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Domestic Electricity Demand through City Integrated PhotoVoltaic Systems for Composite Climate, in High Density States of India– Case of Aligarh

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ABSTRACT

The study analyses City Integrated Photovoltaic System and its ability to achieve a targeted green energy in composite climatic where demand variation in high. The focus is on cities in high density states. It takes Smart City - Aligarh as a case and assesses the maximum renewable production capacity and need for optimization in a variable demand. It also analyses the socio-economic characteristics of the city and suggests best financial plan for a targeted result and comments on the current renewable energy program in India. The outcome of the study will help setting targets for renewable energy programs in the Indian context.

Terms and Abbreviations

CO_2e	-	Green house gases represented in CO_2 equivalent,
DNI	-	Direct Normal Irradiance
EWS	-	Economically Weaker Sections
GHG	-	Green House Gases
GHI	-	Global Horizontal Irradiance
GWH	-	Gigawatt Hour = $1x10^6$ KWH
HIG	-	Higher Income Group
INR	-	Indian Rupee
KWH	-	Kilowatt Hour = 1 Unit of Electricity
LCOE	-	Levelized Cost of Energy
LIG	-	Lower Economic Group
MIG	-	Middle Economic Group
MU	-	Million Units of Electricity = $1x10^6$ KWH
PV	-	Photovoltaic
RE	-	Renewable Energy
RESCO	-	Renewable Energy Service Company
SPM	-	Suspended Particulate Matter

1 Introduction

Increasing greenhouse gas (GHG) emissions are a major climatic concern of modern world. Primarily it is due to burning of fossil fuels. Reduction of GHG emission is possible through increased use of renewable or green energy. It can also assure overall sustainable development in near future. Available in multiple forms as solar, wind, geothermal, hydro, bio-energy and ocean power; renewable energy has been used historically. Complete switchover to renewable energy has however not been possible due to unreliable nature of the renewable energy sources. More environmentally friendly sources of energy as solar energy, wind energy and ocean power are used less frequently because of high variability and costlier technologies.

India being a developing nation has a rising energy demand. To sustain the current growth rate of 8%, the compound annual growth rate in energy sector should be 5%. (TERI 2015). It is expected that the total energy demand of India is likely to shoot up by 2.7-3.2 times between 2012-2040. Electricity demand alone will become 4.5 times, as compared to base year 2012 (Niti Ayog 2017). Having 17% of world's population, India's share in gas, oil and coal reserves is only 0.6%, 0.4% and 7%, respectively (Niti Ayog 2017). Energy imports in India are in the form of crude oil imports at 36.46 mmt and natural gas imports at 32.25 bcm(GOI 2016);imports for coal for the financial year 2016-2017 were pegged at 160 mt.(Enincon 2017). Total primary energy import of India in 2015-16 was 46% rising from 38% in 2011-12 (Jain 2016).

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In 1947, 46% of power production was through fossil fuels whereas in 2017 it increased to 79.5% (Ministry of Power 2018). From 2001 to 2017, the percentage of fossil fuel based production has fluctuated between 77-81% (Ministry of Power 2018), indicating a limiting condition being reached where fossil fuel based production may rise to meet future demands if current trends of development of energy infrastructure are followed.

Hence renewable energy interventions in India can be looked upon from multiple perspectives of reducing green house gas emissions as well as self reliance in energy.

1.1 Domestic Electricity Demand and Emissions

Since independence, domestic consumption of electricity increased from 10.11% of the total consumption to 15.16% of the total consumption of electricity by 1989-90 (Ministry of Power 2018). Post liberalization period saw a surge in domestic demand and by the end of 2017, domestic demand stood at 24.11% of the total consumption of electricity (Ministry of Power 2018), an increase of almost 9% (of total demand) in 27 years. India's residential electricity consumption has increased steadily from 75629 GWH in the year 2001 to 273550 GWH of electricity in the year 2017 (Ministry of Power 2018), an increase of 3.6 times. Corresponding to change in domestic electricity demand, GHG emissions increased from 1.8 $x10^5$ tonnes CO_2e in 1947 to 2.0 $x10^7$ tonnes CO_2e in 1991. From 2001 to 2017, emissions have increased 5.5 $x10^7$ tonnes CO_2e to 2.0 $x10^8$ tonnes CO_2e an increase of 36 times since 2001 and an increase of 100 times since globalization. 25-100 % domestic power through renewable will result in reduction of electricity based emissions by 6-24%.

