Solar PV mini-grids versus large-scale embedded PV generation: A Case Study of Uttar Pradesh (India)

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This is the pre-publication version of the paper that has been accepted for publication in Energy Policy. This is the unedited, unformatted version of the paper and this is shared to comply with the open access requirement of UK Research Councils. This may be cited as follows:

Bhattacharyya, SC; Palit, D; Sarangi, GK; Srivastava, V and Sharma, P, 2019, Solar PV mini-grids versus large-scale embedded PV generation: A case study of Uttar Pradesh, Energy Policy (in press), DOI: 10.1016/j.enpol.2018.12.040.

Abstract

Despite significant grid expansion during the last decade, globally India has the highest number of people lacking access to electricity. Mini-grid has been suggested as a possible electrification option and the new mini-grid policy of the state of Uttar Pradesh has attracted global attention. Relatedly, the drive for grid extension restricts off-grid areas to very remote locations and enhances the risks for mini-grid projects. Simultaneously, the pledge for increasing renewable energy share in the power supply mix opens the possibility of large-scale embedded renewable energy generation in the rural areas. This paper investigates the viability of solar PV-based mini-grids using a discounted cash flow analysis and considers the UP-policy prescriptions to explore the case of a megawatt (MW)-scale grid-connected solar PV under a power purchase agreement. It identifies the viability support requirements for both cases under different business conditions. It finds that mini-grids are not a viable proposition if the tariff prescribed in UP is used and that other cost minimising support (such as capital subsidy or low interest debt or an output-based subsidy) would be required to attract private investments. Large-scale solar projects, on the other hand, are more viable and can be an attractive proposition for rural electrification in the Indian context.

Keywords: Solar mini-grids, large-scale solar PV, viability, rural electrification, support systems

1.0 Introduction

Out of 1.1 billion people lacking access to electricity in 2016, India accounted for 22.5% (or 239 million) (IEA, 2017). Electricity access situation in India is fast changing as India has stepped-up its efforts towards universal electrification through targeted access measures with the aim of providing universal electricity access by 2019 (Sustainable Energy for All, 2017). In fact, India has made significant progress in electrification over the past five years when millions of households got connected to the grid under the National Rural Electrification Programmes. India has extended the electricity grid to around 99.8% of the villages[1] but around 51 million households are still lacking access to electricity[2]. Forty six million rural households and five million urban households are estimated to lack access to electricity. The recently launched programme '*Saubhagya Yojana*' (or Pradhan Mantri Sahaj Bijli Har Ghar Yojana) aims to provide access to all by 2019 although the target looks quite optimistic.

With the recent drive for grid extension, off-grid solutions are being pushed to remote areas in India. These solutions come in two generic forms – stand-alone systems and local-grid systems, although hybrid options such as networking of stand-alone systems are also emerging, but stand-alone systems tend to be a costlier option and Chattopadhyay et al. (2015) indicate that a transition from solar home systems to mini-grids will generate more power and reduce costs. However, off-grid projects tend to be less attractive to private investors (Schmidt et al., 2013) due to small investment volume, high risk and low return[3]. Renewable energy-based projects face undue competition from fossil fuel subsidies and investors face

[1] http://www.ddugjy.gov.in/mis/portal/index.jsp as on 25th March 2018.
[2] As per Government of India estimates for the launch of Suabhagya – Sahaj Bijli Har Ghar Yojona (https://powermin.nic.in/sites/default/files/webform/notices/OM_SAUBHAGYA_SIGNED_COPY.pdf).

[3] Investment required for mini-grid projects falls below the investment threshold of private corporate investors. High transaction cost and effort on a unit basis makes small investment unattractive. Financial institution do not fund because they have to spent same or more time and effort to fund small mini grid project vis-a-vis finding utility scale solar projects. Bundling can address the issue, but understanding about the functioning of mini-grids is also an issue. Also banks are more comfortable funding projects, which have PPAs rather than projects which are entirety dependent on retail tariff with uncertain collection efficiency. This also calls for larger plants with part generation tied via PPA to better project bankability & thus viability.

significant macro-economic, regulatory and political risks while making investment decisions in a developing country like India. The risk for mini-grid investment increases as the grid extension process intensifies and high risks make return expectations prohibitively high, making investments unviable (Bhattacharyya, 2013). While the connection problem is being resolved to a large extent through grid extension, the availability and reliability of electricity continues to be problematic and mere connection in rural areas does not necessarily mean reliable supply. In this context, a large number of private sector based mini-grids has been set up and in many areas consumers appreciate their reliability vis-à-vis the grid (Graber et al., 2018).

In the Indian context, thus two opposing forces are clearly visible:

1) Various states with electricity access deficits (such as Uttar Pradesh, Bihar and Jharkand) have come up with policies for attracting mini-grid investments to support their electricity access efforts. It is interesting to explore whether village-scale mini-grids are viable under such policy terms and conditions.
2) The government aim of extending the grid acts as a major concern for village-scale mini-grids. Comello et al. (2017) have identified the possibility of stranded assets in mini-grids due to grid expansion and consider this as the gateway barrier for mini-grid investment in India.

If grid becomes a reality in a rural location, the government objective of providing reliable electricity round-the-clock may be difficult to realise due to poor distribution sector management. In addition, financial constraints to support infrastructure development, poor governance and inconsistent pricing and subsidy policies also hinder reliable electricity supply through the grid. There are also inherent issues of operational inefficiencies arising from old infrastructure that results in extremely high transmission and distribution losses (current above 21% in India). Renewable energy mini-grids at the decentralised level could avoid these issues but under the threat of grid extension, the mini-grid business remains a risky investment proposition.

Whereas grid extension increases India's dependence on thermal electricity, the renewable energy-based mini-grids would contribute to India's climate pledge under the Paris Agreement to increase its renewable electricity share to 40% by 2030. However, if grid extension leads to stranded mini-grid assets, the climate benefit of mini-grids would not be realised. Instead, integration of larger renewable energy-based electricity generation projects in rural grids along the lines of independent power producers could improve power supply condition and contribute towards emission reduction objectives of India, while taking advantage of scale economies of power generation.

The purpose of this paper is to analyse how a stand-alone mini-grid investment compares with a grid-tied large-scale renewable power generation system at a village cluster level in the context of Uttar Pradesh (UP)(India). We also identify enabling conditions and support systems required for their financial viability. Although Comello et al. (2017) has investigated the mini-grid investment in UP, they did not consider the support mechanisms required to ensure mini-grid viability. Further, the possibility of embedding large-scale generators at the rural sub-transmission or distribution grid level has not been considered. Ramchandran et al. (2016) considered alternative business service models and support strategies but they did not consider recent changes in the mini-grid policy environment in India. Bhattacharyya and Palit (2016) recommended steps for creating an enabling mini-grid environment but this did not focus on the possibility of rapid grid extension. We bridge this gap and make an original contribution to knowledge. The novelty of our study arises from the following: 1) the recent policy developments in mini-grids, particularly the mini-grid policy in Uttar Pradesh (India), have been captured; 2) alternative business delivery options and financial support systems are considered to derive policy insights; 3) the feasibility of large-scale grid-tied solar PV generator in a rural area is considered to compare the attractiveness of investment opportunities. While the paper focuses on India, given the recent emphasis on mini-grids globally for enhancing electricity access, the paper has relevance for Sub-Saharan Africa and South Asia and the new knowledge can assist these countries to plan their electrification efforts properly. India has never considered MW level PV generator in rural areas and focussed either on sub 100 kW scale micro grids or large utility scale solar power plants. Here we are arguing the case for large-scale solar plants (~2 MW) at the village cluster level for rural electrification.

The paper is organised as follows: section 2 presents the regulatory environment for mini-grids in India. Section 3 presents the methodology, assumptions and model inputs while section 4 discusses results. The policy recommendations and conclusions are presented in the last section.

