Localization–affordability–saturation for speedy distribution of solar study lamps to millions

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Millions of rural households in India lack access to clean basic lighting which hampers the ability of children to study during dark hours. Over 81 million students are likely to be dependent on kerosene lamps for basic lighting. Despite programmes focusing on disseminating solar lanterns since the last three decades, penetration is limited owing to three main barriers: affordability, absence of after-sales services and unavailability in rural markets. This paper presents the localization–affordability–saturation (LAS) model that addresses these main barriers by bringing together three institutional spheres – government, corporate and NGOs for speedy upscaling. This paper illustrates experiences and challenges that have emerged from field testing of the model through Million Solar Urja Lamp Programme while disseminating 1,000,000 solar study lamps to rural school children residing in more than 10,000 villages in India. Though implemented successfully, applicability of LAS model can be hindered due to dependence on subsidies, bottlenecks in local manufacturing infrastructure, absence of market mechanism and its relevance in providing complete lighting solutions.

Keywords: Affordability, kerosene, localization, rural, saturation.

A persistent issue all over the world is lack of access to clean, basic lighting. According to a 2015 report[1] of the International Energy Agency (IEA), 1.2 billion people in the world do not have access to electricity with 20% of this population (i.e., 237 million)[1] residing in India. Despite electrification programmes being operational from 1950s (ref. 2), there is significant gap between the urban electrification rate at 96% and 74% in rural. This disparity is a matter of concern, as 68% of the Indian population resides in rural areas[3].

India is the second most populous country in the world, with a population of 1.2 billion[2]. Sixty five per cent of this population is below the age of 35 years and 30.7% below the age of 14 years[3]. Because the population in the ages between 0 and 14 years will reach working age in the next 5–20 years, it is imperative to educate them well. More than 43% of households in India depend on kerosene lamps as their main source of lighting[2]. A child residing in such a household does not have access to basic clean light for study. NUEPA (2014) revealed that about 189 million students, enrolled in classes 1 to 12, reside in rural areas[4]. Considering this, 81.2 million students in India are likely to use kerosene for their basic lighting needs that include studies. One kerosene wick lamp consumes approximately 21.6 ml/h (ref. 5). A student using one wick lamp for four hours in a day for 365 days in an year consumes about 30.24 litres of kerosene at an annual cost of about INR 471.77 (US$ 7.04) when the real cost is INR 943.24 (US$ 14.07) minus the subsidy[6]. On a macroscale, total kerosene subsidy in India adds up to about INR 312.56 billion (approximately US$ 5.1 billion), which accounts for 19% of the overall fuel subsidy in India[7–10].

Conventional methods of setting up power plants to provide electricity to rural areas in India offer a long-term solution to lighting problem, but do not address the immediate energy requirement. As 17% of the world's population reside in India, setting up of conventional power plants to meet the country's energy needs will require a large natural resource base. India, however, possesses only 6.8% of the world's coal reserves, 0.3% of the world's oil reserves and 0.7% of the world's gas reserves[11]. Another critical factor in addressing energy needs is the time required to set up a power plant, which is currently 4–5 years. Based on these factors, it is estimated that 106 million rural students[4] enrolled in classes 5–12 are likely to graduate from school without

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access to grid-based lighting, especially for study purposes.

Progress of solar lantern programmes in India

Solar photovoltaic (PV) systems present a feasible lighting solution in rural areas of India. India has a geographical advantage with 300 sunny days and average daily solar radiation varying between 4 and 7 $kWhm^{-2}$ for different parts of the country[12], which can be leveraged towards tapping solar potential. In the last three decades, several initiatives such as the National Solar Photovoltaic Energy Demonstration (NASPED) Programme[13], the Rural Renewable Energy Systems[14] and the Urja Gram (Energy Village) Programme[14] have been undertaken in India to address the lighting problems faced by rural communities. NASPED and other programmes mainly remained at the demonstration level, failing to make any significant impact[15] as the overall installation of solar lanterns in India increased merely from 0.365 million in the 1990s to 0.817 million in 2010 (refs 13, 16, 17). The growing challenge of climate change and the necessity to sustainably meet India's energy needs led to the launch of National Solar Mission (NSM) by the Government of India in 2010 (refs 18, 19). One of the established goals of the NSM is to distribute 20 million solar lighting systems by 2022. However, solar lantern installations have been decreasing with only 32,826 and 27,841 lanterns disseminated in years 2011 and 2012 respectively, making the target of 20 million solar lighting systems seem unachievable[20–22]. Solar lantern programmes have also been implemented by other agencies such as The Energy and Resources Institute under the 'Lighting a Billion Lives' (LaBL), which was launched in 2008 and has distributed over 122,240 lanterns in India[23,24].

