Distribution of improved cook stoves: analysis of field experiments using strategic niche management theory

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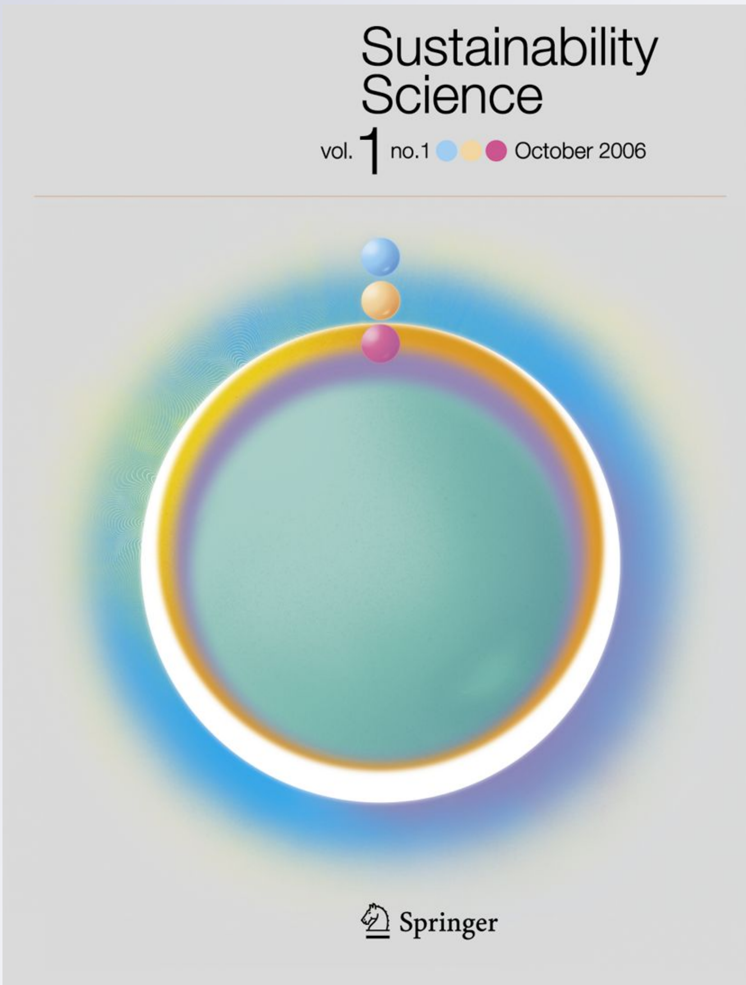

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SPECIAL FEATURE: ORIGINAL ARTICLE Socio-technological transitions

Distribution of improved cook stoves: analysis of field experiments using strategic niche management theory

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Abstract Close to three billion people globally and over 800 million in India are dependent on direct combustion of unprocessed solid biomass fuels in inefficient traditional mud stoves. Current cooking practices, besides causing serious health problems, are also being linked to emissions of climate change and pollution agents such as black carbon and ozone precursors. In India several initiatives have been taken up to tackle the problem but the present trajectory of limited technical and social change in cooking energy use is nonetheless persistent in rural areas. In order to develop and scale up alternative cooking technology options, we have analyzed, using the principles of strategic niche management, two projects implemented by The Energy and Resources Institute (TERI) in nine villages in India. The assessment, while highlighting reasons for stability of the current cooking regime, also points to triggers that can destabilize the regime. The focus is also on assessing the influence of protection in the form of subsidies on the process of transition. User preferences relating to social and technical aspects have been analyzed, pointing to forced draft cookstoves as the preferred option notwithstanding cost reductions to address affordability concerns. The assessment indicates that while it is critically important to understand and address the preferences of users and to improve the technology, scaling up will depend on stove cost reduction through further research. Creativity in effective financing schemes and support structures put in place by fostering public–private partnerships are also needed.

Keywords Cook stoves · Strategic niche management · Rural energy · Sustainability transition

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Introduction

More than 2.7 billion people, primarily living in rural areas of Asia, Africa and South America, are dependent on direct combustion of unprocessed solid fuels such as wood, dung and agricultural residues in inefficient traditional mud stoves for meeting their cooking and space heating energy needs (IEA 2011). For instance, in India, close to 13 million rural households (855 million people) use solid unprocessed bio-fuels such as wood, agricultural waste, and dried cattle manure in traditional mud stoves for cooking purpose (NSS 2011; IEA 2011). Solid biomass-based fuel burning in mud stoves is characterized by incomplete combustion, resulting in emission of pollutants such as particulate matter, carbon monoxide, nitrogen and sulfur oxides and other toxic compounds including poly-aromatic hydrocarbons, which occur inside, mostly poorly ventilated kitchens in rural areas (Kim et al. 2011; Desai et al. 2004). The negative health effects of such cooking practices are well documented and half a million premature deaths and nearly 500 million cases of illness are estimated to occur annually as a result of exposure to smoke emissions from biomass use by households in India (UNDP/ESMAP 2003). Recent literature also links current cooking practices with emission of climate change agents such as black carbon

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(BC), and ozone precursors, making it an environmental hazard (Rehman et al. 2011).

