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A techno-economic comparison of rural electrification based on solar home systems and PV microgrids

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ABSTRACT

Solar home systems are typically used for providing basic electricity services to rural households that are not connected to electric grid. Off-grid PV power plants with their own distribution network (micro/minigrids) are also being considered for rural electrification. A techno-economic comparison of the two options to facilitate a choice between them is presented in this study on the basis of annualised life cycle costs (ALCC) for same type of loads and load patterns for varying number of households and varying length and costs of distribution network. The results highlight that microgrid is generally a more economic option for a village having a flat geographic terrain and more than 500 densely located households using 3–4 low power appliances (e.g. 9 W CFLs) for an average of 4 h daily. The study analyses the viability of the two options from the perspectives of the user, an energy service company and the society.

1. Background

Most PV projects for decentralized rural electrification applications (globally as well as in India) are based on stand-alone (off-grid) solar home systems (SHSs) typically in the capacity ranges of 35–100 Wp. In India, 450,000 SHS have been reportedly deployed till July 2009 (MNRE, 2009). Off-grid PV power plants, typically in the range of 1–500 kWp, and with independent distribution network (microgrids)[2] have also been considered in India for rural electrification. About 5 MWp of cumulative microgrid capacity exists in the country, most of which is located in the Sunderbans region of the West Bengal (MNRE, 2009). SHSs supply DC electricity for domestic end-uses primarily lighting and are usually owned by the user households. Microgrids, usually set-up by an Energy Service Company (ESCO), supply AC electricity to different load points through a low tension distribution network and the users pay for the electricity they consume.

The choice between having SHS for individual households or providing electricity with a PV microgrid would therefore require a comprehensive understanding and acceptance of benchmark criteria for evaluating techno-economic viability of one system vis-à-vis the other in a given situation and would have to be analyzed from the perspective of three main stakeholders:

(a) The user/community – would like to weigh the costs of owning and maintaining a solar home system (SHS) with that of paying for the electricity services provided through the microgrid.
(b) The Energy Service Company (ESCO) – would like to evaluate the commercial viability of providing SHS on lease with that of building and operating a microgrid to provide electricity services to rural communities.
(c) The society or the government – would like to assess the financial burden of subsidies, if any, for making SHS affordable as compared to setting up a microgrid for rural electrification and/or developmental programmes.

In an attempt to address the above issues this paper presents the following:

(i) Review of experiences from the literature on the design, dissemination and usage of SHS and microgrids.
(ii) A comparison of design and operational aspects of SHS and microgrids.
(iii) Techno-economic comparison of SHS and microgrid from the perspective of the user, energy service company and the government.

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[2] A microgrid is an electricity distribution network operating typically below 11 kV, providing electricity to a localized community. It derives electricity from a diverse range of small, local generators using both fossil fuels (diesel) and renewable energy technologies (PV, wind, small hydro, biomass, etc.). It usually has its own storage in the form of batteries.

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2. Description of SHS and microgrid

A typical SHS consists of PV module(s) that charge a battery bank to supply DC electricity to DC based appliances such as CFL lamps, fan, TV, etc. The charge controller which is an integral part of the SHS controls the energy inflow and outflow into and from the battery bank. The SHS can be considered as an alternative to conventional fuels (e.g. kerosene, candle, battery operated torch, recycled battery used to power TV) used for providing electricity for basic amenities in households that are not connected to the grid. SHS are ideally suited for domestic lighting and small power applications, but have limited scope for income generating activities or overall community development, such as the provision of street lighting, safe drinking water and vaccine refrigeration.

As compared to SHS which are designed and installed for use by an individual establishment (or household, as used in this paper), microgrids are designed to generate electricity centrally and provide the same for various applications to establishments spread within a designated geographical area. They usually supply 220 V 50 Hz three-phase or single phase AC electricity through low-tension distribution networks to households for domestic power, commercial activities (e.g. shops, video centers, computer aided communication kiosks, small grinders), and community requirements such as drinking water supply, street lighting and vaccine refrigeration. Microgrids essentially have (a) centralized electricity generating capacity mainly consisting of PV array, (b) a battery bank to store the electricity, (c) power conditioning unit (PCU) consisting of junction boxes, charge controllers, inverters, distribution boards and necessary wiring/cabling, etc., all located within an appropriately constructed building and (d) power distribution network (PDN) consisting of poles, conductors, insulators, wiring/cabling; service lines, internal wiring and appliances to individual households. An appropriately designed PV based microgrid can easily supply power for up to 24 h if combined with other systems such as diesel genset, biomass gasifier or wind electric generator.

Solar home systems and microgrids are both supported with grant (up to 90% of capital costs) under the RVE programme of MNRE, which aims at providing basic electricity services to communities living in remote locations where grid extension is techno-economically unviable (MNRE, 2009). Accordingly, two models of SHS (with PV module of 37 and 18 Wp, respectively) and PV power plants (microgrids) of minimum 1 kWp are approved under the Remote Village Electrification (RVE) programme for the year 2009–10.

3. A review of literature pertaining to system design, dissemination programmes and user's perspective on SHS and microgrid

There is ample literature on SHS dealing with system design and configurations, policies and programmes, economics and financing, user's perspective and O&M issues, etc. (Hankins, 1993; Cosgrove-Davies and Cabraal, 1994; Gunaratne, 1994; Nieuwenhout et al., 2000; Martinot et al., 2001; Barua, 2005; Chaurey and Kandpal, 2006, 2007, 2009; Arun et al., 2007). However, there are some studies available on microgrids per se (Christofides, 1989; Kivaisi, 2000; Chakrabarti and Chakrabarti, 2000; Ibrahim et al., 2002; Cole, 2003; Chaurey et al., 2004; Manolakos et al., 2004; Nouni et al., 2006; Jiayi et al., 2008; Alzola et al., 2009; Bakos, 2009, Kirubi et al., 2009; Kumar et al.,. 2009; Moharil and Kulkarni, 2009) and few on comparative analysis of SHS and microgrids. One of the earlier studies has compared roof-mounted highly decentralized PV electric power systems with centralized village energy centre for typical energy requirements in an Indian village and has shown that the latter is financially superior as compared to the former on account of economic viability of the two systems. Further, the study also indicates a number of other benefits such as better maintenance, superior load management, improved security, etc. that are associated with the centralized village energy centre (Saha, 1981). Advantages of microgrids over SHS in terms of enhanced electrical performance and reduction of storage needs are also supported by Aulich et al. (1998). However, the study also cautions that cost-effective measures have to be compared with additional cost features such as cost of distribution network and interconnections required for setting up microgrids.

Similar results are shown by Dakkak et al. (2003) who have compared stand alone systems vs centralized systems and have found the advantages in terms of increased rate of charging of batteries, high overall efficiency and low costs of systems. The importance of analyzing energy consumption and power flows at households and village level, and socio-cultural aspects while opting for SHS or microgrids has been highlighted in a Brazilian study taking the specific examples of island and mountainous communities. The study proposes a decision support tool on the basis of life cycle costs of the two systems and emphasizes the need to establish a system regulation for microgrids similar to that of SHS (Hauschild and Zilles, 2005). Contrary to the above findings, a GTZ project in Senegal indicates that SHS might be more economical for small village energy needs as compared to village power plants citing the high cost of rural distribution network (Schmidt-Kuntzer and Schafer, 1993). SHS are also reportedly preferred over microgrids by communities on account of independence in operational and management aspects irrespective of village size or load (Vallve and Serrasolses, 1997).

