

Impact and Pathways of Transitioning to Solar Energy in Rural India

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Abstract: *Although India has almost reached the historic goal of universal electrification, the challenge of supplying 24x7 power for all remains. Due to the low and distributed electricity demand in rural areas and the prevailing poverty, delivering uninterrupted power to every household is a drawn-out process. Despite its growing economy, India has low conventional energy resources compared to its required energy, and can harness the huge potential of solar energy as it lies in the tropical belt. This paper analyses the impact and pathways of the transition towards solar energy in rural India. By analysing data from a successful project—named Solar Mamas—of Barefoot College International, it highlights the benefits in climate change mitigation, rural employment creation and income generation for women, and democratisation of access to energy for hundreds of communities, all while helping India meet its 2030 SDG targets.*

Keywords: Rural India, Solar Energy, Barefoot College International, Solar Mama

1. Introduction

The Government of India has made extraordinary progress in electricity access by connecting every village to the grid in April 2018. By March 2019, the government had almost executed its undertaking to connect all willing rural households¹ (REC, 2018). The final stage of achieving high-quality and uninterrupted power for every household is going to be a challenge that will extend well after connections have been made available (Government of India, 2017). In rural areas, the demand density is low and fragmented whereas the supply and service costs are exceedingly high: this is a deterrent for India's state-owned distribution companies (Mukherji, 2017). Hence decentralized backup lighting and power will likely be needed for the next decade or two².

India faces exploding demand and insufficient supply. With the expanding economy growing 6% to 6.5%³ per annum along with the population growing at a rate of 1% per annum, India's low conventional energy⁴ resource cannot meet the demand. However, India can harness the huge potential of solar energy as it lies in the tropical belt and receives sunshine year around. Of the G20 countries, India is ranked fifth in Solar Power and is the only one on track to achieve its targets under the Paris Agreement⁵. Due to its favourable location in the solar belt, India is one of the best recipients of solar energy with abundant availability and the initial target of 20 GW capacity for 2022 set by the Indian Government was achieved four years ahead of schedule.^[3]

Kerosene: Even though kerosene is far from an ideal fuel,

households used to depend on subsidised⁶ kerosene as a source of light and cooking fuel. Rural India has unreliable power supply—such as blackouts, and voltage surges, rationed hours of electricity available per day, hence kerosene lamps continued to remain an important backup source for lighting as they are reliable and decentralised.

Although kerosene has wide-ranging detrimental effects, kerosene is cheap and efficient and is used due to the subsidies provided by the Indian government. Injuries, poisoning, fires, and explosions cause negative externalities of consumption⁷. The emission of fine particulates, carbon monoxide, nitric oxides (NOx), and sulphur dioxide when burned may diminish lung function and increase risks of asthma and cancer as a result of indoor pollution.

Continued reliance on kerosene is not a socially or economically viable option as it can lead to levels of pollutants that exceed WHO guidelines⁸. In addition, it gives low levels of light, limiting education and income-generating opportunities. When international oil prices rose, as in 2018, the subsidy cost of kerosene to the government soared leading to budget blowouts. Finally, a quarter of all energy-related residential greenhouse gas emissions in 2013 were the result of kerosene usage.

Solar: Today solar products offer better lighting, and the ability to plug in and charge devices. Due to the recent development in the efficiency of photovoltaic cells and the technology to scale up, the solar options are cheaper than kerosene over their lifetime.

¹<https://powermin.gov.in/en/content/saubhagya>

² Based on meeting with power and regulatory sector experts in UP on November 14, 2018.

³<https://www.reuters.com/article/us-india-budget-renewables-idINKBN1ZV3S8>

⁴Conventional sources of energy can be described as non-renewable sources of energy which have been used since a long time e.g. Coal, Petroleum

⁵<https://www.ibef.org/industry/power-sector-india.aspx>

⁶Subsidies involve the government paying part of the cost to the firm; this reduces the price of the good and should encourage more consumption.

⁷Negative externalities occur when the consumption or production of a good causes a harmful effect to a third party.

⁸<https://www.iisd.org/system/files/publications/india-kerosene-solar-swap.pdf>

Pros

- 1) Solar energy is appropriate for India as India is the third most polluted country in the world⁹. Solar energy does not release CO₂ and other gases which pollute the environment.
- 2) In energy deficient country like India where the supply cannot meet the demand, where power generation is costly, solar energy is the best alternative means of power generation as it is inexhaustible.
- 3) As a solar energy system can be installed anywhere, a power or gas grid is not needed to get solar energy. Consequently, it is cheaper compared to other sources of energy as it has no running costs.