2.0 Regulatory environment for mini-grids in India

The Electricity Act (EA) 2003 governs the electricity industry in India and requires that electricity access is provided to all areas using a two-pronged approach: (1) extension of grid-connected supply and (2) use of stand-alone systems including those based on renewable sources of energy. The Act permitted stand-alone systems (including those based on renewable sources of energy) as a rural electrification option and exempts generation and distribution of electricity in a rural area from obtaining any license from the regulator. However, Palit and Bandyopadhyay (2015) observe that the exemptions provided under section 13 and section 14 of the Act remain ambiguous, causing regulatory uncertainty.

The National Electricity Policy (NEP) and the Rural Electrification Policy (REP) support the option of decentralised distributed generation with local distribution networks when grid extension is not feasible. The Rural Electrification Policy (REP) allows the possibility of setting the tariff through mutual agreement between the supplier and the consumers. The new Tariff Policy, notified in January 2016, has also offered the purchase of power by the grid as and when the grid reaches the village.

In addition to the federal government initiatives, several state governments have undertaken initiatives to promote decentralised renewable systems. Specific reference is made to Uttar Pradesh, which has published its mini-grid policy in February 2016[4] and the Uttar Pradesh Electricity Regulatory Commission has issued the Mini-Grid Renewable Energy Generation and Supply Regulations, 2016 (MREG&S Regulations, 2016)[5]. The policy and the regulations allow for state government subsidy to support mini-grid development, provide exit options to mitigate the risks of grid extension, and specify tariff and supply

[4] http://upneda.org.in/sites/default/files/all/section/Mini%20Grid%20Policy%202016.pdf
[5] http://upneda.org.in/sites/default/files/all/section/MiniGrid%20regulations%202016.pdf

quality requirements. The details are provided in Annex 1. While the policy offers two implementation pathways – with state subsidy and without state subsidy, it is not clear whether the developer can avail additional support from the Ministry of New and Renewable Energy (MNRE). The analytical contours of our study are partly defined by the Uttar Pradesh mini-grid policy. In addition to UP, some other states (such as Bihar, Odisha[6], Madhya Pradesh, Jharkhand) have also produced guidelines/ frameworks or policies on mini-grids. Moreover, more than 15 states have declared state specific solar policies with provisions related to promotion of mini-grids. The governance environment is likely to become clearer once the policies and regulatory co-ordinations improve and the federal government comes out with the mini-grid policy.

3.0 Methodology, model inputs and assumptions

3.1 Methodology

The study uses a discounted cash-flow analysis of mini-grid projects of two specific sizes, namely a 25 kWp mini-grid project in Uttar Pradesh considering the prevalent mini-grid size of 20-30 kW in India where we apply the terms prescribed by the UP Mini-Grid Policy and a large 2 MWp grid-connected renewable energy distributed generation and supply project in a village location that serves as a mini-grid and sells excess power to the grid to find out whether they are financially viable and attractive investment propositions. The analysis is done for a village location in Sitapur District of Uttar Pradesh, having latitude 27.55N and longitude 80.65E.

We have considered solar PV-based mini-grids as they are prevalent in India. This was also done to limit the scope of analysis for this study. Given the policy thrust on solar PV in India, it is also meaningful to lay emphasis on solar energy-based mini-grids. However, a similar analysis can be performed as an extension work considering other technologies or even considering hybrid-technologies. The solar radiation for the

[6] Odisha has come up with a policy in November 2016 known as 'Odisha Renewable Energy Policy 2016'. This policy has a specific section on RE based mini/micro grid (Section 8.1.1 of the policy).

location was obtained from PV-Watts Calculator and the model is calibrated to match the annual electricity output of a solar PV system in the above location.

The financial viability has been analysed using a financial simulation approach. This is explained in Figure 1. The financial simulations focused on viability gap of a project based on its discounted cash inflow and outflows over the project lifetime. Cash inflows were determined through the consumer mix, tariff parameters and saleable electricity produced by the plant. The saleable electricity is the gross electricity production less distribution losses as found in typical mini-grid projects in India. The cash outflow is based on interest on debt, return on equity, depreciation charges, operation and maintenance costs, insurance charges and battery replacement expenses as appropriate. The financial parameters, consumer mix, and tariff parameters are varied in different simulations to investigate their effects on the viability of the project. The viability gap is bridged either with a fixed viability support or a variable support instrument and the support required is obtained iteratively to arrive at a zero-viability gap.

The levelised cost of electricity supply (LCOE) is used as the break-even cost of electricity supply. This is the minimum price that the plant has to get in order to break-even over the lifetime of the plant. The LCOE is calculated as the ratio of lifetime cost and lifetime electricity generation (Reichelstein and Yorston, 2013). At this price, the supplier will be able to take care of borrowing costs and pay a reasonable return of equity and ensure return of the capital. All calculations have been carried out in an Excel worksheet.

<<Figure 1 here>>

3.2 Model inputs and assumptions

To operationalise the above model, various inputs have been used. The capital cost for mini-grids is based on the benchmark costs prescribed by the Ministry of New and Renewable Energy (MNRE), India for solar PV-based mini-grid systems. Similarly, the costs for MW-scale projects are taken from the benchmarks prescribed by the Central Electricity Regulatory Commission (CERC). For mini-grids[7], Rs. 300/Wp (4.62 USD/Wp) is used whereas for the MW-scale project[8], a cost of Rs 53/Wp (0.82 USD/Wp) is used[9]. The costs include plant and equipment costs, distribution network (for mini-grid only), metering, land acquisition and civil construction costs. Additional assumptions are made for the following: the O&M cost is taken as 3% of the capital cost. The O&M cost is assumed to increase 5% per year. 2% of the capital cost is taken as the cost of insurance for the plant per year for the mini-grid and 1% for the large solar plant. The output is assumed to de-rate 1% per year and the life is taken as 20 years (Ernst and Young, 2016). It is assumed that the technical and commercial loss in the system is 15%[10], and the saleable output is obtained after deducting the energy lost in the system. These assumptions are based on our experience of mini-grid projects developed in India.

In line with the MNRE guidelines, depreciation is allowed to the extent of 90% of the capital cost of the asset and a stepped-linear depreciation scale is used in which 70% of the depreciation takes place in the first 12 years of the plant life and the remaining is depreciated over the rest of the plant life. Following the guidance given in accounting standard for government grants, the asset value net of capital grant is has been considered for depreciation[11].

For discounting purposes, the weighted average cost of capital is used. The weighted average cost of capital represents the rate of return required by the investors and hence it is used as the discount factor.[12] Any available capital grant is applied first and the capital investment requirement is reduced by the grant amount. The balance of capital is funded through debt and equity at a 70:30 ratio (as in TNERC, 2017). The amount of grant capital is varied in the analysis to find the sensitivity of projects to capital subsidy.

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[7] http://mnre.gov.in/file-manager/UserFiles/CFA-offgrid-decentralised-solar-applications-programme-2014-15.pdf.

[8] http://www.cercind.gov.in/2016/orders/SO17.pdf. Similar cost data is also reported here: https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf.

[9] One US dollar is equivalent to about 65 Indian rupees.

[10] Equivalent to average AT&C loss incurred by some of the better managed discoms in India and the target loss set by Ministry of Power for discoms in India.

[11] This follows the guidance given in accounting standard AS12 in India (http://www.mca.gov.in/Ministry/notification/pdf/AS_12.pdf, last accessed on 30th June, 2018).

[12] Frankfurt School – UNEP Collaborating Centre for Climate and Sustainable Energy Finance (2015) also uses the same.

Different debt tenures are considered and an interest rate of 12% per year (Chawla, 2016) and a return on equity of 20% per year are used in the analysis (TNERC, 2017).

