Energy for Sustainable Development 63 (2021) 113–118

Contents lists available at ScienceDirect

Energy for Sustainable Development

The evolving role of solar-based lighting solutions in rural India: Global lessons for distributed renewables

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ARTICLE INFO

Article history:
Received 24 February 2021
Accepted 27 May 2021
Available online xxxx

Keywords:
India
Energy access
Energy poverty
Rural electrification
Renewable energy

ABSTRACT

From solar lanterns to home systems and minigrids, distributed renewable energy (DRE) has become increasingly competitive as an alternative to grid extension in household electrification across many parts of the emerging world. We explore how DRE use in Indian households has evolved against the backdrop of massive public investment in grid extension. Using two rounds of the 2015–2018 ACCESS household data from six Indian states, we estimate the impact of household electrification via grid extension on DRE ownership and use. We find that demand for solar microgrids and minigrids has all but disappeared, whereas demand for solar home systems and lanterns as backup solutions to intermittent grid electricity supply continues to grow. Most notably, while grid electrification has increased from 66% to 85%, solar lantern ownership has grown from 1.2% to 5%. The use of DRE as a backup solution to government electrification schemes seems driven by changes in quality of electricity supply. These analyses confirm that intermittent grid electricity supply is key to understanding the solar lantern's continued popularity. The results show that where population density, household income, and government commitment all favor grid extension, the most affordable DRE technologies can still play an important role. These lessons offer insights into the development of solar-based lighting markets in other regions, such as Sub-Saharan Africa, where grid extension continues but grid electricity remains intermittent in supply.

Introduction

Distributed renewable energy (DRE) offers a potentially groundbreaking alternative to traditional grid extension for rural electrification. As the cost of solar power generation has decreased and the DRE industry has grown (Aklin, 2021; Alstone, Gershenson, & Kammen, 2015; Ma & Urpelainen, 2018), grid extension is no longer the obvious priority for energy planners. Where electricity demand and population density are low, DRE now offers a potential least-cost alternative. Indeed, the International Energy Agency expects two-thirds of all new electricity connections by 2030 to be based on DRE (IEA, 2017). In Sub-Saharan Africa, for example, DRE is a key technology in universal electricity access, given low population densities and long distances between communities (Trotter, Cooper, & Wilson, 2019).

In many countries, however, DRE competes with an existing electric grid infrastructure. From Ghana to India to Indonesia, high grid penetration rates change the nature of DRE demand, as many households can choose between connecting to the grid, relying on DRE, or combining the two (Heynen, Lant, Smart, Sridharan, & Greig, 2019; Sergi et al., 2018; Urpelainen, 2014). The economics of DRE look very different in villages that already have grid electricity connections, as households can be connected to the grid simply by extending a distribution line. DRE providers in communities with grid electricity, or the potential for gaining access in the future, must provide better value than the electricity utility.

How, then, does grid extension change the role and potential of DRE? Here we explore the evolving role of distributed renewable energy in rural Indian households using two rounds of the ACCESS survey (Mani et al., 2018; Aklin, Cheng, Urpelainen, Ganesan, & Jain, 2016), with household energy access data on over 8500 households from six North Indian states. Recent studies relying on these data offer a general picture of electricity access in these states but do not tackle the dynamics of distributed power in the context of these broad macro-level changes in electricity access. The 2015 and 2018 rounds of the survey allow us to examine how the rapidly expanding Indian electric grid has shaped demand for various DRE technologies – solar lanterns, solar home systems, and solar microgrids – that offer services such as lighting and mobile charging. Because the Government of India started a massive household electrification campaign, Saubhagya, in 2017, we can observe how more extensive grid electricity coverage, driven by ambitious public policy, has shaped rural DRE markets in rural India, where 168 million households (45%) had no electricity according to the 2011 Census of India.

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https://doi.org/10.1016/j.esd.2021.05.009

In 2015, DRE markets were still nascent in India, but there was general optimism in the sector because hundreds of millions had no electricity at home. DRE was seen as a complement to grid extension in areas with difficult geography and low population densities (e.g., mountain states) (Palit, 2013). A 2014 survey of off-grid companies in India showed that 19% of the industry never operated in grid-electrified villages, while 45% said they sometimes operated in such villages (Singh, 2016).

