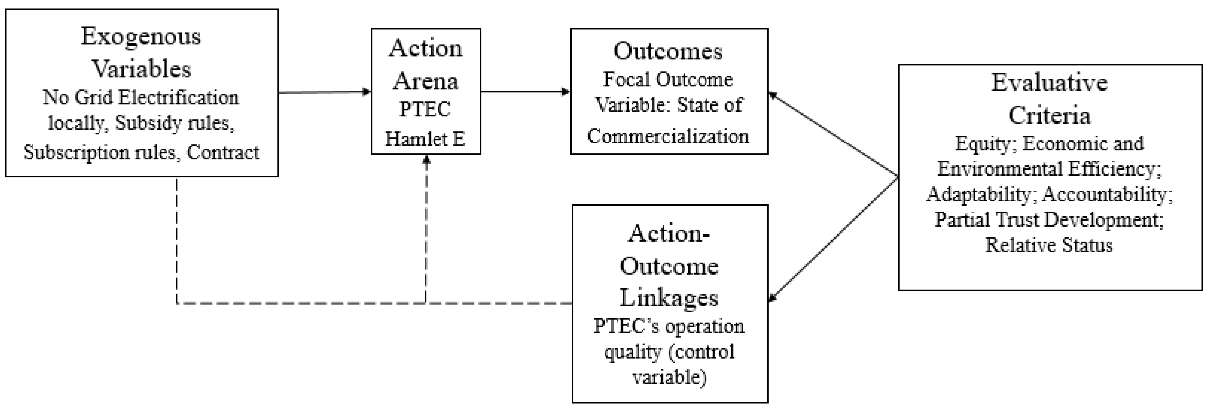

Figure 13
Stage VI: Hybrid Model
Source: Adapted from Ostrom (2005)

Tables

Table 1: Gaps in Co-evolutionary NIS

Limitations of National Innovation Systems	***Extant Solutions in Literature***	***To What Extent the Solutions help NIS Analyse Discrete Eco-Innovations/ Gaps***
Macro approach - The concept is too broad for rigorous micro level analysis (Andersen, 2004).	Focus on technological, sectoral, regional innovation systems and socio-technical systems	Narrowing the focus is not enough – concept still too macro in nature.
Structural focus- This downplays the role of agency; not enough attention to institutional interaction	Socio-technical systems study the interactions between actors and structures	These interactions are useful in studying eco-innovations
Passive demand side - Users have become innovators with open innovations.	Socio-technical system (Geels, 2004) and sectoral systems (Faber and Hoppe, 2013). Geels (2004, 2006) offers a schematic of dynamic interactions between actors and systems through institutions. Faber and Hoppe (2013) offer an aggregated demand analysis.	Aggregation will not work for a discrete innovation because the innovations may be commercialised, diffused and adopted by different entities and groups, each of whom may have different objective functions.
Extant research pays less attention to the innovation stages of commercialization, adoption, and diffusion.		
Failure to establish inter-linkages between institutions as the elements used to define and describe NIS are heterogeneous	Study interactions between analytical dimensions (systems, institutions and actors) rather than institutions	Can help study innovations but not eco-innovations as ecological systems are excluded.
Neglects to explain the transition of new innovation systems from old ones. Need to understand the dynamics of NIS over time.	The multilevel perspective helps in explaining the technological transitions (Geels, 2006)	There is still a need to explain the non-technical side of innovations and their transitions.
Downplay of institutional diversity by recommending (re)design of institutions. The NIS approach is used to describe and compare only the most important institutions, their activities and interactions for benchmarking		Each innovation situation is unique and therefore a micro-level interaction is required to understand them better
Sub-systems are treated as black-boxes	Geels (2004) very effectively opens the black-box of institutions. However, there are other sub-systems (Norgaard, 2006) that play important role in innovation dynamics and their black-boxes need opening too.	The socio-technical innovation systems talks about the technical sub-system and social system interaction. However, other sub-systems like environment, values and norms have remained unexplored.

