Original research article

Beyond technical smartness: Rethinking the development and implementation of sociotechnical smart grids in India

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A R T I C L E   I N F O

Keywords:
Smart grid
Sociotechnical
Incrementalism
Energy access
India

A B S T R A C T

How smart grids are understood and defined will influence the kinds of smart grids users will encounter in the future and their potential impacts. Practitioners and policymakers largely perceive smart grids as technological interventions. However, a number of social, financial and governmental interventions can also make grids smart, i.e., more efficient, more responsive, more inclusive and more robust. Drawing on qualitative research done using elite interviews, site visits and document analysis of eight micro-grids in India, this paper provides concrete examples of what could be understood as social, financial and governmental smartness, and in doing so, broadens the knowledge on smart grids beyond the technical understanding.

This paper argues that social, financial and governmental interventions are central to ‘smartness’, and that multifaceted and relational sociotechnical approaches will build cheaper, just, more democratic and sustainable smart grids. The paper observes that smart grids are not conceived as smart grids but rather develop incrementally. An incremental approach, rather than pushing a premeditated set of ideas and technologies, reduces adoption of non-contextual interventions as well as unnecessary investments in new technologies. The paper recommends that policymakers and practitioners should understand and develop smart grids as sociotechnical and incremental grids.

1. Introduction

The European Commission’s description of smart grids cites notions of automation, adjustment, consumption, adaptation and prices [1]. While these elements encompass technical, social, financial and governmental aspects, technological thinking predominantly drives the smart grids design and implementation. For example, in a UK Energy Research Council (UKERC) survey of over 100 experts on essential functions of smart grids, the top five responses are “all purely technical” ([2]:5). Similarly, the Indian Smart Grid Forum’s description hails technological innovation above other components: “Smart Grid development is one of the most important technology revolutions currently taking place as electricity grids are the world’s largest pieces of infrastructure still to be digitalised” (Mr Reji Kumar Pillai, President, India Smart Grid Forum, [3]) (emphasis added). Practitioners and policymakers often see smart grids as interventions centred on using information communication technologies (ICTs) to enhance the efficiency, responsiveness, and resilience of electricity grids [4,5]. Yet, a number of social, financial and governmental smart interventions contribute to making Indian micro-grids efficient, responsive and resilient.

How policymakers and practitioners understand and define smart grids often dictates what aspects and which people get included and excluded from them [6]. The purposes behind developing smart grids are inherently social, financial and governmental – e.g. expanding energy access [3], ensuring financial security for electricity utilities [7], and reconciling consumer and producer interests [8]. Also, the impact of smart technologies on vulnerable people is a matter of concern [9]. In demand-side management, evidence shows that preferred solutions differ depending on the problem’s definition as technical or social [6]. When defined as social problems, spaces are created for social innovations and participatory methods [6]. Evidence suggests that technical interventions alone are insufficient [10,11] to address the social, financial and governmental purposes. In the case of sub-Saharan Africa, Welsch et al. [12] call for a focus on smart planning, smart people, just access and smart and just financing. Primarily technological thinking risks overlooking these aspects and interventions. Smart grids require social, financial and governmental interventions.

Building on these, this paper answers the following research question: What characterises smart grid innovations in micro-grids in India and what learnings do they provide to rethink the idea of smartness?

Drawing on data from eight micro-grid case studies in India, this paper provides concrete examples of ‘social smartness’, ‘financial smartness’ and ‘governmental smartness’, like smart meters (Section
5.1) and joint liability groups (Section 5.2). Building on scholarly work that treats infrastructures as sociotechnical systems [13,14], the paper argues that ‘smart’ is more than just technical: smart grids are sociotechnical grids that consist of interconnected elements of technical, social, financial and governmental smartness.

The sociotechnical thinking puts the local socio-cultural and institutional context at the centre of smart grid developments. By doing this, this paper widens the arena of ‘smart’ to argue that: (1) Technologies are not smart inherently unless they consider the context. An electricity meter is smart only if it is both socially and technologically smart. (2) Technologies may not always be needed; Social organisation or financial mechanism can also make the grid smart. These arguments go to the root of the question – what is ‘smart’ in smart grids.

As this section has explained, and the paper demonstrates further through case studies, smart is about making electricity grids ‘better’ than before: more efficient in operation, more responsive to consumer needs, more socially inclusive and more financially robust. The paper elaborates how some micro-grids in India achieve these through non-technical means and provides technical examples that potentially make micro-grids worse for vulnerable people.

Because of these reasons, if a transition to smart grids is to happen, smart should encompass social, financial and governmental. This more comprehensive view of smartness will help policymakers and practitioners: (1) avoid investing in technologies for purposes that can be fulfilled without technology; (2) avoid technological fixes that make some things worse for already vulnerable people. In that way, discussing social, financial and governmental smartness – ways of making the grid ‘better’ – is also a political tactic to make these aspects central to the smart grids policy and practice work rather than afterthoughts. Referring to the non-technical examples in this paper as ‘smart’ is a political device to expand smart beyond technological boundaries.