Our results underscore a major change in DRE's role for rural energy access. In our sample, the rural electrification rate was 66%. By 2018, sample rural grid electrification rates had increased to 85%, and both producers and consumers were increasingly aware of Saubhagya's growing reach. Our results confirm that this sea change both dampened demand for DRE and shifted the focus away from leapfrogging over grid connectivity to using DRE as a backup for reliability and flexibility. As a result, more expensive solutions, notably micrograms and minigrids, appear to have lost ground to solar home systems and lanterns.[1]

Specifically, the use of diesel and solar microgrids decreased from 2.3% to about 0.1%, as recently electrified households disconnected from local microgrids and new customers did not replace them (other types of microgrids, such as those powered by biomass, were not present in our sample). Although our survey data may have failed to capture important microgrid clusters, our analysis suggests that it is highly unlikely that they have become substantially more common. At the same time, the use of solar home systems and solar lanterns has continued to expand. Ownership of solar home systems and lanterns increased from 3.1% to 3.8% and 1.2% to 5%, respectively, with solar lanterns growing fourfold in only three years. However, almost all of this growth was from secondary lighting sources, and the use of solar home systems as primary sources increased only from 1.8% to 2.1% while lanterns as primary sources increased from 0.3% to 1.1%. We demonstrate that these changing patterns are linked to the Government of India's national household electrification campaign (Saubhagya) and the continued problem of intermittent electricity service, as low daily hours of electricity available to households are a strong predictor of continued reliance on DRE.

These findings offer global lessons for distributed renewables. India is, thanks to its high population density and rapid progress with grid extension, ahead of most lower middle-income countries in rural electrification (Blankenship, Kennedy, Mahajan, Wong, & Urpelainen, 2020). In Sub-Saharan Africa, the electric grid is reaching villages more slowly (IEA, 2017). But as grid extension continues, the market for solar-based lighting, and distributed power generation more broadly, will likely change. For the purposes of integrated rural electrification planning and solar-based lighting markets alike, understanding how grid extension shapes household demand will be essential. Our results suggest that while grid extension will shrink the market for larger systems that are substitutes for grid connectivity, it need not reduce the demand for smaller, affordable products that provide reliable lighting and mobile charging solutions. As long as grid electricity service remains intermittent, grid extension can co-exist with a market for basic solar-based lighting acting as a *complement*. Meanwhile, regions that are very difficult and expensive to reach with grid extension may benefit from larger systems that serve as *substitutes* for the electric grid by providing enough electric capacity for larger appliances (e.g., fridges and freezers) and productive loads (e.g., electric irrigation pumps).

Rural electrification in India

Global interest in DRE stems from technological progress and the nature of the rural electrification challenge. As rural electrification rates climb, the remaining unelectrified population becomes poorer and more remote on average, since the easiest villages to electrify are large in size, wealthy by local standards, and close to major population centers and electric infrastructure. The cost of distributed solar power generation has decreased rapidly over time, thereby creating a viable alternative to grid extension. Thus, as electrification rates have increased across countries, the opportunity for DRE-based rural electrification has grown.

In India, governmental policy has focused on grid extension (Blankenship et al., 2020; Palit & Bandyopadhyay, 2017). Already in 2005, the Rajiv Gandhi Rural Electrification Programme (RGGVY) aimed to electrify all villages. Success was declared in early 2018, and since then the Saubhagya scheme has focused on providing free or heavily subsidized connections to achieve universal electrification. The Government of India declared the scheme a success in December 2018, and recent household surveys indicate rural electrification rates of over 90% in India (NSS, 2018), a massive increase compared to 55% in the 2011 Census of India.

As a result of near-universal grid electricity access, India offers a unique setting for exploring the potential roles that DRE might play. With virtually all villages and most households now electrified, DRE is no longer an exclusive alternative to grid electricity access in India. Rather, it plays a complementary role by providing enhanced reliability (Sharma, Agrawal, & Urpelainen, 2020). In India, DRE plays a secondary role to grid extension. Solar lanterns, home systems, and microgrids are no longer sought to replace electric grid connectivity. Instead, they can provide improved reliability for energy services that do not require large amounts of power, such as lighting and mobile charging. Such reliability remains an important concern in India, given that grid electricity supply remains intermittent in many rural areas (Singh, 2016; Urpelainen, 2016). In the ACCESS sample, the median household reported only 15 h of supply per day in 2018 (Jain et al., 2018).

