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Trials and tribulations: Lost energy access gains in rural India☆

Michaël Aklin[a,*], Johannes Urpelainen[b]

[a]University of Pittsburgh, United States of America
[b]Johns Hopkins SAIS, United States of America

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ABSTRACT

Rural electrification has advanced rapidly in many developing countries. Under conditions of poverty and weak infrastructure, however, households face a risk of backsliding. We use two rounds from the ACCESS survey of rural households in six northern Indian states to explore factors that drive losses in household electricity access. About 7% of households with electricity in 2015 lost it by 2018. We identify household wealth and off-grid access as major drivers of lost energy access. A standard deviation's increase in a household's wealth index reduces the likelihood of disconnection by 1.5 percentage points. Off-grid households are 8 percentage points more likely to lose access than grid-connected households. These findings underscore the importance of defending realized gains in countries where household electrification is driven by policy while rural poverty remains prevalent.

Introduction

Rural electrification has advanced rapidly across the world, with global electricity access increasing from 73% in 2000 to 86% in 2016 (IEA, 2018). This progress, however, masks variation in performance. In many countries, household electricity access has expanded in tandem with improved quality of supply and fewer outages. In other countries, progress has been less even. In India, for example, household electrification rates are approaching 100% but the quality of electricity service often remains poor. In many areas, quality of electricity service has deteriorated and households have lost access to electricity.

The study of the determinants of electricity access has grown considerably over the last few years. The reason is twofold. First, electricity access has been identified as a crucial determinant of economic development, including in rural areas (Dinkelman, 2011; Khandker, Barnes, & Samad, 2013). Second, a large number of households remained without electricity despite many policy initiatives to curb their number (Aklin, Harish, & Urpelainen, 2018). As a result, research has sought to identify the causes of electricity poverty. Suspects include the availability of energy resources (Madureira, 2008), geography (Chaurey, Ranganathan, & Mohanty, 2004; Deichmann, Meisner, Murray, & Wheeler, 2011), wealth (Greenstone et al., 2014), or political factors (Aklin, Bayer, Harish, & Urpelainen, 2018b). Since then, researchers have devoted considerable efforts in identifying policies and technologies that effectively increase the number of households that have access to electricity (Alstone, Gershenson, & Kammen, 2015; Palit & Bandyopadhyay, 2016; Bhattacharyya & Palit, 2016).

The common feature of these papers is that they explain why some households (or countries) improved while others stagnated. Our interest is slightly different. It lies in studying households that saw their electricity access *worsen* over time. While success stories are to be celebrated, we wish to avoid adopting an approach that selectively focuses on improvements. As we show next, a nontrivial number of households experienced a decline in electricity access. Who are these households? What characteristics predict reversals? We are interested primarily in understanding who loses access to electricity, whether it came from the grid or distributed power systems. This discrete outcome captures an increase in energy poverty that can be linked to household characteristics. Other outcomes that can indicate worse access include a decline in the number of daily hours of electricity and the number of days with blackouts.

As the drivers of deteriorating energy access remain poorly understood, we take a first step toward shedding light on this problem. We theorize that households lose energy access for two primary reasons: problems with infrastructure and financial hardship. On the one hand, poor maintenance of infrastructures, which is usually the responsibility of governments, can contribute to loss of previously gained energy access. On the other hand, households may decide that the service is too expensive. Affordability has been identified as a

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* Corresponding author.
E-mail address: aklin@pitt.edu (M. Aklin).

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critical problem of access to electricity, including in India where relative spending on energy has tended to increase over the past decade (Kemmler, 2007; Winkler et al., 2011; Alkon, Harish, & Urpelainen, 2016; Sankhyayan & Dasgupta, 2019; IEA, 2019; Kennedy, Mahajan, & Urpelainen, 2019).

Aside from infrastructure and income, we explore additional potential drivers of losses. First, we consider the role of education, which could increase the value of household electricity. More educated households might value electricity more for the services it provides, such as lighting for reading. Second, we consider several socioeconomic factors that have been associated with poor energy access: the gender of the household head, the caste to which the household belongs, and its religious affiliation (Bridge, Adhikari, & Fontenla, 2016; Sankhyayan & Dasgupta, 2019; Aklin, Cheng, & Urpelainen, 2019; IEA, 2019). Marginalized groups could plausibly be at greater risks of reversals because of their status. Lastly, we examine the type of electricity connection (grid versus decentralized power). Different types of power systems may have different life spans. Distributed power benefits from considerable flexibility, which increases its appeal but also allows both suppliers and consumers to disrupt access on short notice (Alstone et al., 2015).

To test these hypotheses, we exploit new panel data on rural electricity access in North India (Aklin, Cheng, Urpelainen, Ganesan, & Jain, 2016; Jain et al., 2018). The ACCESS data are ideal to study these questions on three grounds. First, surveyed households provided a wealth of energy access data. Second, the sampling was done to ensure representativeness of the rural population. Lastly, households were interviewed twice over a three-year period. The longitudinal structure of the data allows to sketch a clear picture of losses in electricity access. In the ACCESS survey, over 8500 households from Bihar, Jharkhand, Madhya Pradesh, Uttar Pradesh, Odisha, and West Bengal were interviewed in 2015 and 2018. This survey enables us to identify which households, among those that benefited from electricity access in 2015, lost it by 2018. It also allows us to explore whether infrastructure quality declined by looking at the number of hours of electricity per day or the number of blackouts. We then regress loss of access against variables capturing household income and wealth, education, gender, caste and religious status, the type of electricity access they had in 2015, as well as village-level characteristics such as distance to the nearest town, and a range of potential confounding factors.

The rest of this paper is structured as follows. The next section provides background information on electricity access in India over the last decades. We then spell out our own inductive approach to study reversals in access. The third section includes our research design and the definition of the key variables used in the empirical analysis. The fourth section reports descriptive statistics and the estimates of our econometric models. We also contextualize our results in the broader electricity access literature. The last section concludes.