In India, several initiatives have been taken up in recent years to tackle the unsustainable practice of direct combustion of solid biofuels in traditional stoves (Venkataraman et al. 2010). Yet, the present trajectory of limited technical and social change in the rural cooking energy situation is nonetheless persistent and is likely to continue in the same direction (IEA 2002). Government initiatives to introduce clean cooking alternatives like liquefied petroleum gas (LPG) have had limited success as penetration in rural India is limited to only economically affluent rural households (Nautiyal and Kaechele 2008; Pachauri and Jiang 2008). In spite of subsidized prices in India, high up-front costs associated with the equipment needed to use LPG (stoves and cylinders), low population density, poor road infrastructure, and lack of supply security and low economies of scale in rural areas pose challenges to commercial viability of LPG distribution networks at current prices, hindering its wider adoption among rural households (Pachauri and Jiang 2008; UNDP/ESMAP 2003). Another clean cooking technology, biogas, is capital intensive, with no tangible monetary savings on invested capital if biogas is used for cooking only in households with access to non-monetized fuel (Quadir et al. 1995). Large-scale dissemination of biogas is also restricted by household level ownership of cattle, as a minimum of four to five cattle are required per household to maintain a family size biogas plant irrespective of availability of sufficient land and water (D'sa and Murthy 2004; Quadir et al. 1995).

The above discussion indicates that cooking technology switching in rural households in the developing world in general, and India in particular, has emerged as one of the key concerns related to transitions to a more sustainable energy sector (Rehman et al. 2010). However, in the absence of accepted benchmarks for biomass-based cooking energy provision, the term "improved cookstove" has become a catch-all phrase that encompasses a range of different cooking technologies that may enhance either heat transfer efficiency or combustion efficiency or both with varying degrees of performance and cost (Kar et al. 2012). The existing scenario necessitates creation of "spaces" where interested players like stove developers and grassroots implementers can develop, customize and disseminate improved cooking technologies. Such experimentation with technology and dissemination models is required as the first step towards sustainable transition in the rural energy sector.

The Energy and Resources Institute (TERI), a not-for-profit research institute based in New Delhi, has undertaken two "societal experiments" that provide insight into consumer psyche and assess/improve upon cooking technologies. We have used the strategic niche management (SNM) framework to examine these experiments.[1] Transition scholars view SNM as an important tool with which to "understand and manage" innovations (like clean cooking technologies) and "facilitate their diffusion" (Witkamp et al. 2011). The socio-economic, cultural and technological characteristics of the current rural cooking energy regime are reported in this paper. We have also assessed and highlighted the primary reasons for stability of the socio-technical regime (usage of mud stove), which are characterized by deep and embedded links between technologies, habits, cultural norms and practices, together with a high level of inertia (Rehman et al. 2010; Kemp et al. 1998; Berkhout et al. 2010). We have also described the 'technological niche' created under these two experiments where technology innovations are protected from existing regime pressures. The analysis of experiments using the SNM framework led to identification of various drivers that may enable a regime shift from traditional mud stoves to less smoke-emitting and more energy-efficient improved cooking technologies.

SNM experiments

The two experiments were carried out by TERI in nine villages in the state of Uttar Pradesh in India. The first experiment focused on development, customization and dissemination of environment friendly sustainable technologies, which included improved biomass cookstoves, in eight villages. Supported by the Department of Science and Technology (DST), Government of India, this experiment (hereafter referred to as DST) provided a platform for user trials for improved cookstoves. In order to introduce instability into the current regime, the experiment focused on two aspects. First, optimization of cookstove technology was approached by taking into consideration the socio-technical needs of the local population, e.g., vessel dimensions and family size. Second, a sales and service set up through local entrepreneurship was set up. In the process of arriving at a new design, a total of eight improved stove models were tested first in the laboratory and then some selected models were trial tested at the rural household level to determine the efficacy of the technology to identify the needs of households (TERI 2010).