Although the improved performance of DRE has drawn attention to the possibility of 'leapfrogging' (Zerriffi & Wilson, 2010) – rural electrification without grid electricity connections – government schemes to increase household electrification have preempted this approach. Therefore, while the Saubhagya scheme has brought household electrification rates close to 100%, many households remain without power because they cannot afford the monthly fees (Blankenship et al., 2020).

We explore these issues using two rounds of the ACCESS data from six Indian states. In the ACCESS survey, households from six states were interviewed first in 2015 and then again in 2018. This panel data set allows us to explore how the surge in grid connectivity has shaped households' DRE choices.

Materials and methods

Data collection

The main data used in this paper is the ACCESS dataset, which was collected via two surveys fielded in 2014–2015 and 2018 across six Indian states (Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal) (Jain et al., 2018). Overall, 714 villages located in 51 districts were selected. To ensure spatial representativeness, a district was selected from each administrative division (except for West Bengal and Odisha, where more districts were selected given the large size of divisions). In each village, the survey team sought to interview 12 households picked at random. The total number of observations is 17,635. Out of these, 8563 households were interviewed in both waves (for 17,126 responses) and 509 were solely interviewed in the second wave.[2]

Each respondent was asked a wide range of questions regarding energy access. In addition, the survey included questions on the respondent's and his/her household's socioeconomic background (gender,

[1] Our sample contains very few microgrids.

[2] The survey was fielded by Morsel, a professional survey company that has extensive experience in these regions. Data quality checks were completed both by Morsel and by the research team to ensure data of high quality.

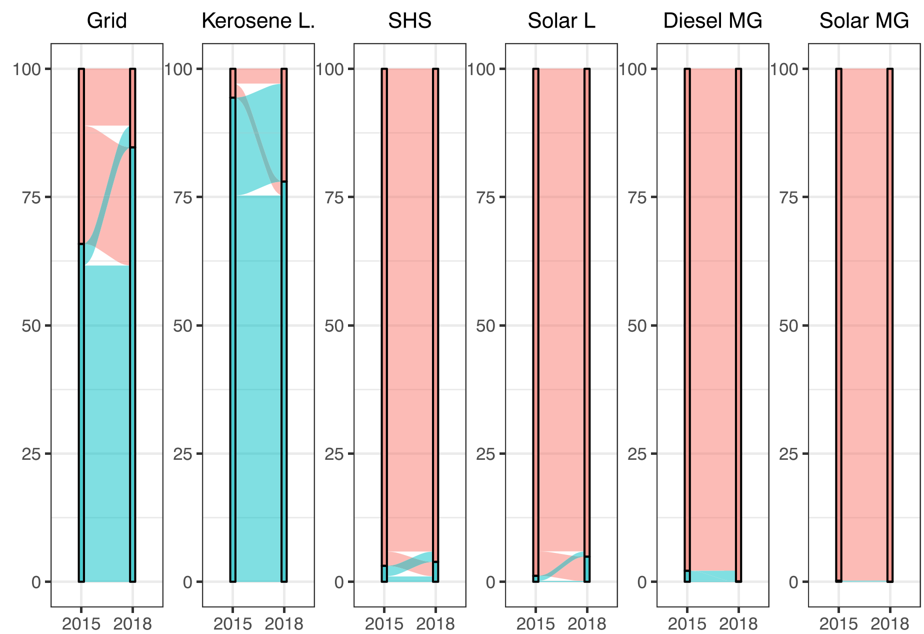

Fig. 1. Share of ownership of (or access to) various sources of lighting (blue=percentage of households that have access or own a source of lighting; red=percentage that do not). Note that households can have access to several sources; see Fig. A3 and Table A10 for data on combinations. *Grid* refers to grid electricity (8563 observations). *Kerosene* refers to kerosene lighting (8563 observations). *SHS* refers to solar home systems (8523 observations). *SHS* refers to solar home systems (8523 observations). *Diesel MG* refers to diesel microgrids (8563 observations). *Solar L* refers to solar lanterns (8523 observations). *Solar MG* refers to solar microgrids (8563 observations). See Tables A4 to A6 for full results. Unweighted sample. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

caste, age, and so forth). The survey lasted about 45 min. The key variables used in this analysis are summarized in Tables A1 (overall), A2 (2015), and A3 (2018).

We construct two main sets of outcomes. First, we create a series of dichotomous variables that take value 1 if a household has access to, or owns, a particular source of lighting (see Section A1 in the Appendix for exact wording of questions). These are: the grid, solar home systems, diesel microgrids, solar microgrids, solar lanterns, and kerosene lanterns. Note that households can simultaneously own/have access to more than one such source. In fact, the modal category is for a household to have two of these sources. Second, we generate a variable that indicates which of these a household considers to be its primary source of lighting.