The paper also observes that sociotechnical smart grids do not develop through a pre-determined intention to create smart grids but rather are incremental. Designers develop micro-grids into smart grids in a stepwise fashion, by identifying one problem at a time and devising one solution at a time. This paper recommends an incremental problem-solution approach for developing smart grids rather than pushing a premeditated set of ideas and technologies. Section 4 further elaborates the incremental problem-solution perspective.

2. Literature review

This section provides a background for this paper and its broader relevance by reviewing the literature on social sciences and smart grids, sociotechnical systems and incrementalism.

2.1. Smart grids in social sciences

In the last 5–7 years social scientific studies, many published in this journal,1 have demonstrated that smart grids bring together many different factors [15]. For example, Throndson and Ryghaug [16:165] explore material participation of citizens through smart meters and find an “energy citizen” half-heartedly accepting the logic of reduced CO₂ emissions through her ‘participation’ but who is dissatisfied by the lack of more substantial engagement. Naus et al. [17: 132] find local energy cooperatives making participation more substantial by balancing between “too personal or too distant” means of cooperation. Some give a taste of reality by providing evidence of experts’ unrealistic hopes on smart meters as the ‘silver bullet’ for user and market concerns [16]. As people’s private energy consumption comes into public domains, others remind about data security and privacy [18]. Others usefully flag the social scientific preoccupation with complexity and remind that

“simplification, abstraction, and homogeneity” are often necessary for the design and operation of sociotechnical systems like electricity grids ([19]:108).

Within the social science literature, smart meters are key loci of interactions between the technical and the social ([15]:154). However, social scientists also need to “widen the narrow ‘smart ontology’ – the belief in a technological fix” ([10]:52–53) and demonstrate that not just the operation of smart grids – their user interactions – but also their designs themselves are sociotechnical rather than just technological. As Schick and Gad ([10]:58) argue, smart grids need the “complex entanglements and generative fluidity of social, technical, political and organizational issues and approaches”.

This paper adds to the knowledge through concrete examples of interactions between the social, technical, financial and governmental in the design and operation of smart grids. In addition, most social scientific work on smart grids is limited to European, North American, and to some extent, Australian experiences. This paper extends this literature to the global South by bringing in the Indian experience.

2.2. Theoretical background

2.2.1. Sociotechnical systems

There are multiple coexisting approaches, discourses and entry points for understanding, analysing, designing and implementing smart grids. Throndson ([20]:283) finds distinct economic, technical and social narratives for smart grids. These aspects are often also entangled, as demonstrated by Skjelsvold et al. ([21]:259), who argue for “linking different forms of practice across collectives, epistemic foundations and through different technologies and objects”. However, practitioners and policymakers largely still approach smart grids from a “dominant technological perspective” ([2]:5; [3]).

This follows the research and policy work on energy, which has an artificial separation of the ‘social’ and the ‘technical’ [14]. This divide is counterproductive because it disregards the “broader social conditions” for embedding technical innovations and ignores the “materiality of the socio-technical systems” that shapes social and technological outcomes ([14]:1361). To navigate this divide, social scientists of energy have engaged with sociotechnical systems: an understanding that social and technical are intertwined, enabling and disabling each other [22]. Sociotechnical systems see “technologies not simply as designed and engineered material objects” but as an entanglement of “producers, infrastructures, users, consumers, regulators and other intermediaries” ([23]:459).

Human Geographers have widely used sociotechnical perspective to demonstrate how material and social flows produce and sustain energy infrastructures ([24]:1936–97). This literature establishes that sociotechnical relationships in the form of “corporate interests, regulatory standards, social expectations, hybrids of human-software-hardware intelligence, and historical legacies of organization and supply” constitute “even the most digitized infrastructures” ([25]:138). For example, looking through the sociotechnical lens, Bulkeley et al. ([13]:9) understand smart grid as “a governmental programme that attempts to order and direct electricity systems”.

Following this sociotechnical logic, Section 5 provides evidence that smart grids are not just about technical smartness, i.e., layers of ICTs, but also about social smartness, financial smartness and governmental smartness, and their entanglements. That is, they consist of layers of socio-cultural processes and organisations, layers of financial systems and layers of governmental organisations that produce and sustain, but also limit and torment smart grids. Smart grids depend on new configurations of users, new social alignments and new financial and governmental arrangements “through new forms of sociotechnical relation” ([13]:32).

2.2.2. Incremental vs radical change

The technological discourse on smart grids often promises and

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1 See ERSS volume 9, Pages 1-188 (September 2015): Special Issue on Smart Grids and the Social Sciences
argues for a radically different future [26], especially considering the rapid actions required in response to climate change [27]. Leapfrogging of technologies in developing countries can facilitate such radical change by leaping “over energy and environmental problems” of richer countries ([28]:123). Smart grids promise such leapfrogging and radical change. Countries like India that lack well-developed centralised electricity systems can leapfrog to smart systems and induce a radical change. In such cases, technologies are seen as “silver bullets” that will change things without any side effects ([28]:123).

Stephens et al. ([27]:210) explain that the dominant electricity system actors often define smart grids in incremental terms, as they are wary of radical changes that may destabilise the system or upset their consumers. Sustainability transitions thinking also frames innovations like smart grids as radical and accords them the agency to destabilise existing dominant regimes [29]. However, whether smart grids are radical or incremental innovations is not this paper’s concern. This paper is concerned with the process of development of smart grids and finds from the empirical evidence that this process is incremental. Human Geography literature on incrementalism is useful in understanding this.

