Solar Feasibility for Urban Households- Space Limitations for Solar Installation

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***Abstract*: With the trend of falling costs associated with solar energy production, solar adoption is currently picking momentum in India at the state and federal level. Solar power is being adopted by universities, factories and other large entities readily, but is not prevalent for small scale consumption or for land owners of smaller plots in urban areas. These landowners represent a large chunk of development and their adoption can bring solar energy to the masses, galvanizing forces of agglomeration of economics.**

Surface area for installation of solar power is essential for solar adoption at any meaningful scale, especially for residential use. Installation of a solar array below the requirement leads to supplementation by the electrical grid and dealing with two different power sources and thus unpopular. The paper calculates this requirement for the average household and a minimum energy demand threshold is identified, below which solar adoption will not make sense to the urban household. Further, the area required for solar installation to meet this demand threshold is calculated. The paper finds this area requirement to be out of reach for most households, which has been identified as an impediment to solar adoption by urban households.

Keywords* : *Renewable Energy, Sustainable Development, Urban Planning, Renewable Energy Policies, Housing Policy, Urban Planning.

I. INTRODUCTION

with the accumulating scientific evidence of climate change, governmental actions and policies are working to create a feasible environment for capital to flow from high-carbon to low-carbon intensive activities, foremost among which are concerns of energy generation through renewable resources.

Globally, staggering drops in the prices for renewable energy generation technology has overturned the market for energy production. This trend decline is set to continue for another two decades with costs of solar installations dropping by at least two-thirds among other renewable sources of energy (Bloomberg New Energy Finance, 2017).

US$25 trillion are expected to be invested in energy in the coming 15 years, which provides a unique opportunity to plan and invest in energy efficiency and sustainable energy generation. Not only will it boost economic growth, it alleviates pollution and greenhouse emissions and even provides improved energy access through the decentralized nature of renewable energy generation (The New Climate Economy , 2014).

UNEP further advocates aligning the financial system with sustainable development in order to mobilize not just governments but also the economic engines and business powerhouses across the globe for pushing sustainable development goals (United Nations Environment Programme, 2015). The report comments that the transition to 'a more inclusive and less resource intensive and low carbon economy' has increasing possibility of success in the current global situation of low interest rates and decreasing costs of sustainable technologies, including renewable energy production.

Domestically, solar power prices have dropped to a point where it can now compete actively with coal power and are predicted to fall to around 10% cheaper than coal power by 2020. It is thus being presented as a mainstream alternative to energy generation in a country with frequent power cuts and where nearly 300 million people live without electricity (Wu, 2016).

Solar power in India is on the rise. There are various initiatives by the government of India to popularize the adoption of large scale solar deployment across the country. The Indian Prime Minister has admittedly set an ambitious goal of bringing 100 gigawatts of solar power operational by 2022, among other measures to bring large scale solar adoption to India. There are large scale investments to improve energy infrastructure to accommodate large scale solar deployment, servicing both government and private producers of energy (Wu, 2016). Net Energy metering is adopted in various Indian states as well, to help domestic producers of solar power (Bijli Bachao, 2017).

Databases have been made available to the public for finding out feasibility of solar projects (Ministry of New And Renewable Energy, 2015). Various subsidies and incentive programs have been introduced for lowering the hurdles of adoption (World Bank, 2016). Further, state policies make it mandatory for larger plots to adopt solar power (Josel, 2015).

Despite all of these initiatives solar power adoption is mostly popular with larger entities while smaller homeowners, especially in the urban areas, tend to forego such investments due to hurdles such as upfront cost and a lack of awareness and precedents and availability of reliable conventional power sources (Lobello, 2013), (Mathiesin, 2016) and (Union of Concerned Scientists, 1999).

Urban demand for electricity is characteristically different from rural demand for the same. While rural households demand much lesser electricity in comparison to urban areas, the supply they receive is a lot more unreliable as well, even

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going as far as lack of rural electrification in some areas.

Because of this unreliable nature of electric supply, rural areas exhibit a tendency to easily adopt solar alternatives, especially when their demands are easily met by a single solar panel per household. Conversely, the reliability of conventional power supply for urban areas provide competition to small scale renewables like rooftop solar. The demand for electricity in an urban household is also not quelled by a single panel. Thus, recognizing the limitation of suitable surface areas for installation of solar panels is essential for calculation of solar feasibility.