1.2 High Density States – Composite Climate and Renewable Energy Scenario

Considering a large population of India, how renewable interventions are done becomes important. States with high population and population density such as Uttar Pradesh and Bihar need a more sensitive approach. The two states,together, amount to around 24% population of India. State-wise installed capacity of wind power (IWTMA 2018) suggests lack of thresholds or low availability of wind power in most parts of these states. Costlier CSP may not be possible due to high capital costs, leaving Solar PV as the most viable option. Further pressure on land means, that on field installations should be last consideration. Hence how much we can produce within the city becomes more important.

These states also have composite climate (Fig 1). It is characterized by weather conditions, different than normal, for half of the year. Daytime temperature varies 32-45 degrees in summers to 10-25 degrees in winters; night temperature is 27-32 degrees and 4-10 degrees respectively. Monthly demand (total including domestic) of Uttar Pradesh varies from 11448 million kwh (CEA 2018)of power in hot weather conditions to 8172 million kwh (CEA 2018) in moderate climatic conditions; a variation of 40%. Bihar again shows a variation of 35% in monthly demand with 2548 MU and 1889 MU (CEA 2018) as the peak and lowest monthly demands respectively. Further analysis of these states reveals that the peak demand of the states corresponds to lowest solar insolation values in the region (NREL 2010).

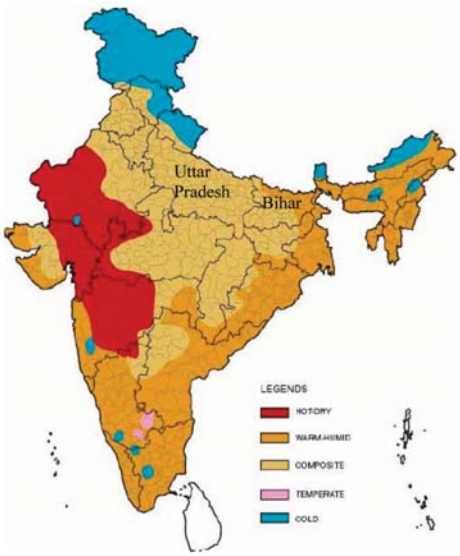

Figure 1- Climatic Zones of India (USAID ECO-III Project 2009)

Rising demand along with a rising domestic component means a major impact on carbon footprint can be made with renewable interventions for domestic demand in electricity sector. Trends of renewable energy infrastructure development in past two decades show stagnation thus indicating exhaustion of alternate sources like hydro-power, environmental issues or other cost related issues. PV systems with incremental approach are more likely to keep the pace of infrastructure development in sustainable direction.Further due to limited land resources, cost factors and renewable energy type availability it becomes more important to look into the cities for production potential, in the thickly populated states. Large variation in demand as is obvious from the power consumption data and lowest insolation values during peak demand requires cost optimization particularly in this case. With no research so far till date on the topic, the study will be the first to investigate the potential of the city in renewable PV production for a complex urban environment and suggest a suitable economic solution for that.