Laboratory testing was carried out as per internationally accepted protocols, namely Water Boiling Test version 3.0, and Controlled Cooking Test version 2.0. For user trials, in

[1] Kemp et al. (1998) defined SNM as "the creation, development and controlled phase out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology, (2) enhancing the further development and the rate of application of the new technology".

each of the eight project villages, ten households willing to cooperate and provide help for conducting various experiments were selected. However, efforts were made to short list willing households, which were selected in such a way so as to represent different types of cooking fuel usage (e.g., fuels like biomass energy fuels, coal, charcoal, kerosene, LPG, biogas, etc.), economic status, housing characteristics (such as location of kitchen/stove-indoor/outdoor), and ventilation conditions in the house. These households were provided with the short-listed models on a rotational basis (on a weekly basis), viz. each of the selected household would have access to all the short-listed models of improved cook stoves. The rationale behind the concept of rotation of devices was to enable a household to compare various devices to reduce bias and judge user acceptance from a common platform.

Under the project, awareness generation camps were organized, which resulted in both awareness and interest (manifested in queries received in our site offices about the cook stove) from villages in the vicinity of the experimental sites. A business value chain was developed where local entrepreneurs linked up with stove manufacturing companies to cater to interested potential consumers. In the vicinity of the experimental sites in a rural market area, a retail outlet dealing with improved stoves, solar lanterns, and other renewable energy/energy efficient products was opened to provide interested consumers with the opportunity to see the product first hand, purchase it and get the stove serviced locally, when necessary.

The second experiment, Project *Surya* (hereafter referred to as *Surya*), with support from United Nations Environmental Programme (UNEP) and Scripps Institute of Oceanography, University of California, San Diego (UCSD) introduced improved biomass cookstoves in almost all households in one village. Based on the results of the user trial in the DST experiment and field trials to measure BC concentration levels in rural kitchens, the best IC model was used for dissemination. The experiment had a mandate to lower the baseline level of indoor air pollution with special focus on BC at the indoor (household) and ambient (village) level. The experiment further focused on assessing user preferences and attitudes related to cookstoves with the objective of bringing about a transition in the existing cooking energy regime. A baseline survey in *Surya* was designed strategically for assessment of social, cultural, technological and economic characteristics of the present regime. The survey was carried out in four project villages/hamlets comprising of 487 households. Of these, 404 households participated in the survey, and 83 households had either migrated to cities for the duration of the survey or were not willing to participate in the survey. The survey captured the opinion of both the primary decision maker of the house (generally, the eldest working male member) and the primary cook of the house (generally, the female member). The survey had three distinct sections. The first section dealt with the socio-economic indicators of the household, such as family size, occupation, assets and monetary income, The second section dealt with the primary decision maker's perspective on his/her willingness to purchase a new stove, maximum possible investment, and benefits he/she would look for in such a stove, The third section sought information from the primary cook about the cooking pattern-schedule, fuel sourcing and usage, reason for continued usage of mud stove and benefits she/he would seek from a new stove. The surveys were carried out prior to distribution of stoves to assess their expectation about a new technology. As the households are already locked into the existing regime, it was deemed appropriate, from the lens of transition, to understand the factors that could motivate them to switch to an alternative technology. The strategy served two crucial purposes. First it gave an insight into the reasons for current regime dominance due to which there may not be a "felt need" for alternatives. Second, the survey helped to understand the relative advantages desired by stove users in any new technology, which can be interpreted as a latent need. This second insight is critical to nurturing innovation in stable regimes, contributing to initiation of the process of regime change (Raven 2005).

Viewing these interventions through the lens of SNM, the two transition experiments represented small initiatives in which the earliest stages of a process of socio-technical learning took place. The experiments brought together new networks of actors such as research institutions, policy makers and development agencies with knowledge, capabilities and resources, cooperating in a process of learning related to user acceptance of existing cooking technologies as well as development and application of new cooking technologies in the selected environment.

Existing regime: biomass as the main fuel source

In the project area the average family size comprises six members. Cooking in the project villages is invariably the responsibility of women, and they typically spend about 4 h a day on cooking. There are typically two major cooking sessions in a day—one in the morning and another in the evening. However, each cooking session on an average lasts for about 1.5–2.5 h daily. The staple diet in the households consists of rice, vegetables, pulses and *chapati*—kneaded and baked wheat bread (TERI 2010).

Traditionally, locally procured biomass such as firewood, crop residues and dried (cattle) dung cakes are used as fuel in traditional cooking devices locally known as *chulha*, made of clay, with one or two burners that require quarterly maintenance. While majority of households used firewood as main cooking fuel, some households used cattle dung cake as primary fuel. For the households that use firewood, the average wood consumption is around 6 kg per day per household. A majority of families in the villages do not purchase fuel wood, but collect it from the roadside or their own fields. With regard to other fuels, crop residue is used in the households generally for igniting the *chulha*. However, in the post-harvest season, the share of crop residue in the fuel mix is higher compared to the annual average. About 1 % of households have LPG but its usage is infrequent and serves the purpose of quick cooking, for example preparation of tea for a guest. A single cylinder containing 14.2 kg LPG usually lasts for more than 3 months (TERI 2010).