One complication to identify primary use arises from the fourth option. If a household owns both a solar home system and a solar lantern, then it is not clear which one is the primary source. This only affects 36 households in total. In this special case we assume that the primary source was the solar home system; it seems reasonable to assume that solar home systems are unlikely backups to solar lanterns, whereas the opposite is much more plausible. Ownership rates are summarized in Tables A4 (overall), A5 (2015), and A6 (2018). Primary usage statistics are reported in Tables A7 (overall), A8 (2015), and A9 (2018).

Our key independent variables of interest are: (a) time (changes between 2015 and 2018), (b) Saubhagya-based electric connections, and (c) hours of grid electricity supply per day. The first represents the change observed between the two surveys. Dividing the estimated coefficient by three gives an approximate estimate of the average yearly change in the outcome. The second independent variable is an indicator that takes value 1 if the household responded 'yes' to "Has your household been electrified under Saubhagya?" and zero if not. Overall, 2.7% of the respondents said that this had been the case. Our last primary independent variable is the number of hours of grid that are available per day at the village level. We take the average village-level number of hours (between 0 and 24) based on our respondents. The sample mean is just short of 13 h of electricity per day, with a range from 0 to 23 h.

In the models discussed below, we adjust our estimates for various household features. We generally include household monthly expenditures (in log) and educational attainment of the household head. Many otherwise relevant variables, such as the caste status of the respondent, are not included given that most of our models include household fixed effects which account for these time-invariant features.

Statistical models

Using these two sets of outcomes, we estimate several statistical models. We use linear additive models that we estimate with ordinary least squares. The models generally take the following form:

$$\text{Outcome}_{i,t} = \tau_t + \phi_i + \mathbf{X}_{i,t}\gamma + \varepsilon_{i,t}. \quad (1)$$

Greek letters are parameters (or vector of parameters) to be estimated from the data. The parameter τ is the effect of the three years

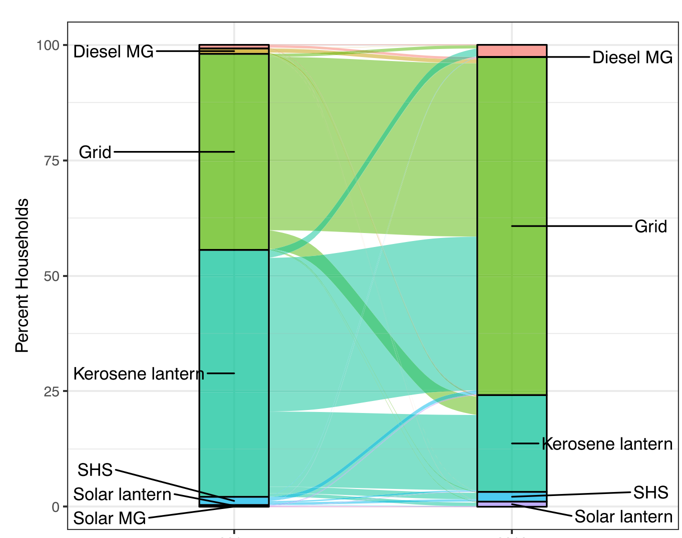

Fig. 2. Primary source of lighting in 2015 and in 2018. Unweighted sample. See Tables A7 to A9 for full results.