2 Literature Review

Current energy policy of India aims at reducing the emission intensity by 33-35% by 2030 (base year 2005) and the capacity of non fossil fuel based electricity generation is targeted at above 40% by 2030 (Niti Ayog 2017). City Integrated Energy Programs such as Solar City aim is to reduce the projected fossil fuel based demand by 10%. (MNRE 2019). At present, 60 cities are proposed to be supported, at least one from each state (MNRE 2019). 48 cities have been given in principle approval (MNRE 2019) out of which sanction has been given to 31 cities (MNRE 2019). The program identifies cities with population of 0.5 lakh to 50 lakh as targets of Solar City (MNRE 2019). Whereas such programs show assumed targets, they still lack a logical approach – where can we get most sustainable output from and analyzing the most sustainable option for feasibility. Different aspects of a renewable program are – correct technology and target as well as inclusive approach. In a country with large population, bio energy is not considered a viable option as land for food production is considered of prime importance. In such a situation, on field installations is therefore not a long- term sustainable model of approach. City that has already built structures should be used for production first. Therefor the current study focuses on production of city as well as how much can be produced from it with cost optimization.Also, at present the is no specific approach of any government program regarding financial model. It therefore becomes pertinent to analyze whether finances can be arranged from the user-end or government has to participate.

Some of the successful financing or implementation models of RE are Community Choice Aggregation (CCA) and Green Bond Financing. Most of these methods have been adapted in developed countries. The Chicago CCA Program offered savings up to 25-30% based on 50% renewable purchase (IRENA 2016). Such model requires aggregation of demand (by multiple municipalities or communities) and competitive bidding to lower rates of power.Green Bond Financing has been used as a method of low interest financing of renewable projects in countries such as South Africa. (IRENA 2016) Deferred taxes are incentive based measures for renewable energy implementation through individual financing. Public financing can also be achieved by higher and stable energy prices for longer duration, leading to cost recoveries. Net metering system allows the user to produce their total daily demand or less within the sunlight hours and only pay for the units consumed beyond the renewable production capacity, from the local grid. Whereas in developing nations such models have been successful owing to social security & active participation from end user, in developing nations such models may fail because of day to day struggle of end user.The study will enquire on acceptance of such models within various social brackets and whether a targeted model is likely to fail, due to socio economic aspects if it is left to people to participate based on their discretion

100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for 139 Countries of the World (Jacobson, et al. 2017)is one of the most comprehensive studiescovering India which propose a100% renewable energy through wind water and sunlight, by 2050. The study showed benefits and infrastructural calculations based on general assumptions. Current study elaborates how RE-PV implementation can be done at urban level in cities with composite climate when density is high, cities unplanned, and demand has high variation. Also the study weighs whether the investment methods will find acceptance and which method is most likely to yield a targeted result by providing direct benefits in terms of energy price reduction.

2.1 Study Area - Aligarh City

The study area Aligarh is in composite climatic zone of Uttar Pradesh. It has a wide variety of developments, typical to an Indian City, with planned as well as unplanned growth patterns seen in the city. Most areas have saturated packets of land, ideal for analysis of PV output rather than cities where sporadic development has happened.

It has an old city area which over the period has developed into a high-density development. New planned areas have low density whereas unplanned areas have also grown into high density zones, againa characteristic of most Indian cities. Being a smart city (ASCL n.d.) it is most likely to have renewable interventions in near future. The city had a population of 874408 in 2011 (GOI n.d.)

3 Methodology

In a complex urban environment, density is the factor deciding per unit availability of solar energy. Therefore, a density-based classification of urban spaces has been done for demand and production matching. With density-based classification done, one space of each type has been taken for sampling. A total of 400 door to door samples (primary survey) were taken from all the space types, in the proportion of population of each urban space type in the city. The 400 sample represents a margin of error of 5% with a confidence level of 95% for the population under consideration. The data collected included electricity demand of each household, there preference for renewable energy policy and their socio-economic characteristics (Appendix 5). Electricity demand was recorded in terms of appliance use for a specific period of activity. Renewable policy preference included preference for prevalent models of renewable energy implementation.

The samples were classified into consumer types according to their electricity demand. Average production to demand matching was done for each consumer type, for each urban space type, and scaled for each urban space type in proportion of each class type present for the urban space type. Further the demand to production matching has been scaled to the city level in proportion of the total population of each urban space type in the city. Each urban space type was also examined for demand matching through public spaces.