For the mini-grid project, we consider three scenarios – a residential customer only business model, a dominant commercial load model and an anchor load model to identify how the viability changes. The consumer mix in the base case is taken as 100% residential. The effects of a 10% residential load and an anchor load are also analysed. The tariff parity with the grid system is assumed for the consumers. Specifically, the residential consumers are assumed to pay a tariff of Rs 5/kWh (0.077 USD/kWh) and the commercial consumers pay a tariff of Rs 12/kWh (0.18 USD/kWh). The residential tariff corresponds to the UP Mini-grid Policy stipulation for up to 100 W load for 8 hours.

Where the project does not break-even without support, a viability gap funding is used to reach the break-even point through an iterative process.

Different scenarios are considered in the analysis. The financial performance of projects under different levels of grant funding, debt tenure, debt cost, consumer mix, and alternative tariff cases is analysed. We also verify the sensitivity of outcomes with respect to technical and non-technical losses.

4.0 Results and discussions

The results for the mini-grid project are reported first, which is organised in three sub-sections for three cases being analysed. The findings for the large project are then presented.

4.1 Analysis of a typical 25 kW mini-grid system

Given that the consumer mix affects the project viability, we have considered a residential only supply, a predominantly commercial load case and an anchor load model.

4.1.1 Financial viability analysis of a residential only supply

This case considers supply to residential customers who pay a tariff of Rs 5/kWh as prescribed in the UP Mini-grid Policy. The financial viability of the project is analysed considering different levels of capital grant (0% to 100%) while assuming that the plant incurs the benchmark costs. Figure 2 indicates the LCOE of the project for different levels of grant. At no capital subsidy, the break-even price is as high as Rs 87.4/kWh

(1.34 USD/kWh) and at 100% capital subsidy, the LCOE reduces to Rs 27.8/kWh (0.43 USD/kWh). This suggests that a 25 kWp solar plant even with 100% capital subsidy is not a cost-effective proposition if it sells electricity at Rs 5/kWh to residential consumers. Although the O&M costs are low for a solar PV plant, the cost of battery replacement at a regular interval has to be taken care of through the tariff, which makes the electricity supply cost high even when the system gets 100% capital subsidy.

<<Figure 2 here>>

If the service charges Rs 5/ kWh to residential consumers, the total subsidy requirement for the 25 kWp system amounts to Rs. 17.18 million (0.26M USD) with no capital subsidy and Rs 12.11 million (0.19M USD) with 100% subsidy. The viability gap reduces linearly as the capital subsidy rate increases from zero per cent to hundred per cent. Thus, the viability of a residential load only mini-grid business following the UP Mini-grid policy remains questionable. At 30% capital grant, an estimated net present loss of Rs 15.66 million (0.24M USD) emerges, which does not make the project attractive to any private investor. To bring down the break-even tariff, the natural tendency for the investor is to compromise on quality to economise on capital costs. We find that if the capital investment is reduced by 50%, through such compromises, the break-even tariff comes to about Rs. 30/kWh (0.46 USD/kWh) with a 30% capital subsidy for residential-only supplies. This is the model being used in India by some private suppliers who are enlisting the required number of customers that a plant can support and are providing supply for LED lamp-based lighting at a flat monthly rate to enhance the cost recovery of the plant. However, this raises an important equity issue: why should the off-grid consumers be disadvantaged because of their remoteness or low demand and why should they pay a high kWh rate for the service? Given that the consumers are likely to be poorer as well makes such a tariff regressive. The social cost of no electricity access is high and so there has to be a mechanism by which mini-grids can be supported so that there is tariff parity, though their actual cost of supply in remote areas may be high.

Instead of a high fixed tariff to the consumers, an alternative option would be to enforce price parity at the consumer end but to allow the supplier to receive an output-based incentive in the form of a viability gap funding (VGF) from a universal service obligation fund. Figure 1 indicates the declining rate of a variable VGF as the capital subsidy rate increases. For a 30% capital grant or subsidy, the plant requires about Rs 64/kWh (~1 USD/kWh) as the variable VGF while for a 100% capital subsidy, the variable VGF reduces to Rs 22/kWh (0.34 USD/kWh) for a full recovery of the benchmark costs.

Even when the government provides capital subsidy, this is available on successful completion of the project. The investor thus is required to mobilise the initial capital and can claim the capital subsidy in due course. The delay in recovering the subsidy has financial implications for the investor. In addition, if a variable VGF is used, the delay in payment of such funding will increase the borrowing for the working capital, which can be a legitimate business expense for the supplier.

The subsidy burden for the government and the utility is an important issue to consider. Figure 2 shows that the subsidy burden reduces with higher grant proportion. This is due to the reduction in the carrying cost of capital but clearly the subsidy reduction is less steep compared to LCOE or VGF.

As the interest on loan has a clear influence on the levelised cost of electricity supply, the interest rate was varied in steps of 5% from 0% to 15% per year. Figure 3 indicates the change in LCOE as the interest rate is varied for different levels of capital subsidy. If the loan becomes interest free, the cost of supply reduces to Rs 60.2 per kWh (USD 0.93/kWh) for no capital subsidy and Rs 32.6/ kWh (USD 0.5/kWh) for 100% capital subsidy. A similar trend is visible for other interest rates. At around 80% capital subsidy, the LCOE becomes very similar for all interest rates, which acts as a tipping point. This happens because of the influence of the discount rate – at lower interest, the discount rate becomes smaller, which reduces the time value influence on the net present value.

<<Figure 3 here>>

Similarly, the tenure of debt has an impact on the LCOE and the cash flow. The sensitivity of LCOE, variable VGF and total subsidy amount due to changes in the debt tenure is captured in Fig. 4. With shorter debt tenure, the break-even cost of supply, the variable VGF amount and the subsidy requirement reduces. With a 10-year tenure, the LOCE reduces to Rs 77.7/kWh (USD 1.19/kWh) for the base case (all other variables remaining unchanged). However, a shorter tenure of loan makes repayment difficult due to inadequate internal resource mobilisation for loan repayment. Accelerated depreciation will be required which will affect the results.

<<Figure 4 here>>

The technical and non-technical loss is another variable that has a significant influence on the results. The analysis above is based on the average loss of 15%. However, given the small size of their operation and the possibility of using advanced metering and monitoring systems, the losses can be reduced. The best operating systems tend to have a loss of 10%. The sensitivity of LCOE to any change in technical and non-technical loss is shown in Figure 5. Three loss levels are presented – 15%, 10% and an aspirational level of 5%. As expected, with a reduction in the loss, LCOE reduces, which in turn reduces the viability gap per unit of electricity sold. The gap between power generation and power sold reduces and this allows the expenses to be spread over a larger base, thereby reducing the LCOE and support requirement per unit of electricity sold. But because the consumers are assumed to pay a nominal tariff of Rs 5/kWh in this case, the total subsidy requirement does not change appreciably.

<<Figure 5 here>>

The above analysis offers the following lessons:

a) A solar PV generated mini-grid based supply still remains a costly option, requiring a relatively high break-even price, which is practically impossible to recover through customer tariffs alone. Even with a 100% capital subsidy, price parity with the regulated grid supply cannot be achieved as the project will not be financially viable for the project developer.

b) Price parity with the grid supply can only be achieved through a combination of capital grant and VGF. Higher the capital grant allowed, lower is the variable VGF required.

c) Alternatively, the financial viability can be ensured through capital grant and a flat rate tariff, which has to be comparatively high to ensure adequate revenue recovery.

d) A high initial capital grant reduces the overall subsidy burden for the government and can be an appropriate financing mechanism to enhance access to energy.

e) The results are sensitive to interest rate and debt tenure and a lower interest rate or debt tenure can reduce the cost of supply and subsidy requirement but the loan repayment may be an issue in a reduced tenure loan.

f) As cost reduction is essential to ensure project viability, there may be a natural tendency to compromise on technical standards for delivery infrastructure.

g) Similarly, any reduction in technical and non-commercial losses also reduces the LCOE and brings down the cost of supply.