Rural electrification in India

Progress over time

Rural electrification has progressed rapidly over the past decades both in India and globally. According to data from the International Energy Agency, fewer than one billion people lack access to electricity as of 2018 (IEA, 2018). In contrast, about 1.7 billion people were in such a situation in 2000 (IEA, 2017, 39). Much of these gains were made in Asia and South Asia. After years of struggle, India stands out for its rapid progress over the last two decades. Numbers vary but estimates suggest that about half a billion people obtained access to electricity since 2000 (IEA, 2017, 39). In April 2018, Prime Minister Narendra Modi announced that every village in India had been electrified.[1] Less than a year later, he announced a similar milestone for household access.[2]

Aggressive electrification policies contributed to this success. The Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) scheme (launched in 2005) and the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) program (launched in 2014) paved the way for the provision of electricity in rural areas (Chindarkar, 2017; Palit & Bandyopadhyay, 2017; Thomas & Urpelainen, 2018). These efforts tended to focus on improving the transmission and distribution of electricity. RGGVY, for instance, sought to provide power to 100,000 unelectrified villages and improve access to 300,000 additional villages across rural India by improving electric infrastructures (Burlig & Preonas, 2016).

Better infrastructures helped improve supply of, and access to, electricity (Burlig & Preonas, 2016). However, many households remained off the grid. Part of the problem stemmed from lack of affordability. Connections costs remained, in some cases, prohibitively high. For instance, utilities charged for a long time high connection fees to compensate for low tariffs (Palit & Bandyopadhyay, 2017). Other households remained concerned over their electric bills (Jain, 2018; Kennedy et al., 2019). Poor households were therefore at higher risk of being excluded from the grid.

The Saubhagya scheme was designed to tackle this problem (Mehra & Bhattacharya, 2019). Launched in 2017 by Prime Minister Modi, this program was designed to increase grid access by focusing on last-mile obstacles (Jain, 2018; Kennedy et al., 2019). A key component of the program was to make grid connection free for the poorest households (based on 2011 census data), and affordable for the rest (500 rupees, or about USD 7 at August 2019 exchange rates, which can be paid in installments) (Jain, 2018).[3] This, in turn, allowed many households to gain access to the grid.

This is not to say that Saubhagya solved the problem of electricity access. Two sets of concerns remain unaddressed. First, despite public announcements, many households still remain without electricity. Saubhagya ignored households that did not seek to be connected to the grid.[4] This could happen, for instance, if a household found electric bills too expensive, or if it illegally connected to the grid. Affordability remains a challenge.

Second, the quality of supply still constitutes a major problem across large parts of India. While comprehensive data on the quality of electricity service is not available, the ACCESS survey offers insights from over 8500 rural households in six energy-poor states (Madhya Pradesh, Uttar Pradesh, Bihar, Jharkhand, Odisha, and West Bengal) (Aklin et al., 2016; Jain et al., 2018). These households were interviewed twice: once in 2015 and once in 2018. The data confirm the general trends noted above. Electrification rates increased between 2015 and 2018, from 70% to 86%. The quality of supply increased as well, but uninterrupted electricity remains unavailable to many households. In 2015, households connected to the grid benefited from about 12.7 h of electricity per day (median: 12 h). Three years later, grid-connected households had 15 h of power per day (median: 16 h). The numbers were lower for households that used distributed power: in both waves, they had electricity for about 4.5 h per day (median: 3 h).

[1] "India election 2019: Bringing power to the people" *BBC*, March 26, 2019, https://www.bbc.com/news/world-asia-india-47499917.

[2] "India likely to achieve universal household electrification by January-end" *Financial Express*, January 20, 2019.

[3] Note that RGGVY also contained measures to help poor households connect to the grid. On this, see also "How Modi's Saubhagya Yojana Simply Repackaged an Already-Repackaged Scheme" *The Wire*, September 29, 2017, https://thewire.in/energy/narendra-modi-saubhagya-scheme-electrification (accessed August 1, 2019).

[4] "Power problem - On Saubhagya scheme," *The Hindu*, September 27, 2017, https://www.thehindu.com/opinion/editorial/power-problem/article19758243.ece (accessed August 1, 2019).

An inductive approach

Our primary data comes from the 2015 and 2018 ACCESS survey, which we describe below. We consider the sample of households that had electricity (in one form or another) in 2015 and then examine whether the same was true or not in 2018. Our main outcome consists of a dichotomous indicator that distinguishes households that lost access to electricity between 2015 and 2018 and those who maintained it. Likewise, we investigate who suffered from more blackouts and who benefited from fewer hours of electricity per day.

We then estimate a series of statistical models to understand which household and community characteristics predict deterioration of access to electricity and quality of service. We organize potential predictors in several groups. To begin with, we examine whether household income and wealth affect the odds of worsened access. Households' ability to pay for services has long been identified as a critical obstacle to electricity access (Kemmler, 2007; Winkler et al., 2011). The share of income devoted to energy consumption represents is often high and deters the poorest households from connecting to the grid (IEA, 2019). Worse, the energy burden (the ratio of energy expenses over total expenses) has been shown to be increasing for many households in India (Alkon et al., 2016). The situation is made worse by the difficulties that utilities have to recover their costs. To reduce the gap between tariffs and spending, utilities have been found to use strategies such as high connection costs, which represent an additional burden to households (Palit & Bandyopadhyay, 2017, 115). As a result of sometimes prohibitive fixed and variable costs, households may find electricity unaffordable (Kennedy et al., 2019; Sankhyayan & Dasgupta, 2019). For our analysis, the implication is that poorer households should have a lower willingness to pay for electricity, and therefore are at greater risk of losing access to electricity.

The next set of predictors are socio-economic in nature. These include education, caste, religion, and the gender of the household head. Besides its effect on income, education offers several benefits. The value of electricity is plausibly higher for individuals with higher levels of formal education. These would be the households that, for instance, are more likely to read and to put their children through school (Chakrabarti & Chakrabarti, 2002; Currie & Moretti, 2003; Belzil & Hansen, 2003). This would increase the subjective value that a household would attach to the kind of services provided by electricity, and therefore increase the likelihood that such service would be kept in the long run. A household that values electricity less may find that the opportunity cost of spending on electricity is too high.

Education may be correlated with loss of access for other reasons. Formal education can improve a person's ability to obtain services from bureaucrats. Bureaucrats have been found to be more likely to respond to individuals with a high educational background (Slough, 2019). Given the role played by the government in providing and maintaining the electric grid, understanding how to obtain benefits or maintenance can be particularly helpful.

Caste and religion are strongly correlated with a range of issues ranging from neglect to outright discrimination (Aklin et al., 2019). Members of Scheduled Castes and Scheduled Tribes could plausibly be the first ones to suffer from weaker investments in the quality of infrastructures. Likewise, households led by women could suffer from unequal access to public support and be more exposed to bad economic conditions (Deaton, 2008).