The above-mentioned data clearly indicates that biomass in general, and fuel-wood in particular, are the main sources of fuel in the project area. The widespread use of biomass clearly indicates a level of stability of the current cooking regime that is centered on solid biomass being burnt directly in traditional mud stoves, making it important to ascertain the reasons for continuity of existing practices.

Regime stability

There are no direct monetary costs attached to the production and maintenance of traditional stoves in rural societies across developing nations (Kar et al. 2012). Field observations have indicated that women in rural households have the skillset (passed on over generations) to build a mud stove from locally available mud and bricks within a few hours and they can use it after sun drying for 2–7 days (depending on weather). Once cracks appear on the stove body after 6–10 months of usage, the stove is repaired with a layer of clay on the crack or destroyed, and a new one quickly built.

Survey data indicates that the strength of the current regime derives from the existing favorable economics of using traditional stoves. This is borne out by the fact that a majority (84 %) of respondents reported zero or negligible capital investment as the primary reason for their continued use of traditional mud stoves (Fig. 1). Further, for 77 % of households, linkage of mud stoves with local tradition/customs was the second most important reason for continued usage of mud stove, while 73 % of respondents reported that their habituation to mud stoves would count as the third most important reason for their dependence on such stoves; 51 % of respondents stated that the fourth most important reason for continued usage of mud stoves is because they are user friendly. On the other hand, 38 % of respondents stated that 4th most important reason for preferring traditional mud stoves is because they do not need any technical expertise to operate or service.

In contrast to many transitions where the cost economics advantage of alternative technologies has emerged as driver of regime change (Raven 2005), in the case of improved cookstoves cost emerges as the biggest barrier as no commercial technology alternative can surpass the negligible investment that is required for the traditional stoves. It is indeed exceptional for innovation to occur considering the alternative option for the consumer entails zero monetary cost.[2] Similarly, social beliefs, including user convenience and compliance with existing cultural practices, also emerged as important regime stability factors, which validates the theory of regime stability (Geels 2004).

Barriers to regime change

The alternative cooking technologies are either mature (LPG) or other improved cookstove models at a relatively less advanced stage of development. When questioned about the reasons for not switching to alternative technologies 88 % of households expressed satisfaction with the traditional cookstoves and due to the absence of "felt" need, over 63 % of households were reluctant to try alternate technologies (Fig. 2). Lack of availability as well as knowledge about availability of alternatives also emerged as dominant factors contributing to existing regime stability which in turn led to anxiety about the unknown or perceived uncertainty about alternate technologies (Fig. 2).

Triggers for potential regime instability

Instability in a regime is not a precondition to transition; even stable regimes change over time (Raven 2005). It is important to identify if the users (critical component of actor network) of a regime are sufficiently 'open', 'stable' or 'adaptive' to accept innovations, and then to identify triggers of regime change to expedite and increase the resource efficiency of the process (Raven 2005; Kemp et al. 1998). Triggers of regime change were identified by an assessment of desired features in alternative technologies that can provide a competitive advantage over existing technology regimes and assessment of alternate technologies in the context of user expectations.

The survey revealed that 74 % of households ranked affordability as the most important factor that would attract

[2] Field experience suggests that if the household is purchasing fuel wood, fuel savings are considered during the decision making process of whether to purchase an improved stove. Other indirect costs, such as health, drudgery and other social costs, are often ignored during decision-making.