From the literature review, it appears that there could be two categories of issues that might influence a decision in favor of SHS over microgrid or vice versa. These would be related to economics of delivered electricity services on a life cycle basis; and operations, maintenance and management aspects, both from the user's, government's and private sector's perspective. Connected load, electricity consumption or demand pattern, local solar resource conditions, terrain as well as distribution of load centers in a village are important factors that influence the economics of delivered electricity from SHS and microgrid options. Similarly, availability of after sales service, availability of finance and other fiscal incentives may be considered while opting for SHS or the microgrid. Table 1 lists some of the features of SHS and microgrids for the purpose of comparison.

4. Design and operational aspects of SHS and microgrid

Setting up a PV microgrid to service a small community for only lighting applications may be unviable when compared with SHS on the basis of initial costs only. However, there might be villages where microgrid would be more cost effective as compared to SHS even to serve only domestic loads depending upon many factors; some of which are site specific such as geographical terrain and location of houses within the village. Others could be related to the technologies available and used in systems, particularly those for end-use appliances. Quality considerations in terms of reliability and availability of energy and operation and maintenance (O&M) requirements are some additional factors that will influence a choice between SHS and microgrid. A comparison of different aspects including design, efficiencies, applications, O&M, etc. are worth considering prior to undertaking a comparative analysis of SHS and microgrids.

Table 1
Comparative features of SHS and microgrid configurations.

SHS	Microgrid
Autonomy and independence to the user to manage its loads and energy consumption	Energy supply and hence its consumption by the user is often controlled by a third party owning and operating the microgrid
Usually owned by the user, hence the user is responsible for all repairs, replacements and maintenance requirement throughout the useful life of the system	Households have an option to acquire the connection to the microgrid upon paying an upfront fee and monthly charges. The user does not incur any maintenance cost towards the system, except perhaps for repair and replacement of appliances used within the house/premise
Designed to service fixed type of household loads mainly consisting of lighting and some small appliances such as TV/radio	Sufficient flexibility to service and manage diverse loads in domestic, community and livelihood segments
Designed with autonomy to service all loads at all times of the year with possibility of PV power not utilized if battery is fully charged due to system not in use for a few days	Battery bank capacity optimized to service loads within acceptable levels of reliability throughout the year. At the same time, it is possible to ensure that no PV power is wasted due to fully charged battery bank
Use of single PV module only	Possibility to add multiple generators (wind/diesel) in hybrid mode
Operations in off-grid and stand-alone mode only	Possibility with grid interconnectivity in future and energy exchange within connected loads and with the grid leading to improved load management
Use of customized DC appliances, usually with energy efficient designs	Use of AC appliances that are easily available in the market. Risk of using energy in-efficient locally manufactured appliances
PV module installed at user's premise, hence susceptible to theft, vandalism, tampering due to its easy accessibility	PV array guarded within the fenced boundary thereby minimizing the risks of theft and vandalism
Dispersed systems requiring O&M services at scattered locations	Ease of O&M of the entire system due to its centralized location
Energy consumption and load management within the control of the user, often leading to deep discharge of batteries	Better monitoring of energy consumption due to fixed hours of operation of the power plant at the generation level and use of individual meters and/or load controlling devices at the consumption level

4.1. Design

An SHS is usually designed to provide reliable electricity services to a single household without allowing any capacity shortage or loss of peak load at any time of the year. Hence, the battery size usually incorporates 2/3 days of autonomy in case solar radiation is not adequate to charge the battery in a single day during certain periods of the year. The microgrid, on the other hand, is designed to have a battery bank capacity that meets average loads most times in an year based on an assumption that not all users will be connected at all times, and not all connected users at any given point in time will switch on all connected loads. In other words, a microgrid has a built-in diversity factor (DF)[3] (ratio of the sum of all individual peak loads to the average load) that allows for battery optimization and hence overall cost reduction. The value of DF is always greater than unity (NFPA, 2009). However, similar to SHS, microgrid also has 2/3 days of autonomy built in while designing the battery bank to take care of partially or fully cloudy days.

4.2. Efficiency

An SHS is a DC system that generates, stores and uses DC electricity usually at the same voltage levels throughout the cycle. Loss of energy from generation to consumption cycle in this system is mainly due to inherent losses associated with each component in the system such as battery (charging and discharging efficiency), charge controller and end-use appliances which include luminaire with CFL and a small inverter. A microgrid generates and stores DC electricity, but distributes and uses AC electricity. Components used in a microgrid offer better efficiencies as compared to those used in an SHS. For instance, the battery bank in a microgrid typically uses single batteries of 100/500/800 Ah capacity each (TERI, 2005) that have better charging/discharging efficiency as compared to a single battery of 12 V, 20/40/75 Ah used in an SHS. Similarly, the charge controllers and inverters in a microgrid use state-of-the-art technologies and therefore offer better efficiencies and reliability as compared to charge controllers and small inverter for CFL used in an SHS that are often manufactured locally without any quality control (Masheleni and Carelse, 1997; Schlumberger, 2007; Schmela, 2007).

4.3. Applications

An SHS is designed to service fixed connected loads mainly for domestic lighting applications with option of using small capacity DC appliances such as fan or TV/radio. A microgrid can accommodate users with varying connected loads and can provide electricity to a variety of other applications such as street lights, water pumping, computer systems, cold storage, etc. with proper load management (Gon Chaudhuri, 2007). The DC appliances used in an SHS are specially assembled for this purpose and may not always adhere to quality standards (Chaurey and Kandpal, 2007). AC appliances used in a microgrid are available off-the-shelf and are usually regulated by the respective standards and prevailing norms for safety and reliability.

4.4. Operation and maintenance

SHS are typically disseminated through ownership model with the user of the SHS owning the system and therefore takes on the entire burden of O&M throughout the useful life of the system. SHS can also be offered on lease/rental basis to reduce the burden of up-front as well as the O&M costs to the user, but such cases are rare in India. In the absence of an effective after-sales-service network for SHS, the user may find it cumbersome to use the SHS as he/she does not usually have an access to quality spares and trained technicians to undertake repair/replacement jobs in an SHS (Chaurey and Kandpal, 2007). The dispersed locations of the SHS users may also pose a problem in getting O&M services as compared to the microgrid where all equipment is placed at a central and accessible location and hence, are easy to maintain. In case of microgrid, it is the fee-for-service model that is prevalent.

[3] Diversity factor is defined as the ratio of the sum of the individual maximum demands of various parts of a power distribution system to the maximum demand of the whole system. The diversity factor is always greater than unity. http://www.its.bldrdoc.gov/fs-1037/dir-012/_1766.htm.

The microgrid, like any other infrastructure facility is usually set-up on a built-own-operate-maintain model wherein a qualified ESCO with necessary competence builds, operates and maintains the microgrid on behalf of the funding organization who in most cases has been the government till now.[4]

The same ESCO also provides O&M service to the household to ensure a reliable functioning of the overall facility. The ESCO recovers its overheads, O&M costs and profits from the total fee it collects on monthly basis. In the users' perception, a microgrid normally has all the features of grid power supply, e.g. power plant, overhead (or underground) power distribution lines, service connections, household meters, etc. that brings it close to the conventional power supply system.