Our last determinant of loss at the household level is the type of electric connections a household has: grid or off-grid. The growth of electricity access across northern India was fueled by both an expansion of the grid and by off-grid technologies such as solar home systems and micro-grids (SPI & ISEP, 2019, 10). By including an indicator for the grid, we can evaluate whether this mode of connection is more resilient over the long term than another. We hypothesize that the grid, given the higher investments it requires, is less likely to face reversals. Customers can, in theory, be disconnected by distribution companies (DISCOMs), but there are several reasons to think that this is less common. For instance, lack of payment does not automatically lead to disconnections. People can bribe bill collectors or politicians can pressure operators not to collect bills at all (Min, 2015). And even if they are disconnected, people can still steal electricity (Smith, 2004).

Off-grid systems, in contrast, can be dismantled on short notice. This could happen if consumers consider them to be too expensive for the services they provide (Aklin, Bayer, Harish, & Urpelainen, 2017). Alternatively, suppliers may dismantle their system if it fails to cover their cost (Yaqoot, Diwan, & Kandpal, 2017). Many off-grid power providers, which tend to be privately run, struggle to find optimal billing strategies (SPI & ISEP, 2019, 11). A study on adoption of off-grid technology in Uttar Pradesh shows that adoption of solar micro-grids is shaped by a household's wealth, which suggests that costs may affect a household's willingness to use such technology (Aklin, Bayer, Harish, & Urpelainen, 2018a). Recognizing the diversity of technologies that are included under the "off-grid" label, we later unpack the effect of solar home systems, micro-grids, and lanterns.

Besides household-level factors, we study whether poor infrastructure leads to loss of access. Households may be unwilling to pay for poor supply, which itself can be caused by weak infrastructures. When power is intermittent, the opportunity cost of paying a monthly electric bill declines. In fact, several studies have identified the critical role played by electric infrastructures (Thomas & Urpelainen, 2018). Communities that can reap off the benefits of electricity may have an easier time maintaining them. Others may face significant challenges.

The low quality of distribution infrastructure is related to broader difficulties in the power sector. Indian DISCOMs regularly make headlines for their poor financial situation. This precarious situation is partly caused by theft and poor billing practices (Smith, 2004; Northeast Group, 2014; Sharma, Pandey, Punia, & Rao, 2016). The problem is made worse by regular political meddling in the provision of electricity (Min, 2015). As a result, according to a report by Shakti Foundation (2018, 10), DISCOMs' aggregate technical and commercial (AT&C) losses reached almost 25%. The financial consequences are severe: analysts expect the total debt of DISCOMs to reach USD 37 billion by the end of 2020.[5] Lack of revenue, in turn, jeopardizes the ability of DISCOMs to engage into much-needed investments. As resources become increasingly stretched thin, infrastructures may fall apart.

While we cannot directly observe shocks to the power infrastructure, we can identify which villages are at higher risk of supply-side problems. In particular, distant villages are more likely to suffer from transmission and distribution disruptions. As distance to larger urban centers increases, so do both the odds that electric cables get damaged. Furthermore, the cost of replacement also increases in distance. Village size may operate in the opposite direction: as a village becomes larger, its importance grows and so does the value of replacing crumbling infrastructure.

Research design

We briefly discuss our data and key variables and then present out statistical model. The next section presents the results of our analysis.

[5] Rs 2.6 lakh crore at an exchange rate of USD1.44 to 100 rupees. See "Square one: Discom debt to reach pre-UDAY levels this fiscal" *CRISIL*, May 6, 2019, https://www.crisil.com/en/home/newsroom/press-releases/2019/05/square-one-discom-debt-to-reach-pre-uday-levels-this-fiscal.html

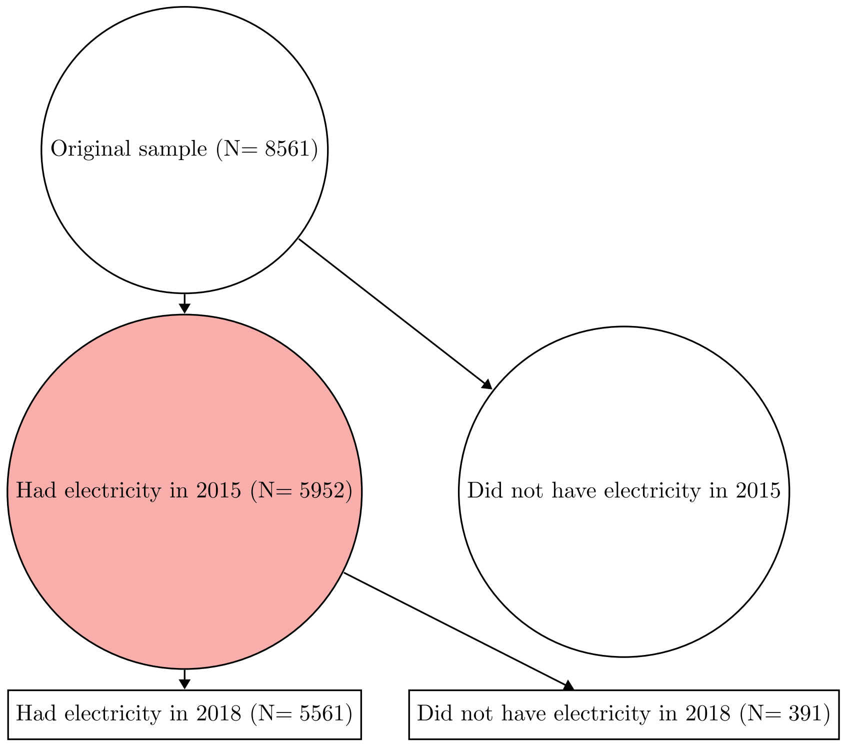

Fig. 1. Flow chart summarizing the sample. The subsample used in this paper is highlighted.

Sample

Our primary data source is ACCESS (Aklin et al., 2016; Jain et al., 2018). The survey was fielded twice: the first time in 2015, and a second time in 2018. In both surveys, over 8500 households were interviewed. The survey focused on energy access writ large, though it also contained a broad range of socioeconomic and demographic information. Additional information is provided in the Appendix (Section A2).

We remove from the data households that did not have electricity in 2015 (Fig. 1). Households were asked whether they benefited from any kind of electric connection, whether through the grid or through an off-grid system. Households that had a connection were kept in the sample, the others were discarded. Our interest lies solely in those households that benefited from electricity access and were at risk of losing it. This leaves about 5952 households, though the exact sample may be smaller because of non-response.

We next discuss the variables used in this analysis. These variables are listed in Table 1.