Cons

- 1) Solar energy cannot be generated during the night or during inclement weather, requiring large batteries and inverters to store energy for use during such times. This can make the upfront cost of a solar system prohibitive.
- 2) The land space required to install solar panels is quite large and cannot be used for other purposes, and may be riddled with land rights issues as other such projects have been in India. Though decentralised rooftop solar systems do not suffer from these drawbacks.
- 3) The amount of energy produced is quite low relative to other forms of energy for a given surface area. Efficiency in solar panels is simply the measurement of energy output in a given surface area; the more efficient a panel the less space it takes up; however, it is more expensive. The energy density for solar energy that produces electricity is particularly low.
- 4) Currently there is no good way to manage/recycle solar panels that have reached the end of their life, thus causing environmental issues.

Subsidies

Due to these health and environmental issues, the Government of India eliminated the subsidies for the consumption of kerosene through India's Public Distribution System (PDS). High kerosene consumption is used to account for 15 percent of global consumption (Energy Information Administration [EIA], 2013) as seen in Figure 1.

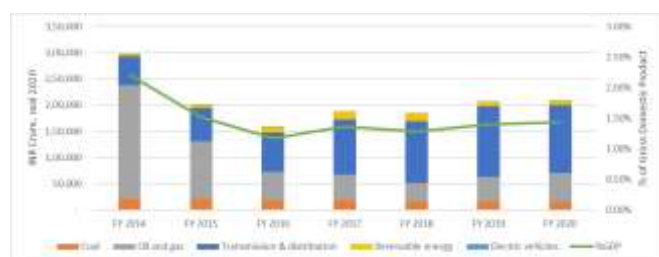


Figure 1: Total quantified energy subsidies, FY 2014–FY 2020 (INR crore, real 2020)¹⁰

In 2018-19, the government of India spent USD 1.2 billion on kerosene, 9% of all fossil fuel subsidies in the country¹¹. While energy subsidies are vital for increasing energy access and poverty reduction, they are also often improperly

focussed, providing disproportionate benefits to the richest customers, and having no place in a world shifting to low-carbon sources of energy to combat climate changes. However, the kerosene subsidy system distribution had deep failings and it was estimated that close to 50 percent of subsidized kerosene that was allocated to households “leaked” in the process of distribution through the “black market”, theft and adulteration, at a substantial cost to public finances (Clarke, 2014)

While kerosene use and the current system of kerosene subsidy distribution were highly problematic, where the penetration of grid electricity is limited (in particular remote rural areas) off-grid solar applications can effectively replace kerosene to light homes leading to significant environmental benefits. Solar applications provide clean, cost-effective, reliable, and powerful and lighting to households.

In April 2019, the Ministry of New and Renewable Energy entreated the Ministry of Petroleum and Natural Gas to deflect part of the kerosene and cooking gas subsidy building towards solar options. The research by IISD shows that public resources are fluctuating: kerosene subsidies fell from USD 7.7 billion in the fiscal year 2014 to USD 0.9 billion in the fiscal year 2019 (Bridle et al, 2020), while major new policies on solar irrigation and solar rooftop photovoltaic products were announced in February 2021.

In remote areas, solar products such as lanterns, home systems, and mini-grids provide backup power. By shifting the subsidies from kerosene to off-grid solar photovoltaic products the energy transition for underprivileged households can be financed. However, most households are dependent on kerosene as their primary source of lighting (if unelectrified) or as a coping strategy during outages. Switching to solar significantly reduced the fiscal and household expenditure: solar products are now inexpensive than kerosene over the lifespan of the technology. Table 1 shows that, once the upfront costs of solar products are stretched over two years and government subsidies for kerosene are taken into account, solar products result in savings compared to kerosene lamps. The net cost of the exchange is the amount the government could save by switching support to these technologies. Furthermore, the government would save the losses from fuel diversion and budget blowouts caused by unpredictable oil prices.

Table 1: Cost comparison of solar products with subsidized kerosene (INR per month per household)¹²

	Units	Solar lantern**	Solar home system**	Solar microgrid^
Technical Parameters				
Solar panel capacity	Watts	2.35	10	400
Lighting capability		One 1.1W LED; 100 lumens	Two 2.4W LED; 440 lumens	Two 2.4W LED; 440 lumens
Battery capability		3.7V, 2.2Ah	12V, 7.2Ah	12V, 400Ah

¹²Policy approaches for a kerosene to solar subsidy swap in ... (n.d.). <https://www.iisd.org/system/files/publications/india-kerosene-solar-swap.pdf?q=sites/default/files/publications/india-kerosene-solar-swap.pdf>.