4.5. Capital cost

An SHS uses small capacity PV modules (18/37/50 Wp) as compared to microgrid that uses 75/80/100/120 Wp and even bigger capacity PV modules to form an array. The conversion efficiencies as well as unit cost in terms of Rs./Wp are expected to be better in large capacity modules as compared to the small capacity ones. Similarly, unit cost of battery in terms of Rs./Ah is less for large size battery used in microgrid than for those used in SHS (TERI, 2005). Such cost reductions, as sizes and volumes grow, are due to changes in production processes and changes in input prices and are likely to make a microgrid more competitive (on the basis of Rs./Wp) as compared to the SHS. The additional cost of inverter(s) and distribution network used in a microgrid may however, offset these cost advantages.

5. Design of SHS and microgrid

The techno-economic comparison presented in this study is based on designing SHS and microgrid for the same number of households and for the same type of electricity services and comparing them on the basis of annual costs as well and cost of generation of electricity. Following assumptions are used for designing the SHS and microgrid:

(a) Number and type of appliances as well as their duration of usage in a household serviced by an SHS is same as that of a household serviced by a microgrid. In other words, the electricity requirements in the two cases are same. However, the DC electricity may differ on account of the different levels of efficiencies of inverters used in SHS and in a microgrid as explained in earlier section. This aspect will influence the sizing of the battery and PV in the two cases.
(b) PV and battery capacity required to service a single household is estimated separately for SHS and microgrid using common system design principles taking into account (i) efficiencies of all components, (ii) design days of autonomy for no/low sun days, (iii) maximum depth of discharge for battery, (iv) field related losses due to temperature, dust, shadow and mis-match within solar cells in a module, and (v) diversity factor for microgrid.
(c) The other operational parameters i.e. availability of solar radiation, annual days of operation, and daily hours of operation, etc. are considered to be same in both the cases.
(d) A diversity factor (DF) of 1.1 based on past experience of setting up microgrids in India is used (TERI, 2005).
(e) Households serviced by microgrid use AC appliances, while those having an SHS use DC appliances. However CFL is used for domestic lighting in both the cases. Since CFL is an AC device, it requires a small inverter placed inside the luminaire used in case of an SHS.
(f) Efficiencies of batteries and inverter improve with their sizes and are reflected in sizing microgrid and SHS. Accordingly, these efficiencies are taken as 85% and 90% for batteries and 90% and 95% for inverters in SHS and microgrid respectively.
(g) State-of-the-art charge controllers used in a microgrid usually incorporate maximum power point tracking (MPPT) and offer efficiencies in excess of 90%, while locally made charge controllers often used with SHSs have efficiency in the range of 80–85%.
(h) While losses due to temperature and dust remain same for microgrid and SHS, those due to mis-match vary on account of better matching of solar cells used in large capacity PV modules in microgrid as compared to small capacity PV modules in an SHS. The mis-match factor is assumed to be 15% in SHS and 10% in microgrid. Dust derating factor and temperature correction factors are taken to be 10% each in for both SHS and in microgrid.[5]
(i) Operating voltages for battery bank are selected on manufacturer's recommendations. Accordingly 24/48 V is selected for microgrids up to 4 kWp; 72/96 V for 4–10 kWp and 120 V for microgrids of higher than 10 kWp capacity.
(j) Since SHS and microgrid both use tubular plate deep discharge type low maintenance lead-acid batteries, their MDoD is considered to be the same in both the cases.
(k) Benchmark costs of SHS and microgrids as approved by MNRE for its various programmes have been considered for estimating the ALCC.
(l) In case of microgrid, additional cost of power distribution network depending upon the spread and terrain of the village has been incorporated.

In order to design SHS and microgrid, a base case of a community with "N" households is considered. Each household has a load of L Watts and is required to operate this load for "h" hours per day. For the purpose of this analysis, a special case of domestic lighting is considered as initially most of the rural PV applications are essentially confined to lighting only.

The battery capacity required to service each of the household using an SHS can be determined as

$$\mathrm{SHS\_Batt(Ah)} = \left[\frac{L \times h}{\eta_{\mathrm{invSHS}} \times V \times \mathrm{MDoD} \times \eta_{\mathrm{battSHS}}}\right] \times D \quad (1)$$

where V represents the operating voltage of the battery, D the days of autonomy, η_{battSHS} the charging/discharging efficiency of the battery and η_{invSHS} the efficiency of the inverter for the CFL.

The required PV module capacity in W_p is determined as

$$\mathrm{SHS\_PV}(W_p) = \left[\frac{L \times h}{\eta_{\mathrm{invSHS}} \times \eta_{\mathrm{battSHS}} \times \eta_{\mathrm{cc}} \times (1-f_{\mathrm{temp}}) \times (1-f_{\mathrm{dust}}) \times (1-f_{\mathrm{mismatch}}) \times \mathrm{EHFS}}\right] \quad (2)$$

where η_{cc} represents the efficiency of the charge controller, f_{temp}, f_{dust} and f_{mismatch} the losses in PV array respectively due to cell temperature, dust and mis-match among several modules due to

[4] With private sector's entry into rural infrastructure sector and government schemes such as RGGVY which encourage private sector to be project developers for undertaking decentralized distributed generation (DDG) based rural electrification, this scenario is likely to change towards public–private-partnership (PPP) model in future (Ref: RECINDIA, 2009).

[5] PV array installations in a microgrid might be able to reduce the impact of temperature on its overall performance on account of better air-circulation and hence cooling of PV modules. The same benefit of air cooling may not be achieved in an SHS installation where PV modules are often mounted directly on the thatched roof on the rural households.

Table 2
Sizing SHS and microgrid.

		SHS	Microgrid
Number of households	Units	50	50
Diversity factor	Fraction	1.00	1.10
AC Power required per CFL	Watt AC	9.00	9.00
Number of 9 W CFL used	nos	4.00	4.00
Total AC power required	Watt AC	36.00	36.00
Hours of operation per day	h/day	4.00	4.00
Total AC energy required per day	AC Wh/day	144.00	6545.45
Inverter efficiency	Fraction	0.90	0.95
Total DC energy required per day	DC Wh/day	160.00	6889.95
Operating voltage	VDC	12.00	48.00
Charge (Ah) to be supplied per day	Ah	13.33	143.54
Battery efficiency	Fraction	0.85	0.90
Charge(Ah) to be given by battery per day	Ah/day	15.69	159.49
Maximum depth of discharge (MDOD)	Fraction	0.70	0.70
Days of autonomy	Day	3.00	3.00
Size of the battery	Ah	67.23	683.53
Nearest available battery size	Ah	12V, 70 Ah	48V, 700 Ah
Efficiency of charge controller	Fraction	0.85	0.90
Charge to be supplied to battery per day	DC Ah/day	18.45	177.21
DC energy to be provided by the PV array	DC Wh/day	221.45	8506.11
Loss of energy due to ambient temperature	Fraction	0.10	0.10
Loss of energy due to dust etc.	Fraction	0.10	0.10
Loss of energy due to mis-match among solar cells	Fraction	0.15	0.10
DC energy to be generated for providing the required value	DC Wh/day	321.65	11,668.19
Equivalent hours of full sun-shine (EHFS)	h	5.00	5.00
PV requirement	Wp	64.33	2333.64
PV requirement per household	Wp	64.33	46.67
PV module capacity for SHS	Wp	70.00	
Total PV capacity	Wp	3500.00	2350.00

shadow and other factors and η_{battSHS} the charging/discharging efficiency of the battery.