Source: Prepared by the authors

Table 2: Gaps in MLP for Application to Study of Discrete Innovations

Limitations of Multi-Level Perspective	***Responses to Limitations***	***To What Extent MLP needs to be Adjusted to Analyse Discrete Eco-Innovations***
Structural focus- The structural focus downplays the role of agency (Smith et al., 2005).	"MLP accommodates agency in the form of bounded rationality (routines, search activities, trial-and-error learning) and interpretive activities…certain types of agency are less developed, eg. Rational choice, power struggles, cultural-discursive activities" (Geels, 2011, pp.29-30)	Due to the macro focus of MLP, the reproduction and enactment by actors in concrete activities is not apparent. MLP introduced in a framework that has a micro focus will better address the structure versus agency issue.
Hierarchical levels- MLP is often summarised as 'micro-meso-macro' hierarchy." (Geels, 2011, p.37).	MLP levels are actually different degrees of structuration of local practices or stability, and not necessarily hierarchical (Geels, 2011).	A levels approach, combining micro and macro perspectives, engenders a more integrated understanding of systems (Kozlowski and Klein, 2000). But even without the issue of the presupposition of hierarchy, levels pose the problem of demarcating the boundaries of each level which in reality are ambiguous (Rousseau, 1985).
Bottom-up change models where "radical innovations emerge in technological niches, then enter small market niches and subsequently diffuse into mainstream markets and replace existing regimes" (Geels, 2011, p.32).	Need for attention to the ongoing process of transition (Geels and Schot, 2008)	The focus on evolution of one stage to the other is inherent to systemic dynamics, therefore, it would be better if analysis of innovations shifted from a framework of innovation systems to a framework that places innovations at the intersection of two or more systems
Operationalization of regimes- Regimes are too homogeneous or monolithic (Smith et al., 2005). Most applications focus on a single regime.	Though regimes appear to be "coherent blocks" on the surface, they are composed of internal interactions (Geels, 2011).	There is need to connect the changes at regime level with those at the micro level as well as establish simultaneous existence of multiple regimes.
Socio-technical landscape as residual analytical category.	Geels (2011) suggests to include regime shifts as contributing factors to landscape changes.	This would explain what leads to changes in the landscape and not how changes occur at the landscape level.

Source: Prepared by the authors

Table 3: IAD Framework Components and Features

Main Components	*Auxiliary Components*			
Participants • Decision-making entities • Number: individuals, teams or composite actors • Attributes- age, sex, education, experience (knowledge and skill) etc**.**	Positions • Connecting links between participants and actions. • Standing set of authorized actions.	Actions • A value on a control variable that a participant hopes will affect an outcome variable. • Choice: specific action selected by a participant from the set of authorized actions. • Strategy: a complete specification of the moves to be taken in all possible contingencies.	Control • Omnipotence: total control over an outcome variable. • Partial Control: ability to control ranges between zero and one. • Impotent: no control over the values of a state variable.	Information: • Complete information: each participant knows the full structure of an action situation. • Incomplete information: who knows what at what juncture becomes important.
Potential outcomes: the set of physically possible results.	Unintended outcomes: When all outcome variables are not known or exact measurements are not possible.	Nature of Outcomes: • Physical results; • Material rewards; • Valuation placed on the combination of the first and second.	Opportunity: The range of the values of the outcome variables potentially affected in a situation.	Status quo: none of the values on any of the state variables have changed.
Action-outcomes linkages: Link between control variable and state variable that causes the state variable- to come into being, to disappear, or to change in degree.	Certainty: Every available action is linked directly with one and only one outcome.	Risk: One-to-many relationships between actions and outcomes with known objective probabilities.	Uncertainty: One-to-many relationships between actions and outcomes with unknown objective probabilities -	
Power: The value of the opportunity (the range in the outcomes afforded by the situation) times the extent of control.				
Connecting action situations: by linking action arenas	Organizational linkages: series of within organizational action situations linked through outcomes in sequence	Multiple level analysis- nesting of arenas across several levels of analysis, like: • Operational rules (day-to-day); • Collective-choice rules; • Constitutional choice; • Meta-constitutional rules	Level-shifting: Shift within previously established rules to making decisions about the rules structuring future actions.	
Analysing	Predicting Outcomes	Evaluating Outcomes: • Efficiency; • Equity etc.		