For optimization of costs through PV production, demand for each class has also been split for various periods within a day. Also with seasonal demand variation taken into account, cost optimization by demand to production matching and costs thereof by Level Cost Assessment of Energy for the representative periods has been done.

In a country like India which is developing and average income is low, a lot of programs fail due to inability of the end user to pay or other need-based priorities of the consumers which incapacitate the consumer to divert funds towards compulsory purchase models. On the other hand, investment can be either fully externally funded or funded by the end user in terms of cost recoveries or actual investment. Hence it is necessary to examine whether expecting any investment of end user is possible or will it fail any targeted renewable program.

Collected sample has been examined for paying capacities, economic classification and interest response to programs (adoptability analysis) where end user bears the final cost or helps in cost recoveries without any direct financial benefit. This will help in designing investment discourse for a more accurate target that can be achieved.

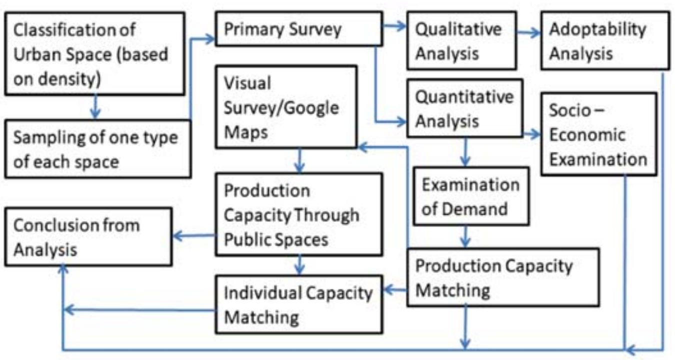

Figure 2- Methodology

3.1 *Classification of Urban Spaces*

Ward density has been used for classification of urban spaces for sampling. Three types of classified urban spaces are:

- Development Type 1 - or the New Unplanned Development, having densities in the range 25000-35000 persons per sq km.

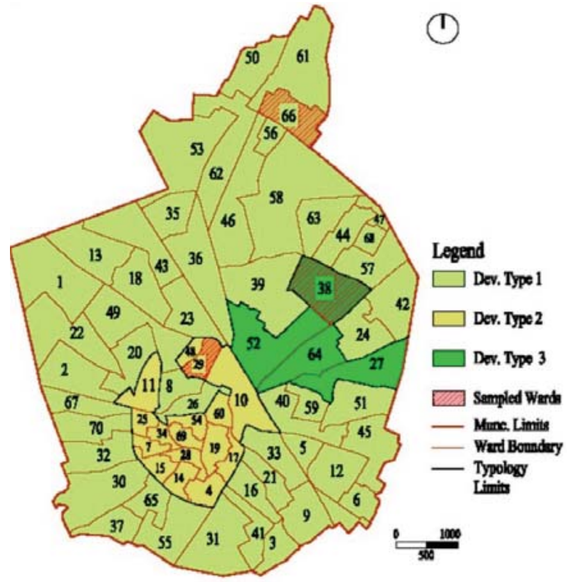

Figure 3- Development Type Distribution and Sampled Wards (Source- Aligarh Municipal Corporation)

- Development Type 2 - or the Old City, having densities over 50000 persons per sq km or above.
- Development Type 3 – or New Mixed Development having densities ranging 10000-15000 persons per sq km and. It is a mix of planned and unplanned zones.

One type of ward from each category has been sampled to establish demand, production capabilities and socio economic examination.Sampled wards were 66, 29 and 38 respectively.

3.2 *Quantitative analysis*

Quantitative analysis comprised of demand and production matching through public and private spaces and assessment of renewable investment capacity of end user.