⁹<https://www.iqair.com/en/world-most-polluted-countries>

¹⁰<https://www.iisd.org/gsi/mapping-india-energy-subsidies-data/>

¹¹<https://www.iisd.org/articles/india-subsidy-swap>

Economic Parameters				
Capital cost of solar product	INR	1,300	3,400	175,500
No. of households served		1	1	50
Life cycle of product	Months	24	24	24
Levelized monthly cost per household over 2 years	INR	54	142	146
Kerosene average monthly cost per household*	INR	70	70	70
Monthly cost of change per household	INR	-16	71	76
Average monthly govt kerosene subsidy per household*	INR	113	113	113
Net monthly cost of kerosene to solar swap	INR	-129	-41	-37

*Average monthly household kerosene consumption assumed as 2.63 litres based on the average value of four sources: National Sample Survey Office, 2014; Jain et al., 2018; Odisha Sun Times Bureau, 2018; Gill et al., 2018. Average household costs and government subsidies are calculated by using the market average of retail and Public Distribution System (PDS) kerosene between April and October 2018 (Indian Oil, 2019a, 2019b).

**The reference prices were based on sample products for the solar lantern, Sunking Pro 200 (Greenlight Planet, 2019) and SHSS, Subham Solar SHLS-2 (Subham Solar Solutions, 2019).

^Solar Microgrid specifications are based on specifications quoted by five microgrid developers to TERI under the Lighting A Billion Lives Initiative (TERI, 2019).

Solar products can be used in households, at a community level and for productive use. There are several successful projects where households use solar power such as the Zanskar Shade at the foothills of the Himalayas and the Gram Oorja project in Maharashtra where the grid is unreliable due to the topography. At a community level, solar panels are used in primary health care centres and in schools. With longer-lasting batteries, three-phased power, additional solar panels and a greater capacity of the solar grid, the villagers can potentially utilize the pumps for irrigation, sugarcane crushers and motors to modernize their agricultural practices.

2. Data Study in India

The Solar Mamas Programme

Since 1984, the Barefoot Solar Department of India train illiterate and semi-literate women from marginalized villages around the world to become Solar Mamas. These Solar engineers are taught practical skills in solar electrification. Once trained for a period of 6 months, Solar Mamas return to their villages with skills and equipment to electrify at least 50 homes each and to repair and maintain the unit. Furthermore, the Solar Sakhi programme trains women for 3 months to become entrepreneurs to create their own markets and sales networks for Renewable Energy product distribution that will cover mid-range to last-mile

communities. This programme is a catalyst to create employment for women, by boosting their income and providing self-reliant solutions for village communities while working toward several of the UN's Sustainable Development Goals.

Data Description

In India, Barefoot college gathered data across seven states: Andhra Pradesh, Karnataka, Manipur, Bihar, Karnataka, Jharkhand and Chhattisgarh. This programme impacted 7000 households wherein 140 solar mamas electrified about 50 houses each. This randomized data is for a baseline survey of 690 households in 2017-18 and an end-line survey in 2019-20 of 695 households. As demonstrated in the table below the savings for kerosene is 110 per month or 1320 annually. The investment was Rs 15000 per for one home solar lighting system which comprised of a 40W solar panel on the roof, a battery of 40Ah, 4 LED lamps of 4W and wire of 30 m (to facilitate cooking in the night), and a charge controller of 12W.

At a community level, the contributions were maintained by the Village Electrical and Environment Committee (VEEC). The money collected was stored in the revolving fund. One area in the village is identified where a 300 W solar panel is installed. This Rural Electronic Workshop (REW) is used at a community level for various reasons: studying, sewing, weaving, etc. In addition to encouraging the use of solar energy, it cultivated a sense of community ownership of the solar energy system, educated the women and facilitated the long-term care of the system.

This data was collected from 2017-2020 by a grant from various donors which promotes the solar mama programme and education. The survey comprised over 70 questions and captured details like the family size and social category, in addition to changes in health and economic indicators, the impact can be measured quantitatively and qualitatively. The difference between the baseline and the end line findings is displayed in the tables and figures below. Table 2 shows the reduction of the average consumption and expenditure for energy and lighting. Table 3 highlights the long-term fringe benefits concerning Literacy and health.