Outcome variables

Our first outcome consists of an indicator that equals 1 if a household lost access to electricity, regardless of the source. Specifically, the variable takes value 1 if a household was coded as having “any electricity (whether from the grid, from a solar household system, from a diesel generator, or from a micro grid)” in 2015, but not in 2018. This outcome captures a discrete change in electricity access. One advantage is that it does not depend on connections to the grid, which is only one of several ways that people in rural India consume electricity. This and all other variables are summarized in Table 2.

In the appendix, we explore two additional set of outcomes. The first captures whether a given household faced a higher rate of blackouts. Households were asked in both surveys how many days they suffered from blackouts over the previous month. From this, we can study both the change in the number of blackouts as well as an indicator that takes value 1 if the number of days increased between 2015 and 2018 and zero otherwise.

The last set of outcomes derives analogous quantities but replaces the number of blackouts with the number of hours (per day) that electricity is available. We examine both the change 2015–2018 as well as an indicator that flags households who experienced a net decline in the number of hours during which they benefit from electricity.

As noted above, these outcomes are of less immediate interest to us, given our focus on household-level variation. To remain connected to the grid or keeping a solar home system is a decision that takes place, in general, at the household level. In contrast, hours of supply or blackouts are features of the infrastructure and may therefore indiscriminately affect all households within a given region. We do not claim that these supply-side problems do not matter; however, they are not our primary research objective in this paper.

Explanatory variables

We proxy income with monthly expenditures. Given that our population consists mostly of farmers with irregular income, expenditures represent a more reliable measure to capture revenue flows. Median monthly expenditures reached 5000 rupees (about USD72), with a strong right skew.

To verify the robustness of our estimates on the effect of income, we also check whether wealth is a predictor of loss. Wealth is computed as an index (via factor analysis) that combines responses on the amount of savings, the ownership of a bank account, and the number of items that the respondent possesses.[6] The index is centered at 0 and has a standard deviation of 1. The appendix provides

[6] These items include animals (number of cows, buffaloes, chickens, cow and buffalo calves, goats, and other animals) and housing features (number of rooms, beds, tables, chairs, bikes, motorcycles, and cookers).

Table 1
Overview of the variables used in the analysis.

Variable	Description	Measurement
Outcome variables		
Electricity loss	Indicator that flags households that lost electricity access	$\{0, 1\}$
Blackouts (1)	Indicator that flags households that had more blackouts in 2018 than in 2015	$\{0, 1\}$
Blackouts (2)	Change in the number of blackouts per month, 2015–2018	$[-30,30]$
Hours of electricity (1)	Indicator that flags households that had fewer hours of electricity/day in 2018 than in 2015	$\{0, 1\}$
Hours of electricity (2)	Change in the number of hours of electricity/day, 2015–2018	$[-24,24]$
Predictors		
Expenditures	Monthly household expenditures (in log)	$[0, \infty)$
Wealth	Household wealth, based on an index built from non-electric asset ownership.	$(-\infty, \infty)$
Education	Formal education (highest level attained)	5 categories
Caste	Caste membership of household	5 categories
Religion	Religion of the household	[Hindu, Muslim, other]
Grid electricity	Access to the grid in 2015	$\{0, 1\}$

additional information on how this variable was constructed (Section A2).

Next, we estimate the effect of formal education. Respondents were asked for the highest educational attainment of the household head. Responses were split between no formal schooling (which we use as our baseline category), up to 5th standard, up to 10th standard, 12th standard or diploma, or graduate and above.

Likewise, we asked respondents about their caste or tribal status as well as their religion. We set General Class as the baseline category. Other responses included Scheduled Caste, Scheduled Tribe, or other Backward Class. Religions included Hindu (baseline), Muslim, or others. Finally, we include an indicator that takes value 1 if the household is led by a woman.

The last household level predictor is whether the household had access to the grid in 2015 ($=1$). Alternatives include solar home systems or micro-grids. Our conjecture is that different types of electricity technologies have varying levels of persistence. Off-grid technology can be expensive for the end-user, especially since it often provides limited supply. The most basic systems, for instance, allow power for lighting and phone charging but little else. As aspirations ratchet up, then the value of off-grid technology might decrease. The expansion of the grid is costly, but once the basic infrastructure is in place, reversals are (presumably) less likely. Note that the total cost of grid may be higher than off-grid. Our analysis, however, is taking place from the perspective of the consumer and therefore our argument rests on end-user costs.

At the village level, we draw on census data to adjust for the distance to the nearest town and the size of the population of the village. These variables account for geographical challenges to the provision of electricity and the size of the demand side. We conjecture that distant and small villages are more likely to suffer from lack of investments, which would undermine their access to electricity. In both cases, we take the log of the variable.

Statistical model

Our main model takes the following form:

$$\begin{aligned}
&\Pr(\text{Loss of electricity 2015–2018}=1)_i \\
&\quad= \beta\text{Expenditures (log)}_i + \kappa\text{Wealth}_i \\
&\qquad+\eta\text{Education}_i + \tau\text{Caste/Tribe}_i + \phi\text{Religion}_i + \gamma\text{Female HH}_i \\
&\qquad+\lambda\text{Grid}_i \\
&\qquad+\alpha\text{Distance to town (log)}_v + \phi\text{Population (log)}_v + \psi_d + \varepsilon_i,
\end{aligned}$$

Table 2
Summary statistics. Sample limited to observations measured in 2015 among households that had any electricity.

Determinants of loss of electricity						
	Mean	Median	S.D.	Min.	Max	Obs.
Household-level variables						
Electricity loss	0.07	0.0	0.2	0	1	5952
Expenses (log)	8.46	8.5	0.6	6	11	5952
Wealth index	0.09	−0.2	1.1	−2	8	5952
Female head of HH	0.05	0.0	0.2	0	1	5952
No formal schooling	0.27	0.0	0.4	0	1	5952
Up to 5th standard	0.31	0.0	0.5	0	1	5952
Up to 10th standard	0.22	0.0	0.4	0	1	5952
12th Standard or diploma	0.11	0.0	0.3	0	1	5952
Graduate and above	0.09	0.0	0.3	0	1	5952
Scheduled caste	0.16	0.0	0.4	0	1	5952
Scheduled tribe	0.10	0.0	0.3	0	1	5952
Other backward caste	0.47	0.0	0.5	0	1	5952
General	0.27	0.0	0.4	0	1	5952
Other caste	0.00	0.0	0.0	0	0	5952
Hindu	0.86	1.0	0.3	0	1	5952
Muslim	0.13	0.0	0.3	0	1	5952
Other religion	0.01	0.0	0.1	0	1	5952
Grid electricity	0.95	1.0	0.2	0	1	5952
Village-level variables						
Village pop (log)	7.70	7.7	1.0	5	10	5952
Distance to nearest town (log)	2.53	2.6	0.9	0	5	5667

Table 3
Change in electrification status, 2015–2018. Percentages rounded up. Our main sample is the combined set of people who had electricity in both years and those who lost it over this time period. The last column (*Percent [if Elec in 2015=1]*) reports the percentage of people who kept or lost electricity among those who had it in 2015.