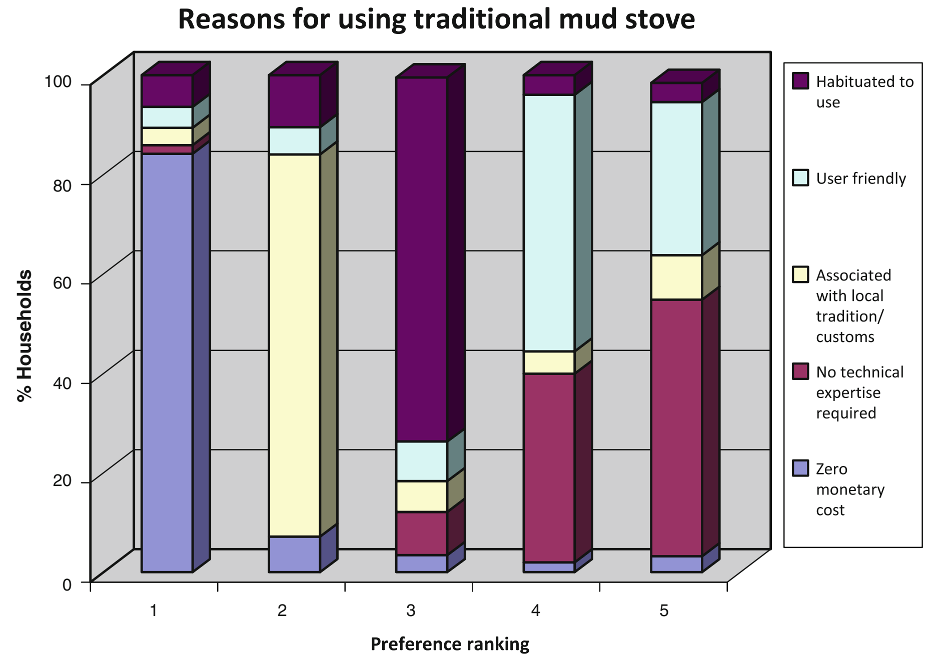


Fig. 1 Regime stability factors: current technology usage triggers

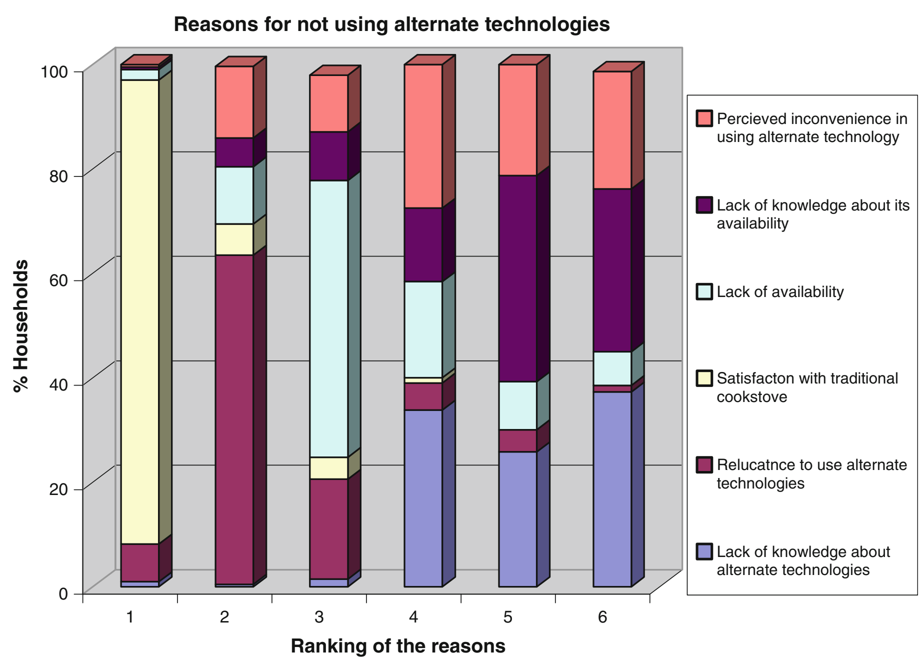


Fig. 2 Regime stability factors: alternative technology barriers

them to a new technology (Fig. 3). This indicates that there is openness to regime change but economic factors are the primary drivers when households are making a decision about adoption of an alternative technology to replace the existing "free" technology. 60 % of households ranked reduction in time taken for cooking as the second most important motivator for switching to alternate cooking technologies, while 50 % of respondents cited convenience of use as the third most important factor for acquiring an alternative technology (Fig. 3). This indicates that users may prefer an "affordable" alternative technology, which results in significant saving of time and effort. The majority of households ranked efficiency and cleaner cooking as less important factors, indicating that households lack awareness or give lower priority to the negative effects of the current technology regime (Fig. 3).

The survey clearly corroborates earlier findings that a complex web of social, economic, cultural, technical, organizational and individual factors determine the adoption of new technologies [such as improved cookstoves] (Segal 1994). Hence, technical efficiency parameters (thermal efficiency and combustion efficiency are