Regardless of three decades of efforts by the government and other stakeholders towards diffusion of solar PV lighting solution through programmes and pilots, the penetration is not even 1% in India[2]. About 76.93% of sub-districts have less than 1% and only 1.16% of the sub-districts have more than 10% of households using solar as their main source of light.

Limitations of current programmes for scaling up

Literature identifies three predominant reasons for low penetration of solar PV systems in rural areas despite possibility of various solar solutions. First, off-grid solar solutions are generally perceived as expensive and beyond the reach of the rural poor[25,26]. Solar lamps are generally produced in urban areas with high transportation and other overheads involved. Till now most programmes by the government towards diffusion have focused on subsidy as a financial instrument for poor rural households to gain access to clean lighting solutions. Second, generating confidence in off-grid solar products has remained a challenge due to unreliable after-sales service, which often results in a higher number of non-functional systems over time[27,28]. Unavailability of trained local technicians to provide repair services is a primary concern amongst users, hindering the adoption of off-grid solar lighting solutions. The presence of servicing facility in urban areas results in delay for availing after-sales service and also tends to be costly. Third, off-grid solutions are not easily available in urban or in rural markets. Non-existent distribution channels make it difficult for households to access off-grid solutions[29,30]. Furthermore, for private players, rural areas do not present a financially attractive market to sell solar products.

In addition to the aforementioned reasons for low penetration of solar technology in India, another critical reason is inherent weaknesses of the three implementing institutional spheres and fragmented nature of their implementation. The state has the ability to mobilize large resources; however it does not have the dexterity for diffusion of technology at the grassroots level. On the other hand, civil society particularly NGOs have grassroots presence with reasonable rapport with local communities, but lack wherewithal to implement large scale programmes. Corporate houses despite having demarcated resources[31] suffer from a myopic vision and interests limited to vertical integration of markets that restricts their activities normally to certain pockets of immediate market interest. The complementary strengths of these institutional spheres have to be harnessed to avoid fragmented nature of implementation and speedy scaling up.

LAS model for large upscaling

In order to address the reasons identified above for low penetration of solar technology, Indian Institute of Technology (IIT) Bombay has evolved the 'localization–affordability–saturation' (LAS) model. It has three interlinked and interdependent core concepts of localization, affordability and saturation. 'Localization' focuses on knowledge and skill transfer to local communities by involving them in deployment of technology in rural areas and simultaneously providing employment for people. It represents local harnessing of renewable energy by creating a distribution network that offers a distinctive advantage of locally trained people catering to need of after-sales service. In doing so, there is emphasis on transferring basic know-how of appropriate renewable technology by imparting systematic training to local people for diffusion and maintenance. Localization is envisaged as the backbone of this initiative as most other initiatives have either failed or yielded limited success due to their strategic limitations in building locally dependent systems. 'Affordability' is an important aspect and absence of it hinders speedy diffusion and upscaling of appropriate technology in developing countries. Affordability emphasizes on reducing the cost barrier thus becoming instrumental in speedy penetration of technology into rural markets. Ensuring affordability creates a positive effect on demand for technology and enhances reach to remote parts. 'Saturation' builds on reaching maximum number of beneficiaries in a specific geographical area within a defined time span. It enables better logistics, operational management and repair and maintenance at lower costs, allowing rural population to access clean energy. Saturation emphasizes on concentration in a single location due to which it has advantage of familiarizing sizeable population to new technology which leads to social acceptability and eventually creates demand for related technology. LAS model brings together three institutional spheres of the state, the civil society and the corporate for speedy diffusion of appropriate technology at a wider geographical spread.