Change in electrification status	Number	Percent	Percent [if Elec in 2015=1]
Had it both years	5561	65%	93%
Lost it	391	5%	7%
Gained it	1833	21%	
Did not have it in either year	776	9%	
Total	8561	100	100

where i denotes a household, v a village, and d a district. All right-hand side variables are measured in 2015, while the outcome is measured as a change between 2015 and 2018. The sample is limited to households that had electricity in 2015. We leverage variation within districts (ψ) to reduce concerns over major geographic, socioeconomic, and political differences across regions. We use linear probability models below, but verify that our results remain robust in nonlinear specifications in the appendix (Table A1). All standard errors are clustered by village.

Results

We briefly present descriptive statistics before turning our attention to the econometric estimates.

Descriptive results

We first sketch the landscape and how it evolved between 2015 and 2018. Drawing from our entire panel, we find that the majority (65%) had access to electricity of some kind in both years. A sizable group (21%) gained access during the same period. A further 9% of households did not have access in either year.

Of interest to us is the fourth group: households that had electricity in 2015 but lost it by 2018. We find that such a situation concerns about 5% of our sample, or 391 households (which represents 7% of those who had electricity in 2015 Table 3). Henceforth, our sample will consist of households that had electricity both years and of those who lost it. These are the set of people who benefited from electricity in 2015. Our query consists of understanding why some households lost electricity access while others maintained access.

We can explore the geographic clusters behind changes in electrification rates. In Fig. 2, we plot their mean change by district. On average, only three districts saw their electrification rates decline. However, at the household level, the picture is less encouraging. Out of 51 districts, at least one household lost electricity access in 48 of them. We find such households in each of the six states in our sample, with the share of losers ranging from 2.5% (West Bengal) to 5.7% (Uttar Pradesh). Overall, Uttar Pradesh and Madhya Pradesh seemed to have suffered more setbacks. On the opposite side, Bihar and West Bengal suffered the fewest losses.

So far, we relied on objective measures of electricity access. Another facet of energy poverty consists of *subjective* assessments by consumer. Here, we explore changes in satisfaction with artificial lighting. Satisfaction is measured in both survey waves on a Likert scale from 0 to 2. Changes can therefore range from −2 to 2. We report these changes by district in Fig. 3. As before, we find that improvements were geographically clustered in some states. Bihar, notably, saw increases in satisfaction in most districts. What is striking is that 11 districts experienced a net decline in average satisfaction. In line with our previous findings, Uttar Pradesh sees dissatisfaction in several of its districts, and about half of the districts with declining satisfaction are located there.

The aggregate changes are indicated in Table 4. These numbers emphasize that raw connections do not provide the entire story. We find that satisfaction declined for about 24% of all households. In a small number of cases (6%, or 535 households), the decline was particularly stark, as these households switched from being fully satisfied in 2015 to unsatisfied three years later.

To conclude this descriptive section, we relate loss of electricity to declining satisfaction levels. In Table 5, we regress changes in satisfaction levels on an indicator that takes value 1 for households that lost electricity between 2015 and 2018. The sample is limited to households that had electricity in 2015. We include a range of potential confounders. We find that losing electricity access leads to a decline in satisfaction by about half a point. To situate this estimate, note that it represents about half of a standard deviation of the dependent variable. The effect of losing electricity, therefore, explains a considerable amount of variation in satisfaction between our two surveys.

Predicting loss of electricity access

Losing electricity translates in a substantial loss of satisfaction. We next seek to characterize the type of household that lost electricity between 2015 and 2018. The results are reported in Table 6. We estimate linear probability models. For nonlinear logit estimates, with very similar findings, see Table A1.

We draw several conclusions from these results. First, income and wealth play a crucial role in retaining access to electricity. Households that lost access are poorer in terms of wealth and spend less (our proxy for income). For instance, a one-standard deviation increase in our wealth index (about 1 point) results in a reduction in the probability of losing electricity by about 1.5 percentage points. The effect of expenditures is of a similar magnitude (model 1); the loss of precision in the estimate of model 8 makes sense given its closeness to our wealth index.

One explanation for these results resides in the cost of (legal) electricity connection. We find evidence that cost plays an important role in energy decisions. Among households who lost electricity and yet could have access if they wished to, 82% mentioned that electricity bills were too expensive and 87% said that connections are too costly. In contrast, only 46% explained that they did not wish to get electricity because it is too unreliable. Cost appears to be a key determinant in worsened electricity access.

The second family of results concerns education. We find that the level of formal education of the household head is a reliable predictor of loss: the less educated, the more likely a household is to lose electricity access. The effect is monotonic in education levels. Compared to a respondent that did not complete formal education, a highly educated respondent will be about 3 to 4 percentage points less likely to lose its connection. Notice that the effect is robust to adjusting for wealth and income. As noted earlier, one interpretation for these results is that highly educated households may have an easier time navigating the energy bureaucracy. Another interpretation is that households with higher levels of education place greater value on electricity given the comfort it offers for reading.