4.1.2 Financial viability for a predominantly commercial load model

In this case, it is assumed that the load mix is composed of 90% commercial load and 10% residential load, which is in line with a condition allowed by the Uttar Pradesh Mini-grid Policy. It is assumed that the commercial consumers pay a tariff of Rs 12/kWh whereas the residential consumers pay a tariff of Rs 5/kWh. The full benchmark cost prescribed by MNRE is used along with other assumptions as indicated in the case of residential only case. The results are presented in Figure 6.

<<Figure 6 here>>

The LCOE remains the same as before but the viability gap reduces due to higher commercial tariff. The variable VGF required is slightly lower than the residential only case but as before the service remains financially unviable with tariff revenue and additional support either through viable gap funding or capital subsidy or a combination thereof is required.

If there is no capital subsidy, either the project developer would need a variable viability gap support of Rs 75/kWh (USD 1.15/kWh) or the commercial consumer tariff would have to be increased to Rs 82/kWh (USD 1.26/kWh) to ensure full cost recovery. Clearly, this results in a very high tariff that is unaffordable by many commercial consumers and would make the project unviable. If the project cost is reduced by 50% through cost saving measures and prevalent MNRE subsidy, the commercial tariff can also be reduced by 50% (Rs 41/kWh or 0.63 USD/kWh) to break-even. While commercial consumers may afford to pay such a tariff, it is much higher than grid parity tariff and puts additional financial burden on the rural consumers.

4.1.3 Financial viability of an anchor load model

In the anchor load model, it is assumed that 80% of the demand comes from the anchor load while the rest is residential. Residential consumers pay Rs 5/kWh while the anchor load tariff is used as a balancing figure. Other assumptions remain same as before. The LCOE does not change as the cost side of the equation is not affected.

Figure 7 presents the main results. If the anchor load pays the grid parity tariff applicable to a commercial consumer, the mini-grid investment does not become a viable proposition without any subsidy. As the figure indicates, with no capital subsidy, the business makes a staggering financial loss of Rs 15.69 million (or $0.24 million). The financial loss reduces to Rs 3.2 million ($0.049 million) with a 100% capital grant but still the project is not viable. If the anchor load pays a balancing tariff to break-even the costs, the tariff becomes Rs 92/kWh (USD 1.41/kWh). This is much higher than they pay for diesel-based supplies and it remains doubtful whether large commercial consumers such as telecom towers will be willing to accept such a high tariff. The balancing tariff becomes Rs 29/kWh (USD 0.45/kWh) at 100% capital subsidy. While this tariff can be acceptable to the users, 100% grant-funded projects remains an unlikely commercial proposition.

<<Figure 7 here>>

If tariff parity is the objective, then some viability gap funding will be required to ensure financial attractiveness of the mini-grid investment. A variable VGF is considered in the above figure to supplement the capital grant. It shows that a payment of Rs 75/kWh (USD 1.15/kWh) will be required to balance the books when there is no capital subsidy whereas a funding of Rs 16/kWh (USD 0.25/kWh) will be required when 100% capital grant is available. The subsidy burden on the government ranges between Rs 15.71 million (USD 0.24 million) for no capital grant case and Rs. 10.85 million (USD 0.17 million) for the 100% capital grant case.

From a project developer's perspective, when the project viability has to be ensured with a capital grant of 30%, the negotiated tariff route becomes a more preferable option. Mini-grid developers in India are often using a flat rate tariff of Rs 150-200 per month for a basic level of supply to residential consumers. This is considered to be the amount residential consumers pay to buy kerosene and hence are willing to pay that much for a better quality of light. Assuming that the residential consumers pay a flat tariff of Rs 150/month for a basic level of consumption of 5kWh/month, their effective tariff comes to Rs. 30/kWh. In such a case, the balancing tariff for an anchor load would be Rs 67 (USD 1.03/kWh) for a 30% capital subsidy[13]. As the project developer is likely to require a smaller distribution network and given that non-technical losses are likely to be less due to limited number of residential consumers, it is possible to benefit from some economy in capital costs and better revenue generation. Considering these possibilities (i.e. capital cost reduces to Rs 200/Wp and the distribution losses reduce to 10%), the balancing anchor load tariff becomes Rs 39/kWh (USD 0.6/kWh) for a 30% capital subsidy, which appears to be in the acceptable range.

To summarise, the anchor load model:

1) Would find it difficult to recover full costs without a certain amount of capital subsidy or viability gap funding. Enforcing grid-parity tariff makes the projects more dependent on support systems and hence more vulnerable.

[13] The effective come will be Rs 50.kWh/month if the basic consumption is 3kWh/month, which can be from a 15W of load served for 6 hours a day for 30 days per month. The balancing tariff looks viable in such a case.

2) Would benefit from the possibility of a negotiated tariff. With a capital grant of 30%, a viable business can be developed with a reasonable negotiated tariff, as long as the project does not require an extensive distribution network and manages technical and commercial losses well.

4.2 Analysis of a larger-scale project (2 MW)

It is assumed that a grid-tied 2 MWp solar PV plant is being installed in a rural location of which 25 kWp is being considered as part of the distributed generation scheme and the rest is eligible for the feed-in tariff applicable for a large solar PV plant.[14] Being a large-scale project, it attracts economies of scale that reduces the capital investment need per kW of capacity. The benchmark capital cost for this plant is considered as Rs 53/Wp. The larger plant being grid-tied, it does not require any battery bank and there is no battery replacement cost in this case. The energy generated is directly transferred to the grid, thereby avoiding the battery-related costs. However, for the smaller 25 kWp plant considered for local mini-grid, the battery bank will be required and the replacement cost is accounted for in the analysis.

The plant is assumed to have a life of 20 years (Ernst and Young, 2016). The grant capital share is kept as variable while 30% of the balance is taken as equity and 70% is assumed to come from debt. The debt tenure is taken as 10 years at an interest of 12% per year (Chawla, 2016) while the return on equity is taken as 20%.The weighted average cost of capital is taken as the rate of depreciation. These assumptions reflect closely the prevailing conditions in Indian projects.

As before, we consider a number of cases to find out the support requirement to ensure financial viability of such a project. We consider that the large project receives a feed-in tariff, and the DDG component charges Rs 5/kWh to residential consumers and Rs 12/kWh to commercial consumers and has a mix of 80:20 for residential and commercial consumers. For a given feed-in tariff and retail tariff, the financial balancing is achieved varying the capital grant amount.

[14] The size of the generation plant depends on the ability of the network to evacuate it and availability of land to house PV panels. These are assumed to be available in the given location. India has installed a large number of MW-scale PV projects under national and state schemes. The size ranges between 1 to 25MW (http://www.pv-insider.com/development-india/documents/PV-Utility-Scale-Map-India-Final.pdf), including many between 1 and 2 MW.

Figure 8 provides the levelised cost of electricity for this system. The levelised cost at full benchmark cost (i.e. no capital grant) comes to Rs. 8.56/kWh (USD 0.13/kWh). This is a very reasonable electricity generation cost from a renewable energy source and is an attractive investment proposition. The break-even cost declines rapidly with the proportion of capital grant. At 100% capital grant, the levelised cost becomes 5 paise/kWh. With a capital subsidy of 50%, the break-even price reaches Rs. 6.85/kWh. Clearly, the viability of a larger plant can be easily appreciated. The levelised capital subsidy per unit of electricity varies from Rs. 72/kWh (USD 1.1/kWh) for 100% subsidy to no subsidy for the unsubsidised case.

<<Figure 8 here>>

Lower capital cost arising from the scale economies along with shorter debt tenure considered here has reduced the unit subsidy cost. The small DDG plant which is appended to the larger plant is effectively subsidised by the larger plant to recover its costs. Given its expenses and income are insignificant compared to the larger plant, it is not elaborated further here.

