The Solar Fiasco: An Analysis of the Techno Economic Viability of Rooftop Solar PV Systems for Powering India's Economy

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Abstract

India as part of its renewable energy target, aims to install 40 GW of rooftop solar power by 2022. This has led to massive investment in the solar sector. This paper analyses the technical and economic feasibility of rooftop solar panels in Delhi. The paper also looks at payback period from a different angle by including O&M and financing expenses into the calculation. It concludes that a 1 kW rooftop solar system is viable only for higher consumption of domestic electricity. It is also seen that literature in general underestimates the cost of solar systems by looking only at up-front cost. The cost can be upto 4 times the original capital expense after including the financing and O&M expenses.

1 Introduction

Energy is one of the key drivers for a country's economic development. The per capita consumption of electricity in India has risen by 60% in just a matter of 9 years from 631.4 kWh in 2005-06 to 1,010 kWh in 2014-15 (GoI, MoP and CEA, 2015; Bhaskar, 2015). Even with this drastic increase, the per capita consumption remains low compared to developed countries such as USA (12,988 kWh), Japan (7,836 kWh), France (7,374 kWh) and UK (5,407 kWh) (World Bank Database, 2014). Even though the peak demand of 148 GW is significantly lower than the generating capacity of 302 GW (GoI, MoP, CEA, 2015; GOI, MoP and CEA, 2016), the country still faces a peak power deficit of 9% (FICCI, 2013). About 78 million rural households in India reportedly still lack access to grid electricity. These reasons along with the continual depletion of fossil fuel resources, makes it pertinent to look at non-conventional electricity generation options.

There is growing pressure on developing countries like India whose energy production and consumption are rising, from the international community, to reduce the carbon footprint of their economy. Conventional energy production systems such as thermal, nuclear and large hydro power plants have high carbon footprints. Hence, there is a renewed interest in renewable energy based energy production systems such as solar wind and tidal energy based systems.

India being a large recipient of solar energy in terms of annual solar irradiance, the governments in the recent past have given enormous impetus to solar power based energy production systems in the country through several policy measures, most importantly heavy capital subsidies for solar power equipment. Though the targets set for solar power generation are huge (100 out of the 175 gigawatt of power from renewable energy), there is too little empirical analysis of the economics of solar power generation and use.

The economics of using solar power based energy production systems is not amenable to any simple formulation of costs and benefits, but instead depend on several factors, including the cost of (alternative) conventional energy production systems that are possible in the situation under consideration; the indirect costs associated with the use of alternative conventional energy sources or the indirect benefit of solar power in that situation; the value of land, which is likely to be used up for setting up the solar panels; the battery requirement, the possibility of using the system as a captive power generation system, and the cost of grid congestion. Hence, it is obvious that the economics of solar power generation is situation specific and need to be thoroughly evaluated.

This paper looks into the feasibility of rooftop solar systems for residential purposes, which is one of the options being advocated by the government in India. The paper first looks at the energy scenario in India, followed by the potential for renewables and finally looks into the technical and economic viability of rooftop solar systems.

2 Methodology

This paper utilises secondary sources such as existing literature and government databases for data collection. Major technical assumptions have been based on literature and vetted through interactions with industry personnel. There are numerous factors that affect cost, energy production and payback period for a rooftop solar system. To reduce the variables and facilitate comparisons across a number of scenarios, the paper looks at the installation of a 1kW system in Delhi. A specific city is chosen for the ease of analysis across different categories of domestic electricity consumption.

There are two formulae that are important to this analysis. First is the one for the number of units of electricity generated annually by the rooftop system. This has been defined as:

$$Annual\ Electricity\ Production = DNI * PR * Panel\ Surface\ Area * (1 - Technical\ Loss\ (in\ \%)) * Panel\ Efficiency$$

Where,

DNI	–	Direct Normal Irradiance (in $kWh/m^2/year$)
PR	–	Performance Ratio of system
Technical Loss	–	Losses in system due to net-metering
Panel Efficiency	–	Efficiency of panel to convert solar energy to electricity

The Assumption used for estimating each variable has been mentioned in Table . Finally the financial analysis (specifically payback period) is carried out with the help of annual cash flows. The cash flow each year is defined as

$$CF_i = B_i - O_i - C_i$$

Where,

CF_i	–	Cash Flow in i^{th} year
B_i	–	Benefits in i^{th} year (cost of electricity generated by system)
O_i	–	Operation and maintenance cost (including replacement cost) in i^{th} year
C_i	–	Capital investment in i^{th} year (only applicable for i=1)
i	–	Year

The cumulative cash flow estimated at the end of each year provides an estimate for the return on investment for the solar rooftop system.

