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Four ISEP scholars review the evidence on small solar systems' impact on household welfare and suggest guidelines for policymakers. Focusing on four randomized controlled trials (RCTs) in South Asia and Africa, the authors find consistent evidence that off-grid solar systems reduce household kerosene consumption, but mixed evidence for education and health benefits, and weak evidence for economic benefits.

Solar panels in Uttar Pradesh, India.

SMALL OFF-GRID SOLAR SYSTEMS DISPLACE KEROSENE, BUT EVIDENCE FOR SOCIAL AND ECONOMIC IMPACT REMAIN WEAK

Michaël Aklin, University of Pittsburgh
Patrick Bayer, University of Glasgow
S.P. Harish, College of William and Mary
Johannes Urpelainen, Johns Hopkins SAIS

INTRODUCTION

Small off-grid solar systems usually provide enough power for basic services such as lighting, mobile charging, and televisions. A review of recent randomized controlled trials offers robust evidence for reduced kerosene expenditures, but the evidence for broader social and economic impact remains weak.

The decreasing cost of solar power has created a growing off-grid electrification industry. Most applications of off-grid solar power are small systems, such as portable lanterns or home systems. They can provide enough power for basic needs like lighting, mobile charging, fans, and televisions. While it would be unrealistic to expect such small systems to produce transformative impacts, even basic energy access could in theory contribute to education, health, and livelihoods. The social and economic benefits of such basic energy access are not obvious, but recent randomized controlled trials can help policymakers understand the value of small solar systems. Our review of recent randomized controlled trials *(N=4)* with small off-grid solar systems shows robust evidence of reduced kerosene expenditures but the evidence for health, educational, and economic benefits is either mixed or limited.

ANALYSIS

More than a billion people live without electricity at home, but the decreasing cost of solar power has made off-grid energy access an attractive alternative to conventional grid extension. Solar lanterns can replace kerosene lamps for portable lighting and often even allow mobile charging. Solar home systems can power multiple lights, mobile chargers, fans, televisions, and other small electric appliances. Solar micro-grids can offer these benefits to dozens in one village.

The numbers are impressive, too. According to an IRENA (2015) report 20 million households worldwide are already served through solar home systems and another 5 million households through renewables-based micro-grids, most of them from solar PV unit. The number of installed solar home systems increased almost five-fold from 1.3 to about 6 million during the eleven years 2002-2013 (IRENA 2015, 20).

Sales of solar lanterns in Asia were about 3 million per year in 2011, virtually all of them coming from India, with India being the fastest rising market according to Bloomberg New Energy Finance's most recent market report (BNEF 2017). African cumulative sales amounted to 8 million in 2013 (IRENA 2015, 21), to see 2 million units sold in Africa in the first half of 2016 alone (BNEF 2017). Overall, sales in solar lanterns and solar home systems peaked at 4.3 million units in the same period, up by 48% compared to the year before (BNEF 2017), indicating continued market growth in renewable off-grid systems.

How valuable is basic energy access from off-grid solar systems? On the one hand, even basic energy access is qualitatively different from no power at all. Compared to a dim kerosene wick, a bright LED light can help children with their homework and other family members with daily chores. An electric fan can bring relief during the hot season and an inexpensive mobile phone offers rapid and reliable communication with the outside world. Thus, small solar systems can offer basic energy access at a relatively low cost.

On the other hand, basic energy access has many limitations. It does not allow refrigerators, freezers, air conditioners, machinery, or groundwater pumping for irrigation. The cost of each kilowatt-hour for such large loads of power remains higher than when households use power from larger systems, such as the national grid or a large mini-grid. Small solar systems are only competitive when electricity use remains low.

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Recent randomized controlled trials – field experiments that resemble medical trials for new drugs – offer important insights into the value of small solar systems. Over the past three years, several scholars have conducted rigorous studies that quantify the benefits of small solar systems in different circumstances. We compiled these studies, focusing only on randomized controlled trials that have already undergone peer review in scientific journals, to better understand impact.

We found four studies that qualify. They focused on solar micro-grids in India (Aklin et al. 2017), solar kits in Rwanda (Grimm et al. 2017), and solar lanterns in Bangladesh (Kudo et al. 2017) and Uganda (Furukawa 2014). While randomized controlled trials on small solar systems remain all too rare, these studies can help policymakers assess the value of investing in off-grid solar power depending on local conditions and the goals of policy.

Experimental studies from India (Aklin et al. 2017) and Rwanda (Grimm et al. 2017) show that small off-grid systems generate modest but meaningful reductions in household energy expenditures. Aklin et al. 2017 evaluate the impact of installing solar micro-grids for two bright lights and mobile charging in the state of Uttar Pradesh. They find that when solar micro-grids are installed, monthly purchases of kerosene from the black market decrease by almost fifty rupees (USD ~0.8). Monthly purchases of heavily subsidized kerosene from government shops, however, remain unchanged.

Grimm et al. (2016) focus on the impact of low-cost "solar kits" that also offer lighting and mobile charging, as well as a radio, in Rwanda. The authors offer the kits for free and find that the use of lighting expands substantially among households that were offered solar kits, and that traditional energy expenditures – candles, kerosene, batteries, and mobile phone charging – decrease by 557 Rwandan francs (USD ~0.92) per month.

The evidence on educational benefits is decidedly mixed. Furukawa (2014) studied the effect of free solar lamps in Uganda. He found that solar lamps increased study time but actually worsened test performance, though he also notes that the quality of the solar lamps used was not very good. Kudo et al. (2017) offered free solar lanterns to students in Bangladesh and found that both attendance and study time increased, but these changes did no improve academic

Initiative for
Sustainable Energy Policy
Energy, Resources and Environment
Rome Building, 4th Floor
1619 Massachusetts Ave, NW
sais-isep@jhu.edu
@sais-isep
www.sais-isep.org

performance. In their study, Grimm et al. (2016) found only limited evidence for increases in study time among children, as only boys in primary school increased time spent on studying.

The evidence for health improvements from off-grid solar power is also modest. Grimm et al. (2016) find that households report better air quality after adopting solar kits, but these positive perceptions disappear in survey questions about actual health outcomes.

Finally, experiments so far have not found evidence for changes in economic activity. Aklin et al. (2017) find no evidence of changes in household expenditure savings, or home business. Grimm et al. (2016) focus on time allocation to productive activities, and find no evidence of changes from solar kit adoption.

To summarize, small solar systems produce modest benefits for rural households. On the one hand, there is evidence for modest reductions in energy expenditures and some suggestive evidence of potential educational benefits. On the other hand, broader economic benefits beyond reduced energy expenditures remain limited and uncertain.

POLICY RECOMMENDATIONS

- *Where grid extension is expensive or impractical, including large areas of Sub-Saharan Africa, small solar systems can offer basic energy services to households. Savings from reduced kerosene use can reduce the cost of using solar power.*

- *Thus, small solar systems can play an important role in providing the rural poor, who cannot afford a grid connection, with basic energy access under the United Nations' Sustainable Energy For All initiative.*

- *The evidence on education and health benefits from small solar systems is mixed and depends on local conditions. Policymakers motivated by education and health benefits should not offer generous subsidies to small solar systems without seeing the results of a rigorous pilot study first.*

- *The evidence on economic benefits and expanded livelihood activities is weak. Policymakers should not expect rapid economic growth from small solar systems.*

- *Randomized controlled trials on the benefits of small solar systems published in refereed journals remain rare. Off-grid solar policy would benefit from a research program focused on estimating the benefits of small solar systems in different conditions.*

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