BENEFIT-COST ANALYSIS

ENERGY LAST MILE

Rural Household Electrification: A Comparative Analysis of Conventional versus Renewable Pathways

RAJASTHAN

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RAJASTHAN PRIORITIES
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An India Consensus Prioritization Project

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List of Abbreviations

ARR	Aggregate Revenue Requirement	KV	Kilovolt
AT&C	Aggregate Technical and Commercial losses	LT	Low tension
BCR	Benefit Cost Ratio	MOP	Ministry of Power
CAGR	Compound annual growth rate	MSMEs	Micro, Small and Medium Enterprises
CCC	Copenhagen Consensus Center	MVA	Megavolt-ampere
CEA	Central Electricity Authority of India	MW	Megawatt
CGPL	Coastal Gujarat Power Limited	NPV	Net Present Value
CO2	Carbon Dioxide	O&M	Operations and Maintenance
DDUGJY	Deen Dayal Upadhyaya Gram Jyoti Yojana	PDCOR	Project development company jointly promoted by Government of Rajasthan and IL&FS
Discom	Distribution Company	PPAC	Petroleum Planning & Analysis Cell
		RBI	Reserve Bank of India
GCV	Gross Calorific Value	RERC	Rajasthan Electricity Regulatory Commission
GHG	Greenhouse Gas Emissions	RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
GW	Gigawatt	ROE	Return on Equity
INR	Indian Rupees	SDGs	Sustainable Development Goals
JdVVNL	Jodhpur Vidyut Vitran Nigam Limited	Solar PV	Solar Photo Voltaic
Kcal/Kg	Kilocalories per Kilogram	USD	US Dollar

Academic Abstract

A vast majority of the population without access to electricity in India resides in rural areas. Several dedicated programmes funded by the Government of India have been initiated in the past to address the challenge of rural electrification such as, the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) initiated in 2005, the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) initiated in 2015 and the most recent Saubhagya Scheme launched in 2017. From all aspects, fossil fuel powered grid extension has been the focus of government measures to provide access to electricity. The emerging context of rise in global GHG emissions (especially from electricity production) and India's ambitious target of adding 175 GW of renewable energy to the country's energy mix; assessing the role of renewable based distributed generation was considered important.

This study utilizes a cost benefit analysis approach to examine three interventions directed towards rural household electrification in currently un-electrified households in the Bikaner district of Rajasthan. These interventions are:

1. Grid Connectivity – conventional fossil fuel based grid
2. Solar Micro Grids – renewable based distributed generation
3. Diesel Micro Grids – fossil fuel based distributed generation

The objective of the study is to present different pathways to rural electrification and compare them on the consistent basis of costs incurred to implement and benefits accrued. The study finds that based on the available evidence, both grid connectivity and diesel micro grid have favourable benefit cost ratio (BCR), and solar micro grid has the lowest BCR. In particular, at the current revenue generation level, the cost of solar based distributed generation model was quite high. Both grid electrification and diesel micro grid were viable interventions. Further, sensitivity analysis has been conducted to evaluate the impact of several variables on the overall feasibility of the three interventions.

Policy Abstract

The Problem

Access to electricity is a critical input on the pathway to modern economy and a key driver of social and economic development. Household electrification holds the potential to change the nature of productivity within homes as well as in market outcomes. The welfare benefits of electrification are realized through inter-related pathways such as that of lighting, health, education, productivity, labour participation, enterprise development and income generation (Khandker, et al., 2012).

A vast majority of the population without access to electricity in India resides in rural areas. The electrification rate in urban areas was 97% compared to electrification rate of 74% in rural areas as of 2016 (IEA, 2017). Several dedicated programmes funded by the Government of India have been initiated in the past to address the challenge of rural electrification such as, the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) initiated in 2005, the Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY) initiated in 2015 and the most recent Saubhagya Scheme launched in 2017. While most government programmes focused on village level electrification, household electrification came to the forefront much later.

As of October 2017, 10 districts in Rajasthan reported less than 50% achievement in household electrification. Of these, Bikaner district was selected for this study as it reported a relatively low 49% achievement on the intensive electrification (households) program and only 16% Below Poverty Line (BPL) households with access to electricity. While wrting this paper, the base data for Saubhagya scheme presented on the online dashboard (website http://saubhagya.gov.in/) maintained by the Ministry of Power stated that 62% of rural households in Bikaner had been electrified and the balance 38% do not have access. [1]

While grid connectivity is the mainstay of providing electrification to rural households under central schemes, the geography and the average direct normal irradiance for Bikaner (5.47

[1] As this paper was being finalised, the dashboard was updated and showed the percentage of households to be electrified in Bikaner was 34%, not 38%. This small change would not affect the broad conclusions of this study.

kW/m^2/day) makes it potentially a good location for setting up distributed solar power generation. In order to assess the most viable option, this study conducts a cost-benefit analysis of three pathways.

India's per capita electricity consumption was approximately 1100 units per annum in 2017. As per a study on residential electricity consumption published by Prayas in 2016, annual per capita residential electricity consumption in India in 2014 was 153 units. (Prayas Energy Group, 2016) The study also revealed that during the last decade, the residential electricity consumption grew at an average rate of 8% annually. It was assumed that future rural demand for residential electricity consumption will grow at the same rate. Based on the Saubhagya Dashboard information, it was assumed that 38% of total rural households in Bikaner need to be electrified. Further, new households due to incremental population growth will also need to be electrified. The time horizon for studying the costs and benefits of these interventions is 10 years with 2019 as the first year. Benefits are assumed to accrue starting from the first year. All costs were assumed at 2017 price level and labour costs were escalated at the real wage rate.

Intervention 1: Grid Electrification

Overview

This intervention envisages connecting all un-electrified households to the electricity grid serviced by Jodhpur Discom (JdVVNL) with daily continuous 24 hours supply. The grid is assumed to be predominantly coal fired and the cost of generating electricity has been calculated based on a representative new thermal power plant operating at high efficiency. The capital (fixed) cost of power generation for the incremental consumption has been included in the cost. Also included are costs required to create transmission assets, distribution network and installation of electricity meters to service the un-electrified households. In order to generate costs, the Discom will recover revenue as per tariff schedule approved by the state regulator.