The assumptions for all the variables have been mentioned in Table 5. The Levelized Cost of Electricity (LCOE) is used to compare cost of electricity from different sources. For estimating LCOE, first the initial capital investment has been levelized over the lifetime of the system. The operation & maintenance cost and replacement costs are computed for each year. These provide the total cost for each year the system functions. This total cost is divided by the electricity produced over the lifetime to arrive at LCOE.

3 Overview of Energy Sector in India

India's Energy Mix

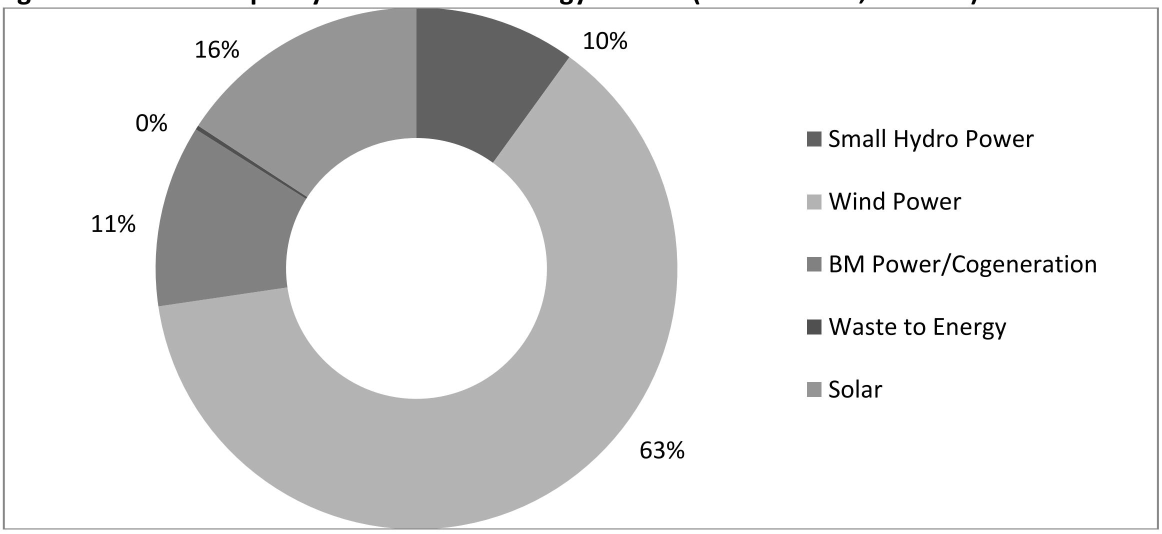
India's electricity demand has increased from 376 TWh in 2000 to 897 TWh in 2013 (IEA, 2015). As of March 2016 the installed power generation capacity in India is 302 GW (GOI, MoP and CEA, 2016). Bulk of the power generation (70%) is still from thermal power plants (coal, diesel and gas). The remaining is divided among nuclear (2%), hydro (14%) and Other Renewables (14%). Table 1 and Figure 1 shows the detailed break up of installed power generation capacity in India.

Table 1: Installed Capacity in India (in MW)

	Thermal				Nuclear	Hydro	RES	Total
	Coal	Gas	Diesel	Total				
State	64,321	6,975	439	**71,734**	0	28,092	1,964	**101,790**
Private	69,462	9,978	555	**79,995**	0	3,120	40,886	**124,001**
Central	51,390	7,555	0	**58,945**	5,780	11,571	0	**76,297**
Total	**185,173**	**24,509**	**994**	**210,675**	**5,780**	**42,783**	**42,849**	**302,088**

(Source: IRAP Analysis based on GOI, MoP and CEA, 2016)

Figure 1: Installed Capacity of Renewable Energy in India (% of Total 42,849 MW)