II. CONCEPT OF DEMAND THRESHOLD

There is an essential energy demand, which constitutes of a minimum number of lights, fans and other appliances required in a household. There is no meaning to installing solar panels by a home owner if it will not even run lights and fans. Therefore, the minimum requirement must be fulfilled, and any production below this limit will obstruct adoption of solar power by that household. This is defined in the paper as ‘energy demand threshold’ or simply ‘demand threshold’.

III. CALCULATION OF DEMAND THRESHOLD

Threshold demand for every household is not considered equal. The paper assumes that size of household and thus the number of rooms will decide the demand threshold value for each category of household, where it is understood that a single value for demand threshold may not hold true for every household. As for the bare minimum requirements of lighting, fans and one or two appliances, it varies largely by the size of the house and the number of rooms. Simply, lighting up three rooms requires thrice more energy than one.

Table 1: Carpet area-wise classification of households under credit linked subsidy scheme (CLSS), PMAY

Classification	Carpet Area (sqm)
E.W.S.	Upto 30
L.I.G.	30-60
M.I.G. 1	60-90
M.I.G. 2	90-110

Source: (Pradhan Mantri Awas Yojana, 2017)

Table 2: Average operating power consumption of household appliances (2006-2031)

		2006	2011	2016	2021	2026	2031
Lighting	W/hr	37	39	38	38	39	38
Small electronics /appliances	W/hr	56	49	51	54	55	56
Large appliances	W/hr	604	675	728	754	766	772
Fans	W/hr	39	38	37	37	37	36
Air cooler	W/hr	250	241	235	232	231	230
Air-conditioning	W/hr	1,973	1,883	1,834	1,817	1,811	1,809

Source: Derived from (The World Bank, 2008)

Table 3: Average duration of electric consumption (2006-2031)

		2006	2011	2016	2021	2026	2031
Lighting	Hr/day	2.5	2.5	2.5	2.5	2.5	2.5
Small electronics /appliances	Hr/day	2.9	2.9	2.9	2.9	2.9	2.9
Large appliances	Hr/day	5.02	5.02	5.02	5.02	5.02	5.02
Fans	Hr/day	6.9	6.9	6.9	6.9	6.9	6.9
Air cooler	Hr/day	3.9	3.9	3.9	3.9	3.9	3.9
Air-conditioning	Hr/day	1.6	1.6	1.6	1.6	1.6	1.6

Source: Derived from (The World Bank, 2008)

A classification of households based on areas is made based by PMAY guidelines concerning carpet areas as shown in Table 1. Table 2 and Table 3 comprises of averages of various categories of appliances and electrical or electronic items within a household and the duration of use respectively (The World Bank, 2008).

Minimum room sizes as given in Model Building Byelaws (Model Building Bye-laws, 2004) suggest a room size of 7.5 sqm to 9.5 sqm among other requirements of a low income household. A total of 20 to 25 sqm of area per room can be assigned, using values of kitchen, toilet spaces etc., assuming attached toilets and large kitchens for M.I.G. categories of households in current times. Using this metric, Table 4 assigns an average room count per household category and corresponding requirements for lighting, fans, appliances etc.

Table 4: Category-wise minimum energy demand per household (2016)

	E.W.S.	L.I.G.	M.I.G. 1	M.I.G. 2
Carpet Area (sqm)	Upto 30	30-60	60-90	90-110
Total rooms	1	2	3	4
No of lights	2	3	4	5
No of fans	2	3	4	5
Large Appliances	0	1	2	2
Small electronics /appliances	1	2	3	3
Energy Demand (Watts/hour)	201.0	1054.7	1908.5	1983.5
Energy Demand (Wh)	848.2	4999.0	9149.9	9500.4

Source: Author

Lastly, the minimum energy demand per category is calculated using average power consumption as given in Table 2. This energy demand can be referred to as the threshold demand for a household. Based on this, 201 W/hr is minimum energy demand for an E.W.S. household where the residents will at the least use two lights, two fans and a small appliance. Using this value, most E.W.S. households can easily satisfy their energy demand through 201W equivalent solar panel.

Similar values of 1055 W, 1909 W and 1984 W per hour, if installed via solar, should make feasible for these households to run a corresponding number of appliances for L.I.G., M.I.G. 1 and M.I.G. 2 respectively.