3.2.1 *Demand Classification*

Due to seasonal nature of energy use in composite climate, demand data for each sample was recorded for three different weather conditions, Hot Weather/ Warm Humid Conditions, Cold Weather Condition and Transitional Weather Conditions. Allocation of each demand type to a day in a month is based average climatic data of the month.

Production only during sunlight hours through Solar PV and infrastructure for consumption during sunlight as well as post sunlight hours requires demand classification into small portions. Best cost optimization results can be had by analyzing the device use during various parts of the day and hence End User Demand Projection Method was used and intraday demand was recorded based on human activity pattern. Regular equipment such as lights, fans and cooling equipment were recorded in hourly tables and multiplied with their power rating to generate hourly demand.

For other equipment, demand was allocated to intraday hours based on equipment and its nature of use. End use method formula, extended to hourly energy use is:

$E_h = S_i \times P_i \times F_i$

E_h = Total hourly energy consumption in kwh (kilo watt hour)

S_i = Penetration level or the number of type of i_{th} appliance per consumer

P_i = Power required by the i_{th} appliance in kw (kilo watt)

F_i = Fraction of hour for which the appliance was used

To calculate emissions from electricity the assumed value is 0.94 kg CO_2e/kwh (Mittal 2012) of electricity by coal fired plants. Further it has been factored to account for 76.3% of production by coal fired plants in UP (UPERC 2017). Criteria pollutants values have been taken as 6.2gm/kwh SO_2 7.2gm/kwh NO and 2.2gm/kwh SPM of electricity (Mittal and Sharma, Anthropogenic Emissions from Energy Activities in India n.d.)

3.2.2 Production capacity through rooftop Solar PV and installation on available public spaces

In Indian conditions, roofs are still used as social and private spaces. Therefore, for calculation of rooftop Solar PV installation capacity, spaces for private/social use were left out from terrace space using the following rules:

- <=25 sq m of terrace space - Minimum of 10 sq m or 75% of the terrace space
- 25-50 sq m of terrace space -Minimum of 18.75 sq m or 66 % of the terrace space
- 50-100 sq m of terrace space - Minimum of 33.5 sq m or 60% of the terrace space
- Above 100 sq m of terrace space –40 m sq terrace space

DNI and GHI data for most months show similar range (NREL 2010)indicating a very small contribution of reflected component to radiation. In a complex urban environment, such reflected component of environment has been assumed to have negligible contribution to the power output. and hence DNI or Direct Normal Irradiance Values have been used rather than GHI to calculate production capacities. Maximum production capabilities have been factored to allow for technological and physical limitations using the formula

Unobstructed Capacity	=	0.2*0.7*Area available for production*DNI
Where 0.2	=	Maximum efficiency of commercial solar cells (Twidell and Wier 2015)
0.7	=	reduction/ safety factor
Obstructed Capacity	=	OF * Unobstructed Capacity
Where OF	=	Obstruction Factor or percentage of time (sunlight hours) a terrace is obstructed by nearby structures limiting its production capacity.

Production through public spaces has been limited to East-West aligned roads wider than 6 m. 1 kw system per 10 m of road length has been assumed. North-South aligned roads have been eliminated as they may face obstruction for most parts of the day from nearby structures.

3.2.2.1 Cost Optimization -Levelized Cost Assessment

LCOE or the Levelized Cost of Energy is the average net present value (NPV)of a unit of energy produced, calculated over the lifetime of the asset. It is ratio of, net present value of fixed capital costs and O&M (operations and maintenance) costs over the life time of the energy project, and total energy units produced over life time of the project.

Systems were designed to see how LCOE changes with demand matching for various periods under technological limitations. Also changes in LCOE on account for obstruction were assessed for different parts of the city.

3.2.3 Socio Economic Examination

For any compulsory purchase model or other forms of end user investment, capacity for compulsory purchase/investment of household was established using the following rules:

- For monthly income < 10000, no compulsory purchase can be done.
- For income above 10000, 10% of income is assumed as a fixed value for compulsory purchase, factored based on the parameters given below.
- Except for permanent government job, for families with organized-sector working members the value is factored by 0.8, for unorganized sectors by 0.5; for each successive dependent as aged dependents, children getting education the value is further reduced by a factor of 0.5.