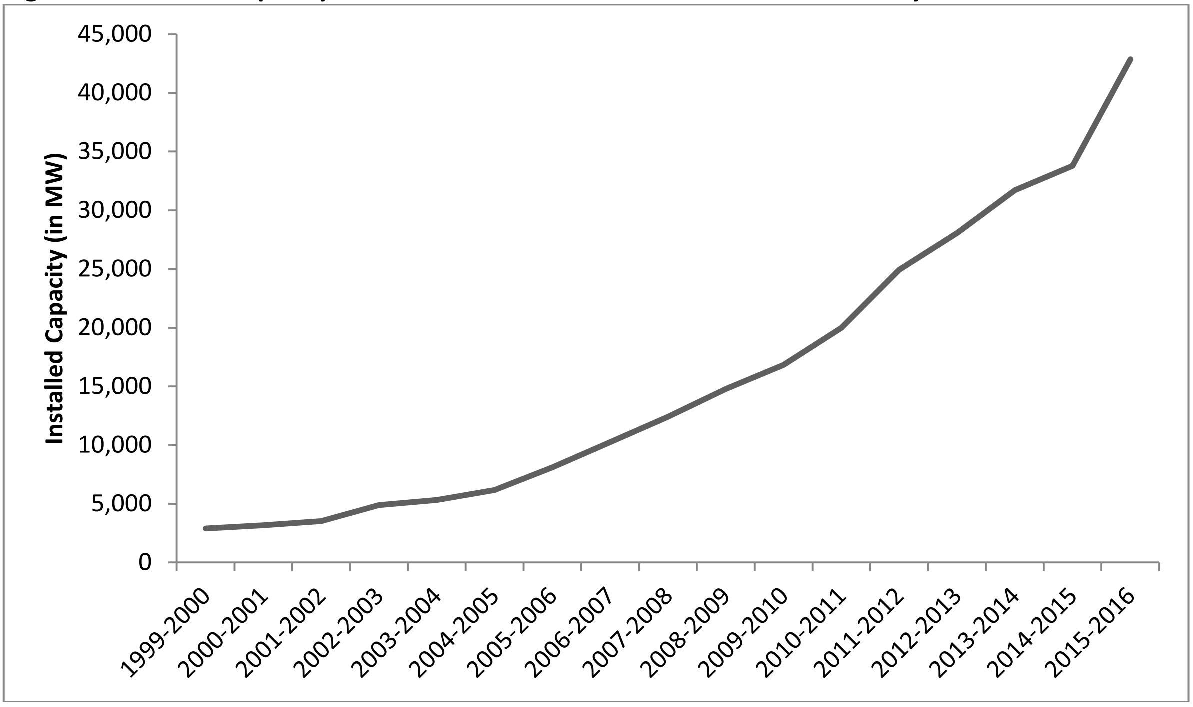


(Source: IRAP Analysis based on GOI, MoP and CEA, 2016)

Potential of Different Sources of Renewable Energy

Even though the Department of Non-conventional Energy Sources (DNES) was established within the Ministry of Energy in 1982, there was no considerable increase in the contribution of renewable energy to India's energy mix till the early 2000's. Currently India has about 43 GW of installed renewable energy capacity (Figure 1) that has grown from 2,906 MW at a CAGR of 18% since 1999-2000. Wind energy has been the predominant contributor to this growth and accounts for 63% of the current installed capacity.

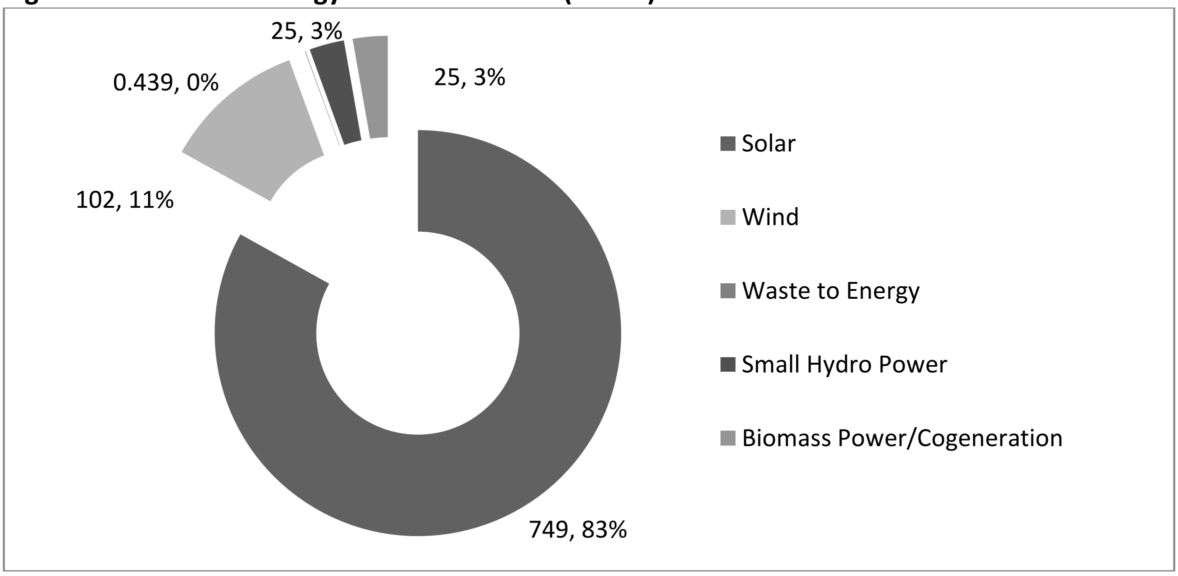
Figure 2: Installed Capacity of Renewable Sources from 1999 to Present Day



Source: MNRE, 2015

The potential for renewable energy production in India is about 901 GW, with solar accounting for 83% of the potential followed by wind (11%), Small hydro power (3%) and biomass/cogeneration (3%) (GWEC, 2012; MNRE, 2014; MNRE, 2014; The Planning Commission, 2014; MNRE, 2016) (see Figure 3). Recent estimates show that the wind potential could be as high as 302 GW (Niti Ayog, 2015), which would increase the renewable potential of the country to 1,101 GW. Though this potential is high on-paper, practically a number of factors such as demand-supply pattern, cost of production, storage, and grid connectivity among others have to be considered to account for the actual production capability.