IV. ROOF AREA REQUIRED FOR MEETING DEMAND THRESHOLD

Various types of solar panels are available in the market with different efficiency ratings

dictating energy output per panel. There are also various array installation types like 1-axis and 2-axis tracking and fixed array systems. The paper assumes 2-axis tracking and Mono-crystalline panels as the basis for calculations of a roof based installation in New Delhi.Mono-crystalline solar panels are the highest rated commercially available solar panels with a rated efficiency of approximately 15-20% with some even reaching beyond 21% (Maehlum, 2015). This means that for every unit of solar incidence, an average of 19% of the energy gets converted to electricity. Considering an annual average solar incidence of 6.41 KWh/m^2/day in the case of Delhi, the highest efficiency of 19% for Mono-crystalline photo-voltaic cells yields 461 Wh/m^2/day considering aspects of ground coverage ratio, system losses for soiling, shading, DC to AC conversion etc. Refer to Table 5 for comparison of Mono-crystalline, Poly-crystalline and thin film photo-voltaic cells with their respective energy output (National Renewable Energy Laboratory). Variations due to weather, unless significant, may be offset by energy storage devices and are thus not discussed in the paper.

Table 5: Calculation of energy output per unit area per day

Solar cell	Solar Radiation (KWh/m^2/day)	Efficiency rating	Ground Coverage Ratio	System losses	DC to AC size Ratio	Energy Output (Wh/m^2/day)
Mono-crystalline	6.41	19 %	0.4	14%	1.1	461
Poly-crystalline	6.41	15 %	0.4	14%	1.1	364
Thin film	6.41	10 %	0.4	14%	1.1	243

Source: Derived from (National Renewable Energy Laboratory)

V. RESULT

Installation area requirement

With the calculation of energy output per unit area per day, one can compare Table 4 and Table 5 to find out area requirement for solar installation for different household categories and their respective energy demands in Table 6.

Table 6: Area required for solar installation per category of household

	Carpet Area (sqm)	Demand threshold (Wh)	Area required by mono-crystalline panels (sqm)	Area required by poly-crystalline panels (sqm)	Area required by thin film panels (sqm)
E.W.S.	Upto 30	848.2	1.84	2.33	3.50
L.I.G.	30-60	4999.0	10.85	13.74	20.61
M.I.G. 1	60-90	9149.9	19.85	25.15	37.72
M.I.G. 2	90-110	9500.4	20.61	26.11	39.17

Source: Author

The area required by an E.W.S. household to meet demand threshold is only 1.84 sqm whereas the same requirement for an M.I.G. 2 household would require 20.61 sqm of available solar installation space for mono-crystalline panels. The requirement increases to 3.50 sqm and 39.17 sqm respectively for the lower efficiency rated thin film panels.

VI. CONCLUSIONS

Although the analysis was conducted using the case study of Delhi and its surroundings, there will be regional and seasonal variations of solar incidence throughout the globe. These variations will require recalculating the installation area requirement based on solar incidences of that region following the same methodology.

The paper also demonstrates that the areas required by solar installations for households are rarely available in the multi-storeyed and dense urban fabric of modern cities. This presents a large hindrance for the adoption of solar energy on a household level.

The most suitable areas available for solar installation in a residential plotted development are on the roof. This is limited by the plot sizes and byelaws of the city and can thus be alleviated by planning for larger plots or amalgamation of plots in already developed areas.

Multi-storeyed apartment construction lacks available space for every resident to install solar panels, but it can also accommodate solar installation for its shared services. This can be taken up in the site planning phase before construction or at the RWA level if already constructed.

Further, the paper notes that the calculation for demand threshold is highly dependent on the power consumption of various electricals and appliances, which would mean that further promotion of efficient electricals would lower the energy demand substantially and thus make it more feasible for solar adoption by urban households.

VII. RECOMMENDATIONS

Since the issue of unavailability of space for solar installations is crucial, the paper recommends that the Masterplan and bye-laws reflect the sensitivity towards solar adoption and the required space allocation. This recommendation entails larger plots for plotted housing whether they are achieved through planning process for new development or through amalgamation of existing plots through an incentive scheme.

Shared renewables are considered a way forward for large scale adoption of solar energy production by households without access to roofs or other suitable installation areas (Coca, 2017). There are several policy recommendations as well by the European Parliament (Directorate General for Internal Policies, 2010), UK Government (The UK Government's Business Taskforce on Sustainable Consumption and Production, 2008), IREC (Interstate Renewable Energy Council, 2015) (Interstate Renewable

Energy Council, 2017) etc for easier and near seamless adoption of renewable energy within their domains, but the Indian Government's stance on the policy aspect is lacking (Ministtry of New and Renewable Energy, 2012).