Similarly, the size of battery bank for the microgrid is estimated as

$$\text{MGRID\_Batt(Ah)} = N \times \left[\frac{L \times h}{\eta_{\text{invMGRID}} \times V \times \text{MDoD} \times \eta_{\text{battMGRID}} \times \text{DF}}\right] \times D \quad (3)$$

where DF represents the diversity factor, η_{invMGRID} and $\eta_{\text{battMGRID}}$, respectively, the efficiencies of the inverter and charging/discharging efficiencies of the battery used with the microgrid. The PV array is sized using the following expression similar to (1):

$$\text{MGRID\_PV}(W_p) = \left[\frac{L \times h}{\eta_{\text{invMGRID}} \times \eta_{\text{battMGRID}} \times \eta_{cc} \times (1-f_{\text{temp}}) \times (1-f_{\text{dust}}) \times (1-f_{\text{mismatch}}) \times \text{DF} \times \text{EHFS}}\right] \quad (4)$$

For the purpose of the analysis, following representative loads are selected:

(a) Case A: Village of N households requiring 2×9 W CFL, each to be used for 4 h daily (a connected load of 18 W per household with an energy requirement of 72 Whr per day).
(b) Case B: Village of N households requiring either (i) 4×9 W CFL or (ii) 2×9 W CFL+1×18 W fan or (iii) 3×9 W CFL+1 DC socket for radio/cassette recorder, etc. Each of these loads is to be used on an average for 4 h daily (a connected load of 36 W per household and an energy requirement of 144 Whr per day).

The values of battery and PV capacity for SHS and microgrid estimated using the above equations along with their respective input parameters and assumptions are presented in Table 2. Accordingly, a household (Case A) using 2 light points of 9 W CFL for 4 h each would require a PV capacity of 32.16 Wp (or an SHS of 35 Wp PV module). Households in Case B would require 64.33 Wp per household (70 Wp SHS). If a village with 50 households in Case B is to be serviced with SHS, a total of 3.5 kWp PV (50 households of 70 Wp SHS each) capacity would be required. On the other hand, about 2.35 kWp of PV microgrid would be sufficient to service the same village. Thus, about 30% reduction in PV capacity is possible in a microgrid as compared to individual SHS (Table 2). This percentage reduction of up to 70% in PV capacity while moving from SHS based service to a microgrid based service using the design principles and guidelines explained in Table 2 is found to be applicable not only for the current case of 50 households with 2 light points each, but also for Case B with households using higher connected load as well as for more number of households in a community. There is also a substantial reduction in the overall battery bank capacity in a microgrid as compared to individual SHS (Table 2).

The techno-economic viability of both SHS and microgrid is studied from the perspectives of an individual user, society and an ESCO on the basis of different technical and financial parameters for different stakeholders. For instance, a user would compare the annual costs of owning and operating the SHS with the total annual payment for the electricity provided by the microgrid. As one of the important decision variables, the society would like to estimate the threshold number of households and their geographical spread after which unit cost of electricity delivered is lower for microgrid than for SHS. An ESCO would like to assess the profitability of an investment in a microgrid.

6. Comparison of SHS with microgrid

6.1. Annual cost of SHS and microgrid

The annualised life cycle cost (ALCC) for an SHS is calculated by summing up costs of all its components (i.e. PV module, battery, charge controller and appliances) multiplied by their respective

Table 3
Annual costs (ALCC) and levelised unit cost of electricity (LUCE) from 35 and 70 Wp SHS.

Components	Capital cost (Rs.)	Life (years)	CRF (fraction)	Annualised cost (Rs.)
SHS – Model 1				
Module (35 Wp)	6600.00	20	0.1339	883.74
Battery (12 V, 40 Ah)	2400.00	5	0.2774	665.76
Charge controller	500.00	5	0.2774	138.70
Appliances (2*9 W)	1500.00	10	0.1770	265.50
Balance-of-systems	1000.00	10	0.1770	177.00
Annual O&M costs				100.00
Total annualised costs	12,000.00			2230.70
Annual electricity generation (kWh)				57.49
LUCE (Rs./kWhr)				38.80
SHS - Model 2				
Module (70 Wp)	13,200.00	20	0.1339	1767.48
Battery (12 V, 70 Ah)	4800.00	5	0.2774	1331.52
Charge controller	500.00	5	0.2774	138.70
Appliances (4*9 W)	3000.00	10	0.1770	531.00
Balance-of-systems	2000.00	10	0.1770	354.00
Annual O&M costs				150.00
Total annualised costs	23,500.00			4272.70
Annual electricity generation (kWh)				114.98
LUCE (Rs./kWh)				37.16
Assumptions				
Discount rate: (i=0.12)				
EHFS: 5 (representing a site that receives an annual average insolation of 5 kWh/m^2/day				
Days of operation in an year: 365				
Capacity utilization factor: 0.9 (representing non-utilization of SHS by the household)				

capital recovery factors[6] (and any other annual costs towards O&M that include service fee of a mechanic/technician, replacement of switches, fuses, etc.) using the following expression:

$$\mathrm{ALCC}_{\mathrm{SHS}} = C_{0\mathrm{pvSHS}} \times \mathrm{CRF}_{\mathrm{pv}} + C_{0\mathrm{battSHS}} \times \mathrm{CRF}_{\mathrm{batt}} + C_{0\mathrm{cc}} \times \mathrm{CRF}_{\mathrm{cc}} + C_{0\mathrm{appl}} \times \mathrm{CRF}_{\mathrm{appl}} + C_{O\&M-\mathrm{SHS}} \quad (5)$$

where C_0 and CRF with their respective subscripts, represent capital costs and capital recovery factors for PV, battery, charge controller and appliances. The ALCC for 35 Wp SHS and 70 Wp SHS at specified values of input parameters are estimated to be Rs. 2230.70 and 4272.70, respectively (Table 3).

A microgrid has fixed costs consisting of generation, storage and power conditioning equipment, and variable cost of power distribution network consisting of length of the total distribution line and number of service connections (or households) that the microgrid intends to service. Conforming to the design and safety guidelines of the electricity supply systems in India, a PV based microgrid of up to 100 kWp is expected to service households within an area that requires about 4–5 km of distribution line. This is on the basis of estimation of drop in voltage per km and per tapping point in the network (TERI, 2005). In addition to the above fixed and variable costs, a certain amount of O&M cost mainly towards the salary of operators is also required for operating and routine maintenance of microgrid.[7]