Implementation Considerations

For grid electrification, investments are divided into 2 tranches – year 1 and 6 to address demand for year 6 and year 10 respectively. The quality of evidence for grid electrification is ‘strong’. The data utilized has been published in the public domain by regulatory authorities, Discom and similar entities from comparable geography. Estimation of environmental costs is based on established methodologies.

This intervention design has been prevalent for decades and poses minimal risks. The main measure of success for the intervention is the speed at which households gain access to electricity and benefits are accrued to the households. The same gets reflected in greater willingness to pay and resultant realization of revenues. There are certain environmental costs due to fossil fuel-based electricity generation, which has been accounted for in the costs of the intervention.

Costs and Benefits

Costs

The net present value of total cost for the intervention is estimated at INR 2,717 Crore at a discount rate of 5%. A break-up is presented in table 1 below.

Table 1 Costs of Grid Electrification

Costs of Grid Electrification	Costs incurred (INR cr)
Cost of additional electricity generated	₹1,598
Capital costs incurred for transmission, distribution and meters	₹185
Operating and maintainence costs	₹751
Social cost of carbon	₹184
Total Costs	₹2,717

Note – all figures assume a 5% discount rate

Benefits

Revenues are generated through recovery of tariff from the connected rural households. Grid tariff is charged in the form of monthly fixed and per unit energy charges, based on the published tariff for 2016-17 and escalated by the projected real wage growth. The escalation by real wage growth is used as a proxy for the increasing willingness to pay (WTP) for electricity. Salvage value of assets at the end of project life has also been included.

With electrification, various welfare benefits will be accrued by private citizens in the form of better lighting, improved outcomes of health, education and productivity. Further, private enterprises are expected to increase and potentially increase their performance with reliable supply of electricity. These benefits are paid through the tariffs and captured in the revenue stream.

The net present value of total benefit from the intervention is estimated at INR 2,736 Crore at a discount rate of 5%.

Table 2 Benefits of Grid Electrification

Benefits from Grid Electrification	NPV of Benefits accrued (INR cr)
Total Revenues	₹ 2,649
Salvage Value	₹ 87
Total Benefits	₹ 2,736

Note – all figures assume a 5% discount rate

Thus the benefit cost ratio (BCR) for 'grid electrification' intervention is 1.01 at discount rate of 5%. To some extent, the BCR may be under stating benefits accrued by the government as taxes applied on several cost categories, the break-up of which are not available. However, we believe these would be minor and hence have not been explicitly accounted for in this analysis.

Intervention 2: Solar Micro Grid

Overview

This intervention envisages providing electricity to all un-electrified households by installing solar micro grids distributed across villages as per local capacity requirement. These micro grids may be serviced by the Discom or provided through franchisee models; alternatively, these may be contracted out to community enterprises or even private players to set-up, operate and maintain. The solar micro grid design includes full battery back-up which we assume would need replacement every 5 years. It also includes additional battery to address intermittency issues i.e. additional battery to ensure that the quality of supply is same or comparable to grid supply. It is therefore assumed that the solar micro grid operator will charge households the same tariff as approved by the state regulator for Discoms, since the quality of supply provided was comparable to grid connectivity.

Implementation Considerations

Additional capital investments are undertaken each year to meet the incremental demand for electricity. The quality of evidence for this intervention is adjudged ‘medium’. The experience of solar micro grids has been varied and this study uses average estimates from various studies, which may not capture all aspects of this geographical area. Besides, the Solar PV industry is currently undergoing a transformation which could lead to significant reduction in costs. This uncertainty has been captured in the sensitivity analysis. The main measure of success for the intervention are the benefits accrued to the households and this is reflected in greater willingness to pay and resultant realization of revenues. There are no additional environmental costs due to implementation of this model.

Costs and Benefits

Costs

The net present value total cost for the intervention is estimated at INR 11,350 Crore at a discount rate of 5%.

Table 3 Costs of Solar Micro Grids

Costs of Solar Micro Grid	Costs incurred (INR cr)
Capital costs of solar micro grids (including PV modules, Inverter/converter, Balance of System costs, Batteries and Soft costs)	₹ 9,745
Costs of battery replacements	₹ 1,387
Operation and maintenance costs	₹ 218
Total costs	₹ 11,350

Note – all figures assume a 5% discount rate

Benefits

With the additional battery back up for the solar micro grid model, it is assumed that electricity provision will be comparable to grid connectivity. Hence, grid tariff as approved by the state regulator is used for revenue estimation escalated by the real wage growth to capture increasing willingness to pay. Salvage value of assets created has also been included.

Due to the comparable quality of supply, same welfare benefits would accrue to private citizens as accrued in the grid electrification intervention. These benefits are paid through the tariffs and captured in the electricity revenue stream of benefits. Some additional minor benefits are also generated in the form of employment and enterprise to maintain the solar micro grid.

The total benefit from the intervention is estimated at INR 8,126 Crore at a discount rate of 5% presented in table 4.

Table 4 Benefits of Solar Micro Grids

Benefits from Solar Micro Grids	NPV of Benefits accrued (INR cr)
Total Revenues	₹ 2,649
Salvage Value	₹ 5,477
Total Benefits	₹ 8,126

Note – all figures assume a 5% discount rate

Thus, the benefit cost ratio (BCR) for 'solar micro grid' intervention is 0.72 at discount rate of 5%. To some extent, the BCR may be under stating benefits accrued by the government as taxes applied on several cost categories, the break-up of which are not available. However, we believe these would be minor and hence have not been explicitly accounted for in this analysis.