Further, since the possibility for individual households to install solar panels or arrays is limited in multi-storeyed apartments, it is recommended that guidelines be drafted at the level of municipality or development authority, in order to run shared services wherever possible on solar energy for integrated townships and RWAs.

Finally, proliferation and promotion of low energy consumption for electricals and appliances is recommended through guidelines or subsidies beyond the current BEE rating system.

REFERENCES

1. Bijli Bachao. (2017). Net Metering policy for roof top PVs in various states in India. Retrieved June 30, 2017, from https://www.bijlibachao.com/using-renewables/net-metering-policy-for-roof-top-pvs-in-various-states-in-india.html
2. Bloomberg New Energy Finance. (2017). New Energy Outlook. Bloomberg.
3. Coca, N. (2017). Shared Renewables Hold Big Potential for Communities Left Out of Clean Energy Programs. Retrieved July 25, 2017, from http://www.resilience.org/stories/2017-07-19/shared-renewables-hold-big-potential-communities-left-clean-energy-programs/
4. Directorate General for Internal Policies. (2010). Decentralised Energy Systems. European Parliament.
5. Interstate Renewable Energy Council. (2015). Near-Term Regulatory Considerations to Maximize Benefits. New York: Interstate Renewable Energy Council, Inc.
6. Interstate Renewable Energy Council. (2017). Guiding Principles for Shared Renewable Energy Programs. New York: Interstate Renewable Energy Council, Inc.
7. Josel, P. (2015). Haryana makes solar power must for all buildings. Retrieved July 3, 2017, from http://timesofindia.indiatimes.com/city/gurgaon/Haryana-makes-solar-power-must-for-all-buildings/articleshow/45712811.cms
8. Lobello, C. (2013). The 3 biggest obstacles to a solar energy boom. Retrieved Junly 03, 2017, from http://theweek.com/articles/463150/3-biggest-obstacles-solar-energy-boom
9. Maehlum, M. A. (2015). Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film. Retrieved July 12, 2017, from http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/
10. Mathiesin, K. (2016). What is holding back the growth of solar power? Retrieved July 03, 2017, from https://www.theguardian.com/sustainable-business/2016/jan/31/solar-power-what-is-holding-back-growth-clean-energy
11. Ministry of New And Renewable Energy. (2015). Indian Solar Radiation Atlas. (Govt of India) Retrieved June 30, 2017, from http://niwe.res.in/indian_solar_atlas.php
12. Ministtry of New and Renewable Energy. (2012). Decentralized systems. Retrieved July 25, 2017, from http://mnre.gov.in/schemes/decentralized-systems/
13. National Renewable Energy Laboratory. (n.d.). PVWatts Calculator India. Retrieved July 12, 2017, from http://pvwatts.nrel.gov/India/pvwatts.php
14. Pradhan Mantri Awas Yojana. (2017). Carpet Area, Super built up area, Flat/ House Size Under PM Awas Yojana. Retrieved July 03, 2017, from http://www.pmawasyojana.co.in/carpet-area-super-built-up-flat-house-size/
15. The New Climate Economy . (2014). Better growth, Better Climate. The Global Commission on the Economy and Climate.
16. The UK Government's Business Taskforce on Sustainable Consumption and Production. (2008). Decentralised Energy: business opportunityin resource efficiency and carbon management. UK Government.
17. The World Bank. (2008). Residential consumption of electricity in India - Draft. The World Bank.
18. Town & Country Planning Organization. (2004). Model Building Bye-laws. New Delhi: Ministry of Urban Development, Government of India.
19. Union of Concerned Scientists. (1999). Barriers to Renewable Energy Technologies. Retrieved July 03, 2017, from http://www.ucsusa.org/clean_energy/smart-energy-solutions/increase-renewables/barriers-to-renewable-energy.html#.WVnZRWiGNEY
20. United Nations Environment Programme. (2015). Aligning the Financial System with Sustainable Development: Pathways to Scale. United Nations.
21. World Bank. (2016). Grid-Connected Rooftop Solar Program. Retrieved June 30, 2017, from http://projects.worldbank.org/P155007?lang=en
22. Wu, H. (2016). India's big move into solar is already paying off. Retrieved June 30, 2017, from http://money.cnn.com/2016/03/07/technology/india-solar-energy-coal/index.html?section=money_latest

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