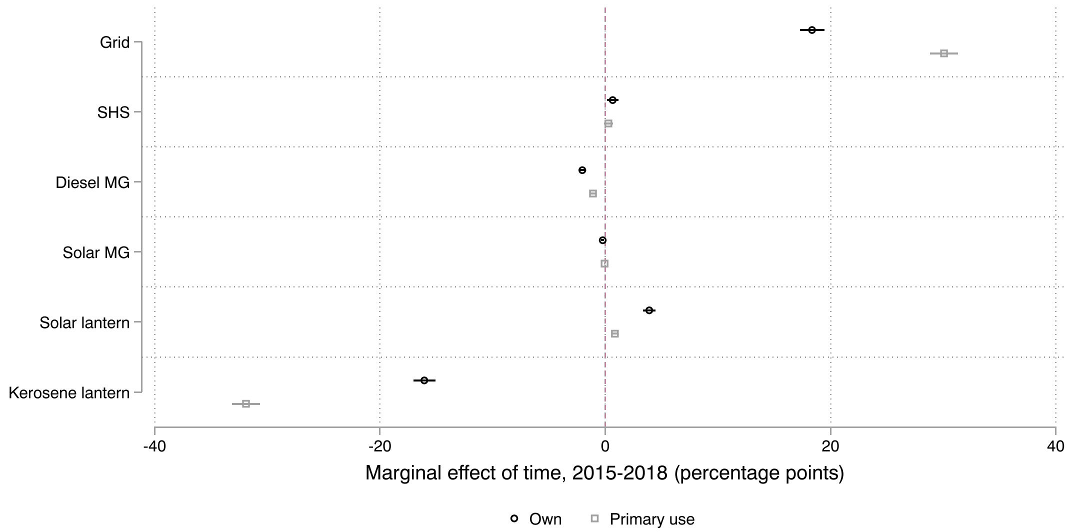

Fig. 3. The plot reports the effect of time (i.e., the change from 2015 to 2018) on ownership and primary usage of various sources of lighting. The estimates come from a model that adjusts for expenditure, education, and includes household fixed effects. The estimates are reported in full in Table A11. Bands represent 95% confidence intervals. Unweighted sample.

between the two survey waves. We include (but do not report) household fixed effects ϕ_i. Since we control for household effects, we do not (and cannot) include other time-invariant variables. However, we can include variables that may have changed over time, such as the respondents' monthly household expenditure (which proxies income) and their level of education. We include them in the vector labeled **X**. This enables us to partial out their effects from the dynamics of distributed power captured by τ, our first parameter of interest. We report the estimates of the key parameters in Table A11 and Fig. 3. Standard errors are clustered at the household level.

We then examine the effect of Saubhagya. Here, we limit the sample to households that did not have electricity in 2015. Then, using 2018 data (i.e. post-Saubhagya implementation), we examine how Saubhagya affected ownership and usage of our various lighting sources. We estimate models like:

$$\text{Outcome}_i = \tau_d + \lambda \text{Saughabya}_i + \mathbf{X}_i \gamma + \varepsilon_i. \qquad (2)$$

Here, we adjust for district fixed effects. This allows us to set aside geographical shocks to electric supply. Standard errors are clustered at the district level. The results are reported in Tables A16 and A17 and in Fig. 4.

Results

We begin by describing changes in ownership of (or access to) various sources of lighting. Fig. 1 shows the increasing dominance of grid access and the decline of kerosene lanterns. Between 2015 and 2018, grid electrification increased from about 66% to 85%, while ownership of kerosene lamps decreased from 94% to 78%. For DRE, ownership of solar home systems grew only slightly, from 3.1% to 3.8%. Solar lantern ownership expanded significantly, from 1.2% to 5%. Diesel and solar microgrid connections collapsed, from 2% to 0.1% and 0.2% to almost zero, respectively.

Access to particular lighting sources does not mean that these are necessarily being used. Many households keep several sources of lighting available. Fig. 2 describes changes in what households refer to as their primary source of lighting. Again, the most important change is replacement of kerosene lamps with grid electricity connections. In 2015, about 54% said that kerosene was their primary source of lighting. Three years later, this number dropped to 21%. The grid became the primary source, with an increase from 43% to 73%. Households also effectively stopped using diesel-powered microgrids. Virtually nobody in the sample used it as a primary source by 2018. Importantly, though, the share of both SHS and solar lanterns as primary sources of lighting increased from 1.8% to 2.1% and 0.3% to 1.1%, respectively.

Having described salient patterns of distributed renewable energy use in the sample, we next turn to explaining these patterns.[3] To begin with, Fig. 3 reports changes in the ownership and usage of each type of lighting source as a function of the time that passed between the two surveys. The coefficient estimates are based on a fixed effects regression on households. The figure shows that primary use of the electric grid and kerosene moved in opposite directions, with changes of +30 percentage points (95% CI: [29, 31]) and −32 percentage points (95% CI: [−33,−31]), respectively. The effects on ownership were smaller, though still substantial: +18 percentage points (95% CI: [17, 19]) and −16 percentage points (95% CI: [−17, −16]). The graph also confirms the pattern of increased solar lantern ownership (+3.9 percentage points; 95% CI: [3.3, 4.4]) and primary use (+0.9 percentage points; 95% CI: [0.5, 1.1]). This, again, is consistent with the idea that primary use is not driving the growth of solar lantern ownership against the backdrop of India's massive grid extension drive.