Strategy for implementing LAS model

LAS model has been field tested and applied for diffusion of solar study lamps by IIT Bombay through the Million Solar Urja Lamp (SoUL) Programme. It is aimed at providing 1,000,000 solar study lamps to school-going students residing in remote rural areas of four states in India, viz. Madhya Pradesh, Rajasthan, Maharashtra and Odisha in the fastest possible way. In order to implement the programme, IIT Bombay, which worked as the Central Coordinating Unit (CCU), brought together three institutional spheres – government, NGOs, and corporate philanthropic sectors. For this programme, funds were sought from government and corporate social responsibility (CSR) sources while the existing infrastructure of grassroot NGOs was used for dissemination of solar study lamps. The following strategies were employed to implement LAS model in Million SoUL Programme (depicted in Figure 1).

Financial strategy

Since target beneficiaries belonged to marginalized sections, a financial strategy was devised to break the cost barrier and make technology affordable. Solar study lamp solution was designed considering the paying capacity of the targeted population, at a cost of INR 500 per lamp (2013–2016) which was inclusive of material, manpower, logistics and repairs. Beneficiary contribution was determined at INR 120 (as on January 2011)[32] (US$ 1.81) per lamp based on the per day wage rate for labour under Government of India's Mahatma Gandhi National Rural Employment Generation Scheme (MGNREGS) to ensure affordability. Thus, the rest of INR 380 (US$ 5.75) per lamp was mobilized from the state as well as the corporate sector. Expenditure on each lamp included: (a) INR 350 to vendors for disassembled kits, transport and delivery, (b) INR 60 to NGO partners for management of assembly, campaigning, distribution and service repair centres, (c) INR 30 for providing free after-sales service for a year, (d) INR 60 to CCU for coordinating with stakeholders, selecting NGOs, training local people, monitoring, maintaining records and conducting concurrent evaluation for mid-course corrections (refer Figure 1). From the beneficiary contribution, 75% of the money remains in local economy in the form of livelihood created through the programme.

Technological strategy

Requirement of clean light for study purposes during dark hours provided the basis for employing a suitable technological strategy. According to IESNA, the amount of light required for reading is merely 150 Lux (ref. 33). This need can be met through an appropriate design in the form of a solar lamp with a 0.5 W LED, 1 W solar panel coupled with a 1200 mAh 2.4 V battery that can provide required luminosity for at least 4 h every day, even during partially cloudy days. Annual energy requirement of this solar lamp is about 730 Wh, which is less than one unit of electricity consumed in an entire year.

Knowledge and skill transfer strategy

Localization emphasizes on knowledge and skill transfer to empower local people and make them independent in maintaining lamps. Technical and operations management manuals were prepared, which provided the basis for conducting trainings related to technical aspects of lamp assembly, campaigning and distribution, while NGO personnel were trained on operations management and record maintenance. CCU combined its expertise in solar photovoltaic technology, industrial engineering and operations management to impart training on lamp assembly, quality check, campaigning, awareness, planning, distribution, repair and maintenance. This training was followed by constant monitoring, supervision and refresher trainings. Training was also conducted for service repair centre managers to ensure proper after-sales service.

Material flow strategy

Localization included the set-up of multiple assembly centres at sub-districts, to cater to the demand and at a few adjoining sub-districts, at the NGO premises. In order to ensure uniform quality and adherence to technical specifications, the lamp components-in-kit-form were sourced from four empanelled vendors. CCU planned and coordinated the material movement between the vendors and the assembly centres. The local assembly centres