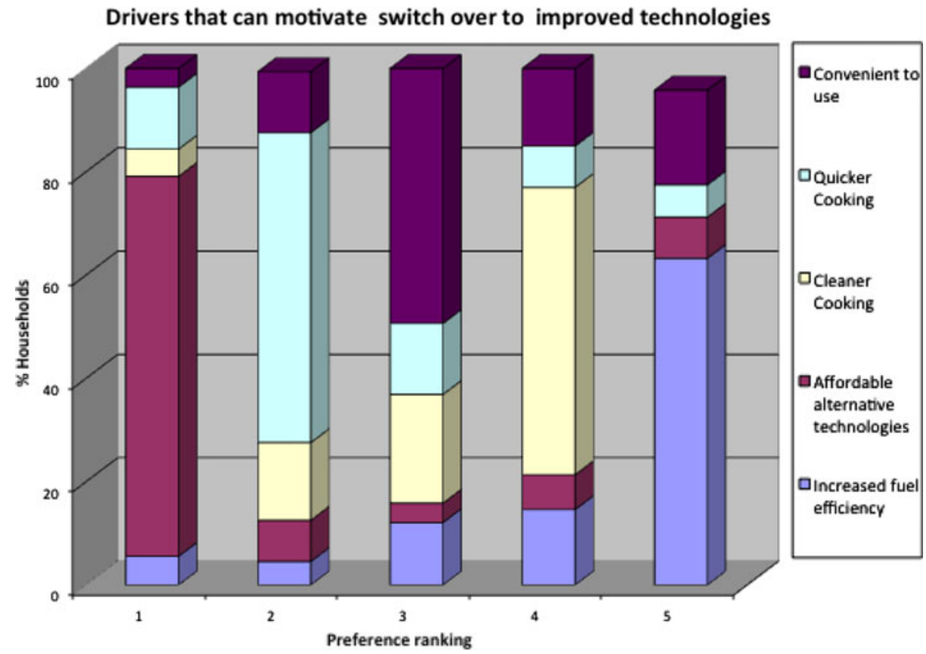


Fig. 3 Desired attributes in alternatives of traditional cookstoves

indicators for fuel savings and emissions, respectively), though important, are rarely the exclusive factor determining whether or not an improved cookstove is widely adopted. For instance, apart from affordability, the technology must meet a variety of cultural requirements, such as ease of cooking.

Introducing instability into the current regime

The introduction of instability in the regime required a marked improvement in the technology so as to offer substantive benefits to the end users. From a technical point of view, the cookstoves can be segregated into two broad categories based on airflow sources, one that naturally enhances the convection flow called "natural draft stoves" and the other in which the air is forced through a fan into the combustion chamber and hence called "forced draft stoves" (Kar et al. 2012). Thus, a portion of the survey focused on the comparison between natural draft and forced draft stoves disseminated for pilot testing that helped in recording and understanding community preferences with regard to different stove options. On the technical aspects, 86 % households felt that natural draft stoves are able to burn multiple fuels, while 67 % stated the same about forced draft stoves (Fig. 4); 83 % of households stated that forced draft stoves were able to reduce smoke while only 59 % stated that natural draft stoves reduced smoke. A total of 73 % of respondents also indicated that time taken for cooking was reduced (in comparison to traditional mud stove) for forced draft stoves, while only 52 % of households stated the same about natural draft stoves (Fig. 4). On the non-technical side, aspects such as the ease of operation, aesthetics, quality of cooked food and burning safety concerns, it was the forced draft stoves that found favor with most households (Fig. 4). Hence, it was evident that destabilization in the current cooking regime could best be introduced by the forced draft cook stove technology.

The desire of households to have a technology that, besides reducing costs, was also convenient, required much less time and produced considerably reduced smoke is addressed by a new stove designed as part of this experiment. The stove has been patented and is currently in the process of being commercialized. It helped considerably in destabilizing the current regime. While the earlier commercially available forced draft stove was in the range of US $70–$90, the new stove is priced around US $45, which is comparable to some commercial natural draft stove models.

Role played by protection

Protection is the main dimension that draws the boundary between niches and regimes, and the different players must strike a continuous balance in exercising and ending protection in an experiment. In the *Surya* and DST experiments, different levels of protection were in place. While in *Surya* initially the cookstoves were disseminated for free, in DST the cookstoves were initially subsidized.

We attempted to understand the interplay of stabilization and protection in the context of improved cooking