Intervention 3: Diesel Micro Grid

Overview

This intervention envisages developing diesel generator based micro grids distributed across villages as per local capacity requirement to provide electricity to all un-electrified households. Similar to solar microgrids, this intervention may also be implemented by different players or by the Discom. In order to address intermittency and peak loads, a Plant Load Factor (PLF) of 75% and safety margin of 1.3 has been assumed in estimating the additional capacity required to meet the electricity demand of the households.

Implementation Considerations

Additional investments are undertaken each year to address the incremental demand for electricity. The quality of evidence for this intervention is adjudged as 'strong'. There is ample historical experience using diesel gensets for power generation across India as well as other parts of the world. Estimation of environmental costs is based on established methodologies.

This intervention design has been prevalent for decades and poses minimal risks. The main measure of success for the intervention is the speed at which households gain access to electricity and benefits are accrued to the households. The same gets reflected in greater willingness to pay and resultant realization of revenues. There are certain environmental costs due to fossil fuel-based electricity generation, which has been accounted for in the costs of the intervention.

Costs and Benefits

Costs

The net present value of total cost for the intervention is estimated at INR 2,722 Crore at a discount rate of 5% as presented in table 5.

Table 5 Costs of Diesel Micro Grids

Costs of Diesel Micro Grids	Costs Incurred (INR Cr)
Capital costs for diesel gensets	₹ 122
Cost of diesel as fuel for power generation	₹ 2,080
Network connection costs for connecting households to the micro grid	₹ 130
Operating and maintenance costs	₹ 117
Cost of additional carbon generated from diesel combustion in gensets	₹ 274
Total Costs	₹2,722

Note – All figures assume a 5% discount rate

Benefits

Based on the estimated capacity addition in the intervention design, electricity provision will be comparable to grid connectivity. Hence, grid tariff in the form of monthly fixed and per unit energy charges is based on JdVVNL's tariff for 2016-17 is charged to households for revenue collection. It is escalated by the projected real growth rate annually. An additional benefit of salvage value of assets created for this project at the end of project life has been included.

Due to this model, similar welfare benefits would accrue to private citizens as accrued in the grid electrification intervention. These benefits have been reflected in the assumption that the tariffs increased at real growth rate match the willingness to pay for these services. Some additional minor benefits are also generated in the form of employment and enterprise to maintain the diesel micro grid.

The net present value of total benefit from the intervention is estimated at INR 2,784 Crore at a discount rate of 5%. Details are presented in table 6.

Table 6 Benefits of Diesel Micro Grids

Benefits from Diesel Micro Grids	NPV of Benefits accrued (INR cr)
Total Revenues	₹ 2,649
Salvage Value	₹ 135
Total Benefits	₹ 2,784

Note – All figures assume a 5% discount rate

Thus, the benefit cost ratio (BCR) for 'diesel micro grid' intervention is 1.02 at discount rate of 5%. The taxes accrued on diesel have been excluded from its price estimation under cost of diesel for this intervention as they are a transfer[2]. Any other taxes have not been explicitly accounted for in this analysis. To some extent, the BCR may be understating benefits accrued by the government as other taxes applied on several cost categories. However, we believe these would be minor.

BCR Summary Table

Table 7 BCR Summary Table

Interventions	Benefit	Cost	BCR	Quality of Evidence
Grid Electrification	₹ 2,736	₹ 2,717	1.01	Strong
Solar Micro Grids	₹ 8,126	₹ 11,350	0.72	Medium
Diesel Micro Grids	₹ 2,784	₹ 2,722	1.02	Strong

Notes: All figures assume a 5% discount rate

[2] An alternative approach would be to include the full costs of diesel including taxes in the cost component, and to assign taxes as a benefit to government. This does not change the BCR significantly.

1. Introduction

Globally, the number of people without electricity access has reduced from 1.7 billion in 2000 to 1.1 billion in 2016 (IEA, 2017). In India, almost half a billion people gained access to electricity since 2000 – electrification rate in the country improved from 43% to 82% between 2000 and 2016 (IEA, 2017). Recent years have seen impressive improvement, as the number of people gaining access to electricity has risen from 28 million per year between 2000 and 2012 to 41 million people per year in 2016 (IEA, 2017). The number of people currently without electricity access is estimated at 239 million, which is a quarter of the estimated population without electricity access globally (IEA, 2017). Successfully addressing the challenge of complete electrification will not only be a big achievement for India, it will also be a significant step towards achieving the global development goals.

Of the population without access to electricity in India, majority reside in rural areas. The electrification rate in urban areas is 97%, while rural electrification rate was 74% as of 2016 (IEA, 2017). The focus on rural electrification has evolved over the decades following independence. Initial years (1950's) focused on electrification of towns with population of 10,000 or more. Following the green revolution, the focus was to provide electricity access for irrigation and later on for commercial purposes (Bannerjee, et al., 2015). While most government programmes focused on village level electrification, household electrification came to the forefront much later. The recent improvements in electricity access have been possible due to dedicated programmes funded by the Government of India, most notably the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) initiated in 2005, the Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY) initiated in 2015 and the most recent Saubhagya Scheme launched in 2017.

From all aspects, grid extension has been the focus of government measures to provide electricity access. The aforementioned schemes have adopted a top-down approach towards electrification, where a part of the funds is provided by the central government in the form of grants and actual implementation is undertaken by the respective states' distribution utilities (Discoms). Since 2000, coal fired power plants have fuelled about 75% of the new electricity access, with renewable sources accounting for around 20% (IEA, 2017).

The aforementioned schemes accepted that grid connectivity is not feasible in all geographies and provisioned for distributed generation models using renewable energy resources in select areas where the grid cannot reach (Ministry of Power, 2009). However, there has been limited interest from government in developing models for distributed generation as the primary source for electricity provision. The main reason for lack of confidence in distributed generation are concerns around technical and financial viability particularly in difficult terrain. Given the low willingness and ability to pay for electricity, financial viability of distributed generation projects in rural areas has yet to be conclusively demonstrated. Subsidies have played an important role in creating the business case for such projects and many see them as stop-gap arrangements till grid connectivity is established.