Figure 3: Renewable Energy Potential in India (in GW)



Source: IRAP Analysis based on GWEC, 2012; MNRE, 2014; MNRE, 2014; The Planning Commission, 2014 and MNRE, 2016

4. Global Trends and India's Achievements in Solar Power

4.1 Global trends in solar power: production, demand, prices

Solar electricity generation in general can be divided into two technologies- Concentrated Solar Power (CSP) ad Photovoltaic (PV). Globally, the installed capacity for PV has increased from a negligible quantity in early 2000 to 177 GW in 2014 (IEA, 2014). The top five countries in cumulative PV installed capacity are Germany, China, Japan, Italy and USA (IEA, 2014). Even though PV technology is more commonly used, it is believed that the use of CSP will increase significantly in the future. Installed capacity for CSP in 2015 was 4.7 GW (CSP Today, 2015).

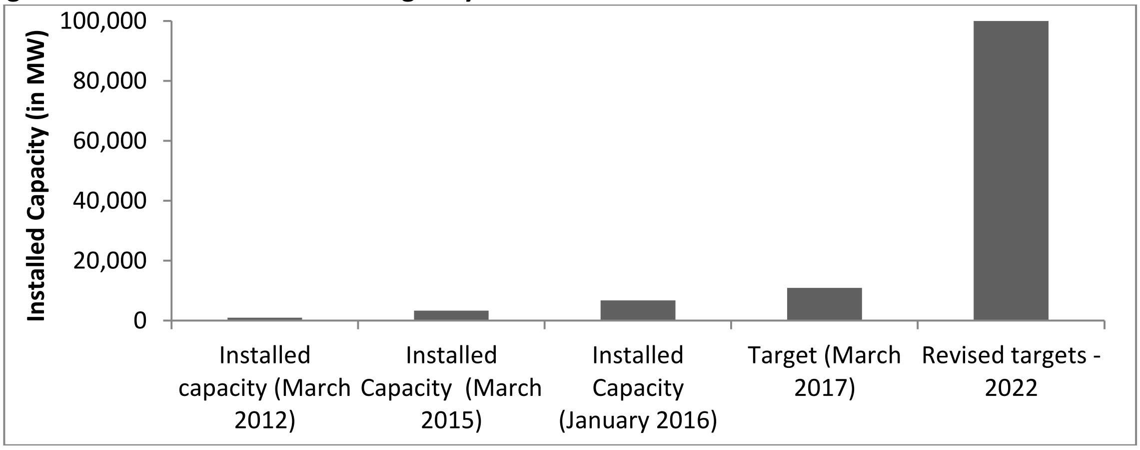
Globally there has been a steady decrease in the overall cost of solar power production. The price of solar photovoltaic modules have fallen by 97% from USD 30/W_{peak} in 1980 to less USD 1/ W_{peak} in 2013 (REN 21, 2014). The cost for installation for PV modules in the USA reduced by 75% in five years between 2008 and 2013 from USD 7/W_{peak} to USD 4/W_{peak} (McKinsey, 2014). While the cost for module production would continue to decrease with the discovery of new materials and cheaper production processes, the major opportunity lies in the downstream costs associated with installation and servicing (McKinsey, 2014). The reduction in costs would make solar economically compatible with traditional power generation technologies.

Research has pointed that in parts of the United States, commercial-scale installations have already attained cost parity, i.e. the generating cost of power from solar PV is comparable to the retail electricity prices that commercial users pay (Reichelstein & Yorston, 2013). This depends on both the current federal tax subsidies for solar power and an ideal geographic location for the solar installation.

4.2 Solar Power Targets and Achievements

According to the Paris Climate Accord, India has targeted renewables to reach 40% of the installed capacity by 2030 (Jai & Sethi, 2015). To be on track for this ambitious target, government of India wants to achieve renewable power generation capacity (excluding large hydropower) of 175 GW by 2022 (MNRE, 2015). Of this, 100 GW is to be met from solar power generation (EY, 2015). The government, as per the 12th five year plan, targets to install 10,941 MW of solar capacity by 2017 (TERI, 2015). This would require another 89,059 MW of capacity to be installed between 2017 and 2022 to meet the ambitious target set by the government.