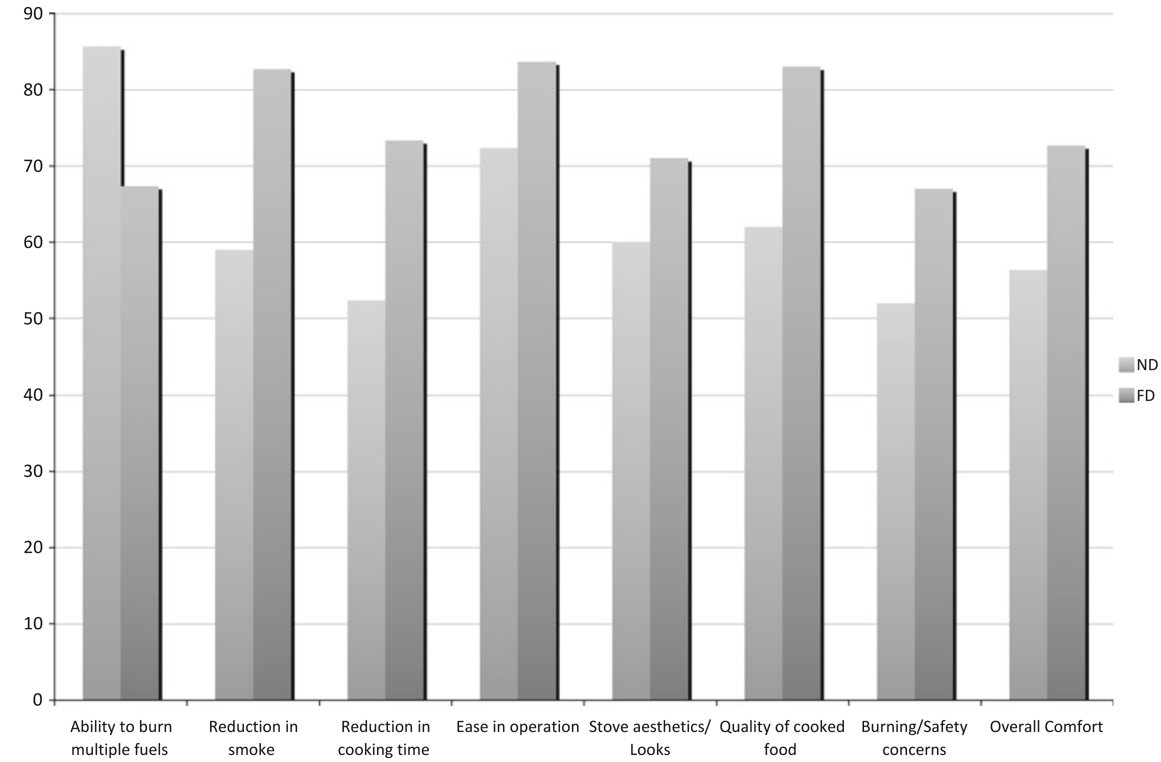


Fig. 4 Feedback from users on the benefits of improved stoves

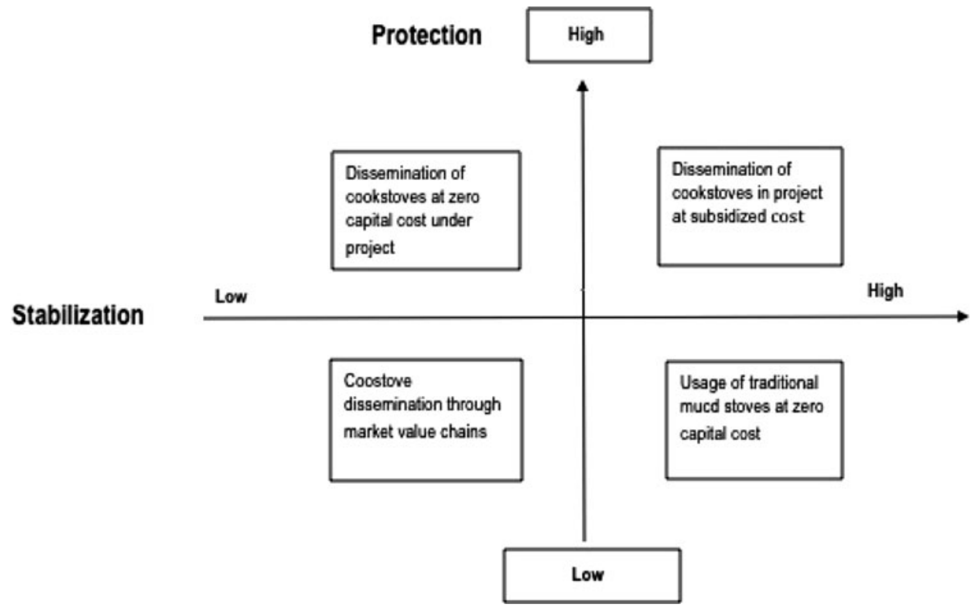
technologies (Fig. 5) using the framework developed by Raven (2005). The horizontal axis represents the level of stabilization as it represents the stability in rules at the niche level and to what extent this level provides a structure to local practices in experiments. The vertical axis represents the level of protection from rules in the regime. The dissemination of cookstoves at zero capital cost under the Surya experiment (upper left-hand corner grid) represents high level of protection (greater subsidy) and low stabilization (less consumer stake as they did not invest in the product). It is an example of a technological niche that happens in the early phase of introduction of technologies where the focus is on field trials ("real life context") of the innovation and learning about its desirability (Raven 2005). On the other hand, the baseline (existing regime) scenario of non-monetized mud stove usage by almost 100 % households (lower right hand grid) is characterized by high stabilization in the long term that requires zero or minimum protection. The initial phase of the DST project when subsidized cookstoves were made available (upper right-hand corner) represents a high level of protection along with higher level of stabilization. The lower left hand corner grid represents the later phase of the DST project when entrepreneurship and creation of a local value chain had been introduced, leading to sales of stoves at market price. Here, protection is no longer needed, or needed only in a limited form while there is more certainty about technological design, functionality and models. It represents the early phase of a market niche.