With new advances in technology for renewable based distributed generation, there is however greater scope for their utilization. Experience across various geographies in India has demonstrated that small scale projects can be designed to meet the needs of rural residential and commercial customers. Additionally, given the context of rise in global GHG emissions (especially from energy sector), and India's ambitious target of adding 175 GW of renewable energy to the country's energy mix; assessing the role of renewable based distributed generation is important.

Financial analysis of various options for electrification typically do not account for social and environmental impacts of interventions and focus only on the investment and the return on it. This study is aimed towards assessing interventions not only from a financial lens but also incorporate social and environmental impact to the extent possible given the contraints of data availability. The cost-benefit analysis approach provides the distinct advantage of identifying pertinent issues and bringing them on the same platform as conventional project design concerns to facilitate informed decision making.

2. Literature Review

Access to electricity is a critical input for the pathway to modern economy and a key driver of social and economic development. Household electrification holds the potential to change the nature and quantum of productivity within home as well as in commercial enterprises. There is ample evidence to show the positive impacts of access to reliable electricity in developing countries (Samad & Zhang, 2016). The welfare benefits of electrification are realized through inter-related pathways such as that of lighting, health, education, productivity, labour participation, enterprise development and income generation (Khandker, et al., 2012). The provision of electricity facilitates the shift of rural economy from a largely agrarian base towards mixed avenues of industry, commerce and knowledge enterprises which plays an important role in poverty alleviation and human development.

Many studies have portrayed the welfare effects of electricity provision to households such as (Bannerjee, et al., 2015); (Chakravorty, et al., 2016) and earlier works of (Dinkelman, 2011); (Khandker, et al., 2012); (Lipscomb, et al., 2013). Electrification combined with a 24-hour a day power supply can lead to upto 17% increase in income. (Samad & Zhang, 2016) The estimated aggregate benefit of reliable electricity access in rural India is estimated at USD 11 billion per year, with USD 4.7 billion from improving the access rate and USD 6.5 billion from improving reliability of supply (Samad & Zhang, 2016). It has been estimated that reliable access to grid electricity in India increased non-farm income by 28 percent during 1994-2005 (Samad & Zhang, 2016). Better lighting in rural households facilitates more study time for children leading to higher school enrolment and grades. It also reduces dependence on alternative lighting such as kerosene lamps which leads to indoor air pollution. Better lighting allows more hours for businesses to operate increasing livelihood opportunities and efficiencies. Once electrified, rural households acquire appliances which improve the standard of living and increased exposure to knowledge and information.

3. About the Area of Intervention

Bikaner is the second largest district in the state by geographical size with a total of 919 villages, of which 857 are inhabited. An estimated 66.1% population of Bikaner resides in rural areas – compared to 75% population of Rajasthan residing in rural areas.

Table 8 Demographic Profile of Bikaner District

Demographic Profile as per Census 2011	Bikaner District	Rural Bikaner
Population	2363937	1563553
Decadal growth rate	24.3%	23.9%
Sex Ratio	905	903
Literacy Rate	65.1%	58.1%
SC and ST population	21.1%	25.7%
Workers to Total population ratio	41.7%	46.8%
Number of households	384944	244971
Household size	6.1	6.4

As per Census 2011, 58.7% of households in the district used electricity as the main source of lighting. The rural-urban divide was stark with 92.5% urban households utilizing electricity for lighting as compared to 40.1% of rural households (Directorate of Census Operations Rajasthan, 2011). However, some progress has been made on the village and household electrification front since then under the various rural electrification schemes such as RGGVY, DDUGJY and Saubhagya Scheme. As per the base data for Saubhagya scheme presented on the online dashboard (website http://saubhagya.gov.in/) maintained by the Ministry of Power, out of the total rural households in Bikaner, 62% had been electrified and 38% remain to be electrified. Within the Saubhagya scheme's data validation, it has been stated that the actual number of rural households in Bikaner are more than estimated in the scheme. Analysis of monthly progress reports from DDUGJY also reveals varying number of total households and as a result it is a challenge to estimate the exact number of un-electrified households.

For this study, the population growth rate of rural Bikaner district has been estimated based on the ratio of decadal growth rate of rural Bikaner to rural Rajasthan between 2001 and 2011 and the annual projected population growth rate for Rajasthan as provided by CCC. Population information for Bikaner district was sourced from the District Census Handbook for Bikaner for Census 2011. The CAGR of change in household size between 2001 and 2011 has been used to estimate household size. Both the aforementioned estimates have been used to project the total number of households in rural Bikaner over the project horizon.

As per a study on residential electricity consumption by Prayas in 2016, annual per capita residential electricity consumption in India in 2014 was 153 units (Prayas Energy Group, 2016). The study also revealed that during the last decade the residential electricity consumption grew at an average rate of 8% annually. In this study, it is assumed that future rural demand for residential electricity consumption will grow at the same growth rate. This per capita consumption forecast was used to estimate the demand for electricity due to electrification of rural households.

Table 9 Electricity Demand Estimation

Variables	Data for 2019
Annual per capital residential electricity consumption	225 units
Annual growth rate for residential electricity consumption	8%
Estimated household size	5.1
Projected total number of households in rural Bikaner[3]	365,713
Estimated number of un-electrified households	138,971

4. Quality of Evidence

All the three interventions have varying quality of evidence. Grid electrification has been the mainstay of power supply for decades and hence the intervention design in this study is based on a 'strong' quality of evidence. The data utilized has been published in the public domain by regulatory authorities, Discom and similar entities from comparable geography. Estimation of environmental costs is based on established methodologies. Solar Micro Grids are still an emerging model using technology which is undergoing rapid change and bringing about dramatic reductions in cost. The quality of evidence for Solar Micro Grids is adjudged 'medium' as this study uses average estimates from other studies, which may not capture all aspects of this geographical area. The quality of evidence for Diesel Micro Grids is adjudged as 'strong'. There is ample experience using diesel gensets for power generation across India in different settings as well as internationally.