Many infrastructures in the global South, like McFarlane’s [30] example of housing in Mumbai, develop incrementally. As McFarlane explains, a context of resource crunch, and pragmatism about what is needed at a particular point and what is not, often drive incrementalism. Such incrementalism involves, and fosters, a constant process of learning, and is more adaptive [30,31]. In that way, infrastructures are a “doing rather than a finished product” ([31]:7).

Building on his study of electricity infrastructure in urban Accra, Silver ([32]:788) defines incremental infrastructures as “in-the-making, undergoing constant adjustment and intervention, and in a permanent state of flux”. This understanding of incrementalism informs the discussions in Section 4.

3. Methods

This paper draws on data collected from eight micro-grid case studies in seven Indian states (Table 1). Most of these projects do not categorise themselves as smart grids but use, or plan to use various ‘smart’ ideas. The study of micro-grids is useful for three reasons. First, various micro-grids in India are in different stages of development towards becoming smart grids. They reveal a number of different approaches and trajectories towards smartness. Second, micro-grids are experimental spaces. Technologies and approaches developed in micro-grids often also influence the national grid. Third, many micro-grids are working towards a national grid connected future where decentralisation will exist with interconnection (Section 5.4). This will also change the national grid.

Fig. 1, shows the spread of case studies on a map of India depicting the prevalence of kerosene as a source of lighting. Most case studies are located in states with the largest percentage of the population dependent on kerosene, i.e. with the smallest percentage of the population with electricity access. This is important because various state and non-state actors are mobilising smart grids in India for two reasons. Other than the usual drivers of creating a grid that is more robust, responsive and powered by renewable energy, smart grids in India are seen as solutions to a lack of access to electricity ([3]:5). The importance of this additional reason comes up in the rest of the paper as many ‘smart’ interventions respond to this specific problem and develop in the contexts of energy and socio-economic poverty. Such responses are critical as “in addition to being smart, socially just power systems are required...to promote access to modern energy services without marginalising the poor” ([12]:338).

This paper is based on qualitative research for which data was collected through three methods. These different data collection methods provided complementary data presenting a richer and contrasting understanding of ‘smart interventions’ in the eight case studies. First, six qualitative semi-structured interviews of one hour each were conducted with key experts – project managers and experts – during September-October 2016. In addition, informal discussions were carried out with several energy sector experts in India. English was the main language for the interviews and discussions with occasional responses in Hindi. The author’s mother tongue is Hindi, which was helpful in accurately translating the material. Second, site visits were conducted to five project sites, which included micro-grids, solar home systems and community solar lighting projects. During the site visits, observational data was recorded through photographs and research diaries. Discussions with local micro-grid operators, project managers and customers were also carried out during the site visits. Third, data were collected through document analysis, including reports, websites and online databases of case study projects, government bodies and industry associations.

The interviews were transcribed. Following a grounded theory approach, the author coded the transcripts, data from documentary analysis and photographs through multiple iterations to extract themes and develop the analysis. This way the empirical data led the analysis and the theoretical followed to make the wider sense of the empirical. During the writing process, quotes were accredited to the case study organisations rather than the individuals interviewed because the individuals were assumed to represent the organisaton’s view.

4. The incremental grid: identifying problems and creating solutions

We will try to see what the challenges are and what technology is available. And really if we can solve these challenges through technology or not.

[...]

We will try to understand those and then in future decide.

Table 1
Summary of case studies.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Case study</th>
<th>Location</th>
<th>Key Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Ashden India Renewable Energy</td>
<td>Assam</td>
<td>Connecting micro-grid with the national grid of India</td>
</tr>
<tr>
<td>2.</td>
<td>Desi Power</td>
<td>Bihar</td>
<td>One of the earliest micro-grid companies in India. Provides electricity for productive loads for small businesses and agriculture.</td>
</tr>
<tr>
<td>3.</td>
<td>Mera Gao Power (MGP)</td>
<td>Uttar Pradesh</td>
<td>Testing smart pre-paid meters and process management apps. Provides electricity for only lighting and mobile phone charging.</td>
</tr>
<tr>
<td>4.</td>
<td>Mlinda</td>
<td>Jharkhand</td>
<td>Using smart pre-paid meters. Provides electricity for productive loads for small businesses and agriculture.</td>
</tr>
<tr>
<td>5.</td>
<td>Naturetech</td>
<td>Uttar Pradesh</td>
<td>Using mobile payment systems. Provides electricity for only lighting and mobile phone charging.</td>
</tr>
<tr>
<td>6.</td>
<td>OEnergy</td>
<td>West Bengal</td>
<td>Testing smart pre-paid meters. Plans to implement micro-grids</td>
</tr>
<tr>
<td>7.</td>
<td>Selco Foundation</td>
<td>Karnataka</td>
<td>One of the earliest off-grid companies in India. Long experience of social innovations to provide energy access to the poorest.</td>
</tr>
<tr>
<td>8.</td>
<td>SunMoksha</td>
<td>Orissa</td>
<td>The only company in India claiming to have a smart grid. Using smart pre-paid meters and process management apps. Provides electricity for productive loads for small businesses and agriculture.</td>
</tr>
</tbody>
</table>
Selco Foundation