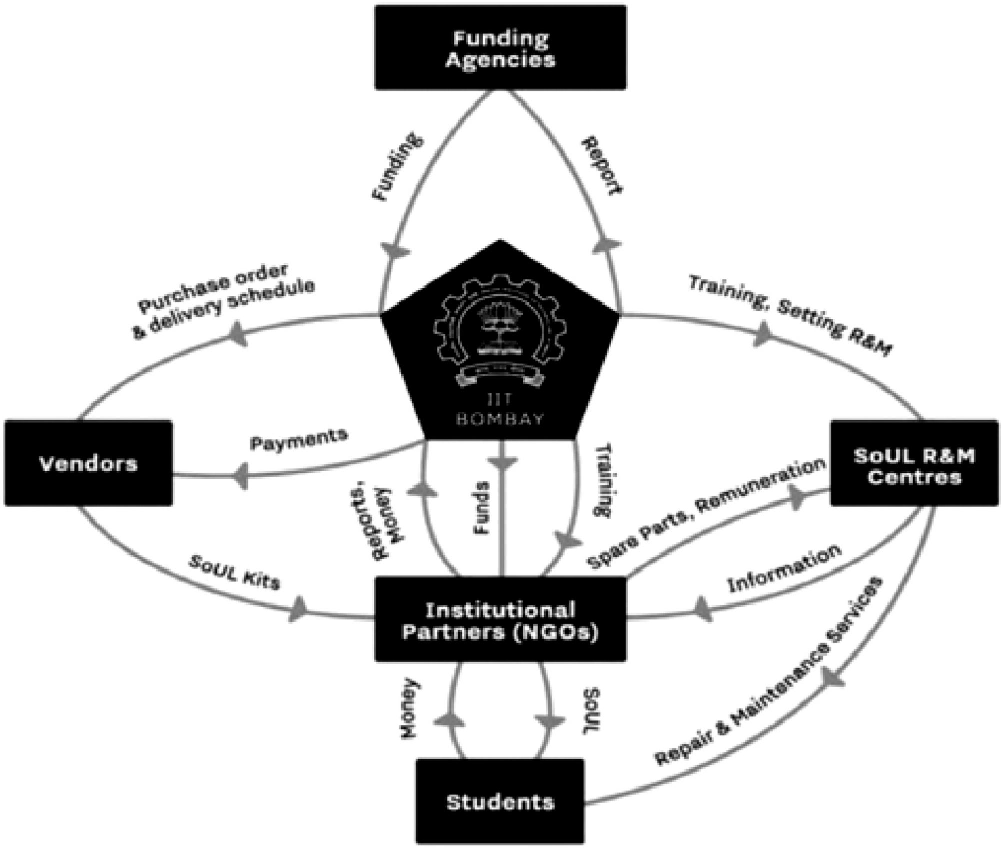

Figure 1. Million SoUL Programme implementation model. The figure presents material, money and information flow during implementation of Million SoUL Programme. It also depicts various stakeholders involved in the programme along with their associated roles.

managed the inventory and the assembly of lamps. The manual assembly process was streamlined, with the assemblers chosen from the local sub-districts. The individual components and the lamp (finished product) were subject to 100% inspection during assembly. Defective and missing components, if any, were duly replaced by component vendors.

Campaigning and distribution strategy

Once a sub-district was determined as an intervention unit, an appropriate strategy to reach the maximum number of beneficiaries, in Million SoUL Programme's case, 75% of enrolled students between classes 5 and 12, was chalked out. CCU was responsible for the delivery of material to the NGOs for assembly and distribution of lamps. NGOs maintained inventory of material supplied, managed remunerations of local people, collected beneficiary contribution and transferred it to the CCU (refer Figure 1). A sub-district was divided into clusters based on the number of schools present and each cluster was allotted to distributors. The information and communication strategy was devised to reach out through villages, *haats* (weekly markets in rural areas) and schools. Demonstration of lamps was done in villages during the night to generate awareness about its benefits. Multiple visits were undertaken in every school to ensure students got the opportunity to purchase the lamp.

Distribution of lamps in two phases is seen in Figure 2. During the first phase, initial take-off was slow as expected with any new technology. As time progressed, faster diffusion of lamps in the intervention area was seen which culminated to saturation, demonstrating an S-shaped curve for phase I. The gap as seen in Figure 2 was taken for a mid-course correction for phase two. Quicker diffusion is seen in phase two as the target of 265,000 was reached in a shorter time when compared to phase I for the same quantity of lamps.

Repair and maintenance strategy

Devising a repair and maintenance strategy was imperative to cater to the beneficiary population for provision of timely after-sales service. The overall cost of lamps was inclusive of the free after-sales service for a year and an amount of INR 30 per lamp was earmarked to enable