Expected future trajectory of transition experiments

Four patterns of niche formation may emerge from the cycle of experimentation, and not all niches lead to the transformation of the dominant regime. In a number of cases the experiment leads, at best, to the formation of a technology or a market niche and stagnates beyond it (Weber et al. 1999; Hoogma et al. 2002). To understand this better it would be useful to look at the various patterns of niche formation. The first pattern involves technological niche proliferation. The experiments carried out by TERI should be further replicated (after modifications to suit local conditions) in various parts of India and in other developing countries. Such initiatives can provide more robust localized evidence and technologies, thereby creating multiple technological niches. A second pattern is characterized by conversion of technological niches into one or more market[3] niches, i.e., when the technology

[3] A small but profitable segment of a market suitable for focused attention by a marketer. Market niches do not exist by themselves, but are created by identifying needs or wants that are not being addressed by competitors, and by offering products that satisfy them.

Fig. 5 Analyses of the stability and protection in the experiments



becomes economically sustainable but has still not dislodged the dominant regime. The cook stove technology solutions has a long way to go in terms of technology innovation and dissemination model development in these multiple technological niches to be able to progress to a market niche. In the third pattern, several stages of technological and market niches makes the innovation a dominant technology, and thus transform the regime. This is not possible in foreseeable future without significant activities linked to the first two patterns. In the fourth pattern, technological or market niche extinction, the novel technology fails to attract further support and becomes (again) a research and development option. This has happened in past cases of improved stove initiatives because innovations failed to deliver on what potential consumers wanted at a specified price.

The technology niche created in the two transition experiments discussed above would be contingent upon the adoption of the disseminated cookstoves by the households, and success achieved in the technological niche in turn would depend on its ability to attack the stability of the existing dominant socio-technical regime (traditional biomass cooking practice in rural areas). While the Surya experiment is still in the process of creating a technological niche, the DST experiment has moved to the stage of technological niche proliferation through the setting up of entrepreneurial ventures. Both experiments are yet to arrive at the stage of regime transformation or market niche creation.

The challenge that the two TERI experiments have highlighted is the need to further reduce the cost of the forced draft stoves from the existing level of $45 (brought down under the project from $80) while adding to the improvement of features. The process is being taken forward in the DST experiment by development of a forced draft stove and inverter that can operate both the stove and a light point using solar or grid electricity.[4] As the additional cost is only $10, dovetailing the lighting option makes the stove more attractive and relatively higher 'value for money' for the community.

Conclusions

Scaling up experiments over wider geographic boundaries requires the formation of a technology niche; however, this in itself would not be sufficient for a regime shift. The technology niche formed eventually has to transform into a market niche, which would have to scale up to wider geographical areas for a regime transformation to happen. Improved biomass cookstoves are expensive compared to the traditional mud stove (without the subsidies), require a significant change in user habits (like fuel processing) for some stove models like TLUD gasifier stoves (Mukunda et al. 2011), and, at the initial level, may not hold much value in the minds of potential users. For a successful transition to a cooking energy regime led by improved cookstoves, these obstacles would have to be addressed, in addition to dealing with long-term challenges of developing cost-effective supply chains to remote rural areas. For example, policy level changes like tax incentives for large-

[4] While most households in the project villages have an electricity supply, power outages are rampant, leading to electricity availability for 4–8 h per day. Major technical faults are also frequent, which results in no power access for 2–7 days at a stretch. This makes the option of solar/battery powered light attractive.

scale stove manufacturing, and facilitating and subsidizing loans to enable purchase of stoves by end users can potentially act as drivers towards large scale stove dissemination. The above assessment indicates that while it is critically important to understand and address user preferences and improve the technology, scaling will depend on cost reduction through further research, and on the creativity with which effective financing schemes or support structures are put in place by fostering public–private partnerships.

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