This quote outlines three steps for making a decision towards smart grids: first, diagnosing the specific problems; second, identifying the available technical solutions; and third, determining whether technology can best address the specific challenges. Problems are diagnosed in two ways. Actors conduct studies in villages they intend to set up micro-grids. This helps to understand the specific context. However, this is often not enough. Once a micro-grid is set up, more issues emerge and need responses. Appropriate solutions – technical or non-technical – are identified for these problems more than once during the project lifetime. In this incremental approach, problems are identified and solutions devised at various stages (see also incrementalism in the

Fig. 1. Location of case studies [69].
electricity system in Accra in [32]. Most micro-grids studied in this research take this approach. The ‘smart’ interventions in the eight case studies did not develop from a blank slate, but rather in response to existing ‘pitfalls’ for Indian micro-grids anchored in their specific socio-cultural contexts.

...we knew all the challenges, so we started addressing them one by one. And at the end of the day we realised that we had a smart grid. It was incremental and it started from addressing the challenges on the field rather than the other way around.

SunMoksha

SunMoksha, the only Indian company claiming to have a smart grid, explains that its smart grid is an incremental grid. Desi Power explained during the fieldwork that it picks and chooses specific smart technologies depending on the local situation and the specific benefits of the technology. Other interviewees working with what this paper categorises as ‘smart’ interventions explain that they did not, or do not, intend to create smart grids. To address the challenges faced in the field, they take up specific interventions. By adopting, designing, and engaging with these interventions in a step-by-step manner some end up building smart grids.

As Section 5 demonstrates, identifying problems and thinking of responses in an incremental fashion is useful. In line with McFarlane’s explanation of incrementalism, rather than going with a pre-mediated set of technologies, this step-by-step approach gives space to think about the most appropriate response, whether technical, social, financial or governmental or a combination of these. Although very much focused on technological interventions, IEA ([33]:6) explains that smartening is “an evolutionary process, not a one-time event”. The incremental approach to building smart grids or building grids that turn out to be smart helps save money or spread the costs over a period. This is critical for the micro-grid sector as it already struggles with limited funding. In addition, most micro-grids have customers with marginal incomes. Keeping investments low helps limit electricity prices.

Keeping the incremental problem-solution approach in mind, some critical challenges for micro-grids guide the discussions of responses that this paper categorises as smart. The interviews, site visits, document analysis data, and the literature in energy access and off-grid energy, point to four challenges [34,35]:

1. Providing 24-hour electricity with limited generation capacity
2. Problems with timely rental collection/payment defaults
3. Operation and Maintenance
4. Lack of educated and trained staff in villages
5. Local conflicts between customers and energy providers
6. Rapid extension of India’s national grid

The remainder of this paper is organised around these challenges. A separate section discusses each challenge and lays out examples of ‘smart’ responses – including technical, social, financial and governmental smartness – to each challenge. While by no means an exhaustive list, these examples provide a window into the diversity of approaches and serve as a base from which to glean potential lessons. Assembling these responses based on their need, the micro-grids follow different trajectories towards smartness.

5. Smart responses to key challenges: the making of a sociotechnical grid

This section illustrates the sociotechnical nature of the four challenges for micro-grids and the responses that this paper categorises as smart.

Innovation happening right now is a lot on technology side, but it is needed much more on the business model side, on the finance and the social side. [...] A smart mini grid will be one that takes into account social, financial, cultural issues. And design in a way that can be highly customisable in a way depending on context.

Selco Foundation

This quote illustrates that energy access and smart micro-grids domains have been technologically dominated and many critical socio-cultural aspects, have received less attention [36,37]. Complementing the long-standing arguments of understanding infrastructures as sociotechnical manifestations [13,14], it puts forward the important proposition that smart grids ought to be thought of in an integrated way, as entanglements of technical, social, financial and governmental aspects, i.e., as sociotechnical smart grids. This paper mainly focuses on disentangling some elements of these sociotechnical systems — technical, social, financial and governmental — while also illustrating their entangled nature. With this, the paper presents smart grids as “co-constituted through the continual interrelation of the diverse elements” ([13]:10). As this paper demonstrates, keeping with their sociotechnical nature, ‘smart’ interventions are relational, i.e., they occur through the coming together and working together of technical, social, financial and governmental smartness. In addition, in a sociotechnical smart grid, not all solutions need to be primarily technical. They can be social, financial or governmental.

Table 2 provides a summary of the key challenges, their solutions, their smartness categories and presence in case studies. Subsequent sections explain these further.

5.1. Providing 24 h electricity with limited generation capacity

...in a micro-grid if you can’t give a solution for 24-hours then you know you can’t do any business.....Because people will be dissatisfied.

AIREC

Most micro-grids in India provide electricity for 6–8 hours in the evening. Rural customers increasingly expect 24-hour electricity, in line with the Indian government’s push to provide 24-hour electricity through the national grid by 2022 [38]. However, limits of infrastructure and financial constraints make 24-hour continuous electricity provision difficult for micro-grids. The off-grid sector suffers from limited funding [39]. Limited availability of government subsidies and low-interest loans create hurdles for funding sufficient infrastructure for 24-hour electricity provision [40]. In addition, micro-grids need to seek higher rentals from customers for more hours of electricity and for the timely recovery of their investments. To keep electricity rentals low, and electrify more people with limited funds, micro-grids work with limited generation infrastructure. SunMoksha expresses these concerns in the quote below.