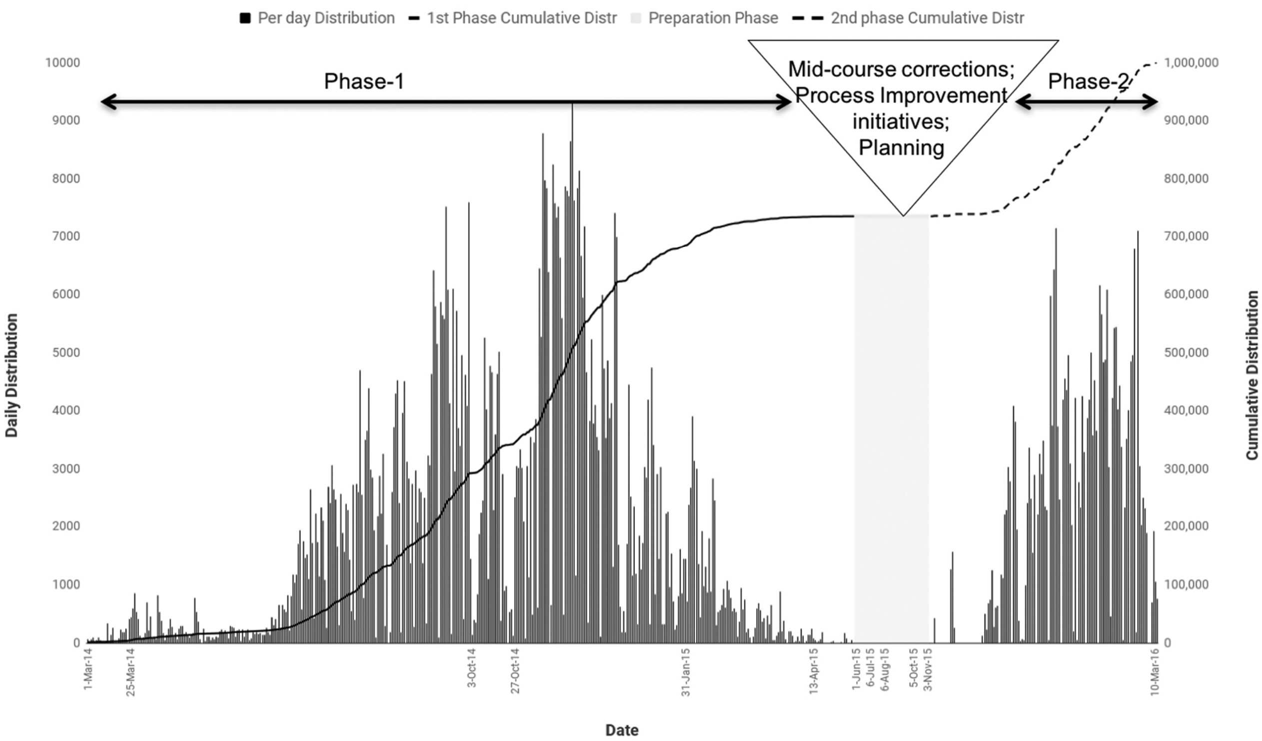

Figure 2. Phase-wise distribution of solar study lamps. Phase I shows a slow start at the beginning of the distribution, eventually picking up pace and then culminating to an S-shape curve. The second phase shows faster diffusion of lamps as compared to phase I. Because the distribution was through schools, there was no distribution during summer months. This period was utilized to make mid-course corrections and process improvements.

provision of this facility. Based on the number of distributed lamps in a given area, service repair centres were established according to clusters catering to roughly 3,000 beneficiaries. Local personnel managing service repair centres received monthly remuneration of INR 2,750 per month for a period of a year. For every service repair centre, a local person was selected from assemblers, distributors or persons having small electric or mobile repair shops. A record of lamps that came for repairs was maintained by the NGO and monitored by the CCU.

Monitoring and concurrent evaluation strategy

Monitoring and concurrent evaluation strategy was formulated to create accountability in stakeholders, ensure transparency and aid continuous improvement in the programme. The framework for conducting concurrent evaluation included quantitative and qualitative methodologies which comprised large scale household surveys evaluating the performance of lamps, assessing demand for solar products and key stakeholder interviews for overall processes improvement. Insights derived led to inputs for mid course corrections and were incorporated into process development for the second phase.

The programme was able to successfully distribute 1 million lamps across 4 states during 2014–2016. The programme was implemented in two phases. The first phase provided 735,000 solar study lamps and the second phase provided 265,000 lamps. It was spread across the geographical area of 65,500 sq. km with beneficiaries from more than 10,900 villages purchasing lamps. The programme emphasized on local livelihood generation, having trained over 1,580 people as assemblers and distributors, and 370 people as service repair centre managers. The amount infused in the local economy was approximately INR 84,000,000 (USD 1,259,937) in the form of remuneration to assemblers, distributors and service repair centre managers. Table 1 shows state-wise distribution and trained manpower.