Next, we investigate what caused the stagnation (or even decline) in distributed power. Our conjecture is that access to the grid crowded out distributed power. In particular, we examine whether the scale of Saubhagya inadvertently reduced the appeal of off-grid technologies. To test this conjecture, we estimate the effect of households benefiting from Saubhagya on ownership and usage of the same set of lighting sources. The results are reported in Fig. 4.

We find that Saughabya reduced kerosene use and ownership, though the effect is imprecisely measured. Specifically, we find that ownership declined by 6 percentage points (95% CI: [−22,10]) and that primary use declined by 10 percentage points (95% CI: [−22,1]). We also find evidence that it reduced the use of solar home systems, with a 4.5 percentage points decrease in usage (95% CI: [−6, −3]) and a 4 percentage points decrease in ownership (95% CI: [−8.7, 0.2]). Importantly, however, the scheme did not result in a decrease in the use of solar lanterns. While primary use of solar lanterns decreased by 2 percentage points (95% CI: [−3.6, −0.7]), there was no statistically distinguishable effect on ownership. This result demonstrates how grid extension has not removed the need for DRE, but rather changed the

[3] The Appendix (Tables A12 to A15) contains additional regression models for each lighting source.

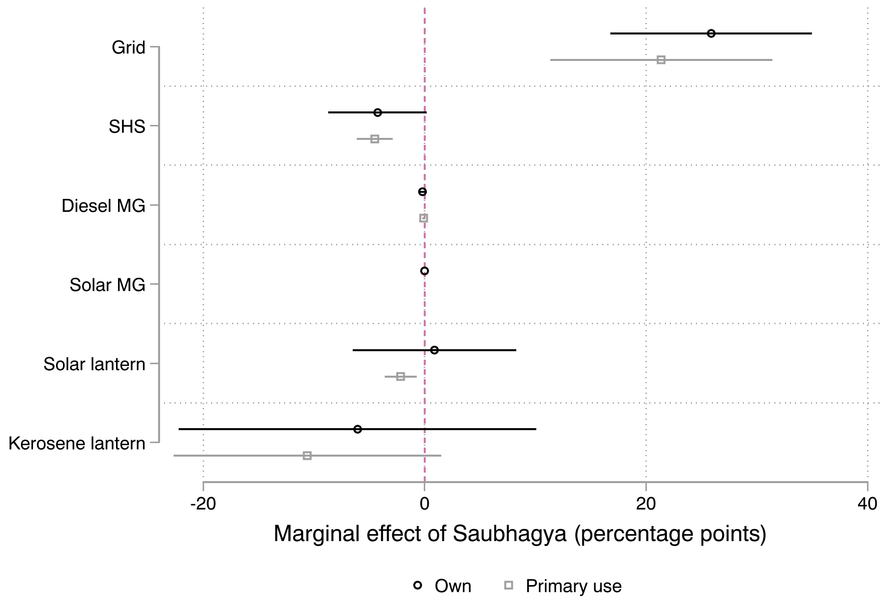

Fig. 4. The plot reports the effect of Saubhagya (i.e., the change from 2015 to 2018) on ownership and primary usage of various sources of lighting. The sample includes households that did not have access to the grid in 2015. The model includes district fixed effects. The estimates are reported in full in Tables A16 and A17. Bands represent 95% confidence intervals. Unweighted sample.

way households use it. Simply put, backup use is crowding out leapfrogging.

In Fig. 5, we next investigate why households continue to use solar lanterns despite grid access. The graph shows a coefficient plot for regressions that predict ownership and usage of lighting sources as a function of average hours of electricity available per day in the village. As the graph shows, hours of electricity have a large impact on kerosene lantern use in particular, with each additional hour reducing kerosene lantern primary use by 2.7 percentage points (95% CI: [−3, −2.4]). Similarly, hours of electricity supply have a large impact on diesel microgrid use (−0.3 percentage points; 95% CI: [−0.4, −0.2]). Most importantly, though, hours of electricity supply have also a negative impact on solar lantern ownership (−0.1 percentage points; 95% CI: [−0.3, −0.07]). Primary usage of solar lanterns, on the other hand, appears unaffected. One reason might be that solar lanterns are, in any case, rarely the primary lighting source for households with electricity access.