[3] These figures are based on projections of total population and household size, informed by Census data from 2001 and 2011. They differ from the number of households on the government's energy portal probably due to different assumptions about household size. Since costs and benefits are linearly related to energy demand, which itself is a function of population and not number of households, this assumption does not change the results presented in this study in any material manner.

5. Grid Electrification

5.1 Description of intervention

This intervention envisages connecting all un-electrified households to the electricity grid serviced by Jodhpur Discom (JdVVNL) to provide 24 hours electricity supply per day. The grid is assumed to be predominantly coal fired generation and the cost of generating electricity has been calculated based on a representative new coal fired (super critical technology) plant which performs at high efficiency. This study has included the capital (fixed) cost to the full extent of incremental consumption due to rural electrification. The study also included capital and operational costs required to create transmission assets, distribution network and installation of electricity meters to service the un-electrified households. In order to recover costs, the Discom will charge tariff as per schedule approved by the state regulator.

5.2 Data

The main data sources are listed in the following table

Table 10 Data Sources for Grid Electrification

Variable	Data	Source
Power factor of grid system	0.9	
Demand "Load" Factor	0.7	
Rates of Assets 33 KV substations 1X5 MVA 2X5 MVA 1X8 MVA 2X8 MVA 1X10 MVA 2X10 MVA 11 KV substations 1X250 KVA 1X400 KVA Lines 33 KV lines 11 KV lines LT lines	 INR 1.43 crore INR 2.13 crore INR 1.74 crore INR 2.76 crore INR 1.71 crore INR 2.7 crore INR 0.075 cr INR 0.1029 cr INR 8,65,100/km INR3,06,720/km INR 2,88,880/km	(UPPCL, 2017)
Population density multiplier	2.5	
Cost of meter	INR 1252 per unit	www.urjakart.com
O&M costs	INR 3264 /customer/annum	(JdVVNL, 2017)
Weighted Average Specific Emissions for Fossil Fuel Fired Stations	1.03 tCO_2/MWh	(Central Electricity Authority, 2014)
Social Cost of Carbon at 5% discount rate	USD 7.6 /tCO_2	(Tol, 2018)
Depreciation rate	5.28%	(RERC, 2014)

Note : Labour costs are escalated at real wage growth estimated by CCC while capital costs remain at 2017 price level

5.3 Calculation of Costs and Benefits

5.3.1 Costs

Cost of Electricity Generation

For this study, CGPL Mundra was considered as a representative plant because of its efficient technology, marginal characteristics and availability of data in public domain. For estimating the cost of electricity generation, several assumptions were based on data from CGPL

Mundra. We have however made several important changes. First, the capital cost has been adjusted to account for under-recovery by CGPL i.e. we assume full fixed cost recovery. Second, we have estimated variable cost based on revised coal price formula, thereby using the full cost recovery approach rather than using significantly lower prices based on old coal price mechanism. Coal price for electricity generation is calculated based on projected Indonesian Melawan coal price (GCV 5400 Kcal/Kg) using World Bank commodity price forecast (World Bank, 2017).

Table 11 Cost of Electricity Generation and supply

Variable	Data for 2019	Source
Projected effective Indonesian Coal Price	INR 3987.7/t	Based on (World Bank, 2017) and (CERC, 2013)
Effective Heat Rate	2050 Kcal/kWh	(CERC, 2013) (CERC, 2016)
Heat Value of Coal	5400 Kcal/Kg	(CERC, 2013)
Auxiliary Electricity Consumption	7.75%	(CERC, 2016)
Variable cost of electricity production	INR 1.64/kWh	Estimates based on (CERC, 2013)
Fixed cost of electricity production	INR 1.58/kWh	Estimates based on(CERC, 2013)
System Load Factor	0.8	(CEA, 2017)
CTU Transmission Losses	2%	Assumed to be close to technical standards
STU Transmission Losses	3.15%	(RERC, 2017)
Discom AT&C Losses	18%	(RERC, 2017)
PGCIL transmission system cost	INR 0.72/kWh	(CERC, 2017)
RVPN transmission system cost	INR 0.29/kWh	(RERC, 2017)
Discom O&M expense per unit	INR 0.65/unit	(RERC, 2017) (JdVVNL, 2017)

Note : Transmission costs and labour costs are escalated at real wage growth in income estimated by CCC while fixed costs remain at 2017 price level

Estimation of additional transmission and distribution assets

The incremental power demand for serving the additional households connected to the grid is estimated to be approximately 159 GWh in 2019. The infrastructure required for electrification have been estimated on the basis of the projected additional electricity demand and current average network elements of the discom. Due to the low population density of the region, additional lines (33KV, 11KV and LT lines) required for grid connectivity have been estimated by using a multiplier of 2.5 times of the average network density of the Discom as existing in 2017. This multiplier is an assumption based on our judgement and discussion with local experts. Additional costs borne for installation of meters at each electrified household have also been included.

Transmission system costs for central, state grids and discom have been escalated by real growth rate projection provided by CCC and transmission losses in central and state grid have been assumed to be straight line as they were close to technical standards (RERC, 2017). Discom AT&C losses have been assumed based on projections provided in RERC order for ARR and Tariff Calculation (RERC, 2017).

Operating and Maintainence Costs

Operating and maintainence (O&M) costs were also incurred, which has been estimated based on the current per customer O&M costs incurred by the DISCOM and the estimated number of customers that need to be serviced during project life (JdVVNL, 2017). Employee costs are escalated based on real wage growth in income while costs of materials have been fixed at 2017 price level.

Cost of additional carbon emissions

Carbon emissions generated from incremental power generation in thermal power plants were estimated based on the Weighted Average Specific Emissions for Fossil Fuel Fired Stations for India provided by CEA (Central Electricity Authority, 2014). Social cost of carbon has been derived from (Tol, 2018).