Figure 4: Grid Connected Solar Target by 2022

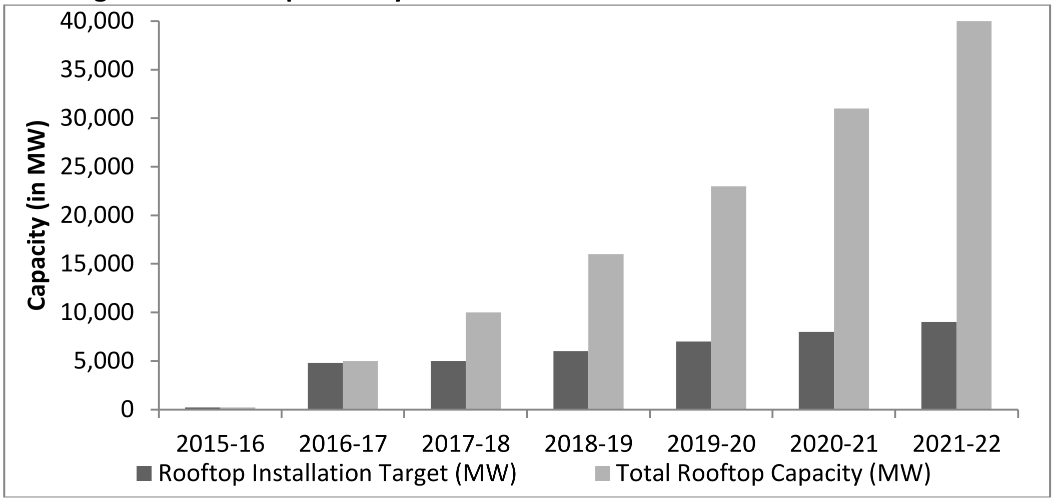


Source- Author's own analysis based on TERI, 2015

5. Solar Rooftop Systems

The Government of India, under the revised target of 100GW grid connected solar power by 2022, will have to install 40GW of roof-top solar panels. Under the proposal, an incremental capacity addition from 4,800 MW in 2016-17 to 9,000 MW in 2021-22 is envisaged for the roof-top category (Refer to Figure 5). 50% of this target has been proposed to be set up in 6 states - Maharashtra (4,700 MW), Uttar Pradesh (4,300 MW), Tamil Nadu (3,500 MW), Gujarat (3,200 MW), Karnataka (2,300 MW) and Andhra Pradesh (2,000 MW) (MNRE, 2015). The government provides a capital subsidy between 30% and 70%. Most of the states have a subsidy of up to 30%. Special states such as North Eastern States, Uttarakhand, Himachal Pradesh, Jammu & Kashmir, Lakshadweep and Andaman & Nicobar Islands have higher rebate, of up to 70% of the capital cost.

Figure 5: Targets for Roof-top Solar by 2022



Source: PIB, 2015

Economic and Technical Viability

The analysis has been done considering Delhi as the location for installation of a 1 kW rooftop system. Thus, the values of Direct Normal Irradiance (DNI) and tariff for grid electricity used have been taken for the case of Delhi. This has been done for ease of analysis as factors like DNI and electricity tariffs would vary from city to city.

The indicative area requirement for installation of a roof-top solar plant is approximately 100-130 square feet per kW (TEDA, 2014). The upfront cost for setting up a 1 kW rooftop plant without storage is approximately INR 92,000 (TERI, 2015; Engelmeier, Rustagi, Khurana, Goel, Chaudri, & Jain, 2014). 43% of the initial cost is that of the PV panel, while the remaining are that of mounting structures, cables, installation costs, etc. (Refer to Table 2).

Battery backup has not been considered as that can alter the economics significantly depending on the extent of battery backup (which is subjective) required. The batteries not only add to the initial cost, cost of recurring maintenance and replacement, but also result in energy loss (during charging and drawing from the battery, thereby adding to the cost per unit of power produced.

Table 2: Upfront Cost for 1 kW Solar Rooftop Plant

Breakup of Cost	Cost (in INR)
Cost of panels	40,000
Cost of mounting structures	12,000
Cost of inverter	10,000
Miscellaneous parts – cables, combiner box	10,000
Installation cost and integrator margin	15,000
Cost of net metering	5,000
Total	**92,000**

Source: Engelmeier, Rustagi, Khurana, Goel, Chaudri, & Jain, 2014 and TERI, 2015

To understand the complete picture, it is important to consider the cost of the system over its entire lifetime of 25 years. Literature points towards an O&M cost between 1 and 1.5% of initial capital expenditure (Engelmeier, Rustagi, Khurana, Goel, Chaudri, & Jain, 2014; TERI, 2014). For analysis in this paper, we have assumed the lower value of 1% with an annual escalation of 5.72% (TERI, 2014). At this rate, the lifetime O&M cost of the system would amount to INR 48,529. Further, the lifetime of an inverter is generally 10 years, which would amount to two changes over a 25 year period. Thus, considering these two components makes the total lifetime cost of a 1 kW solar system INR 160,529 without financing (Refer to Table 3).