Following expression is used to estimate ALCC of a microgrid ($\mathrm{ALCC}_{\mathrm{MGRID}}$):

$$\mathrm{ALCC}_{\mathrm{MGRID}} = [C_{0\mathrm{pvMGRID}} \times \mathrm{CRF}_{\mathrm{pv}} + C_{0\mathrm{battMGRID}} \times \mathrm{CRF}_{\mathrm{batt}} + C_{0\mathrm{pcu}} \times \mathrm{CRF}_{\mathrm{pcu}}] \times [\mathrm{PV}_{\mathrm{MGRID}} \times R]^b + [(C_{0\mathrm{dn}} \times L) + (C_{0\mathrm{sc}} \times N)] \times \mathrm{CRF}_{\mathrm{pdn}} + C_{\mathrm{O\&M-MGRID}} \quad (6)$$

where $C_{0\mathrm{pvMGRID}}$ represents the capital cost of PV array along with its mounting structure and foundation; $C_{0\mathrm{battMGRID}}$, capital cost of battery bank along with its mounting rack; $C_{0\mathrm{pcu}}$, capital cost of the entire power conditioning unit (PCU); $C_{0\mathrm{pdn}}$, capital cost of the power distribution network (PDN) which consists of (a) cost of distribution network on the basis of per km of its length ($C_{0\mathrm{dn}}$) and (b) cost of service connections, internal wiring and appliances on the basis of per household serviced by the network ($C_{0\mathrm{sc}}$); O&M costs mainly towards salary of one skilled and one semi-skilled operator ($C_{\mathrm{O\&M\text{-}MGRID}}$); L and N the length of distribution line in kilometers and number of service connections respectively; $\mathrm{PV}_{\mathrm{MGRID}}$, capacity of the microgrid in kWp; R the benchmark unit cost of the microgrid (Rs/kWp) and b a scale factor for incorporating cost reduction in overall cost of microgrid (without the PDN) due to larger capacity of components used in the microgrid with its effect uniformly distributed over all the components of the microgrid except PDN.

For the purpose of estimating fixed costs of various components of a microgrid, published data from 15 PV based microgrids of up to 25 kWp capacity in India has been used (Nouni et al., 2006) Accordingly, an average cost breakup of various components in the microgrid is estimated as – PV array (53%), battery bank (11%), PCU (20%) and PDN (16%). These fractions would be PV array (63%), battery bank (13%) and PCU (24%) without including the cost of the PDN. Using a benchmark cost of Rs. 350,000/kWp of microgrid and incorporating a value of 0.95 for factor b, the cost of various components considered for estimating ALCC and LUCE for a microgrid are presented in Table 4. For instance:

i. Cost of microgrid without the PDN is Rs. 294000/kWp for small capacity microgrids, typically up to 2 kWp.
ii. Cost of 400 V 3 phase LT distribution line is Rs. 150,000/km in the plains. This cost increases by 10% in hilly terrain and may be 25% more for remote and inaccessible sites with materials carried as head-load (HPSEB, 2009). These costs are based on the use of concrete poles in the network and standard conductors prescribed for carrying quantum of power through certain distances within allowable voltage drop according to

[6] CRF is calculated using the expression $\{i(1+i)^n/[(1+i)^n-1]\}$, where i represents the chosen discount rate and n is the life of the particular component being considered.

[7] The experience is India indicates that the company setting up the microgrid, provides 10 years Annual Maintenance Contract that covers routine servicing and repairs (not replacement of battery and PCU) of all components in the microgrid. It also includes appointment of one skilled and one semi-skilled operator at the microgrid site to switch on and off the electricity supply daily, monitor and maintain the condition of battery bank, etc.

Table 4
Cost of components in a microgrid (Rs./kWp).
Source: Nouni et al., 2006, MNRE, 2009.

Components	PV array	Battery bank	PCU	PDN	Total
Fractional cost of components (with PDN)	0.53	0.11	0.2	0.16	1
Cost of components (with PDN) in Rs./kWp	185,500	38,500	70,000	56,000	350,000
Fractional cost of components (without PDN)	0.631	0.131	0.238	0.000	1
Cost of components (without PDN) in Rs./kWp	185,500	38,500	70,000	0	294,000

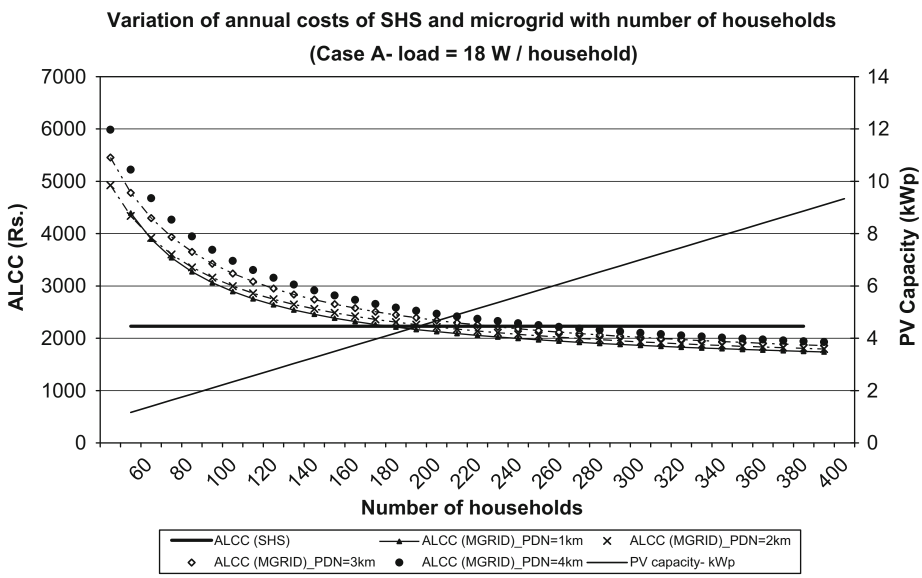

Fig. 1. Variation of annual costs of SHS and microgrid with number of households (Case A – load=18 W/household).

safety and reliability regulations of Central Electricity Authority in India (CEA, 2009).

iii. Cost of service connection is taken as Rs. 1500 per household for 2 light points and one power socket and additional Rs. 1000 for two appliances. Thus the cost of service connection including appliances would be Rs. 2500 per household in Case A and Rs. 5000 per household in Case B.

Accordingly, annualised life cycle costs per household from a microgrid are presented in Figs. 1 and 2, respectively, for Cases A and B. Sample calculation for a few representative sizes of the villages is presented in Table 5.

6.2. Cost of electricity from SHS and microgrid

The levelised unit cost of electricity from an SHS ($LUCE_{SHS}$) is estimated using the following expression:

$$LUCE_{SHS} = \frac{ALCC_{SHS}}{W_p \times EHFS \times 365 \times CUF} \tag{7}$$

where W_p represents rated peak Watt capacity of the PV module, EHFS the equivalent hours of full sun-shine[8] that take care of cloudy days also and CUF, the capacity utilization factor which incorporates non-utilization and outages of systems due to various reasons. Similarly the LUCE for microgrid ($LUCEM_{GRID}$) is calculated using the following expression:

$$LUCE_{MGRID} = \frac{ALCC_{MGRID}}{PV \times EHFS \times 365 \times CUF} \tag{8}$$

where $ALCC_{MGRID}$ is the annual costs of the microgrid and PV represents the installed capacity of the microgrid. A few selected results obtained for Cases A and B are presented in Table 5.

6.2.1. *Sensitivity of LUCE of microgrid with the nature of the terrain and the type of PDN used*

The above analysis has so far considered a plain terrain for which the benchmark costs of Rs. 150,000 per km of distribution line is taken. However, geographical terrain of remote villages, typically those that are to be serviced by microgrids or SHS, are very often characterized by hills, rocks, water bodies, forests and other features that increase the cost of distribution line, if not making it difficult to lay the network.