5.3.2 Benefits

Revenue Estimate

Grid tariff in the form of monthly fixed and per unit energy charges was based on JdVVNL's tariff for 2016-17 escalated by the projected real wage growth annually to account for real price increase (JdVVNL, 2017). With electrification, various welfare benefits will be accrued by private citizens in the form of better outcomes of lighting, health, education and productivity. Additionally, private enterprises would increase and improve in performance with reliable supply of electricity. These benefits have been reflected in the tariffs increase at real wage growth used as proxy for willingness to pay for these services.

Depreciation of Assets and Salvage Value

Salvage value of assets at the end of life has been included. A salvage value of 10% is assumed at the end of life of assets. A depreciation rate of 5.28% is used based on RERC guidelines though the actual life of assets may be more than as defined by these norms (RERC, 2014). In reality, this may be an under-estimation of benefits due to the longer life of assets. However, for consistency, RERC norm have been applied.

5.4 Assessment of Quality of Evidence

The quality of evidence for grid electrification is 'strong'. The data utilized has been published in the public domain by regulatory authorities, Discom and similar entities from comparable geography. Estimation of environmental costs is based on established methodologies.

5.5 Sensitivity Analysis

Several variables were tested for sensitivity under this intervention such as capital cost over-runs, increase in fuel price as compared to forecast, increase in the social cost of carbon incurred, increase in operating and maintenance costs and under-recovery of revenues. The table below presents results of sensitivities where change in the variable results in a significant impact on the BCR. These include variables with relatively higher uncertainty regarding the base case value.

Table 12 Sensitivity Analysis for Grid Electrification

Change in Variable	Resulting BCR at 5% Discount Rate
Increase in estimated O&M costs by 25%	0.94
Under recovery of revenues by 10%	0.91
Under recovery of revenues by 25%	0.76
Base Case BCR	**1.01**

The BCR for this intervention remained close to viability under numerous scenarios. BCR for grid electrification is significantly impacted by under-recovery of revenues by 10% and 25%. Increase in O&M costs also affects the BCR although the impact is much lower. Since these interventions are planned in rural areas with relatively low household incomes, under-recovery of revenues is quite likely as the willingness to pay may be relatively lower compared to Discom tariff and benefits may take time to be fully realized.

To some extent, the BCR may be under stating benefits accrued by the government as taxes applied on several cost categories, the break-up of which are not available. However, we believe these would be minor and hence have not been explicitly accounted for in this analysis.

6. Solar Micro Grid

6.1 Description of intervention

This intervention envisages providing electricity to all un-electrified households by installing solar micro grids distributed across villages as per local capacity requirements. These micro grids may be serviced by the Discom through franchisee models; alternatively, these may be contracted out to community enterprises or even private players to set-up, operate and maintain. The solar micro grid design includes full battery back-up which we assume would need replacement after every 5 years. It also includes additional battery within its design to address all intermittency issues. It is assumed that the solar micro grid operator will charge households at the same level as the per unit grid tariff per month based on consumption, since the model is designed to provide electricity supply comparable to grid connectivity.

6.2 Data

The following data sources have been utilized in estimating the costs and benefits of this intervention.

Table 13 Data Sources for Solar Micro Grid

Variable	Data	Source
Average capital cost for solar microgrid including PV modules (26%), Inverter/converter (13%), Balance of System costs (13%), Batteries (26%), Soft costs (13%)	USD 3500 per KW	(Microgrid Investment Accelerator, 2017)
Labour component	12% of Balance of System Costs	Assumption
System Load Factor	0.7	Assumption
Plant Load Factor	20%	Assumption
Safety margin	1.3	Assumption
O&M labour component	INR 7500 per 200 households per month	(Tongia, 2018)
O&M repairs and maintenance component	1% of capital costs incurred	(Tongia, 2018)
Revenue Generation	Based on Grid Tariff approved by regulator	(JdVVNL, 2017)
Depreciation rate for PV assets	5.83%	(RERC, 2017)
Life of battery	5 years	(Tongia, 2018)

Note : Labour costs are escalated at real wage growth in income estimated by CCC while capital costs remain at 2017 price level

6.3 Calculation of Costs and Benefits

6.3.1 Costs

Capital costs incurred

The incremental capacity addition for serving the unelectrified households in year 1 is estimated to be 169 MW distributed across micro grids. Additional capacity is added each year to address increase in demand and growth in number of households. The solar microgrid capacity required to address this demand has been estimated by assuming a system load factor of 0.7, PLF of 20% and a safety margin of 1.3. The cost estimate of USD 3500 per KW of capacity generation in micro grid includes all major cost components of PV modules (26%), Inverter/converter (13%), Balance of System costs (13%), Batteries (26%) and soft costs (13%)

(Microgrid Investment Accelerator, 2017). Installation labour component has been assumed at 12% of Balance of System Costs and escalated each year by estimated real growth rate.

Cost of Batteries

Life of batteries for solar micro grid has been assumed at 5 years. (Tongia, 2018) Battery back-up installed in year 1 is replaced in year 6 and so on till the end of the project. Battery cost is estimated at 26% of total capital cost component of solar micro grid without escalation or reduction. (Microgrid Investment Accelerator, 2017) An additional battery back up of 10% of total estimated capacity has been added to the microgrid model to address intermittency in electricity generation from solar power. These additional batteries are also replaced every 5 years.

O&M costs

O&M costs (labour component) for maintaining the solar micro grid would also be incurred and are estimated on the basis of salaries paid to one employee servicing 200 households every month. Capital costs incurred for repair and maintenance has been calculated at 1% of capital costs incurred. Labour component were escalated based on real wage growth in income while costs of materials have been fixed at 2017 price level.

6.3.2 Benefits

Revenue Generation from Electricity Provision

With the additional battery back up for the solar micro grid model, the electricity provision will be comparable to grid connectivity. Hence, grid tariff in the form of monthly fixed and per unit energy charges was based on regulator approved tariff for 2016-17. It is escalated by the projected real growth rate annually.