Table 3: Lifetime Cost of 1 kW Solar Rooftop Plant without Financing

Component	Cost (in INR)
Capital Cost	92,000
Operation and Maintenance cost	48,529
Replacement of Invertor	20,000
Total Lifetime cost	**160,529**

Source: Author's own analysis based on TERI, 2015

Further, it must be noted that in most cases consumers buy solar rooftop systems with financing and/or subsidies. To analyse the same, we have taken three scenarios-first with financing and zero subsidy, second with financing and 30% subsidy and finally financing with 70% subsidy. Additionally, the payback period within these three scenarios has been calculated for five different slabs of domestic electricity consumers (in New Delhi). The electricity tariff slabs, per unit cost and assumed electricity consumption per month have been mentioned in Table 4.

Table 4: Assumption for economic analysis

Slab[1]	Assumed Electricity consumption per month (in kWh)	Cost of Electricity[1] (INR per unit)
0-200	181	4
201-400	300	5.95
400-800	600	7.3
800-1200	1,000	8.1
>1201	1,400	8.75

Source: [1] Delhi Electricity Board

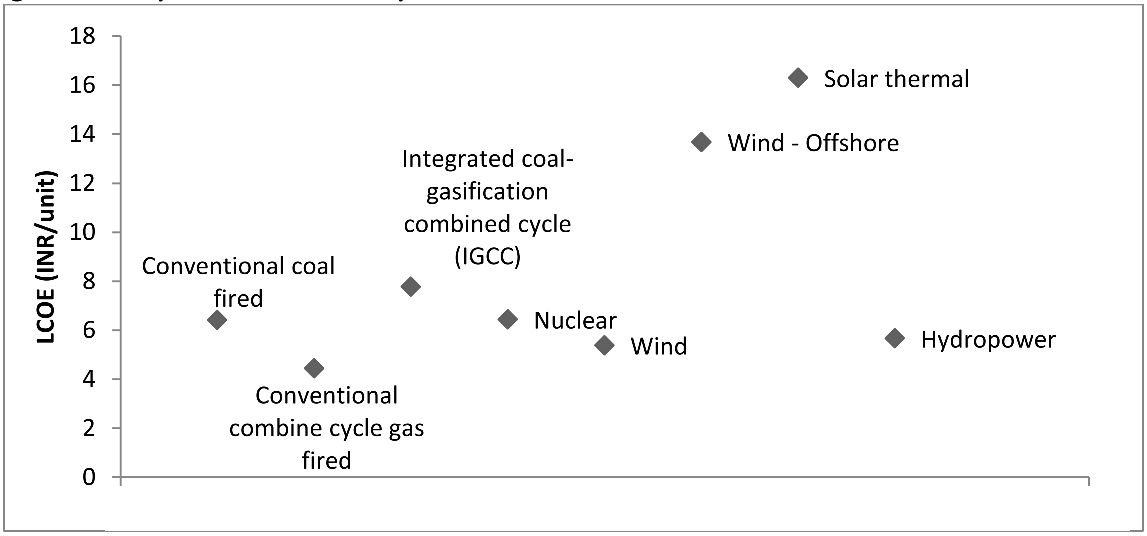
The first step is to calculate the Levelized Cost of Electricity (LCOE). LCOE is used to compare the cost of electricity from different sources. A number of assumptions have been used for this estimation. Initial panel efficiency has been taken at 13.5% with an annual depreciation of 0.75% and a lifetime of 25 years. Performance ratio for the panel is assumed to be 0.75. Direct Normal Irradiance is 1579 kWh/m^2/year in Delhi. The surface area for the panel is 10m^2. The invertor which converts the DC electricity produced to AC has a lifetime of 10 years. For the financial analysis a 10 year loan repayment schedule with 11.5% interest and 10% discount rate is used. These assumptions have been summarized in Table 5.