Source: Ostrom, 2005, pp.32-68

Table 4: Instances of Sub-Systemic Perturbations

Sub-system	***Changes***
Technology	• Invention and innovation- end-of-pipe or radical (disruptive or non-disruptive); • adoption, diffusion, commercialization; • Product, process or organizational changes (eg. Business model innovations, Rebranding, changes in Vision or Mission etc.)
Institutions	• Regulative- new laws, taxation and subsidies, non-monetary incentives or punishments, nudge units, national and international trade regulations; • Normative- costs and benefits (social or private), standards; • Cognitive- environmental valuation
Knowledge	• Research and patents, • New practices
Behaviour	• Reflected in choices made during • Production, • Consumption, • Law making and • Other action situations
Environment	• Change in sea-level, • Change in global temperature • Changes in rainfall patterns • Disappearance and emergence of new species

Source: Prepared by the authors

Table 5: PTEC at a Glance

Services	***Details***	***Expected Benefits/Outcomes***
Power Services	• Domestic & commercial power supply via biomass gasification through its eco-innovation • Domestic power supply via solar DC micro grids • Domestic & commercial power supply via hybrid model	For PTEC • Profits • Carbon credits • Recognition • Tax concessions • Subsidies • Others
Environmental Services	• A net saving of around ₹ 3 crores and 15000 tonnes of carbon dioxide equivalent per annum • Supply of rice husk from local rice-mills • Sourcing of other materials locally to reduce carbon footprint	For Society • Lower carbon footprint For Locals (as individuals) • Better quality of life- Eco-efficiency • Better prices for primary products- Increased value of natural resources like rice-husk and bamboos in their endemic environment
Livelihood Services	• Employment to locals in plant operation • Employment of local women in incense stick making • Training university for skill development	For Locals (as individuals) • Employment • Income • Skill • Rent
Social Services	• Obvious social advantages of electrification • Metering instils value of electricity and prevents its wasteful consumption (another eco-innovation)	For Locals (as individuals) • Accessibility (television, internet use, mobile phones) • Ease • Increased ability to work Society • Responsible consumption habits
Business Development Services	• Franchisees to involve locals as well as business training • Local value addition- rice husk to power, rice husk ash to incense sticks	Locals (as individuals) • Inculcating entrepreneurial capability

Source: Prepared by the authors

Table 6: Co-evolution of Sub-systems, Stage II - Bio-Mass Plants

Sub-system	***Before the games begin***	***After the games culminate***
Behavioural	• Resistance from locals • Considering PTEC's presence harmful ○ For eg. The fear of locals that their cattle would get electrocuted from the distribution infrastructure laid down by PTEC	PTEC's choice to scale up

Institutional	Regulative:
	• Rules laid down by government regarding
	  ○ Rural electrification
	  ○ Subsidies for rural renewable DDG
	• Rules laid down by PTEC
	  ○ Regarding subscription
	  ○ Price per unit of electricity
	  ○ Number of hours of service
	Normative:
	• Government should provide infrastructure services
	Cognitive:
	• Locals
	  ○ Belief that government is the provider of services
	• PTEC
	  ○ Waste management to profit
		Regulative:
		• PTEC
		  ○ Need for informal contract through survey regarding the number of households committed to buying subscription from PTEC
		  ○ Need to monitor operations
		Cognitive:
		• Locals
		  ○ Waste has value

Knowledge	Past experience in family business	• PTEC:
		  ○ Learning how to commercialize an innovation
		  ○ Need to engage locals to build trust
		• Locals:
		  ○ Learning how to use several electrical appliances

Technology	Use of technology developed in the last series of games	-
Environment	To lower carbon footprint To use bio-waste	Doing away with immediate health hazards of pollution from kerosene and diesel use

Source: Prepared by the authors

Table 7: Co-evolution of Sub-systems in Stage III - Evacuation

Sub-system	***Before the games begin***	***After the games culminate***
Behavioural	Resistance from locals- meters broken (at bio-mass DDG locations)	PTEC's choice to move out
Institutional	Regulative: • Rules laid down by government regarding ○ Rural electrification ○ Subsidies for rural renewable DDG ○ Increased focus on solar energy • Rules laid down by PTEC regarding ○ Subscription ○ Price per unit of electricity ○ Number of hours of service ○ Monitoring of operations ○ Wages ○ Hours of work ○ Franchisee related contract etc. Normative: • Government's duty to the people. Cognitive: • Locals ○ Belief that government is the provider of services ○ PTEC an outside private entity and hence not trustworthy	Normative: Government's extending grid to several rural locations, some already served by PTEC
Knowledge	Engaging locals to build trust (local franchisee partners)	• PTEC ○ Need for alternate locations that are not feasible for Grid Extension ○ Need for waste management. ○ Raising the locals' skill for better involvement with PTEC
Technology	Bio-mass equipment improved and setting up time for a plant lowered to a week	• PTEC ○ Need for renewable source ○ New feasible technology
Environment	To lower carbon footprint To use bio-waste	Doing away with immediate health hazards of pollution from kerosene and diesel use