3.3 Qualitative analysis

Socio-Economic classification of households has been used as a parameter to establish the capacity of investment while response for acceptance of possible programs has been used as another parameter of adoptability.

4 Analysis

4.1 Basic Demand Characteristics

Based on the consumption pattern, the households were classified into 6 types of consumers. Primary criteria of consumer classification, is their hot weather demand range(Figure 4). Each member of these classes had their total intraday hot weather demand in the range of 0-5, 5-10, 10-15, 20-35, and 35+ kwh respectively and their contribution to the total domestic demand of the city was 4.6, 14.9, 35.7, 22.6, 13.6, 8.6 percent, in that order.

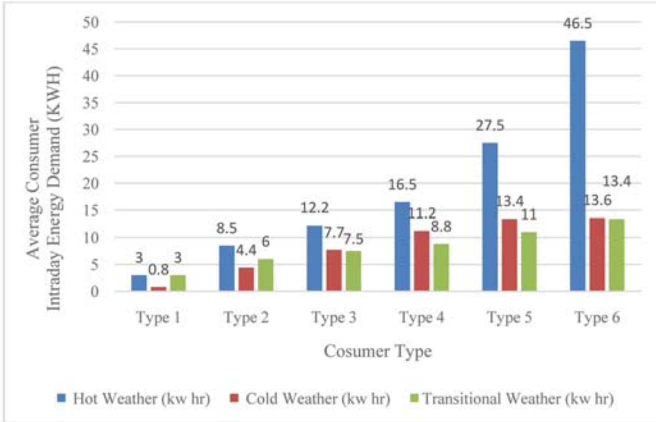

Figure 4: Consumer Type and Electric Energy Demand

Seasonal demand variation is high and for different classes, the variation goes in the range of 1.6 to 3.75 times of the lowest demand for each class respectively. This will require an optimized system design so as to minimize costs while achieving the targets.

Further examination of demand for various consumer types showed that 25-29 percent of their total intraday demand is within the sunlight hours. On urban level it converts as 27% of the total demand within sunlight hours, averaged over the year.

4.2 Production Capabilities

Consumer type production capabilities varied over the wards (Figure 5). Overall, wards 29, 38 and 66 with per capita annual demand of 885, 1424 and 764kwh can produce 51%, 113% and 116% of their annual demands respectively. City level production to demand ratio from rooftop systems was found 0.96.

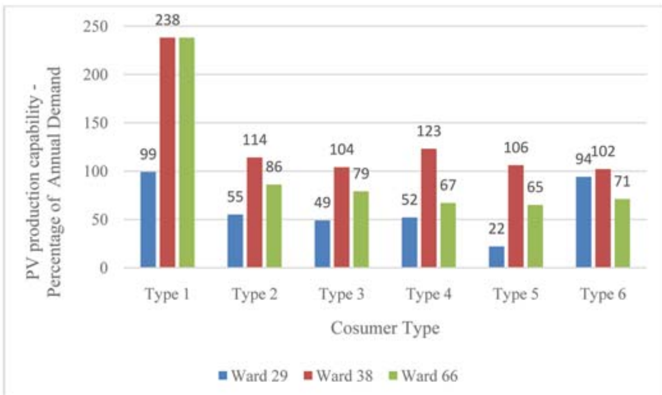

Figure 5: PV Production Capability of Consumer – Ward Wise

Maximum cases of obstruction were observed in old city area (Table 1) that also showed maximum increase in LCOE. Production through public spaces showed low values with reference to demand (Table 1). City canat maximum produce 6% of its demand through public spaces.