We also find some evidence that caste matters. Scheduled Tribes and other backward class were more likely to lose access compared to people from the general class. The effect is 2 percentage point for Scheduled Tribes and 1 percentage point for other backward class. Scheduled Castes, on the other hand, did not differ from the general

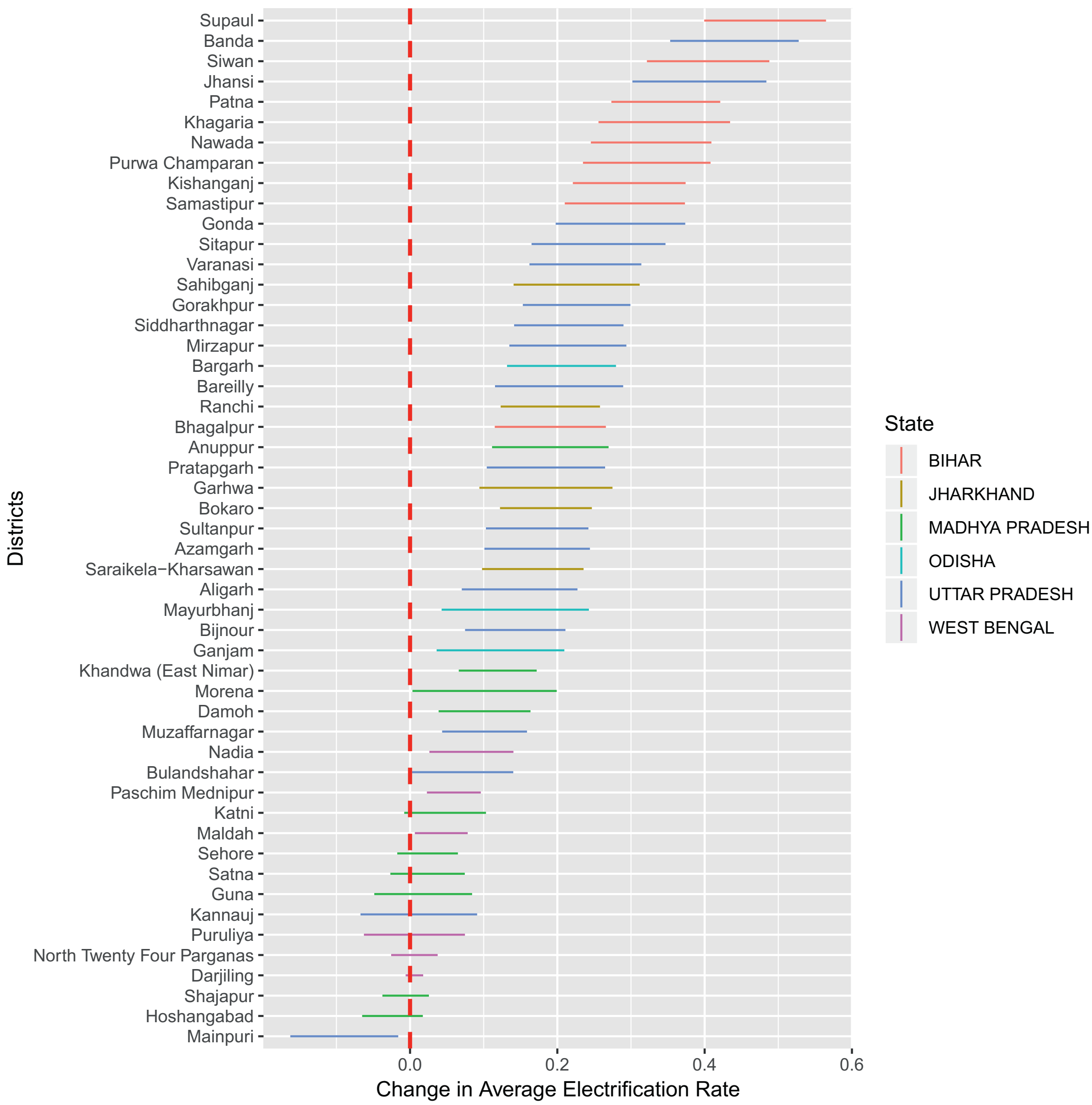

Fig. 2. Change in access to electricity between 2015 and 2018, by district. Point estimates and 95% confidence intervals from a regression of $\Delta\text{Electricity} = \delta_d \text{Districts} + \varepsilon$. Confidence intervals built with heteroskedastic-robust standard errors.

class in a significant manner. The effect becomes smaller and statistically insignificant in the full model (model 8), possibly due to multicollinearity.

We find little evidence that other key socioeconomic indicators affected the likelihood of reversals. Women were somewhat more likely to lose access, but the effect (2 percentage points) is statistically insignificant. Likewise, religiousness did not predict loss of access.

Next, we note that households connected to the grid (in 2015) were considerably less likely to lose electricity than those who used other technologies (−8 percentage points). We pushed this analysis further and examined whether loss rates varied by the type of technology households used for lighting in 2015.[7] The results are reported in Table 7. The first column reports the average likelihood of losing electricity by type of lighting source (adjusting for district effects).[8] The second and third columns use grid access as the baseline.

We find that solar home systems are about 5 or 6 percentage points more likely to lead to electricity loss than the grid. The effect is significant in both models. We also find milder evidence that the same is true for micro-grids (7–8 percentage points), but the effect is less precisely estimated. Since there are fewer households that used either of these technologies, we verify whether their joint effect is significant. The *F* test suggests indeed that we can reject the null that the combined effect of micro-grids and solar home systems is zero. Thus, off-grid access appears less resilient than the grid. We emphasize here that these results warrant a deeper analysis. For instance, future research could investigate the reasons behind these results.

Lastly, we find scant evidence that supply-side factors were instrumental. Neither distance to the nearest town nor the size of the village affected electricity access. While these are proxies and do not

[7] Given that some households use multiple electricity sources, we focused on the primary source of lighting.

[8] The estimates stem from a regression of electricity loss on each type of lighting source, without any intercept included in the model.