Conclusion

This paper has analyzed the evolving nature of distributed renewable energy in rural India. With data on household lighting patterns in six North Indian states from the years 2015 and 2018, we have documented a major change in the way DRE is being used. With the Government of India's household electrification drive, DRE has moved from an opportunity to leapfrog to a backup solution for intermittent electricity service. This shift has, in turn, favored solar lanterns over more expensive alternatives such as minigrids for household electrification.

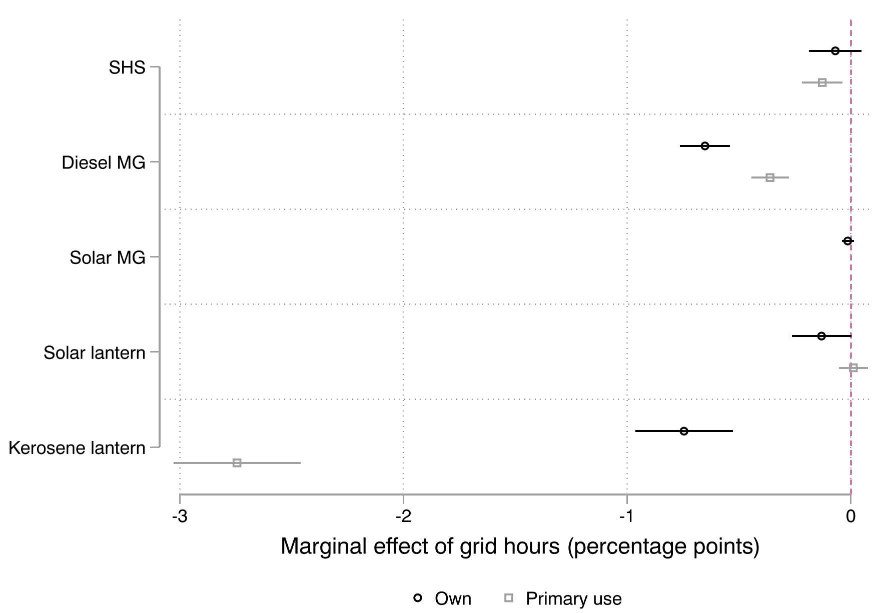

Fig. 5. The plot reports the effect of average hours of electricity availability per day (∈[0,24]) on ownership and primary usage of various sources of lighting. The estimates come from a model that adjusts for expenditure, education, and includes household fixed effects. The estimates are reported in full in Table A19. See Table A18 for similar models using average grid electrification per village instead of mean hours of electricity. Bands represent 95% confidence intervals. Unweighted sample.

The results have important implications for policymaking under the paradigm of integrated energy access. India's case shows how grid extension can achieve universal household electrification. This does not, however, imply that DRE technologies have no use. The far more difficult challenge of improving grid electricity service remains to be tackled, and Indian households clearly value DRE technologies in this regard. For most of them, though, the preferred solution is not an expensive minigrid or microgrid, or even a solar home system. Rather, households purchase comparably inexpensive solar lanterns to secure their lighting and mobile charging needs when grid electricity is unavailable. If it considers these services valuable enough, the Government of India could actively encourage these products through measures such as mass procurement of solar lanterns or purchase subsidies for households. Other DRE technologies play a different role and could be useful in areas that are difficult to reach with the grid. They could also be used for productive applications, such as cold storage or food processing. In the future, these same lessons may apply to other key markets, such as Sub-Saharan Africa, where grid extension and distributed renewables both continue to grow.

The results can also guide private sector investment. Minigrids and microgrids have captured the industry's imagination, but their potential to scale up to meet household needs in India appears limited based on recent trends. We cannot rule out the possibility that other types of microgrids become competitive for household electrification in the future, but this currently seems unlikely. A better investment might be in technologies that increase the brightness, battery life, robustness, and affordability of solar lanterns, which remain in demand among households despite almost universal household electricity access. If the Government of India were to create a mass procurement program for solar lanterns, the DRE industry would have the certainty it needs to invest in product development and market expansion. As long as India's grid electricity service remains intermittent and household income levels in rural areas are low, solar lanterns can play an important role in providing reliable lighting and mobile charging services to poor and marginalized households. Again, such reliability will likely also prove valuable in other markets where grid extension proceeds but the quality of grid electricity service remains low.

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.

Acknowledgements

We are grateful for comments by Abhishek Jain and Harshit Vallecha on drafts of this paper. The survey data used in this paper was jointly collected with CEEW. The survey was implemented by Morsel. We thank both organizations.