As states are moving towards a feed-in tariff-based system for grid-connected renewable electricity, it is interesting to find out how much capital grant is required to ensure viability of such large projects. Uttar Pradesh Regulations provide for feed-in tariff as applicable to rooftop systems (which is Rs 7.06/kWh set in 2014-15) levelised for 25 years for plants less than 5 MW. At this tariff, about 18% capital subsidy is required to break-even (see Figure 9). If the government allows a capital subsidy of 30% capital subsidy, a tariff of Rs 5/kWh (USD 0.077/kWh) is sufficient to break-even.

<<Figure 9 here>>

From the analysis of this larger plant, the following lessons can be learnt:

1) Larger power plants offer benefits in terms of lower cost of electricity supply and can help maintain a reasonable cost of electricity supply. The subsidy or capital support required for such a plant is lower on a unit cost basis and thus offers a better value for money.

2) Appropriate feed-in tariff is essential for the financial viability of a larger project. As noted above, a low tariff of Rs 7/kWh will not ensure financial viability of a large project unless capital grant is made available. The commitment to the tariff for the project duration is also essential to ensure investor confidence in these projects.

3) While off-grid locations may not directly benefit from such large-scale projects, it is possible to bundle projects under an umbrella programme to reap the benefits of lower cost of supply and more effective use of taxpayer money. Aggregated programme level operations are thus a better option than operating in a pilot scale project mode.

4) However, one challenge of such project is that when the PDN is not charged during blackouts, the plant will not be able to feed energy to the grid. If load shedding is high during day time, it will create problem with financials.

5.0 Policy recommendations

India has made significant progress in terms of village electrification with 99.8% of the villages having access to grid electricity. However, about 51 million households are still without access to electricity, many of whom live in so-called electrified villages while others live in non-electrified areas. There is also a serious problem with the quality of supply as many electrified areas remain underserved and receive poor quality supply. Accordingly, the potential for mini-grids arises from two types of areas: non-electrified villages and villages (or even peri-urban areas) where electricity grid exists but the service is poor or inadequate.

While India has experimented with different types of mini-grid technologies, the solar PV-based mini-grids have emerged as the dominant player. Despite having experience in various scales (from a few kW or MW scale), the financial analysis presented in section 4 shows that small-scale projects lead to relatively high cost of electricity and affordable electricity supply requires strong financial support in the form of capital subsidy and often revenue subsidy. This at least can be considered for the part of the market where electricity should be considered as a merit good rather than a fully marketed service (Mishra et al., 2016). The anchor load model improves the revenue generation of the business but viability gap funding is essential to ensure financial viability. While some practitioners argue that mini-grids can thrive, without any intervention by the regulators, based on mutually agreed tariff with consumers, the fact is that mutually agreed tariff has been there as per the provision of the EA 2003. However, private sector mini-grids have not as yet scaled up in India based on such tariff practices. Thus, better incentives to operate the systems efficiently and over the lifetime of the assets are required to ensure long-term sustainability of the service. At the same time, more effort in monitoring and evaluating performance of mini-grids in the country is also required so as to ensure that the incentives or subsidies provided by government or through any other means can be tracked to ensure better outcomes. Our analysis also highlights the importance of low cost financing. Given the high reliance on debt funds, low interest rates will reduce the interest burden and longer tenure allows them to spread the cost. Accordingly, mini-grid project developers need access to suitable financial instruments to manage their project costs.

However, the direct financial support gets offset in a number of ways through social and economic impacts produced by investments. For example, the mini-grid in an off-grid location is likely to displace kerosene-based lighting, which brings a number of economic and social benefits. Kerosene is heavily subsidised in India and the government incurs a bill of $4 billion per year in kerosene subsidies. Out of this about $2 billion is attributed to kerosene use for lighting (TERI, 2014). If the entire fuel-based subsidy for lighting is displaced by renewable electricity, it would save about 6.7 billion litres of kerosene per year that would avoid 18 million tons of CO_2 per year (TERI, 2014). Further, replacement of kerosene use thus contributes to health benefits by reducing morbidity and mortality, savings in terms of expenses on medical care and loss of potential income due to illness or disability (Deora and Chandran-Wadia, 2013). Further, the black carbon produced by kerosene is a more serious global warming agent compared to CO_2 and displacing kerosene use provides a low-hanging fruit towards reducing global warming (Deora and Chandran-Wadia, 2013). Mini-grids also bring other benefits. For example, the businesses are generally small-scale and the mini-grid development can lead to a large number of entrepreneurs in the country. In addition, they generate employment opportunities in rural areas and thus contribute directly to human development and poverty alleviation. It also has gender-related benefits. The investment required for solar mini-grids for even 50,000 villages is a small amount compared to the subsidies handed out by the government under various schemes (Deora and Chandran-Wadia, 2013).

Large-scale power plants benefit from economies of scale and can achieve utility-range electricity prices. The support requirement reduces drastically in such cases and promoting large-scale grid-tied mini-grids or generating technologies can be a cost-effective outcome to reduce fossil-fuel dependence and improve wellbeing.

Based on the above findings, the following recommendations are made:

- Mini-grids need financial support to ensure project viability. Our study shows alternative support mechanisms such as blended financing are possible – capital grants, fixed viability gap funds, a variable viability gap payment or a combination of these. A higher capital subsidy appears to be a less costly option for the government but from a pragmatic perspective, a flexible financing mechanism combining capital grants and a viability support arrangement is likely to be more appropriate.
- As commercial loads and anchor loads improve the viability of mini-grid projects, integration of commercial load and support for their promotion is a logical step for any project. However, given that such developmental activities go beyond the scope of a power project, better coordination with rural development agencies and industry departments can be beneficial.
- In view of rapid grid expansion in India, the cost recovery of mini-grids is likely to an issue, given that the existing feed-in tariff is unlikely to recover the project investments. Grid-tied power generation projects in rural areas in the range of 1-5 MW which can also work as a mini-grid as well as supply power to the grid can offer a better investment opportunity as their cost recovery is feasible under the prevailing feed-in tariff regime and existing mini-grid policies of different states.