For individual users, standalone systems gave a poor performance on LCOE benchmark. The graph (Figure 6) shows a comparative of demand and LCOE change for systems (not accounting for any possible shade) that match the primary consumer type demand during various periods of the day over varying climatic conditions. Only the power that can be used at any particular point of time (due to seasonal variation of demand) was taken to account for LCOE calculations.

Four types of demand periods shown in the graph are sunlight hours demand, total demand till evening, total demand till night and full intraday demand. Sunlight hour's demand is that part of the electricity demand of an individual user that lies within hours of sunlight. Successive demand has been added to this demand to get cumulative demand through other periods.

Systems were designed and optimized for each consumer type so as to give maximum output, during changing weather conditions using excel

Table 1: Urban Space Production Capabilities

	% households having given solar obstruction			Average % increase in LCOE due to obstruction	Area of Production / Household	% demand through public spaces
	0 %	25%	50%		Sq m	
Ward 29	46	33	21	23	11.55	1.25
Ward 38	82	7	11	6.9	36.00	16
Ward 66	64	30	6	15.4	16.55	7

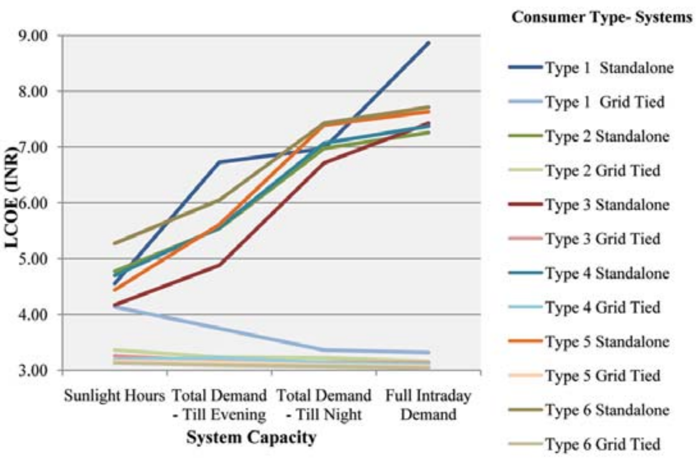

Figure 6: Levelized Cost Performance of Standalone and Grid Tied Systems

sheets. For grid tied systems, the costs include PV system costs, fixed installation costs, evacuation charges and operations and maintenance costs assumed as fixed capital costs. For standalone systems, PV panel costs and recurring costs of maintenance and storage change have been included.

4.3 Socio Economic Characteristics

Calculated investment capacities (Table2)showed that over 15 year period, only Consumer Type 5-6 will be able to pay back the costs of full grid tied installation systems(Table 3). Other classes have lesser capacity and also higher concentration of economic weaker section (Table 2)which may lead to failure of investment of any form for any self-financed net metering system or standalone system.In absolute terms, this will lead to at least 65-70% of the demand unaffected by any renewable energy intervention.

4.4 Qualitative Analysis

Adoptability analysis has shown that 82% of the population expected aid from the government. Other methods of capital cost recovery such as higher and stable energy prices found poor response. 64% people disagreed with the method and only 27% agreed with no more than 10% increase in current prices.

Only 25% of people were interested in investment. Return period expected by 66% of people was 3-5 years while 13% expected a return period of 1-3 years and 21% of people had no response to the question.

Whereas current 96% domestic demand matching is possible through PV interventions within the city, owing to higher LCOE values standalone systems will fail. Variable output for different parts of the city will also discourage individual users from participation. With socio economic characteristics further indicating minimum investment/return from end user, Indian RE programs need to think beyond awareness creation as a tool for RE implementation. It becomes imperative to look towards external funding and develop programs that can give direct benefits to users and encourage participation; only then the renewable programs can be definite and targeted. Such programs will also help participation of users who suffer due to current urban form and are shaded by nearby buildings. The extra structural cost for overcoming solar obstruction due to height of nearby structures will be distributed over many users whereas if the liability of installation is over an individual user, he won't participate owing to higher costs bourne by him/her. On a socio-economic context, it will provide a more equitable approach to the program. Further the program also needs to be incremental to allow for better technologies to be incorporated, when available.