A replication package is available at Harvard Dataverse: "Replication Data for: The Evolving Role of Solar-Based Lighting Solutions in Rural India: Global Lessons for Distributed Renewables", https://doi.org/10.7910/DVN/NVJKFS, Harvard Dataverse.

References

Aklin, Michaël (2021). The off-grid catch-22: Effective institutions as a prerequisite for the global deployment of distributed renewable power. *Energy Research & Social Science*, *72*, 101830.

Aklin, Michaël, Cheng, Chao-yo, Urpelainen, Johannes, Ganesan, Karthik, & Jain, Abhishek (2016). Factors affecting household satisfaction with electricity supply in rural India. *Nature Energy*, *1*, 16170.

Alstone, Peter, Gershenson, Dimitry, & Kammen, Daniel M. (2015). Decentralized energy systems for clean electricity access. *Nature Climate Change*, *5*(4), 305–314.

Blankenship, Brian, Kennedy, Ryan, Mahajan, Aseem, Wong, Jason Chun Yu, & Urpelainen, Johannes (2020). Increasing rural electrification through connection campaigns. *Energy Policy*, *139*, 111291.

Heynen, Anthony P., Lant, Paul A., Smart, Simon, Sridharan, Srinivas, & Greig, Chris (2019). Off-grid opportunities and threats in the wake of India's electrification push. *Energy, Sustainability and Society*, *9*(1).

IEA (2017). *Energy Access Outlook 2017: From poverty to prosperity.* (World Energy Outlook Special Report).

Jain, Abhishek, Tripathi, Saurabh, Mani, Sunil, Patnaik, Sasmita, Shahidi, Tauseef, & Ganesan, Karthik (2018). Access to clean cooking energy and electricity: Survey of states in India (ACCESS). *Survey of states 2018*.

Ma, Siyuan, & Urpelainen, Johannes (2018). Distributed power generation in national rural electrification plans: An international and comparative evaluation. *Energy Research and Social Science*, *44*, 1–5.

Mani, S., Shahidi, T., Patnaik, S., Jain, A., Tripathi, S., Ganesan, K., Aklin, M., Urpelainen, J., & Chindarkar, N. (2018). Access to clean cooking energy and electricity: survey of states in India 2018 (ACCESS 2018). *Council on Energy, Environment and Water; Initiative for Sustainable Energy Policy*. National University of Singapore.

NSS (2018). *"Drinking water, sanitation, hygiene and housing condition in India: NSS 76th round." National Sample Survey, New Delhi.*

Palit, Debajit (2013). Solar energy programs for rural electrification: Experiences and lessons from South Asia. *Energy for Sustainable Development*, *17*(3), 270–279.

Palit, Debajit, & Bandyopadhyay, Kaushik Ranjan (2017). Rural electricity access in India in retrospect: A critical rumination. *Energy Policy*, *109*, 109–120.

Sergi, Brian, Babcock, Matthew, Williams, Nathaniel J., Thornburg, Jesse, Loew, Aviva, & Ciez, Rebecca E. (2018). Institutional influence on power sector investments: A case study of on-and off-grid energy in Kenya and Tanzania. *Energy Research & Social Science*, *41*, 59–70.

Sharma, Anjali, Agrawal, Shalu, & Urpelainen, Johannes (2020). The adoption and use of solar mini-grids in grid-electrified Indian villages. *Energy for Sustainable Development*, *55*, 139–150.

Singh, Kartikeya (2016). Business innovation and diffusion of off-grid solar technologies in India. *Energy for Sustainable Development*, *30*, 1–13.

Trotter, Philipp A., Cooper, Nathanial J., & Wilson, Peter R. (2019). A multi-criteria, long-term energy planning optimisation model with integrated on-grid and off-grid electrification: The case of Uganda. *Applied Energy*, *243*, 288–312.

Urpelainen, Johannes (2014). Grid and off-grid electrification: An integrated model with applications to India. *Energy for Sustainable Development*, *19*, 66–71.

Urpelainen, Johannes (2016). Energy poverty and perceptions of solar power in marginalized communities: Survey evidence from Uttar Pradesh, India. *Renewable Energy*, *85*, 534–539.

Zerriffi, Hisham, & Wilson, Elizabeth (2010). Leapfrogging over development? Promoting rural renewables for climate change mitigation. *Energy Policy*, *38*(4), 1689–1700.