Discussion and conclusion

The LAS model applied in the Million SoUL Programme has demonstrated scale, speed and skill to achieve successful dissemination of 1,000,000 solar study lamps in India. Localization has empowered communities through skill transfer and livelihood generation which led to an investment of around INR 84,000,000 (USD 1,259,937) into the local economy. Active engagement of the local population built trust in the technology. Further, provision of after-sales services became a critical factor for large scale dissemination. Affordability was ensured

Table 1. Statewise distribution of solar lamps and manpower trained

State	District	Block	Lamps distributed	Saturated blocks	Total manpower trained
Maharashtra	4	12	170,614	4	242
Rajasthan	8	18	221,135	5	374
Madhya Pradesh	9	43	519,657	21	793
Odisha	2	24	89,616	7	171
India	23	97	1,001,022	37	1580

through mobilizing financial resources from government and CSR sources which helped faster penetration of solar photovoltaic technology in remote rural areas. Reaching out to maximum number of beneficiaries through saturation of a sub-district for effective planning of logistics ensured scale and possibility of seeding a solar market. Experience of simultaneous implementation at multiple locations and protocols established can be used for replication of other technology interventions of similar nature.

A survey covering more than 11,300 households was conducted after 6 months of distribution of lamps in 20 sub-districts, to evaluate performance of lamps and assess the potential for a solar market. A slight difference was found between the number of male and female beneficiaries, with 46% female students purchasing lamps. Almost 62% of households belonged to tribal communities with 63% households poor as they possessed below poverty line '*Antyodaya*' cards. Over 86% of households depended on agriculture and allied activities. Of the beneficiary households, 25% did not have access to grid electricity and were completely dependent on kerosene lamps for lighting. Beneficiary households did not use kerosene based devices for studying purposes, post lamp distribution. The lamp had multiple uses other than studying, such as irrigating farms, while cooking, for increasing mobility during dark hours, etc. In response to the need for other solar products, around 48% households expressed willingness to spend on solar lighting although most of the households belonged to marginalized communities, with paying capacities restricted to INR 500 (USD 7.50).

Implementation of large scale programmes by applying the LAS model for speedy dissemination of solar study lamps presented multiple challenges. As assembly did not happen within a controlled factory environment, but in rural settings, there was a trade-off between lamp quality and localization. Interviews with key stakeholders revealed that constant monitoring was required during assembly process. The household survey revealed that around 18% of households had non-functional solar study lamps with most common defects due to gathering of dust around the switch. Some beneficiaries could not avail after-sales service due to lack of awareness about the existing free service repair centres. The solar lamp was designed to enable students to study during dark hours, but it was found that the lamp was also used for other purposes which proved to be detrimental to its life. Incapacity of existing vendors to produce in scale led to delays in consignments reaching NGOs, which further resulted in extension of stipulated timeline to saturate the sub-district. Delays and inaccuracies in basic information collected by distributors about beneficiary students led to erroneous records.

While disseminating lamps during the second phase mid course corrections were made on two dimensions; to encourage availing of after-sales service and to overcome challenges faced during the first phase. More durable switches were introduced in the lamp to avoid dust and moisture seepage. A campaign drive for creating awareness of service repair centres and school level lamp repairing camps were organized. An online automation system and database for streamlining data upload with management training for NGO personnel handling activities at the grassroots level was put in place for making operations more effective. Further, a system of incentives and penalties was designed for NGOs to reduce the lead time in assembly, distribution and data management. NGOs also took measures towards greater collaboration among assemblers for methodical assembly. As a result of iterative processes of continuous improvements, a difference was observed between efficiency in phases I and II. Dissemination of 265,000 solar study lamps in the fastest possible way demonstrated greater proficiency in various operational management aspects in phase II.

The LAS model demonstrated in the current programme has only provided an initial lighting solution without providing any pathways for other electricity needs which are more complex and diverse in nature. LAS model emphasizes on making appropriate technology affordable to rural populations through financial support from the government and the corporate sector. This process tends to create dependency in the initial stages and might distort self-sustaining markets. However, the market mechanism to be triggered will have limitations. This is mainly due to the fact that socio-economic strata targeted by such programmes have limited financial capacity in regions where there is total absence of solar products. The scope of challenges for local manufacturing is a major thrust area needed for upscaling such initiatives.

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