On the other hand, for primarily domestic electrical loads, low cost options such as single wire Earth return (SWER) (used successfully in countries such as Tunisia, Mozambique, and New Zealand for supplying single phase electrical power to remote areas) could be used in sparsely populated regions. Capital costs of SWER can be 50% of an equivalent two-wire single phase line and up to 70% less than three-wire three phase systems (SWER, 2009).

In view of the above, sensitivity analyses is undertaken for the cost of PDN, on the lower side as well as on the higher side of the base-case cost of Rs. 150,000/km. Results are presented in Fig. 3.

[8] EHFS is defined as equivalent hours of full sunshine or the total amount of incident solar radiation received on a unit surface area in a day.

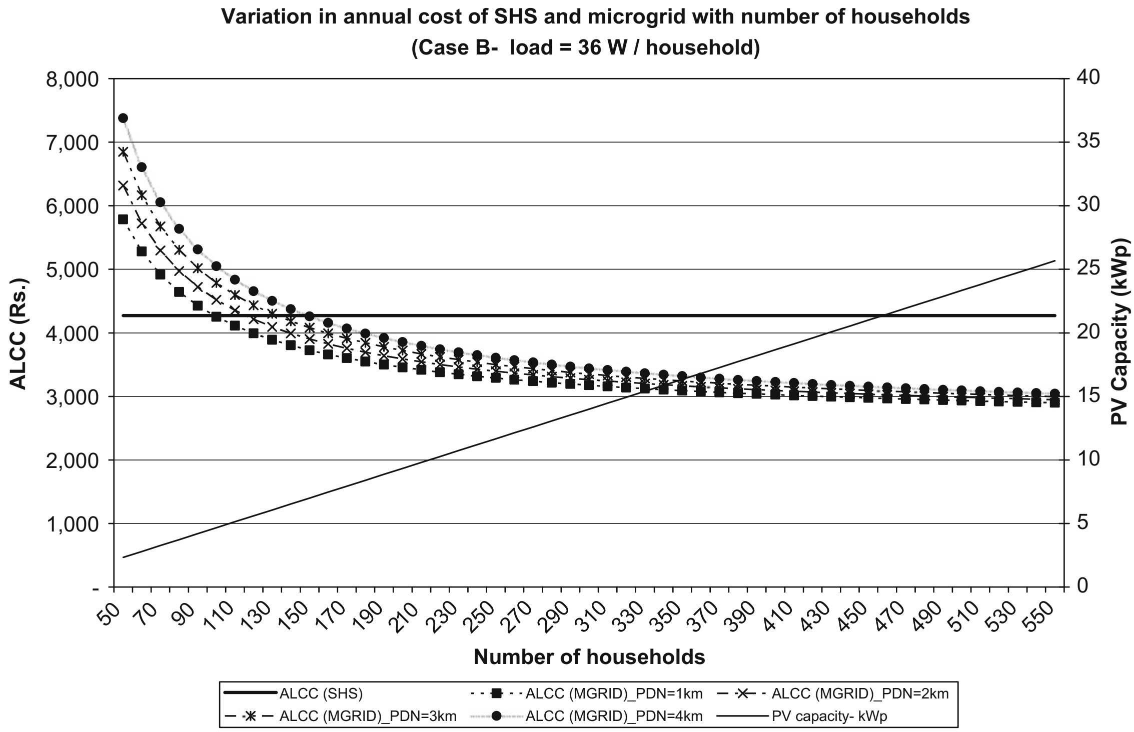

Fig. 2. Variation in annual cost of SHS and microgrid with number of households. (Case B – load=36 W/household).

Table 5
Annual costs (ALCC) and cost of electricity (LUCE) from a microgrid for selected cases.

Item	Symbol	Case I	Case II	Case III
Number of households	N	100	250	1000
Length of PDN (km)	L	1	1	4
PV capacity – kWp	PV	4.67	11.67	46.67
Cost of microgrid (W/o PDN):	C_{0MGRID}	1,270,465	3,033,932	11,323,036
Cost of PV (0.631 of C_{0MGRID}	C_{opv}	801,603	1,914,267	7,144,296
Cost of Batt (0.131 of C_{0MGRID})	C_{obatt}	166,370	397,301	1,482,778
Cost of PCU (0.238 of C_{0MGRID})	C_{opcu}	302,491	722,365	2,695,961
Cost of (PDN+SC+Appl)	C_{opdn}	650,000	1,400,000	5,600,000
Total cost of microgrid		1,920,465	4,433,932	16,923,036
Rs./kWp of microgrid		411,469	379,997	362,584
$C_{opv} \times$ CRF (20, 0.12)		107,334	256,320	956,621
$C_{obatt} \times$ CRF (10, 0.12)		29,447	70,322	262,451
$C_{opcu} \times$ CRF (10, 0.12)		53,541	127,859	477,185
$C_{opdn} \times$ CRF (10, 0.12)		115,050	247,800	991,200
Annualised capital cost		305,373	702,301	2,687,458
Annual O&M cost (fixed)		120,000	120,000	120,000
Total annual costs	ALCC	425,373	822,301	2,807,458
Annual energy generation – kWh		7666.10	19,165.25	76,660.99
Levelised unit cost of electricity (Rs./kWh)	LUCE	55.63	42.91	36.62

Assumptions
Connected load per household: 36 W
Benchmark cost of microgrid with PDN: Rs. 350,000/kWp
Benchmark cost of microgrid W/o PDN: Rs. 294,000/kWp
Economies of scale factor: 95%
Cost of distribution line : Rs. 150,000/km
Cost of service connection including internal wiring and appliances: Rs. 5000/hh
EHFS: 5 (representing a site that receives an annual average insolation of 5 kWh/m^2/day
Days of operation in an year: 365
Capacity utilization factor: 0.9 (representing non-sunny days)
CRF(20, 0.12)=0.1339 @ *n*-20, *i*-0.12
CRF(10, 0.12)=0.1770 @ *n*-10, *i*-0.12
All costs in Rs.

The impact of the cost of PDN is relatively insignificant on the LUCE of the microgrid of higher capacity servicing a large number of households as compared to small microgrids. Therefore, in rough and difficult terrains SHS might be a better option if the community is small and sparsely populated.

7. Viability of SHS vis-à-vis microgrid from the user's perspective

As seen from Fig. 1, the annual cost to the user having a 35 Wp SHS is Rs. 2230.70. Unless the user is a part of the village which