Due to the additional capacity planned in this model, similar welfare benefits would accrue to private citizens as accrued in the grid electrification intervention. These benefits have been reflected in the assumption that the tariffs increased at real growth rate match the willingness to pay for these services. Some additional minor benefits may also be generated in the form of employment and enterprise to maintain the solar micro grid.

Depreciation of Assets and Salvage Value

Salvage value of assets at the end of project life has been included. The depreciation rate for solar PV modules is 5.83% and 20% for batteries.

6.4 Assessment of Quality of Evidence

The quality of evidence for this intervention is adjudged 'medium'. The experience of solar micro grids has been varied and this study uses average estimates from other studies, which may not capture all aspects of this geographical area. Besides, the Solar PV industry is currently undergoing a revolution which could lead to dramatic decreases in costs. This uncertainty has been captured in the sensitivity section for this intervention.

6.5 Sensitivity Analysis

Several variables were tested for sensitivity under this intervention such as capital cost over-runs, increase in fuel price as compared to forecast, increase in the social cost of carbon incurred, increase in operating and maintenance costs and under-recovery of revenues. Three variables have been presented in the following table based on the impact on the BCR as well as future uncertainty compared to current scenario.

Table 14 Sensitivity Analysis for Solar Micro Grids

Change in Variable	Resulting BCR at 5% Discount Rate
Capital Costs Over – Run by 10%	0.65
Capital Costs Over – Run by 25%	0.57
Decrease in the capital cost for Solar Power by 10%	0.78
Decrease in the capital cost for Solar Power by 25%	0.91
Under recovery of revenues by 10%	0.69
Under recovery of revenues by 25%	0.66
Base Case BCR	**0.72**

Capital cost over-runs are common in large scale infrastructure projects and lack of funds can lead to delays in completion among other challenges. Since these interventions are planned in rural areas with relatively low household incomes, under-recovery of revenues is quite likely as the willingness to pay may be relatively lower compared to Discom tariff and benefits may take time to be fully realized. The recent improvement in technology and decrease in cost of power generation from solar PV projects provides us with a likely scenario where the actual capital costs of installing solar micro grids may dramatically reduce, pushing this project towards viability.

As is seen from the table above, the BCR for Solar Micro Grids is negatively affected by cost over-runs and under recovery of revenues. However, decrease in the overall capital costs for setting up solar micro grids can significantly impact the BCR moving it closer to one and making the intervention comparatively more viable.

To some extent, the BCR may be under stating benefits accrued by the government as taxes applied on several cost categories, the break-up of which are not available. However, we believe these would be minor and hence have not been explicitly accounted for in this analysis.

7. Diesel Micro Grid

7.1 Description of intervention

This intervention envisages developing diesel generator based micro grids distributed across villages as per local capacity requirement to provide 24 hours per day electricity supply to all un-electrified households. Similar to solar microgrids, this intervention may also be implemented by different players or by the Discom. The design of the model includes diesel gensets and distribution network connecting households to micro grids. It is assumed that the diesel micro grid operator will charge households at the same level as the grid tariff per unit per month based on consumption, since the model is designed to provide electricity supply comparable to grid connectivity.

7.2 Data

The following data sources have been utilized in estimating the costs and benefits of this intervention.

Table 15 Data Sources for Diesel Micro Grid

Variables	Data	Sources
Capital cost of diesel genset	INR 1 Crore/MW	(Shakti Foundation and ICF, 2013)
PLF of diesel genset	75%	Assumption
System Load Factor	0.7	Assumption
Safety margin	1.3	Assumption
Depreciation rate of Diesel Gensets	5.28%	(RERC, 2014)
Cost of network connection	INR 5000 per household	At par with Balance of System Costs for Solar Micro Grid
Labour component	Additional 12% of cost of network connection	Assumption
Crude oil price forecast for 2019	USD 56/bbl	(World Bank, 2017)
Insurance and Frieght cost 2019	USD 27/bbl	(HPCL, 2018)
O&M cost labour component	INR 7500 per 200 households per month	(Tongia, 2018)
O&M costs capital component	1% of total capital costs	(Tongia, 2018)
Weighted Average Specific Emissions for Fossil Fuel Fired Stations	0.62 tCO2/MWh	(Central Electricity Authority, 2014)
Social Cost of Carbon at 5% discount rate	USD 7.6 /tCO_2	(Tol, 2018)

Note about table : Labour costs are escalated at real wage growth in income estimated by CCC while capital costs remain at 2017 price level

7.3 Calculation of Costs and Benefits

7.3.1 Costs

Cost of Diesel

The price per litre of diesel has been calculated on the basis of World Bank Commodities Price Forecast for Crude Oil published in October 2017 (World Bank, 2017) and an estimated insurance and freight cost based on the price build up calculation for diesel (HPCL, 2018). While Central Excise Duty and Value Added Tax (VAT) would be charged on the retail price of diesel as per the existing rates, these would be accrued by the central and state government respectively. Hence, for this intervention, central and state taxes on fuel have been excluded in accounting for costs. An assumption of 75% load operation for the diesel gensets has been used to estimate the annual diesel consumption.

Capital cost of Diesel Gensets

Capital costs incurred for diesel micro grid are based on Shakti Foundation estimates for diesel genset costs to be INR 1 crore/MW (Shakti Foundation and ICF, 2013). The capacity to be added each year is determined based on the projected electricity demand, a PLF of 75% for diesel gen set, system load factor of 0.7 and safety margin of 1.3.

Network Connection Costs

Each household needs to be connected to the diesel genset micro grid and a cost of INR 5000 was assumed to be incurred per household. An additional labour component of 12% of network connection cost is assumed to be incurred. Labour costs are escalated at real wage growth in income estimated by CCC and capital costs are at 2017 price level.