[I have a] Small power plant, catering to a larger customer base. I require smartness. That brings down the capex [capital cost] big time. [...] Because you can’t put a 100 kW power plant there. And then cater to these with the [rental] collection whatever you get and you know, try to break-even. It is not possible.
### Table 2: Five boxes, solutions, smartness and case studies

<table>
<thead>
<tr>
<th>Issues</th>
<th>Solutions</th>
<th>Sociotechnical Smartness</th>
</tr>
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<tbody>
<tr>
<td>Case Studies (n=7)</td>
<td>Sociotechnical Smart Solutions (n=3)</td>
<td>-1 uses part of the solution that only benefits the company. 0 does not use the solution</td>
</tr>
<tr>
<td>Smartness</td>
<td>Case Studies</td>
<td>Solutions</td>
</tr>
<tr>
<td>-1 uses part of the solution that only benefits the company. 0 does not use the solution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial/Social</td>
<td>MGP</td>
<td>+1</td>
</tr>
<tr>
<td>Technical/Social</td>
<td>SunMoksha</td>
<td>+1</td>
</tr>
<tr>
<td>Technical/Social</td>
<td>Mlinda</td>
<td>-1</td>
</tr>
<tr>
<td>Technical/Social</td>
<td>Naturetech</td>
<td>0</td>
</tr>
<tr>
<td>Technical/Social</td>
<td>Desi Power</td>
<td>0</td>
</tr>
<tr>
<td>Technical/Social</td>
<td>Selco</td>
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<td>Technical/Social</td>
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<tr>
<td>Technical/Social</td>
<td>ONergy</td>
<td>0</td>
</tr>
</tbody>
</table>

1. Providing 24-hour electricity with Smart meters mimic kerosene lamps to facilitate continuous supply by limiting continuous use of kerosene oil which villagers have used for decades [44].

2. Timely rental collection / payment Joint liability groups with smart meters facilitate high rates of rental collection with just access to electricity. As long as their account has credits, they can use electricity any time as long as their account has credits. Without smart meters, customers have a cap for the maximum capacity (Watt or kW) – load profile – of electricity they can use at any given time. Within this cap, they can use electricity continuously for 6–8 hours and pay a fixed monthly rental. Since the rental is fixed, and the period of electricity supply limited, often customers leave electrical devices on throughout this period, even if they do not need them [41]. Ethnographic work in Indian villages has found that many people do not install switches and electricity flow to domestic equipment starts and stops when the micro-grids are turned on and off ([42]:189). There is no control on the quantity of electricity (kWh) consumed within the load and time cap.

With smart meters also users have a cap for the maximum capacity (Watt or kW). Also, they have a limit on the quantity of electricity (kWh) they can use for a particular amount of money. This enables a pay-as-you-go system for users rather than a fixed rental. In pay-as-you-go, just like pre-paid systems for mobile phones, customers can add credits to their account when it is running out and maintain their access to electricity. As long as their account has credits, they can use electricity at any time of the day [43]. MGP explains:

[A] Prepaid meter is.....a very simple step. 24 × 7 services are there. [You can] Use whenever you want. If you want to use 5 h a day, just use it. If you want to use 13 h a day, use it. Pay according to that.

Through smart meters, customers can keep track of their electricity use and their credit balance. They become more careful about their electricity requirements [12]. People receive a continuous supply of electricity but do not make continuous use due to the credit cap. By enabling this, smart meters match economies and use patterns of kerosene oil which villagers have used for decades [44].

Once bought from the market, kerosene is available in households at all times. People have a certain level of control over it [45]. They can use kerosene anytime they require but do not use it continuously for fear of running out and having to spend more money. Like a bottle filled with kerosene, smart meters have credits that customers can use anytime they choose. However, they do not use electricity continuously for fear of running out of credits and having to buy more. By matching this familiar energy source, smart meters embed within them existing sociocultural logic of energy use in villages. This makes them contextual and applicable. The social smartness embedded within this technical device is what makes it work in this context. Rolffs et al. [46] and Gerard et al. [43] make similar arguments about pay-as-you-go financing of solar home systems in Kenya and India respectively.

MGP recently started trialling smart meters. During this research two MGP villages were visited, where the first had smart meters and 24-hour electricity supply and the second had electricity supply only in the evenings. In the past, the second village has had smart meters and 24-
hour electricity. When MGP withdrew meters due to technical problems, some villagers requested the reinstatement of the meters as a way of ensuring continuous electricity supply (discussions with villagers and MGP staff, October 2016).

Smart meters broker continuous electricity supply by curtailing continuous use. Continuous supply gives customers the flexibility of using electricity anytime. The prevention of continuous use allows micro-grids to meet higher customer demand and desire for flexibility with limited generation infrastructure. In a situation of constraints – of finance and infrastructure – smart technologies mediate 24-hour supply, marrying technical requirements with the financial.