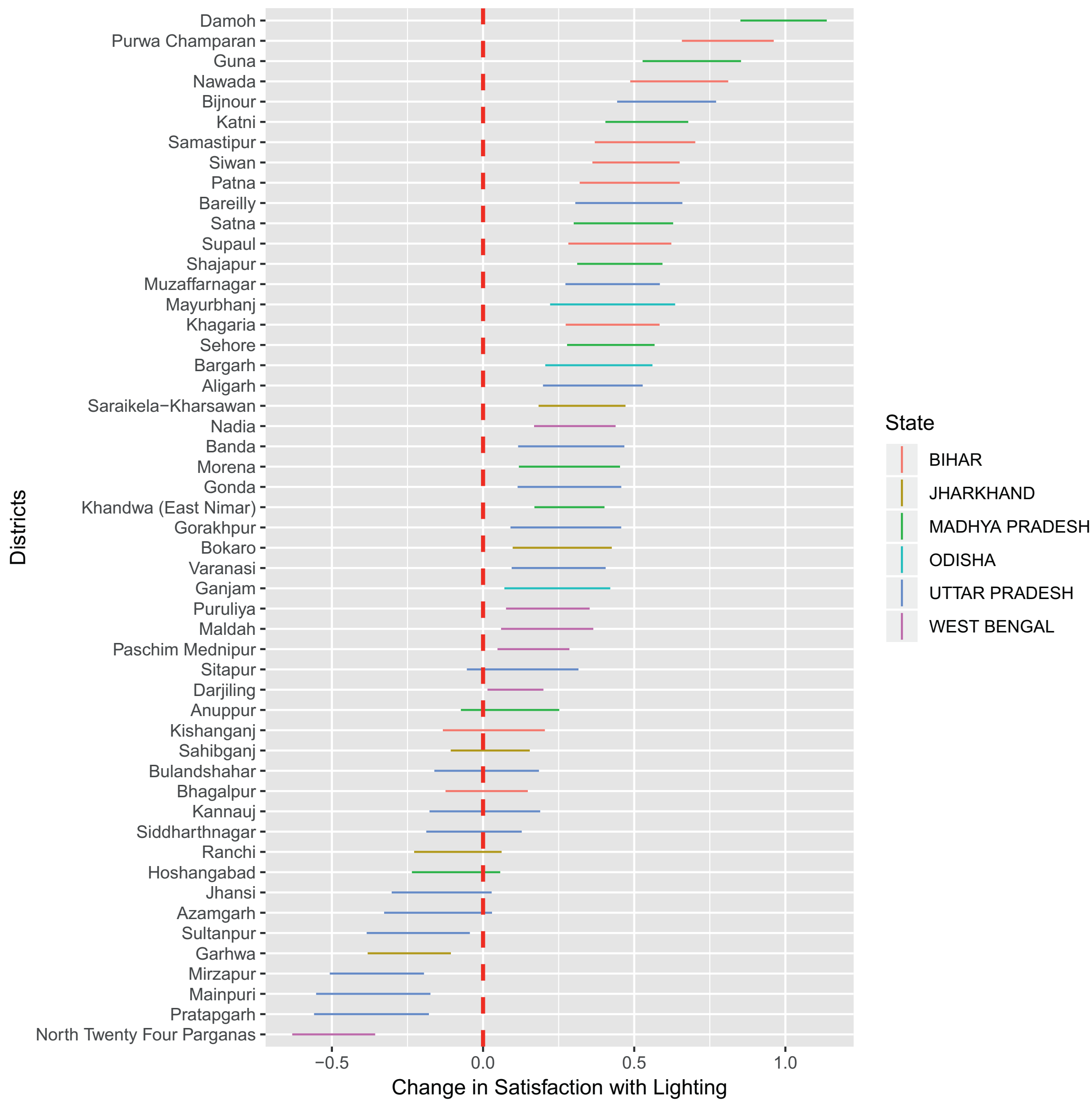

Fig. 3. Change in satisfaction with lighting between 2015 and 2018, by district. Confidence intervals built with heteroskedastic-robust standard errors.

immediately capture negative infrastructure shocks, they do suggest that worsened access was for the most part caused by household-level factors. Additional results, in which the outcome is either a decline in the number of hours of daily electricity (Table A2) or an increase in the number of blackouts (Table A3), point in the same direction. These outcomes more immediately depend on the quality of infrastructures and are less dependent on household-level characteristics. We find very little evidence that any household factor plays a role here. To complete our analysis, we examine whether dissatisfaction with electricity predicts loss (Table A4). We estimate whether grid users who found electricity too expensive, too unreliable, of poor quality were also more likely to lose access (voluntarily or not). We find no evidence that suggests such a relation. Loss of power was uncorrelated with people's assessment of the quality of infrastructures. Likewise, grid users who were unsatisfied, for whatever reasons, with their electricity access were no more likely to lose it than those who were satisfied. This further underscores the crucial role played by demand-side rather than supply-side factors with respect to poorer electricity access.

Results in broader context

How do these results compare to the extant literature on electricity access? Our results confirm findings from cross-national studies that identify income and wealth as important determinants of access. For instance, Onyeji, Bazilian, and Nussbaumer (2012, 523) find that poverty is a predictor of access at the cross-national level. Inglesi-Lotz and Pouris (2016, Table 2) review several studies of electricity demand in sub-Saharan Africa and likewise identify income

Table 4
Change in satisfaction with lighting (on a Likert scale from 0 to 2), 2015–2018.

Change in satisfaction with lighting	Number	Percent
−2	535	6%
−1	1506	18%
Stable	3067	36%
+1	2437	28%
+2	1016	12%
Total	8561	100

Table 5
Explaining variation in satisfaction with lighting. Linear model estimated with least squares. Dependent variable: change in satisfaction between 2015 and 2018 [−2,2]. Sample limited to households that had electricity in 2015. Standard errors clustered by village.

Effect of loss of electricity on satisfaction			
	(1)	(2)	(3)
Loss of electricity	−0.47***	−0.44***	−0.44***
	(0.06)	(0.06)	(0.06)
District FE		✓	✓
Expenses			✓
Wealth index			✓
Debt			✓
Female			✓
Education			✓
Caste			✓
Observations	5952	5952	5952
R^2	0.01	0.10	0.10

*: Significant at the 0.1 level, **: 0.05 level, ***: 0.01 level.

as a key factor affecting its strength. At the household level, our findings confirm those of Kemmler (2007, 19), who studies households in India and notes that household income, education, and literacy are significant predictors of electricity access. Another study from Bangladesh finds that the education level of the household head increases the odds of having an electric connection (Khandker, Barnes, Samad, & Minh, 2009, Table 4). Likewise, Rahut, Mottaleb, and Ali (2017, Fig. 4 and Table 4) study household energy poverty in Timor-Leste and find that electricity access increases with education and income.

On the other hand, we find little evidence that geography (here: distance to the nearest town) matters. This stands in contrast to earlier studies such as Oda and Tsujita (2011, Table 8). One reason for this highlights the importance of studying access and loss separately: it is likely that geography matters to predict electricity access (or lack thereof). However, after access has been obtained and infrastructures built, it is unlikely that geography affects the odds of losing electricity. At this stage, household features become relatively more relevant.

Conclusion and policy implications

Here we have analyzed why some households lost access to electricity. Relying on a longitudinal survey fielded in 2015 and 2018, we find that income, education, and the type of electricity connection all play an important role. Households that were poorer, less educated, and that used non-grid technologies to get electricity were at greater risk of losing power. Financial setbacks, in particular, seem to have been critical. At the same time, we find little evidence that infrastructural shocks or geographical features explain worsened electricity access. Overall, while access improved on average

Table 6
Explaining who loses access to electricity. Linear probability model estimated with least squares. Dependent variable: loss of access to electricity between 2015 and 2018 (= 1). All independent variables measured in 2015. Baseline categories: no formal education, General Class, Hindu. Standard errors clustered by village.