3. Analysis

Household Use

Table 2: Average Use and Expenditure for Energy and Lighting

Energy and Lighting	Average Use in 2017(hours per month per family)	Average Use in 2020 (hours per month per family)
Kerosene (used for cooking and lighting)	3.899	0.03
Candle	1.13	0.001
Battery Torch	1.58	0.47
Energy and Lighting	Average Expenditure in 2017 (hours per month per family)	Average Expenditure in 2020 (hours per month per family)
Kerosene (used for cooking and lighting)	Rs 109.90	Rs 0.01

Candle	Rs 49.30	Rs 0.22
Battery Torch	Rs 51.38	Rs 29.12

Table 3: Additional Benefits

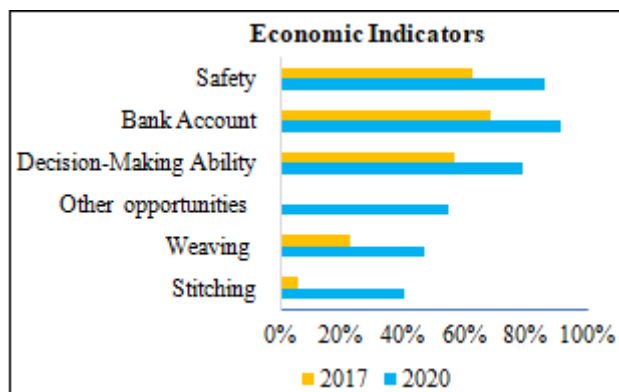
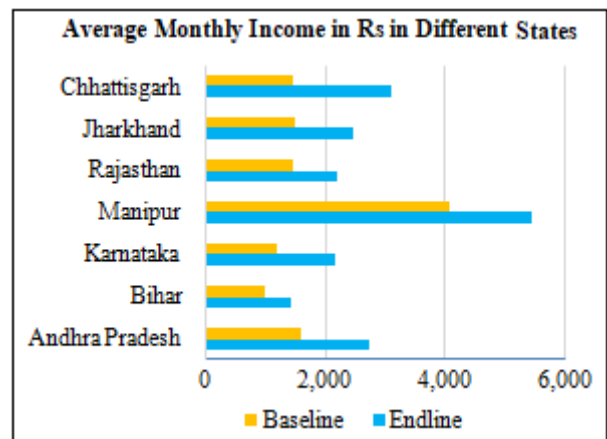
Light Increase	2017	2020
Usage of Kerosene lamp outside the home	77%	13.6%
Usage of Solar light lamps outside the home	3%	50%
Literacy and Health	2017	2020
Literacy	1.7 hrs per day	2.4 hrs per day
Phone Charging at own Home	29.8%	94.2%
Light Source Brightness	10.43%	95.68%
Health		
Black Smoke Emission	94.20%	0.43%
Cough	5.82%	0%
Kerosene Poisoning	22.52%	0%
Black Soot Deposition	4.49%	0%
Lung and Breathing Issues	46.52%	0%
Eye Irritation	84.20%	0%

Productive Use

Upon completion of building, installing, and maintaining solar panels and batteries in their communities, *Solar mamas* learn entrepreneurial skills such as sewing and weaving to launch a craft business; others learn to make and sell coffee or pursue other livelihood skills. Women are empowered: able to make decisions and operate bank accounts. This in turn creates opportunities and opens doors that can significantly enhance the lives of women, their families, and their communities, this is depicted in Table 4. The rise in average monthly income is shown in Figures 3 and 4 – it rose by Rs1,000 per month in a rural household.

Table 4: Other Economic Indicators and Women's Empowerment

Economic Indicators	2017	2020
Stitching	6.09%	40.14%
Weaving	22.9%	46.47%
Other Livelihood Skills and opportunities (Average Income)	0%	54.43%
Women's Empowerment	2017	2020
Decision-Making Ability	56.67%	78.27%
Bank Account	68.26%	91.08%
Safety	62.3%	85.76%

**Figure 2:** Economic Indicators 2017-2020**Figure 3:** Average Monthly Income in Different 2017-2020**4. Policy Recommendations**

The removal of the kerosene subsidy has reduced the fiscal expenditure in the budget. These savings can be redirected towards the upfront capital cost of solar systems. Additionally, these savings could be used for training solar engineers and making them self-reliant. A few recommendations are highlighted below:

- 1) *Awareness — knowledge of a product or service from experience, peer influence, vendor suggestion, an NGO program, or a government campaign:* Through various government campaigns such as mass media, radio, state allowed manufacturer stalls, the awareness for solar products can be raised. In Bihar, where the average family size is large, the magnification of solar savings must be highlighted whereas, in Jharkhand, the price sensitivity should be showcased due to the prevalent black market. As the villagers are more influenced by personal relationships, positive success stories from neighbouring villages need to be broadcast to build credibility. In the case of *Solar Mamas*, it was the collective experience, as women tend to influence and support other women in a similar situation.
- 2) *Acceptance - Quality, Capacity and Access:* The experiences of the villagers with regards to reliability, performance and failures will determine the retention of the solar appliances. The solar systems' ability to meet household needs such as 24x7 lighting, mobile phone charging, appliance use, and improved reliability as against grid electricity, will help with acceptance. These benefits of solar systems in remote areas should be clearly demonstrated at community meetings to establish credibility of these products.
- 3) *Financial Barriers:* As the upfront one-time costs are excessive, it would be prudent if the funds saved from the kerosene subsidy could be repurposed towards helping manufacturers and low-income consumers. By reallocating saved subsidies towards building a fresh ecosystem for decentralised solar products and subsidising the capital cost of ownership, the government will be able to facilitate a shift towards a sustainable source of energy without the entire burden of the energy transition having to be borne by rural consumers. **Manufacturers:** By having policies promoting domestic production and by lowering the interest rates, providing tax rebates, or introducing

longer-duration repayments on solar loans, the manufacturers can be encouraged. They can then be mandated to pass on the cost-savings to consumers. The government should sensitize local bank officials of the various business models of solar enterprises so that they are trained to see solar enterprises as bankable enterprises. **Customers:** The money saved from the subsidy should be used to finance 60-80% of the capital costs to jumpstart the process of owning such systems as the running and maintenance costs are negligible. By decentralizing solar power, and reducing solar tariffs from ~Rs. 7.36/kWh (US 10 cents/kWh) in FY15 to Rs. 1.99/kWh (US 3.57 cents/kWh) in FY20¹³ they can encourage a large-scale transition to solar energy in rural areas.

- 4) *Lack of Skilled Workers and After-Sales Service:* The government should demand accountability from the solar manufacturers who are the recipients of the loans, and simultaneously train the women in the villages to become technical engineers and service agents. For the women not earning before, this opportunity would lead to more disposable income, in addition to the increased income from other activities (Table 4). For the manufacturers, the government should enforce minimum standards for after-sales service. This would build a financially sustainable ecosystem in the absence of kerosene.

5. Conclusion

There is significant experimental evidence highlighting that the adoption of solar energy can indeed be successful and that given enough time, every village can learn to gain electricity. The apparent advantages of solar energy are highlighted in health, finances, climate change and in bridging the digital divide. In the short-term, the perception of safety in the household and community, improved air quality, longer study time and night schools, increase in businesses and economic activity, and social activity are the benefits whereas the benefits in the long term are improved health and hygiene, comfort and convenience, increased household income and education opportunities. A positive externality¹⁴ of solar adoption is the use of LPG cylinders for cooking, where 80 million cylinders were distributed to deprived households¹⁵ as households will move away from kerosene which is also used as a cooking fuel in tandem to using it as a lighting source. Women's empowerment, deforestation and reduced carbon emissions make this a worthwhile change.

The Solar Mamas programme empowers women who come from some of the deprived, most marginalized, climate-devastated places on our planet by exploiting their high accommodative intelligence. Their ability to act competently in adverse circumstances makes them most proficient at leveraging technological tools (yet another amazing

equalizer) to transform their lives. Apart from becoming role models for their families, these girls have become leaders tackling the climate change issues head-on in the persistent pursuit of sustainable development. This beneficial community model is prevalent in a few countries and can be replicated in other developing countries to create solar communities that are financially sustainable, and able to grow and improve their renewable energy. Moreover, the thriving community focuses on women's empowerment and gender equality, and environmental stewardship. And overall, the improved quality of life in social, economic and educational areas. All in all, it is a signature initiative of social entrepreneurship that makes the Barefoot model sustainable and self-reliant.

With new and more affordable solar technologies moving to a sustainable form of energy has never been easier. Awareness needs to be paired with financial incentives to merge into the existing system and in achieving successful widespread adoption and reform of the existing fossil fuel economy.

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¹³<https://www.ibef.org/download/Renewable-Energy-January2021.pdf>

¹⁴A positive externality exists if the production and consumption of a good or service benefits a third party not directly involved in the market transaction.

¹⁵<https://www.pmuy.gov.in/about.html>

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