Out of the eight case studies three – SunMoksha, Mlinda and MGP – use smart meters. One – ONergy – intends to use them in the future. It is common for micro-grids to supply electricity for a limited number of hours per day – mostly for 6–8 hours in the evenings – as Selco, Naturetech and Desi Power, who do not use smart meters, do. However, with smart meters SunMoksha and Mlinda supply 24-hour electricity at prices similar to Selco, Naturetech and Desi Power. By helping to manage the economics of micro-grids, and providing 24-hour supply, smart meters bring technical smartness together with social and financial smartness.

5.2. Problems with timely rental collection and payment defaults

Timely and complete rental collection remains a long-standing problem for the off-grid sector [47]. According to MGP, revenue collection constitutes a bigger problem than electricity provision for micro-grids. Technical interventions like smart meters are one response to this problem. If customers fail to pay, the system automatically disconnects their electricity supply and only reconnects once payment is logged. Using a smart technology the energy provision company protects its micro-grid. However, this approach is not socially smart as it discontinues electricity access for people temporarily unable to pay. This is a problem because “eradication of energy poverty is a long-term endeavour” [33]. If supply is discontinued and households have to go back to polluting and expensive sources like kerosene, the health, education and economic benefits gained from energy access could be lost [48]. Inability to pay rentals is a socio-economic problem more prevalent among poorer people. Embedding protections for such vulnerable customers within smart grids represents a means of distributional justice and is vital to progress the energy justice agenda [49]. Smartness cannot come without justice.

Joint liability groups (JLGs) constitute a ‘smart financial mechanism’ with the potential to help maintain continuous long-term energy access while also protecting the micro-grid company’s revenues. Microfinance sector has used JLGs for several years [50]. Within the energy access sector in India, organisations like TERI and Selco have used JLGs to finance stand-alone devices like solar lanterns and home systems [51,52]. In JLG mechanisms, small groups of 6–10 customers hold the responsibility of rental payments as a group. If a group member fails to pay the rental in a particular week or month, the rest of the group pitches in to pay for her [53]. Among the case studies for this paper, only MGP uses JLGs.

JLGs facilitate the pooling of resources and sharing, already common in the context of energy (see [54]). Sharing and pooling of resources in times of need is a culturally embedded common practice in many Indian communities, especially in villages where kin live nearby and consider each other as extended family. For example, kerosene, the most common energy source, lends itself very well to sharing. It can be distributed in small amounts and lent to a neighbour while still using it in one’s own home [45]. During special occasions like weddings, villagers come together to lend necessary provisions including lighting equipment to households in need [42]:212.

The JLG intervention leverages social cohesion within the community to build financial bridges between the customers and the energy company, protecting company revenues while also responding to energy justice concerns. Through these interventions, companies hold on to customers who are temporarily unable to pay and maintain their long-term revenue flows. MGP informed during the fieldwork that JLGs significantly improved its rental collection rates while the other companies still discussed revenue collection as a major concern. SunMoksha and Mlinda did not use any similar mechanism to maintain people’s access and only relied on smart meters to disconnect those unable to pay rentals.

Micro-grids can deploy this smarter way of revenue collection along with smart meters. The energy companies will have adequate protection and the customers’ will maintain access to energy. Joining mechanisms such as smart meters and JLGs to secure financial flows and maintain electricity flows ties technical, social and financial smartness together. This responds to the call for smart and just financing in smart grids [12].

5.3. Operation and maintenance

Operation and maintenance is another critical problem for micro-grids [38,55]. Many projects fail due to inadequate maintenance [51]. Some smart interventions provide opportunities to improve the maintenance of projects, reduce their costs and positively influence project life [56]. This section illustrates two areas of intervention that tackle a lack of trained staff and local conflicts with customers.

5.3.1. Lack of educated and adequately trained staff

“Knowledge and capacity gaps” affect operation and maintenance of micro-grids [56]:19 by inhibiting timely breakdown reporting and maintenance services [57]. On the other hand, micro-grid companies find it difficult to find educated people to take up such jobs in rural areas [58]. MGP explains: “90% of [our] staff are local” because “nobody wants to come work in these rural conditions” (Interview, October 2016). This is especially difficult for new micro-grid companies who often lack financial resources to pay satisfactory salaries to these staff. This exacerbates the existing problems of maintenance, repair and management.

Companies are now using smart technologies, mobile telephony and smartphone apps to tackle this problem. However, systems using apps or text messaging which require typing of complaints in English or a local language exclude people unable to read or write. Many villages with micro-grids have low literacy levels. The states where the case studies for this paper are located rank low in literacy levels among the 35 Indian states and Union Territories – Bihar 35th, Jharkhand 32nd, Uttar Pradesh 29th, Assam 26th, Orissa 25th, Karnataka 23rd and West Bengal 20th [59]. As a result, many people do not have access to breakdown and maintenance reporting and the associated jobs even with technological mediation. Such technological mediation is not smart.