Source: Prepared by the authors

Table 8: Co-evolution of Sub-systems in Stage IV - More Inventions

Sub-system	***Before the games begin***	***After the games culminate***
Behavioural	• Electricity theft, • Exceeding subscriptions o Especially in bio-mass plant locations	PTEC's choice to scale up this model at apt locations

Institutional	Regulative:
	• Rules laid down by government regarding
	  o Rural electrification
	  o Subsidies for rural renewable DDG
	• Rules laid down by PTEC regarding
	  o Subscription
	  o Price per unit of electricity
	  o Number of hours of service
	  o Metering
	  o Monitoring of operations
	  o Wages
	  o Hours of work
	  o Franchisee related contract
	Normative:
	• Expectations from government
	Cognitive:
	• Belief that government is the provider of services
	• Inability of government and financers to make meaning of the solar micro-grid operation as a commercially viable venture
		-

Knowledge	PTEC: • Experience in Africa and smart metering technology knowledge. Locals: • Learning from time spent in urban areas as migrants (like electricity theft)	PTEC: • Need to lower the fixed costs. Locals: • Learning how to use several electrical appliances and not so obvious benefits of electrification
Technology	Smart meters developed for DC micro-grid.	Technology needed to lower battery cost
Environment	To lower carbon footprint	Doing away with immediate health hazards of pollution from kerosene and diesel use

Source: Prepared by the authors

Table 9: Co-evolution of Sub-systems in Stage V - Need for Business Model Innovations

Sub-system	***Before the games begin***	***After the games culminate***
Behavioural	• Electricity theft, • Exceeding subscriptions, • Resisting cliques	-
Institutional	Regulative: • Rules laid down by government regarding o Rural electrification, o Subsidies for rural renewable DDG; • Rules laid down by PTEC regarding • Subscription, o Price per unit of electricity, o Number of hours of electricity, o Metering. o Wages o Hours of work o Franchisee related contract Normative: • Expectations from government. Cognitive: • Belief that government is the provider of services	Regulative: • Rules laid down by government regarding o Slow substitution of solar with thermal eg. Renewable Purchase Obligation of all thermal powered distribution systems to buy and distribute a certain portion of supply energy produced through solar means Cognitive: • PTEC o Self-sufficiency important for committed finance
Knowledge	PTEC: • Waste management through incense-sticks manufacturing Locals: • Learning from time spent in urban areas as migrants (like electricity theft, constant comparison between PTEC and their urban industrial employers)	PTEC: • Need for committed finance • Need for transparent system and increased involvement of locals to build trust
Technology	-	PTEC: • Technology needed to put solar on AC grid • Technology needed to connect bio-mass electricity distribution system with smart meters • Technology to merge the two renewable electricity generation methods into one
Environment	To lower carbon footprint Waste management	Doing away with immediate health hazards of pollution from kerosene and diesel use

Source: Prepared by the authors

Table 10: Co-evolution of Sub-systems in Stage VI - Hybrid Model

Sub-system	***Before the games begin***	***After the games culminate***
Behavioural	PTEC: • Self-reliant Locals: • Cliques satisfied- younger locals living and working in and around the site	PTEC: • Scaling up the Hybrid Model Locals: • Trust towards PTEC
Institutional	Regulative: • Rules laid down by government regarding o Rural electrification o Subsidies for rural renewable DDG • Rules laid down by PTEC regarding o Subscription o Price per unit of electricity o Number of hours of electricity o Smart-metering o Easy payment o Transparency o Wages o Hours of work Normative: • Expectations from government. Cognitive: • PTEC o Self-sufficiency for committed finance • Locals o Belief that government is the provider of services	Normative: • Expectations from PTEC for even better service Cognitive: • Potentially disruptive innovation helps locals realize that private players can be efficient
Knowledge	• Increased accountability and local participation inculcate locals' trust • Raise certainty of the business environment	-
Technology	• Technology adjusted to put solar on AC grid. • Technology adjusted to connect bio-mass electricity distribution system with smart meters • Technology adjusted to merge the two renewable electricity generation methods into one	-
Environment	To lower carbon footprint	Doing away with immediate health hazards of pollution from kerosene and diesel use

Source: Prepared by the authors