Table 5: Technical and financial assumptions used in analysis

Initial Panel Efficiency (%)	13.5
Cost of Electricity from Grid (INR/unit)	4, 5.95, 7.3, 8.1, 8.75
O&M (percentage of capital cost)	1%
Annual O&M Increase	5.72%
Panel Efficiency Depreciation	0.75%
Panel Lifetime	25 years
Invertor Lifetime	10 years
Performance Ratio	0.75
DNI (kWh/m^2/year) [value for Delhi used]	1579
Area of Panel	10 m^2
Technical loss due to net metering	0.02 %
Loan Repayment Tenure	10 years
Interest Rate for loan	11.50%
Discount rate	10%

The estimation of LCOE considered the sum of the annualized capital cost of the solar PV system and the cost incurred for operation, maintenance and replacement in each year of its life against the total amount of energy expected to be generated by the system. The LCOE for rooftop solar is estimated to be INR 8.98 per unit. This is almost double the LCOE for coal in Asia which is INR 4.74 per unit (Weithoener, 2016). Moreover a look at estimates for LCOE's for plants to be commissioned in 2019 show that rooftop solar energy is not competitive with traditional forms of energy (refer to Figure 6). The LCOE for rooftop solar is 1.4, 2, 1.4 and 1.6 times that for coal, gas, nuclear and hydropower respectively. For rooftop solar to be competitive with coal fired plants, the system cost for a 1 kW plant would have to reduce to 70% of its current value. While the prices of PV panels have been coming down over the years, those for the other components are yet to show drastic reduction in prices. Thus, rooftop solar might not be competitive with other sources in the near future. On the contrary, large scale solar could be made competitive to conventional sources through large scale of operations.

Figure 6: Comparison of LCOE for plants to be commissioned in 2019



Source: PwC, 2014

Since home owners in most cases acquire these systems with the help of financing, it is imperative to include this cost into the overall cost of the system. Considering a loan tenure of 10 years with an interest of 11.5%, the total money repaid amounts to INR 155,217. Thus, the total cost of a 1 kW solar plant with financing and no subsidy is estimated to be approximately INR 223,747. The government provides subsidies in the range of 30-70% to increase adoption among residential consumers. Even a high subsidy of 70%, would get the cost of a 1 kW system to INR 115,094. The financial results have been summarised in Table 6.

Table 6: Financial Analysis Results

	With No Subsidy	**With 30% Subsidy**	**With 70% subsidy**
Loaned amount	92,000	64,400	27,600
Sum to be Returned	155,217	108,652	46,565
O&M (including replacement)	68,529	68,529	68,529
Total Cost including financing	**223,747**	**177,181**	**115,094**

*All figures in INR

Finally, the payback period is an important indicator that determines the return on investment. It must be noted that most estimates usually define payback period as the initial investment divided by the average annual savings. This provides a figure which would in fact be lower than the actual payback period. We believe a more representative estimate for payback period should include the operation and maintenance costs along with replacement costs incurred in the lifetime of the system. Thus, in this analysis, the payback periods have been estimated for two scenarios-first in which the operation, maintenance and replacement costs are included in the total system cost and the second where these are not included. The aim is to see if there are significant changes in payback period for both the cases. The payback period is the number of years during which the cumulative cash flow for the system becomes positive. The expression for annual cash flow has been detailed out in the methodology section.

For estimating payback period, the total savings from the rooftop unit and the units of electricity generated over its lifetime are required. A panel efficiency depreciation of 0.75% per annum has also been accounted for. Thus, the efficiency of the panel would be 11.27% in the 25th

year of operation. Based on these assumptions it is estimated that the solar panel would generate 35,836 units of electricity over a period of 25 years. The monetary savings that this would correspond to depends on the cost of grid connected electricity paid by the consumer. Thus, the total benefit generated over 25 years would range from INR 143,343 (for 181kWh monthly consumption at INR 4/unit) to INR 313,563 (for 1,400 kWh monthly consumption at INR 8.75/unit). These benefits would reduce over the life of the system, owing to panel depreciation. For instance, a household consuming 300 units per month would get a benefit of INR 9,322 in year 1 and INR 7,781 in year 25. The estimated savings for each consumption slab is mentioned in Table 7.

Table 7: Lifetime Monetary Savings for Different Consumers

Consumption per month (kWh)	Slab (kWh)	Tariff per unit (INR)	Lifetime Saving (INR)
181*	0-200	4	**143,343**
300	201-400	5.95	**213,223**
600	401-800	7.3	**261,601**
1,000	800-1,200	8.1	**290,269**
1,400	<1,200	8.75	**313,563**

*This is the average household electricity consumption in Delhi.

With the help of the above estimates we arrive at payback periods for the different scenarios under consideration. For the lowest slab of electricity consumers, the payback period without any subsidy is much greater than the lifetime of the system. Our analysis shows that for the lowest two slabs the difference in payback period with and without the additional costs is significantly high. Even with 30% subsidy a household paying INR 4 per unit for electricity might not be incentivized to buy a rooftop solar system. On the contrary, households falling in the highest three consumption slabs might have significantly higher motivation for such systems, even in the absence of any subsidy. The payback period for these consumers ranges from 14.1 to 18 years. Subsidies would significantly reduce these values to 8.9 to 12.3 years (for 30% subsidy) and 2.8 to 3.7 years (for 70% subsidy).