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List of figures

Fig. 1: Framework for financial analysis used in this study

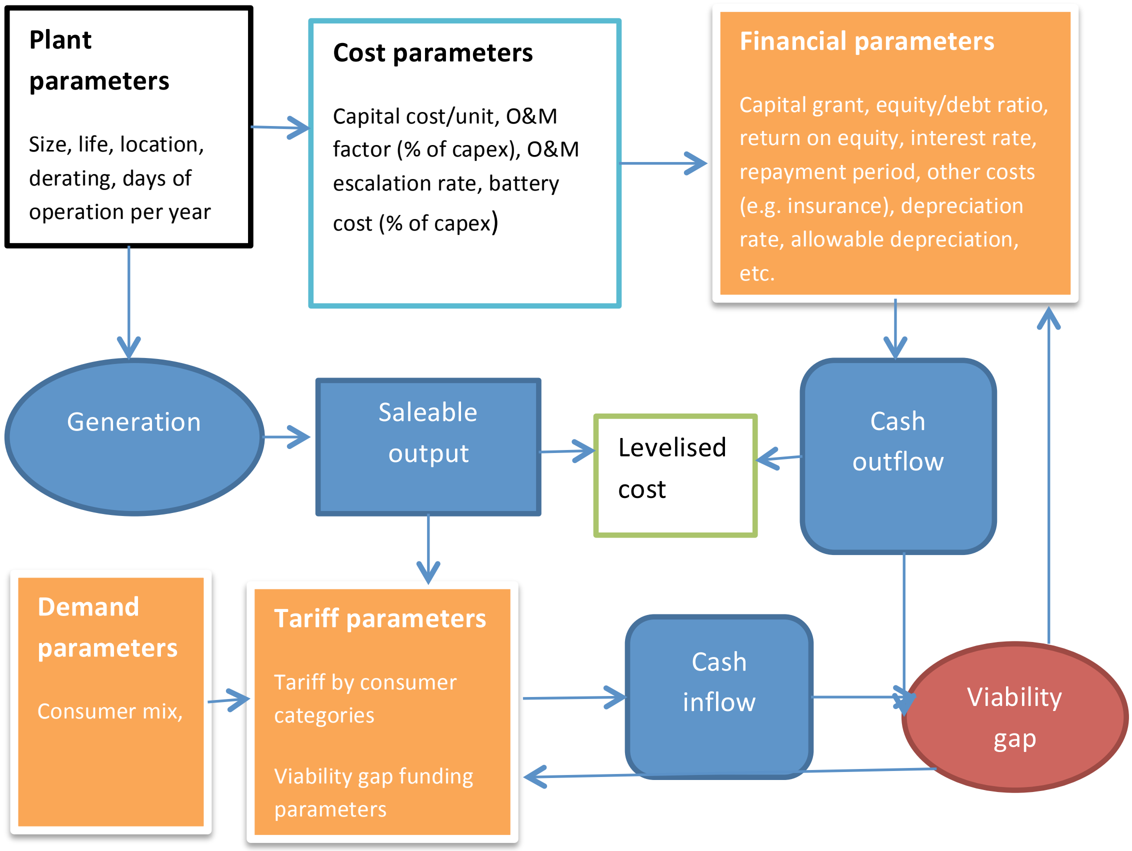


Figure 2 LCOE and variable Viability Gap Funding requirement of a 25 kW plant

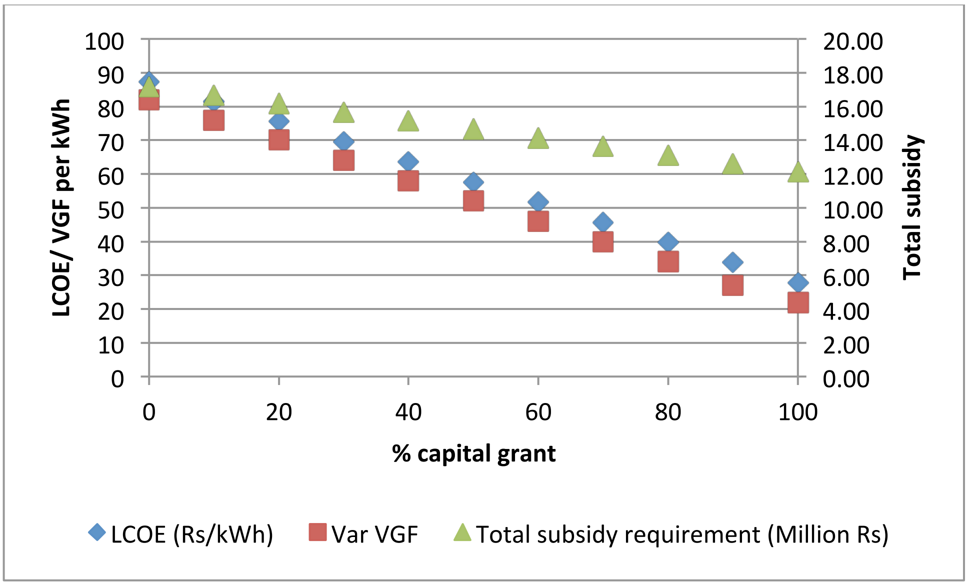


Figure 3 Sensitivity of LCOE to changes in the interest rate

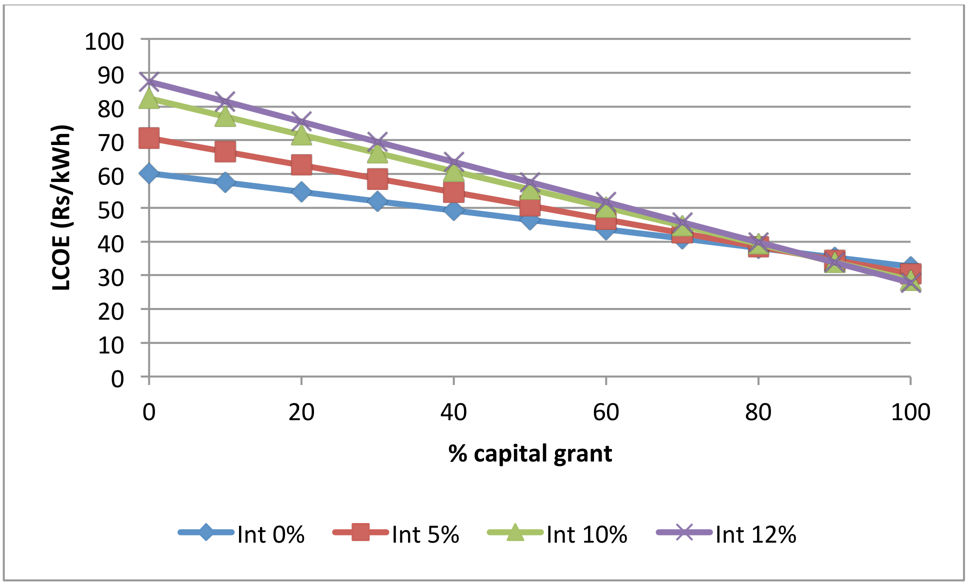


Figure 4 Sensitivity of base case results to debt tenure