O&M Costs

O&M costs for maintaining the diesel micro grid would are estimated on the basis of monthly market wage rate as per (Tongia, 2018). Capital component of O&M has been calculated at 1% of capital costs incurred. Labour component was escalated based on real wage growth in income while costs of capital component are at 2017 price level.

Social Cost of Carbon generated

Carbon emissions generated from diesel combustion in gensets are estimated based on the the Weighted Average Specific Emissions for Fossil Fuel Fired Stations for India provided by CEA of 0.62 tCO_2/MWh of electricity produced (Central Electricity Authority, 2014). Social cost of Carbon has been derived from (Tol, 2018).

7.3.2 Benefits

Revenue Generation from Electricity Provision

With the current design of the diesel micro grid model, the electricity provision will be comparable to grid connectivity. Hence, grid tariff in the form of monthly fixed and per unit energy charges is based on regulator approved tariff for 2016-17 is charged to households for revenue collection. It is escalated by the projected real growth rate annually.

Due to the additional capacity planned in this model, similar welfare benefits would accrue to private citizens as accrued in the grid electrification intervention. These benefits have been reflected in the assumption that the tariffs increased at real growth rate match the willingness to pay for these services. Some additional minor benefits are also generated in the form of employment and enterprise to maintain the solar micro grid.

Depreciation of Assets and Salvage Value

Salvage value of assets at the end of project life has been included. A depreciation rate of 5.28% has been used to calculate annual depreciation and salvage value at the end of the project (RERC, 2014).

7.4 Assessment of Quality of Evidence

The quality of evidence for this intervention is adjudged as 'strong'. There is ample historical experience using diesel gensets for power generation across India as well as other parts of the world.

7.5 Sensitivity Analysis

Several variables were tested for sensitivity under this intervention such as capital cost over-runs, increase in fuel price as compared to forecast, increase in the social cost of carbon incurred, increase in operating and maintenance costs and under-recovery of revenues. Three variables have been presented in the following table based on the impact on the BCR as well as future uncertainty compared to current scenario.

Table 16 Sensitivity Analysis for Diesel Micro Grids

Change in Variable	Resulting BCR at 5% Discount Rate
Increase in Crude Oil price from forecast by 10%	0.97
Increase in Crude Oil price from forecast by 25%	0.91
Increase in Social Cost of Carbon by 50%	0.97
Under recovery of revenues by 10%	0.93
Under recovery of revenues by 25%	0.78
Base Case BCR	**1.02**

The single variable that affects the BCR most was under-recovery of revenues. Other variables with significant impact was an increase in the crude oil price and an increase in the social cost of carbon by 50%. Since these interventions are planned in rural areas with relatively low household incomes, under-recovery of revenues is quite likely as the willingness to pay may be relatively lower compared to Discom tariff and benefits may take time to be fully realized. Additionally, there could be variability in the willingness to pay (WTP) for electricity from diesel micro grids due to preconceived notions of service quality and underlying correlation to the price of diesel in the market. The price of diesel itself directly impacts the BCR for the intervention since volatility in commodity prices are possible and the same may negatively impact the BCR. The taxes accrued on diesel have been excluded from its price estimation under cost of diesel for this intervention as they are a benefit for the government. Any other taxes have not been explicitly accounted for in this analysis. To some extent, the BCR may be understating benefits accrued by the government as other taxes applied on several cost categories. However, we believe these would be minor.

8. Conclusion

A vast majority of the population without access to electricity in India reside in rural areas. Several dedicated programmes funded by the Government of India have been initiated in the past to address the challenge of rural electrification such as, the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) initiated in 2005, the Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY) initiated in 2015 and the most recent Saubhagya Scheme launched in 2017. From all aspects, fossil fuel powered grid extension has been the focus of government measures to provide electricity access. The emerging context of rise in global GHG emissions (especially from electricity production) and India's ambitious target of adding 175 GW of renewable energy to the country's energy mix; demand assessing the role of renewable based distributed generation is important.

This study has examined three intervention options for rural electrification in Bikaner using the cost benefit analysis approach – grid electrification, solar micro grids and diesel micro grids. The analysis finds that at 5% discount rate, based on the available evidence, grid connectivity and diesel micro grids have comparable positive BCR making them viable and solar micro grids has the lowest BCR making it unviable.

Table 17 Summary BCR Table

Interventions	Discount	Benefit	Cost	BCR	Quality of Evidence
Grid Electrification	3%	₹ 3,121	₹ 3,452	0.90	Strong
	5%	₹ 2,736	₹ 2,717	1.01	
	8%	₹ 2,267	₹ 2,142	1.06	
Solar Micro Grids	3%	₹ 9,654	₹ 12,469	0.77	Medium
	5%	₹ 8,126	₹ 11,350	0.72	
	8%	₹ 6,334	₹ 9,958	0.64	
Diesel Micro Grids	3%	₹ 3,179	₹ 3,661	0.87	Strong
	5%	₹ 2,784	₹ 2,722	1.02	
	8%	₹ 2,303	₹ 2,077	1.11	

It is interesting to note from the results of the sensitivity analysis that while several variables such as cost over-runs, increases in O&M costs and fuel prices affect the fossil fuel based interventions marginally; solar micro grids see the most impact due to decrease in capital costs for solar power. Given favourable geographical conditions, the recent advances in renewable technology and uncertainty in future fossil fuel utilization; solar micro grids could provide a viable alternative to established fossil fuel based pathways to electricity provision in the future. Until such advances in technology are realized, grid electrification will remain the most viable alternative for rural household electrification.

Overall, for all three interventions the critical success factor was revenue collected for service provision. This implies that unless willingness to pay for electricity matches or exceeds the current regulator approved tariff, rural electrification projects will face challenges, particularly in the absence of viability gap funding. While we assume that benefits accrued to private citizens will result in willingness to pay, studies have established that rural electrification interventions must focus on least cost supply including limiting and reducing system losses. Rural electrification needs to achieve a fine balance between financial sustainability and increasing access to poor population so that maximum societal benefits are realized.

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