Determinants of loss of electricity								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Expenses (log)	−0.020***							−0.006
	(0.006)							(0.006)
Wealth index		−0.020***						−0.015***
		(0.003)						(0.003)
Up to 5th standard			−0.024***					−0.021**
			(0.009)					(0.009)
Up to 10th standard			−0.029***					−0.022**
			(0.009)					(0.010)
12th Standard or diploma			−0.038***					−0.022*
			(0.011)					(0.012)
Graduate and above			−0.041***					−0.024*
			(0.013)					(0.014)
Female head of HH				0.019				0.011
				(0.017)				(0.017)
Scheduled caste					0.015			−0.004
					(0.011)			(0.011)
Scheduled tribe					0.022*			0.002
					(0.013)			(0.013)
Other backward class					0.014*			0.003
					(0.008)			(0.008)
Muslim						−0.007		−0.014
						(0.011)		(0.011)
Others						0.036		0.034
						(0.033)		(0.033)
Grid electricity							−0.090***	−0.076***
							(0.023)	(0.023)
Village pop (log)								0.003
								(0.004)
Distance to nearest town (log)								0.001
								(0.005)
District FE	✓	✓	✓	✓	✓	✓	✓	✓
N	5952	5952	5952	5952	5952	5952	5952	5667
R^2	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08
Mean of outcome	0.07							
Standard dev. of outcome	0.25							

* : Significant at the 0.1 level,
** : 0.05 level,
*** : 0.01 level.

Table 7
Disaggregating the effect of off-grid vs. grid access, by type of primary lighting source. Linear probability model estimated with least squares. Dependent variable: loss of access to electricity between 2015 and 2018 (= 1). The first model includes all categories and therefore no intercept. Models (2) and (3) include intercepts and grid connection represents the baseline. In Models (2) and (3), the last rows represent the *F* statistic (and its p value) for the test of the hypothesis that the joint effect of micro-grid and solar home systems is zero (the null is rejected in both models). All independent variables measured in 2015. *Controls* includes the same variables as in Table 6. Standard errors clustered by village.

Disaggregating off-grid access			
	(1)	(2)	(3)
Grid	0.08**		
	(0.03)		
Micro-grid	0.17***	0.08*	0.07
	(0.06)	(0.05)	(0.05)
Other	0.10***	0.02**	0.01
	(0.03)	(0.01)	(0.01)
Solar home system	0.14***	0.06*	0.05*
	(0.04)	(0.03)	(0.03)
Solar lantern	0.11	0.03	0.04
	(0.08)	(0.07)	(0.08)
Controls			✓
District FE	✓	✓	✓
N	5952	5952	5667
R^2	0.12	0.06	0.07
F statistic (Micro-grid + SHS)		6.16	4.43
p value for F statistic		0.01	0.04

* : Significant at the 0.1 level,
** : 0.05 level,
*** : 0.01 level.

for our sample, these results point at the risks faced by vulnerable households. Reversals are possible, and while rare, they do happen. In our sample, they happen because of household-specific problems rather than infrastructure shortcomings. This underscores that the set of determinants of electricity access may differ from that of losses.

Our findings offer valuable insights for policymakers, while keeping in mind that our survey data reflects the conditions of a subset of India. As household electrification rates rise across the world, the importance of defending realized gains increases. In countries like India, where government programs instead of rapid rural development have driven household electrification, many rural communities face the risk of reversals. If governments subsidies were to be cut, for instance, the degree to which poorer households would be able to pick up the slack is unclear. Beyond this, our paper points at the fundamental difficulty in creating a sustainable electricity market in India. While many DISCOMs suffer from insufficient funding (partly caused by low tariffs or theft) (Palit & Bandyopadhyay, 2017), our findings show that raising tariffs could exclude many households from the grid. Yet without higher investments, electricity from the grid will remain of poor quality. Possibly, a combination of long-term investments (on the supply side) and means testing for tariffs (on the demand side) might pave the way for sustainable universal electricity access.

To be sure, our study has its limitations. We have focused on India, a country that has benefited from rapid household electrification in the past years along with some improvement in the quality of electricity services. Conducting this study in a country with lower electrification rates and more serious quality issues might offer additional insights. It also bears remembering that while India is not a wealthy country by any stretch, it is economically better off than many countries in Sub-Saharan Africa and Southeast Asia. Where extreme poverty remains more common than in India and electric utilities perform worse, the evidence for our hypotheses might be stronger.

For researchers, possible next steps include exploring these hypotheses and developing new ones for countries with electricity access challenges. One important direction concerns the causal mechanisms that drive associations between wealth, education, and loss of access. Assessing the role of financial difficulties and lack of information, for example, could generate new insights into exactly how households lose electricity access. Qualitative work and semi-structured surveys could produce case studies that show how electricity access is lost – and what policymakers can do about it. Another important direction concerns the durability of decentralized renewable energy. In the literature, decentralized renewables are often seen as a robust and resilient alternative to the grid (Alstone et al., 2015). Understanding why households lose access to them so easily would be important for realizing this goal of resilience and robustness. As noted above, possible hypotheses include high cost, lack of profitability for operator, and infrastructural challenges.

Another major research opportunity concerns the challenge of lost energy access with regard to clean cooking fuels. Here we have focused on electricity access, but cooking fuels could feature even greater challenges. In particular, cooking with liquefied petroleum gas requires that households regularly buy fuel (Gould & Urpelainen, 2018; Kar, Pachauri, Bailis, & Zerriffi, 2019). In such conditions, reversal to increased use of firewood and other traditional biomass in cooking is a possibility. Considering that the health gains from clean cooking are only fully realized when households end fuel stacking, this problem is a serious one from a public health perspective.

For policymakers, our findings raise an important question: how to ensure that gains in household electrification and quality of electricity service are not lost over time? As rural electrification campaigns and power sector reform packages are often one-off, translating their immediate results into sustained performance can be a challenge. As long as rural poverty remains prevalent and electric utilities face difficulties with payment collection and billing, avoiding lost electricity access gains can be difficult. Besides the obvious but perhaps non-actionable solution of rural economic development, improving the regularity of electricity billing is a potentially important solution.

In the worst case, temporary gains in electricity access can be a costly distraction. If households gain temporary access to electricity at a high cost but then fail to pay their bills or otherwise lose connection, the benefits of electricity access can prove elusive. We hope that our results spark discussion about strategies to avoid reversals in energy access.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary information

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2020.01.002.

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