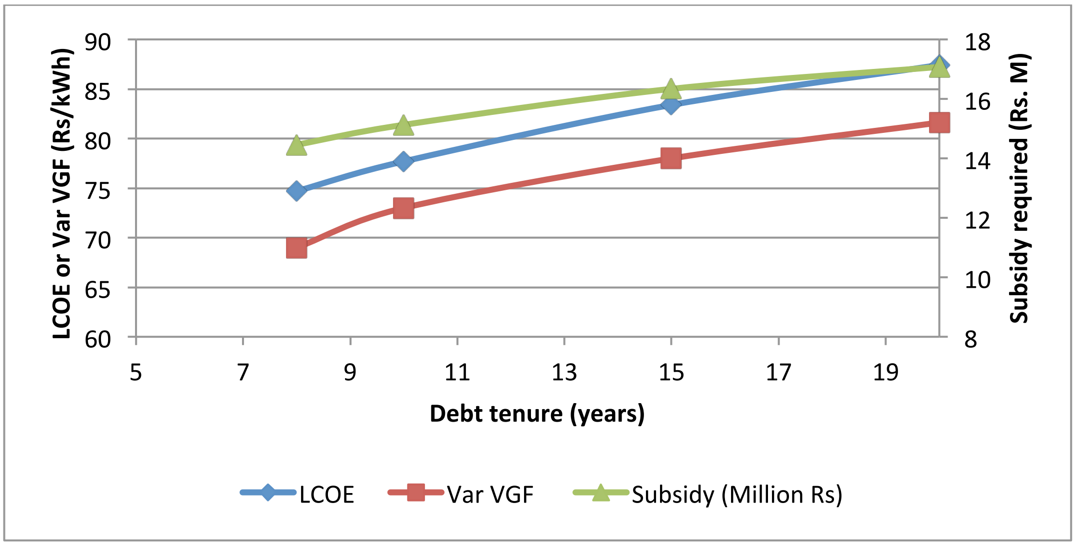


Figure 5: Sensitivity of LCOE with respect to distribution losses

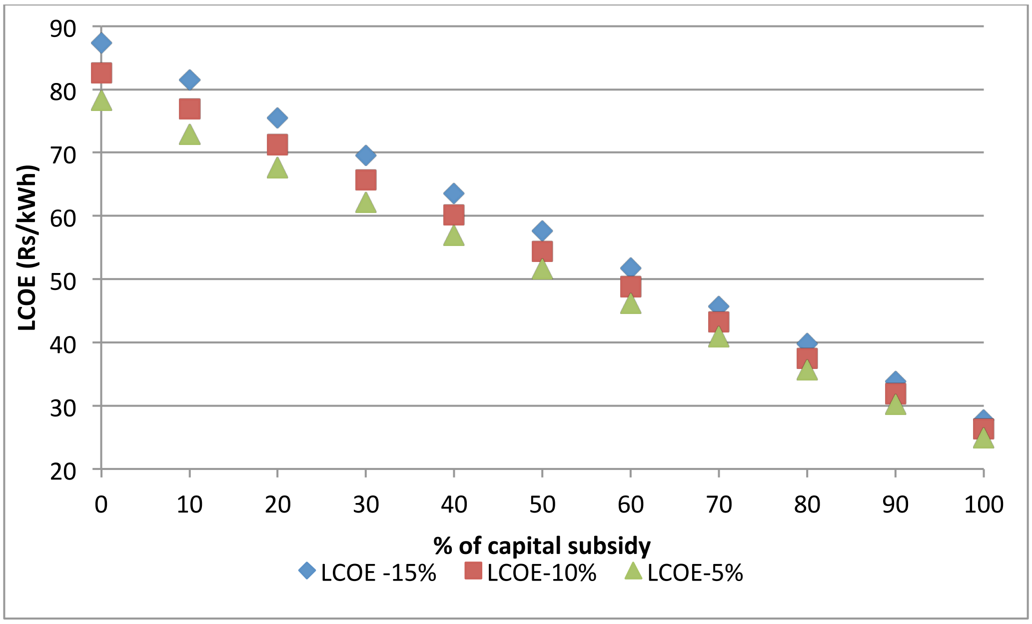


Figure 6: LCOE and viability gap funding requirement for a predominantly commercial load case

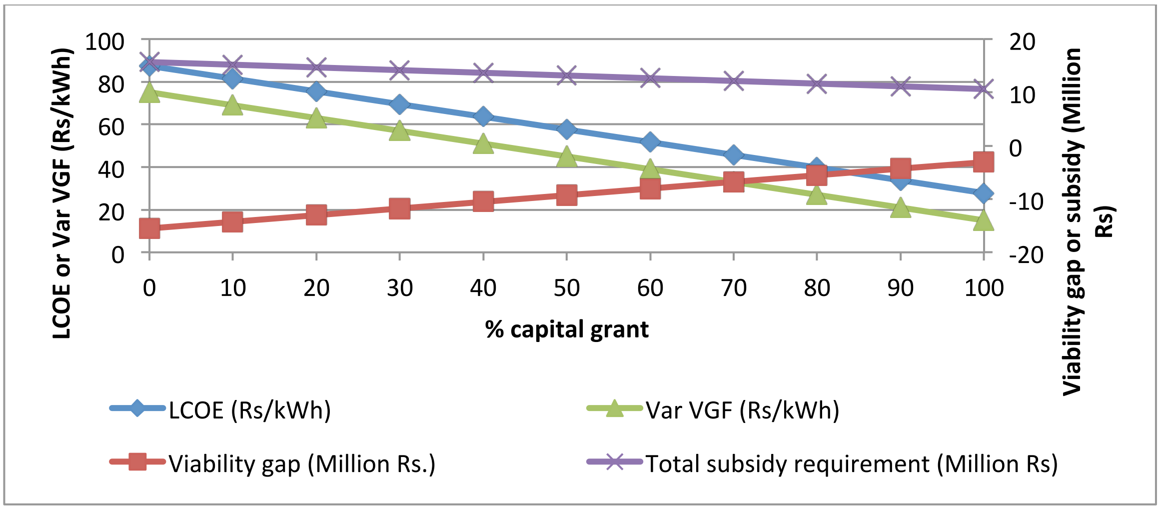


Figure 7 Financial analysis results for the anchor load case

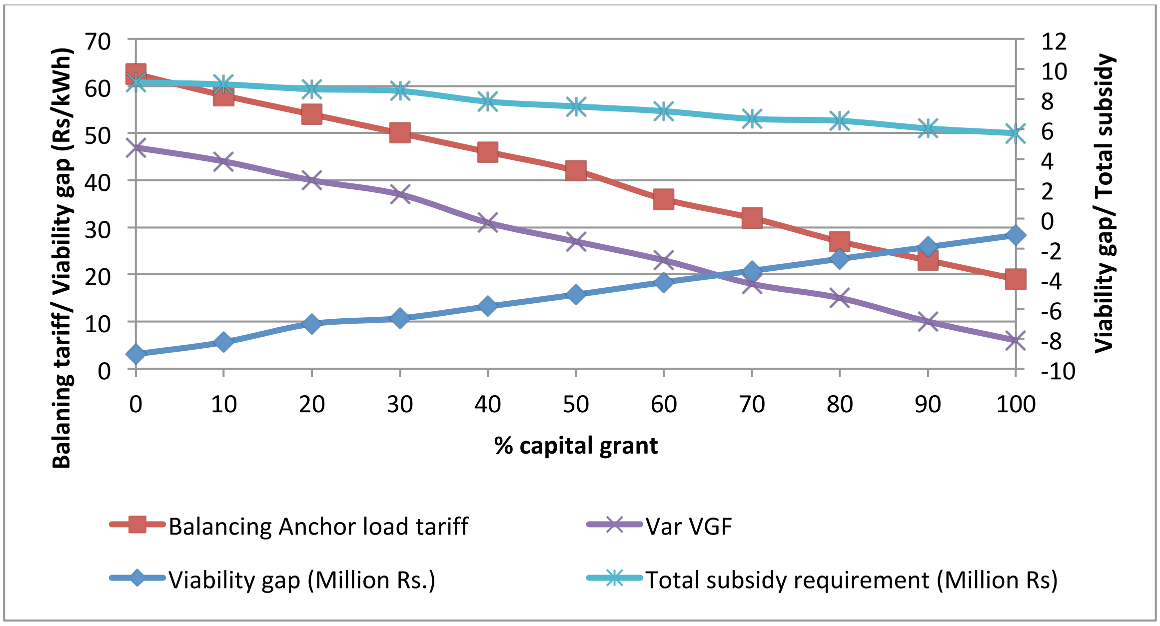


Figure 8 Levelised cost and unit capital subsidy requirement of a 2MW solar PV plant