To work with local, less educated or uneducated people, MGP and SunMoksha also rely on mobile phone applications (apps) that respond to the socio-economic problems of lack of education and skills at the local level. MGP’s apps display pictures of various breakdown options (Interview, October 2016). Clicking on these automatically logs specific complaints into the system. It has similar apps for registering revenue collection reports. In addition to visual options, SunMoksha has added voice commands responsive in local languages to log breakdown and maintenance reports (Interview, October 2016). People can speak into this app to log problems and click photos of breakdowns. These are automatically uploaded to the server and reach trained professionals.
During the fieldwork, Selco explained that part of the maintenance problem emerges from delays inaccurate reporting of breakdowns. The fast relay of accurate information through smart systems, like the apps for the less educated, makes the process of maintenance more efficient, and partly surpasses the unavailability of trained staff. However, companies still need to build enough staff and spare parts capacities in local areas or regional hubs for maintenance issues. Although an incomplete solution, these apps make breakdown logging and maintenance services easier, faster, and more egalitarian. These apps are technologically and socially smart as they are built around the socio-cultural context in which they operate. MGP and SunMoksha can now rely on local, even if less educated, staff and provide more employment to local people.

5.3.2. Local conflicts
Often micro-grid staff are pressured by socially, economically or politically powerful customers to bend the rules for special benefits (see [51] on elite capture). Resistance to such power relations causes conflicts between micro-grid companies and customers. Conflicts also emerge from financial issues – not being able to pay on time, not wanting to pay the amount desired by the company, disagreement on generation and consumption between the company and customers.

Remote monitoring and automation systems reduce such conflicts. SunMoksha can monitor the generation and consumption from its micro-grid in a remote Orissa village from its Bengaluru office (Interview, October 2016). This enables SunMoksha to assess past trends, and predict and respond to future demand and supply scenarios making it more responsive to customer needs. Such analysis facilitates better service and lowers customer dissatisfaction [60]. At the same time, the company can also remotely control the micro-grid’s generation and consumption. By taking control of issues like energy distribution away from local staff, remote control reduces local conflicts between customers and micro-grid staff.

There is an acceptance [among customers] because of the capability of the system. It cannot be manipulated. Earlier what used to happen in any other villages? You don’t pay the bill then somebody has to go to physically disconnect it. You go there; there is lot of resistance. […] They [customers] know that no one can do anything. Software cuts them off. Period! So they have to pay if they want power. Nobody can do anything locally.

SunMoksha
The local staff are not in a position to manipulate the micro-grid to provide special provisions to anyone, nor can they resume electricity supply for someone who has not paid bills; this can only happen from the Bengaluru office. The result is less local pressure on the staff.

However, this also brings the question of social smartness to the fore. While this intervention reduces social pressure for the micro-grids, it results in a power imbalance. The company can exercise more centralised power over customers. The question raised by Sovacool ([61]:21) – could smaller-scale infrastructures…have…a socio-political economy rooted in decentralization and democracy? – is pertinent here. This kind of ‘smart’ approach counters the idea of centralised electricity systems, which encompass not only distributed generation and consumption but also distributed control and management [62]. By taking away local control and the ability to respond to local issues, remote monitoring and control systems threaten a de-contextualisation and de-democratisation of energy supply. This technically smart idea could only be considered socially smart if it achieves its desired aim while also maintaining (or progressing) the democratic structure of the smart grid. This thought needs to stay central in the design and implementation of smart grids.

5.4. Rapid extension of India’s national grid
On the governmental side of micro-grids, their relationship with India’s national grid is important. On 29 April 2018, Government of India (GoI) announced that the national grid had reached every Indian village. It aims to provide electricity connections to every household by December 2018. Micro-grids in previously un-electrified villages struggle after the subsequent national grid electrification [63], due to competition with the national grid, as the AIREC quote below illustrates. Thus, the expansion of India’s national grid has emerged as a threat for the long-term survival of micro-grids.

I am sure it [national grid rural electrification] will cross 90% [households] in next four years.

That is the biggest challenge what your micro-grid will have. Unless your micro-grid is complementary to the grid, your micro-grid will never do any business. Forget about anything; its sustainability is questionable.

AIREC
Based on the case studies, the section illustrates two kinds of relationships with the national grid – coexistence and coordination and concludes that coordination is the ideal opportunity for the long-term sustainability of micro-grids and the national grid.

Although GoI is rapidly connecting villages to the national grid, the electricity supply is discontinuous and supply times inconvenient (middle of the afternoon or late night). Micro-grids fill these supply gaps and coexist with the national grid (see Urpelainen [64] on the uncoordinated integration of grid and off-grid). The Naturtech and MGP projects were in villages already electrified by the national grid, and the national grid infrastructure was being set up in the village with Milinda’s micro-grid (site visits, September-October 2016). The intermittency of the national grid electricity supply created a space for these micro-grids as part of the coexistence model.

We always have been talking that let us have a system to run parallel. Grid we know very well. You take the power but is power available all the time? Or the time you need most? So why can’t we balance it? In the peak time, mini-grids can supply. Off peak you [national grid] supply. Then I [mini-grid] don’t need to run. So that balances also grid plus the mini-grid.