Table 8: Payback Periods for the Different Scenarios (in years)

	Including Additional Cost			Excluding Additional Cost		
Tariff per unit	Subsidy			Subsidy		
	0%	30%	70%	0%	30%	70%
4	<40 years	<40 years	10.9	37.7	18.5	7.3
5.95	27.8	16.1	5.0	17.7	12.2	4.3
7.3	18.0	12.3	3.7	14.3	9.8	3.3
8.1	15.6	9.8	3.2	12.8	8.7	2.8
8.75	14.1	8.9	2.8	11.8	7.9	2.6

*Figures in years

6. Conclusions

It is apparent that solar rooftop system requires heavy investment from consumers even after subsidies. One of the major reasons why the payback period for solar energy systems is usually quoted to be low is the fact that the entire lifetime cost of the and the full cost of the system are not accounted into the cost estimate. The actual cost over the lifetime of the system is almost 2.4 times the up-front cost. A 30% and 70% subsidy places the final cost to 2.75 and 4.17 times the initial investment.

Currently the government provides a 30-70% subsidy for rooftop solar systems. But it will be more productive to provide subsidies based on net electricity consumption. Thus, lower electricity consuming households could be given higher incentives for such systems. The rationale for this is that a solar system would be able to meet a higher share of the demand of households with low electricity consumption. Further, it may also be worthwhile to provide higher subsidy to regions with higher potential. The potential should not only be defined by solar irradiance, but also include a factor for rooftop space availability. Rooftop space is one of the biggest barriers for the system capacity that can be installed. For instance regions endowed with high solar irradiance might not have enough rooftop space available for installation. Thus, rooftop space should be a factor deciding the subsidy on offer.

While the government is investing heavily on solar energy, and targets to reach 40 GW of rooftop solar energy by 2022, how much of the conventional electricity generation burden this would off-set is still debatable. India is still a developing country, and per-capita consumption of electricity is still much less than that of the developed countries. As this per capita consumption increases, it needs to be seen how much of it can be met through roof-top solar systems in particular. In the most likely case, it would probably meet a part of the overall demand for households. Among other factors, this can be attributed to the relatively high cost of small household systems, the erratic nature of power production from these systems and the gap in the demand of electricity and supply from these systems.

In the absence of any subsidy the payback period for a 1 kW rooftop solar plant could be as high as 39 years. The investment for such a system might be feasible for higher electricity consuming households. For a household consuming 1,400 units of electricity monthly, the payback period would range from 3 years to 9 years relying on a subsidy of 70% and 30% respectively. Even for these households a 1 kW system would only offset 8.53% of the electricity demand over the rooftop systems lifetime.

7. Limitations and Scope for Future Research

The current paper has a few limitations and can be expanded to incorporate these different themes.

Firstly, variation in demand for electricity from grid and production of electricity by solar rooftop within a day as well as over an entire year needs to be studied in detail. For instance, while the demand for electricity would be high during morning and evening hours, power generation from solar rooftop would be highest during the afternoon hours. Further, while electricity demand could in general be high during the monsoon period in humid conditions, the generation from solar systems would be low due to cloud cover.

Secondly, the geographic variation in solar irradiance needs to be accounted. The solar irradiance in Delhi would be different from that in Mumbai or Kolkata. Thus, to look at the entire residential sector it is imperative to do the analysis for each region individually.

Thirdly, a thorough study of available residential rooftop area to determine locations that are ideal for setting up solar rooftop systems is required to assess the true potential of the system in urban centres. Ideally this could be done through a GIS based study. It would also be interesting to investigate if there exist a correlation between household electricity consumption, household income and available rooftop space.

Currently the system to decide on subsidy is rather crude and states have a pre-defined level of subsidy. It would be interesting to analyse different approaches to deciding on how much to subsidise and for whom to subsidise. Rudimentarily this could be defined by factors such as average electricity consumption and actual area available for installation among others.

Finally, this paper assumes a constant month-on-month electricity consumption by households. In reality, the consumption would change each month depending on the demand. Thus, an in-depth case study of different households incorporating actual consumption needs to be conducted in order to assess the savings comprehensively.
Finally, the awareness and willingness of consumers to adopt this technology should be investigated further. Also, how it would change with increasing incomes and greater purchasing power over time needs to be probed. Additionally a relation between increasing incomes leading to greater electricity demand would be essential.

Sensitivity analyses for the different variables need to be undertaken. For instance how reduction in panel prices and increasing panel efficiencies would impact LCOE or how changing interest rates would affect payback period.

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