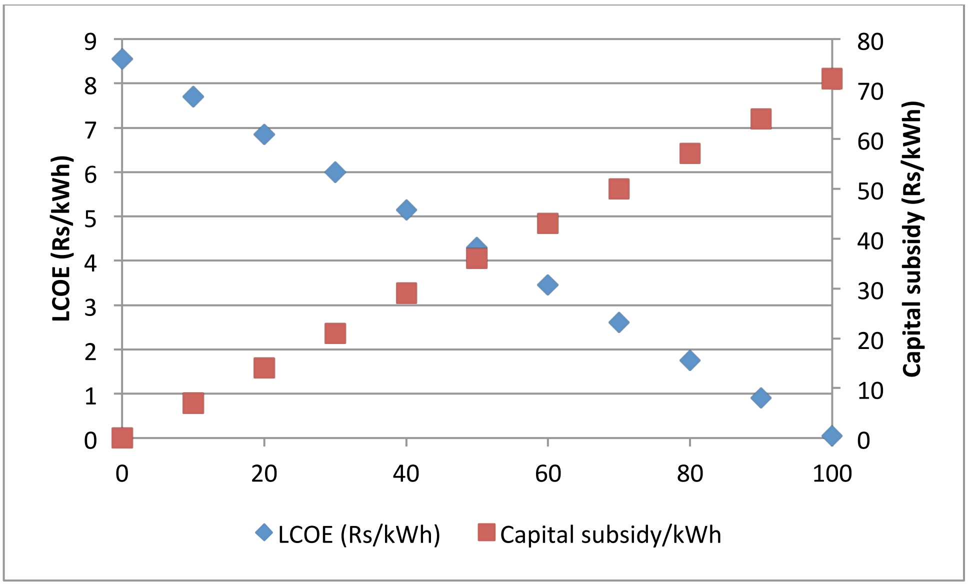
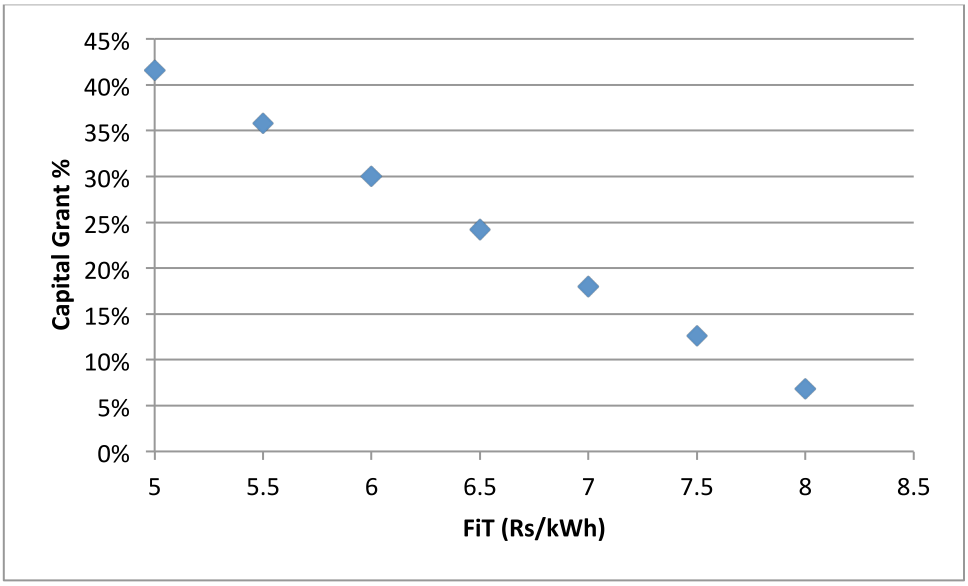


Figure 9 Grant support required for various levels of FIT



Annex 1:

Annex 1: Main features of UP mini-grid policy and regulations

Salient features of UP mini-grid policy

Project Capacity: Mini-Grid Projects of maximum capacity 500 kW shall be installed to electrify the households of villages/ habitations/ hamlets which are un-electrified or are having unavailability of power in peak demand hours.

Implementation plan: With State Government subsidy:

1) State government to provide 30 % subsidy.

2) Built Own Operate and Maintain (BOOM) basis and 10 years mandatory operation and maintenance.

3) Mandatory daily at least 8 hours (3h morning, 5hr evening) for domestic demand.

4) Daily 6 hours of supply for productive and commercial needs.

5) Electricity Tariff: Developer will charge Rs. 60/- per month for load of 50 Watt, Rs. 120/- per month for load up to 100 Watt for 8 hours of daily electricity supply and for the load more than 100 Watt tariff will be on mutual consent between consumers and developer.

Self-identified Projects by the Developers without State Government subsidy:

1) No subsidy by state government;

2) Developer will be allowed to charge tariff from consumers on mutual consent basis.

3) UPNEDA will act as the Nodal Agency for Single window clearance for all Mini Grid Projects which include the task related to issuance and facilitation of desired Government orders, necessary sanctions/permissions, clearances, approvals, consent etc. in a time bound manner.

The villages covered under the installed project shall be considered as last mile stone infrastructure and on the access of conventional grid following two exit procedures will be followed:

1) The energy generated from the plant will be received in the grid by DISCOM at the tariff decided by UPERC/ tariff decided on mutual consent. Project developer will be given priority for authorisation as a franchisee by Discom

2) Based on the cost benefit analysis of the installed project, it can be transferred to the DISCOM at the cost determined on mutual consent between DISCOM and developer.

Project Completion time (6 months' time extension may be granted for delay due to actual/natural reasons at various levels):

1) Solar energy - within 6 months,

2) Biomass /Biogas- within 9 months,

3) Wind energy and small hydro - within 01 year

Use of fossil fuel e.g. coal, gas, lignite, Kerosene, wood etc. is prohibited in solar thermal based projects. In Biomass based projects use of fossil fuel will be permissible as per the standard of Govt. of India. In absence of requisite solar energy, the Genset can be used to charge the battery bank etc. in Solar Photovoltaic Plants.

To ensure the online monitoring, quarterly functionality report should be submitted by projects, which are greater than 50 kW in capacity and installed with Government subsidy.

Land use, environment and stamp duty related incentives will be provided to for the sanctioned projects under Uttar Pradesh State Industrial Policy, 2012 of industries based on solar energy or renewable energy.

The highlights of the UP mini-grid regulations are presented below:

Applicability: New and existing Mini-Grid projects (up to 500kWp);

Models for Business Operations:

Model A: No existence of Grid: - The Mini-Grid Operator (MGO) will be responsible for electricity generation and supply following the BOOM model. The MGO can apply a suitable tariff for the entire quantum of electricity supplied in accordance with the Uttar Pradesh Mini Grid Policy, 2016. The operator can transfer the ownership of the distribution network to the distribution utility on depreciated value of assets, provided the network conforms to the standards of the utility's system.

The operator can either sell 100% to consumers at a mutually agreed tariff or partly to consumers at a mutually agreed tariff and sell excess/surplus electricity to Discoms at Mini-Grid feed-in tariff (FiT), or sell 100% electricity to Discoms according to UPERC RE tariff regulations.

Model B: Grid pre-exists:- The operator has to sell 100% to consumers at mutually agreed tariff or tariff for the Mini-Grid Projects with the State Government subsidy, in accordance with Uttar Pradesh Mini Grid Policy, 2016, for a minimum of period six months. After that MGO may opt for one of the options given in Model A.

Technical Standards for Construction of project distribution network (PDN): MGO shall be responsible for safe Operation and Maintenance of the PDN; as per the Electricity Act and rules regulations made there under. Discom will share Technical Standards for discoms' system.

Standard of Performance: MGO to supply electricity to all willing domestic consumers within 40 meters of PDN, to deploy minimum 10% of the project capacity to cater to domestic consumers in the areas if there is a demand and to supply electricity continuously or intermittently for a minimum period of 5 hours, between compulsory supply hours each day to all the connected consumers.

Technical Standards for interconnection with the Grid: - The inter-connection of the mini-grid with the discom's system shall comply with the CEA (Technical Standards for connectivity of the Distributed Generation Resources) Regulations, 2013 and amendments thereof. Further, the cost for inter-connection network from the mini-grid to inter-connection point shall be borne by the MGO. The Mini-Grid Projects with installed capacity above 50kWp shall ensure that the Technical Standards for construction of PDN comply with Construction manual for design and construction of lines issued by Rural Electrification and Secondary System Planning Organization (RESSPO), Uttar Pradesh Power Corporation Limited (UPPCL), or The Central Electricity Authority (CEA) (Measures relating to Safety and Electric Supply) Regulations, 2010.

Metering Arrangement: The MGO has to comply with CEA (installation and operation of meters), Regulations 2006. Discom will install meter at the interconnection point at its own cost. MGO will install Generation meter at the Mini-Grid project to record the generation of electricity and each outgoing feeder. This will also serve the purpose of Renewable Purchase Obligation (RPO) fulfilment for obligated entity(ies);

Distribution Franchisee (DF) Framework: MGO may undertake the role of Distribution Franchisee provided MGO fulfils the modalities to be specified in the implementation Guidelines for the appointment of the DF by the discom

Payment Security: Distribution Licensee shall prioritize making payments to MGO.

Formation of Technical Committee: The Commission will constitute a Technical Committee at the state level.