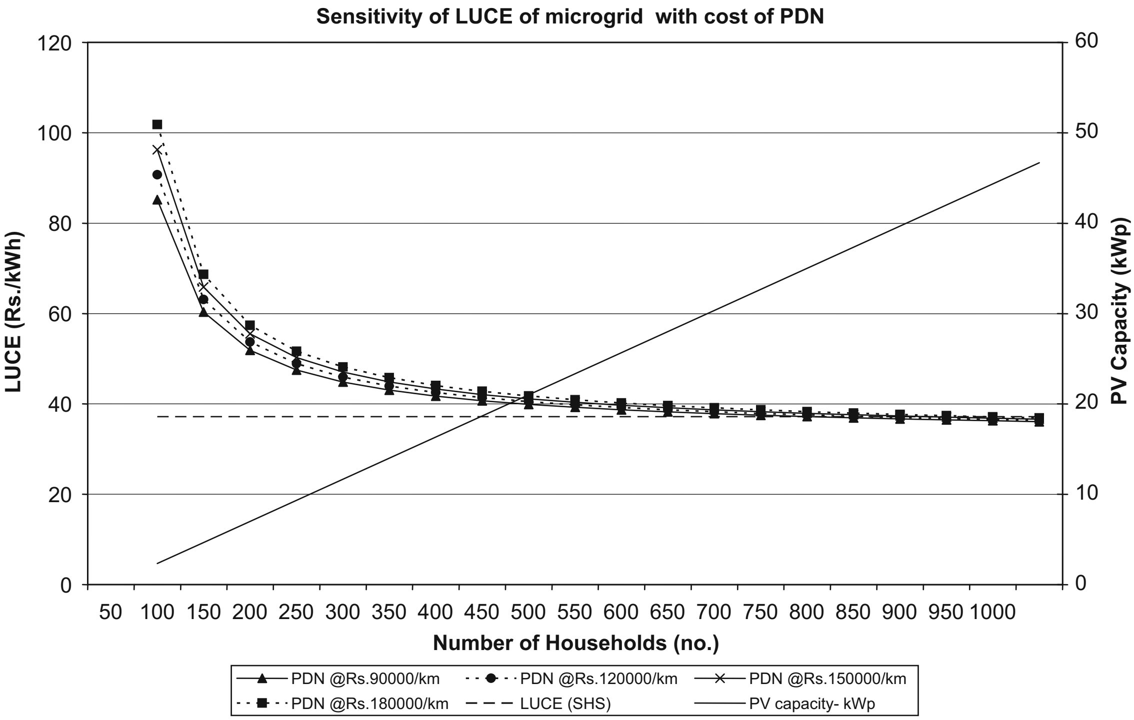

Fig. 3. Sensitivity of LUCE of microgrid with cost of PDN.

Table 6
HOMER simulated results of comparison of SHS with microgrid.

Insolation ($kWh/m^2/day$)	ALCC–SHS (70 Wp) (Rs.)	Capacity shortage – SHS (fraction)	ALCC/household–microgrid (for 100 households) (Rs.)	Capacity shortage – microgrid (fraction)
4.1	4273	0	4072	0.1
4.5	4273	0	4080	0.08
5.0	4273	0	4082	0.06
5.5	4273	0	4083	0.04
5.5	3516 (40Wp PV)	0.04	4083	0.04

has 180 households that can be serviced with 1 km of PDN, the microgrid will be an expensive option as compared to individually owned SHS. Similarly, a minimum of 270 households would be required for microgrid to be viable as compared to individual SHS for a village which has scattered households that require 4 km of PDN. However, if users have more appliances and their electricity consumption is comparable to that of a user of 70 Wp SHS, then a village of 100 households serviceable with 1 km of PDN would find a microgrid more economical (Fig. 2).

In order to see the applicability of the above analysis for communities residing in different climatic zones and receiving different amount of solar radiation, an analysis was performed using HOMER[9] for taking hourly load values and simulating the performance of the system throughout the year for one selected site in India. Sensitivity analysis was subsequently performed for different values of annual average of monthly solar radiation. The technical as well as economic assumptions for performing analysis using HOMER were kept same as that of the rest of the paper. As seen from the results of HOMER shown in Table 6, a community of 100 households using 4 appliances for 4 h each (Case B), and residing closely so that it can be serviced with 1 km of PDN, microgrid would still be a preferred option as compared to 70 Wp SHS on ALCC basis. However, as pointed out by HOMER, there is a finite capacity shortage (as per HOMER, this represents the maximum allowable annual capacity shortage as a percentage of total annual load) or the loss of load in case of microgrid, while SHS meets all the loads at all the times as per the selected design of SHS. The last row in Table 6 indicates that it is possible to have a much smaller SHS to serve the load with same allowable capacity shortage as compared to that of microgrid.[10]

The $ALCC_{MGRID}$ and hence the $LUCE_{MGRID}$ depends on the length of the PDN and number of service connections. For instance, $LUCE_{MGRID}$ of a microgrid of size 2.35 kWp designed to service 50 households (Case B type), spread within an area that can be serviced by 4 km of PDN is estimated to be Rs. 96.26/kWh. Such a high value can be attributed to rather high annual costs (including those of PDN) with low annual energy generation from a small capacity PV microgrid. The same would reduce to Rs. 37.12 for a village of about 890 households spread within 4 km

[9] HOMER – Hybrid Optimization Model for Electric Renewables – developed by National Renewable Energy laboratory, USA is an optimization model for distributed power. It simulates the operation of a system by making energy balance calculations for each of 8760 hours in a year.

[10] HOMER results also indicate that it is possible to have several combinations of capacities of PV module and battery to serve the same load, but with varying degree of capacity shortage. There could be a trade-off between allowable capacity shortage and acceptable LUCE while selecting the SHS design for a given load. (Chaurey and Kandpal, 2006).

Table 7
A combination of number of households and corresponding length of the PDN comparable with individual SHS on the basis of LUCE.

Specifications of SHS	Length of PDN (km) L	Required no. of Households N	Required Microgrid capacity (kWp)	LUCE of microgrid (Rs./kWh)	$N_{\text{threshold}}/L$
Capacity – 37 Wp	1	910	21.23	38.76	910
LUCE–Rs. 38.80/kWh	2	1030	24.03	38.80	515
	3	1160	27.07	38.77	387
	4	1280	29.87	38.78	320
Capacity – 70Wp	1	640	29.87	37.16	640
LUCE–Rs. 37.16/kWh	2	730	34.07	37.12	365
	3	810	37.81	37.12	270
	4	890	41.54	37.12	223

that would be serviced by a PV microgrid of 42 kWp capacity, a value lower than the LUCE of individual SHSs of 70 Wp (Table 7).

Table 7 also shows various combinations of the number of households serviced and the corresponding length of the PDN that can deliver electricity at the same unit cost on levelised basis as that delivered by an SHS. The ratio $N_{\text{threshold}}/L$ (number of service connections per km of PDN) at which microgrid becomes comparable to SHS, decreases as the size of the microgrid increases. Clearly, microgrid based electrification does not seem to be a viable option for smaller communities (50–100 households) and for communities where households are spread out.

8. Viability of renting SHS vis-à-vis setting-up a microgrid from the ESCO perspective

As an alternate model of dissemination an energy service company rents the SHS to households or sets-up and operates a microgrid and sells electricity to the households. In either of the two cases, the SHS or the microgrid is not owned by the household or the community. In this alternate model, the microgrid is to be considered like an infrastructure facility in the village where electricity is generated centrally and is supplied to the households based upon their requirement and willingness to pay. At the same time, the enterprise of generating and supplying electricity should be financially attractive to an ESCO. Similarly, the SHS are procured centrally and are rented and maintained by an ESCO in a profitable manner. Hence the ESCO would require a certain percentage (f_m) of total annual costs of owning and operating all the SHS or microgrid as its enterprise margin charges in order for the business to be viable. In other words, a profit margin or incentive needs to be kept for the ESCO, which has so far not been considered.