Desi Power
India’s national grid will require time to produce sufficient electricity for all consumers [65]; micro-grids remain relevant in such a context. Ulstrud et al. [35] note plans in West Bengal to connect micro-grids into a network that could subsequently connect to the national grid. Smart micro-grids can stabilise local electricity supply, demand and quality; things that the national grid is unable to do in villages. They can feed to the national grid when they have surplus electricity and withdraw to fulfil local demand when they fall short. As Desi Power explains in the quote above, through the use of smart technologies, the national grid and micro-grids can connect to, and synchronise with each other (see also [66]). SunMoksha, AIREC, ONergy and Desi Power support coordination with the national grid for long-term sustainability. AIREC is setting up a project to integrate a micro-hydro and solar hybrid micro-grid with the national grid to provide adequate electricity to one village (interview, September 2016). AIREC has developed the technology and coordinated with government bodies, grid operators and electricity distribution companies.

While the notion of a coordination model exists in the literature, the concept proposed here envisages active coordination and thoughtful co-
development of both systems on equal footing. Urpelainen [64] briefly touches upon this but primarily limits himself to grid and off-grid connection policies. However, a true coordination model requires co-management of supply and demand by the national grid and micro-grids as partners operating on equal footing with the same bargaining power in a way that democratises the electricity network. In the coordination model, local communities will exercise some decision-making authority and have partial energy sovereignty.

The coexistence and coordination models for national grid/micro-grid interaction make the question of long-term sustainability of smart grids relevant. With concrete poles, imported smart meters and dedicated space for generation infrastructure some micro-grids like Mlinza use very high-quality infrastructure8. The permanence demonstrated by Mlinza’s infrastructure quality attested to its long-term planning (site visit and discussions with local manager, October 2016). In the long term, electricity supply through the national grid will increase and become more stable. This is a key reason for Gol’s push towards a smart national grid [3]. In such a case, the coexistence of micro-grids and the national grid will become competition.

Micro-grids can hardly compete with the allure of unlimited electricity from the national grid. Also, micro-grids cannot have low enough tariffs to compete with the highly subsidised national grid [64,66]. In the past, micro-grids have lost customers to the national grid and shut down [67]. Coexistence is at best a medium-term option. Considering the views of most experts and project managers interviewed during this research, and Gol’s commitment to universal electrification through the national grid, coordination model is the smart way to proceed for both micro-grids and the national grid.

The national grid will gain from this as decentralised smart micro-grids will reduce the burden of generation, infuse more renewable energy, provide locally stable electricity supply, and democratise the electricity network. India’s National Smart Grid mission already includes a commitment towards developing micro-grids9 that it should to existing micro-grids. IEA [68] also foresees this decentralised but interconnected pathway for smart grids in developing economies. This coordination of government’s infrastructure and its electrification plans with micro-grids is a part of governmental smartness. To progress governmental smartness smart policies need to be developed [12,64]. Gol and various Indian provinces are taking steps towards this [66]. However, a concerted, unified push in policymaking is required to further grid interconnection and coordination.

6. Conclusions and policy implications

This paper contributes to the existing knowledge on smart grids in two ways. First, learning from diverse interventions used in Indian micro-grids, it provides concrete examples of what could be understood as social, financial and governmental smartness. Second, the paper explains that the smart interventions develop incrementally in response to existing contexts and issues that mar micro-grids in India rather than a predetermined package.

Keeping these in mind, the paper recommends that policymakers and practitioners should understand and develop smart grids as socio-technical and incremental grids. The paper unpacks the sociotechnical smart grid as interconnected technical, social, financial and governmental smartness, and their overlaps. These make smart grids relational interventions in which various aspects of smartness shape each other. This is critical because technological interventions like smart meters could protect the electricity grid’s revenues but at the same time discontinue energy access for poorer people. Social and financial smartness like JLGs could help avoid this. JLGs also illustrate that it is not always necessary to focus on technologies. JLGs, a socio-financial intervention, help make the grid socially more inclusive and responsive, and financially more robust. With this, the paper goes to the root of the question: what is smart in smart grids? Smart is about making electricity grids operationally more efficient, socially more responsive, and financially more robust. This paper recommends decentring the technical and looking at other aspects of smartness and their interconnections to bring efficiency, robustness and responsiveness.

Like the micro-grids that introduced various interventions at different points in time during their operation, smart grids develop by looking at problems and solving them, step by step. Smart grids need not develop through a predetermined intention to create particular kinds of smart grids. They are incremental grids: Grids that develop one-step at a time, one problem at a time, one solution at a time. Rather than starting with a pre-existing repertoire of ICTs, this sociotechnical and incremental problem-solution approach helps grid designers and policy makers avoid: (1) the transposition of non-contextual solutions ill-adapted to local needs and (2) unnecessary investments in new technologies. As evidence in this paper suggests, sometimes the necessary solutions come from social, financial and governmental aspects or their combinations.

A ‘beyond the technical’ approach means first putting the problems to be solved and the socio-cultural context centrally on the design board, and then, connecting them incrementally to appropriate social, financial, governmental and technical solutions that will end up creating a sociotechnical grid. At the same time, there needs to be enough space for identifying further problems and responding to these by modifying previous solutions and introducing new solutions. Incremental investments can be made in incremental steps.

Acknowledgements

This work is part of the ‘Developing and Implementing Smart Grids in India’ project. The project is funded under the Netherlands Organization for Scientific Research (NWO) Societally Responsible Innovation (MVI) programme. Project no. 313-99-307.

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