8.1. Viability of renting SHS

The effective annual cost of renting the SHS to the user if he/she rents it from an ESCO would be expressed as

$$\text{ALCC}_{\text{SHS}(m)} = (1+f_{\text{m}}) \times \text{ALCC}_{\text{SHS}} \tag{9}$$

where $\text{ALCC}_{\text{SHS(m)}}$ represents the total annual cost of an SHS to the user including the enterprise margin (f_{m}) of the ESCO as a fraction of the actual annual cost of the SHS. The incremental cost of renting the SHS vs owning it would thus be

$$\text{Incr}_{\text{costSHS}} = \text{ALCC}_{\text{SHS}(m)} - \text{ALCC}_{\text{SHS}} \tag{10}$$

Similarly, the effective annual costs ($\text{ALCC}_{\text{MGRID}}$) of the microgrid to the community after ESCO involvement can be expressed as

$$\text{ALCC}_{\text{MGRID}(m)} = (1+f_{\text{m}}) \times \text{ALCC}_{\text{MGRID}} \tag{11}$$

The incremental cost of using electricity from the microgrid as compared to owning the SHS would therefore be

$$\text{Incr}_{\text{costMGRID}} = \frac{\text{ALCC}_{\text{MGRID}(m)}}{N} - \text{ALCC}_{\text{SHS}} \tag{12}$$

where N represents the total number of households or users being serviced by the microgrid. It may be noted that the enterprise margin f_{m} is assumed to be same for SHS and microgrid. The incremental burden in both the cases is presented in Table 8 for different values of f_{m}. One option to reduce the incremental burden on the user would be to consider upfront capital subsidy support to the ESCO for initial procurement of equipment for SHS or microgrid:

$$\text{ALCC}_{\text{SHS}} = [(1-f_{\text{cs-SHS}}) \times (\text{ALCC}_{\text{SHS}} - C_{O\&M\text{-SHS}}) + C_{O\&M\text{-SHS}}] + [f_{\text{m}} \times \text{ALCC}_{\text{SHS}}] \tag{13}$$

or

$$f_{\text{cs-SHS}} = \frac{(f_{\text{m}} \times \text{ALCC}_{\text{SHS}})}{(\text{ALCC}_{\text{SHS}} - C_{O\&M\text{-SHS}})} \tag{14}$$

Similarly, the requirement of subsidy (assumed to be equally distributed among all components) in case of an ESCO setting up a microgrid would be estimated using the following expression:

$$f_{\text{cs-MGRID}} = \frac{[(1+f_{\text{m}}) \times \text{ALCC}_{\text{MGRID}} - N \times \text{ALCC}_{\text{SHS}}]}{(\text{ALCC}_{\text{MGRID}} - C_{O\&M\text{-MGRID}})} \tag{15}$$

Since the sizes of the microgrid considered are relatively small (less than 50 kWp), the value of $C_{\text{o\&m-MGRID}}$ (essentially the cost towards salary of one skilled and one semi-skilled operator assumed to be required as minimum and sufficient to operate and maintain the microgrid), is assumed to remain same for all sizes of the microgrid.

The fraction of upfront capital subsidy required for an ESCO to have a viable SHS renting business or a microgrid business as compared to individual households owning SHS for different values of N (number of households) and f_{m} (enterprise margin) is presented in Table 8. As indicated, the ESCO can provide electricity services at comparable costs to SHS owners belonging to a community of 300 households to be serviced with a microgrid with 4 km of PDN even after keeping 25% enterprise margin. The ESCO would not need any capital subsidy in this case. However, for a community of 50 households, the ESCO would need almost 100% capital subsidy to avoid burdening the community from the incremental burden of the enterprise margin. The subsidy requirement per SHS (in case the same is to be provided on rental to the household) is less as compared to the case where electricity is to be provided through the microgrid for smaller size communities having 50 households. As the community size increases, subsidy requirement for the microgrid is less than that required for the option of providing SHS on rental.

Table 8
Requirement of upfront capital subsidy by an ESCO to rent SHS or set-up and operate a microgrid for a village of households to be serviced with 4 km of PDN.

Fraction of subsidy required by an ESCO for setting up and operating a microgrid (fcs-MGRID)							
Number of households (N)	PV capacity (kWp)	Enterprise margin (f_m)					
		0	0.05	0.1	0.15	0.2	0.25
50	2.33	0.62	0.70	0.77	0.85	0.92	0.99
100	4.67	0.20	0.27	0.33	0.40	0.46	0.53
150	7.00		0.06	0.12	0.18	0.24	0.30
200	9.33				0.05	0.11	0.17
250	11.67					0.02	0.08
300	14.00						0.01
Fraction of subsidy required by an ESCO for renting SHS (fcs-SHS)							
Single SHS			0.05	0.10	0.16	0.21	0.26

9. Conclusions

A techno-economic comparison of SHS with that of a PV microgrid for supplying electricity to a village community for domestic applications is presented. A microgrid might be a financially more attractive option for the user, energy service company and the society if the village has a large number of households, is densely populated and lies in a geographically flat terrain. However, in rough terrains SHS might be a better option if the community is small and sparsely populated. Threshold number of service connections per km of PDN at which microgrid becomes comparable to SHS for a particular type of load and its usage pattern has also been estimated. Alternate dissemination model of (a) renting of SHS from an ESCO as compared to owning it and (b) using and paying for the electricity services from a microgrid owned and operated by an ESCO as compared to villagers owning a microgrid have been considered. With ESCO enterprise margin built-in the model, the requirement of capital subsidy support to the ESCO to insulate the user from the incremental cost burden has been estimated. A sensitivity of results (selected) with different values of incident solar radiation (insolation) representing communities living in different climatic zones has been done using HOMER taking into account hourly insolation values and hourly load values. HOMER results have also thrown some light on the capacity shortage or unmet load in case of SHS and microgrid. Key findings are summarized below:

- A village of households using two appliances (totaling 18 W) for 4 h each (Case A) would find it economical to opt for 35 Wp SHS individually rather than going for the microgrid unless the number of households are 180 or more in number and are densely located so that they can be serviced with 1 km of PDN. This number would go to a minimum of 270 households if these are scattered such that 4 km of PDN is required to service them.
- If the households use 4 appliances for 4 h each (Case B), then a village of 100 households serviceable with 1 km of PDN would find a microgrid more economical as compared to having a 70 Wp SHS each. Similarly, if the households are scattered requiring 4 km of PDN, then the critical number is 150 households.
- The above results (Case B) are applicable to communities residing in different climatic zones receiving insolation in the range of 4.1–5.5 kWh/m^2/day, according to HOMER simulations.
- There is a finite capacity shortage (0.04 up to 0.1 of the total annual load) in case of microgrid as compared to SHS, which meets all the loads all the time. However, HOMER points at the possibility of having small capacity SHS to serve the same load with same allowable capacity shortage as that of the microgrid.
- The ratio $N_{\text{threshold}}/L$ (number of service connections per km of PDN) at which microgrid becomes comparable to SHS, decreases as the size of the microgrid increases. Accordingly 320 is the threshold number of household per km of distribution line for Case A type of households and 223 for Case B type of households.
- For an ESCO renting out 70 Wp SHS to 50 households in a village and requiring 25% enterprise margin, about 26% capital subsidy on the cost of SHS is required to be given to ESCO if the user is to be kept insulated from the incremental burden of the enterprise margin. This value would be 99% if ESCO services the same village through a microgrid. However, for a village with 300 households, practically no capital subsidy is required.

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