Table 2: Socio Economic Characteristics (By Consumer Type)

	Type1	Type2	Type3	Type4	Type5	Type6
Monthly Avg.Income (INR)	6000	8750	18350	25000	38000	73000
Avg .AnnualInvest. Capacity(INR)	0	1000	7000	12000	38000	192000
Economic Class Distribution (%)	EWS-100	EWS-100	EWS-91 LIG -9	EWS-72 LIG-27 MIG-1	EWS-18 LIG-62 MIG-20	EWS-0 LIG-24 MIG-75

Table 3: Renewable Equipment Purchase Capabilities

	Percentre covery capabilities w.r.t. system cost for grid tied systems, for15 yr investment capacity (Table 4-d)			
	Sunlight Hours Demand	Total Demand Till Evening	Total Demand Till Night	Full Intraday Demand
Type 1	0	0	0	0
Type 2	48	38	23	16
Type 3	253	184	101	75
Type 4	347	231	126	95
Type 5	548	365	209	152
Type 6	2030	1370	812	548

5 Future demand and proposal

A program that has a technological base and spans over a large period needs to be rationalized to get best benefits from the technology available and allowing inclusion of better technology in future. Higher return period hinders any immediate technology change unless and until costs are recovered, while growing technologies tend to change at a faster rate. Optimization of the renewable program requires both, future demand change as well as technological assumptions.

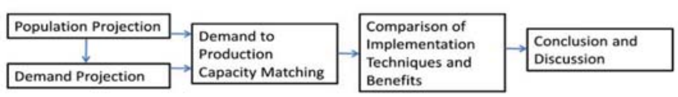

Figure 7- Proposal Methodology

Future population with linear growth trend and power consumption projectionsat 5.01% CAGR (compounded annual growth rate) (CRISIL 2017), show that the total demand of the city is going to increase by 2.86 times by the year 2033 and 4.73 times by the year 2041(Primary Survey). The city production capacity accordingly is going to decline to 44 percent of its total demand by 2033, from current 96 percent(Primary Survey) production capacity, if urban growth is in line with the current trends. The maximum capacity it is can attain is 49% of the total demand if any future growth happens at a density of 10000-15000 persons per sqkm (Primary Survey). By 2041 due to further increase in demand, these production capacities are going to change to 30 and 35 % of the demand respectively (Primary Survey).Therefore the limiting PV production capacity of the city is assumed as 30% of the total demand;whereas Solar City program aims at 10% of projected demand through renewables. New technologies with better efficiency will give better output in near future while the current emissions rates suggest immediate intervention for better environmental results. Hence a systematic approach should be aimed at highest possible targets and allowing for future change in technology. The limiting condition of 30% of the demand is therefore chosen for implementation with incremental approach while taking India as close to its target of 40% electric energy through renewable by 2030 (Niti Ayog 2017). Corresponding targets for each five year period of the program are as under:

2023 – 0.37 billion units(kwh) through rooftop PV systems

2028 - 0.52 billion units(kwh) (total) through rooftop PV systems

2033- 0.71 billion units(kwh) (total) through rooftop PV systems

Socio-economic examination, adoptability analysis suggested that end user investment cannot lead to a targeted program. Also such standalone system will lead to inequitable benefits owing to obstruction.LCOE achieved for grid tied system (Fig 6) is better than 4.9-6.5 per kwh of electricity charges (UPPCL 2017). Hence possible targeted intervention under the circumstances can only be large scale implementation program by third party funding, with a grid tied system.

Consumer Type 1-4 have maximum composition of EWS and LIG classes and are least likely to have psychological or actual capacity to invest even on decline of prices whereas their contribution to the demand is almost 80%. The program should have maximum benefits for these classes. Benefits for other classes can be lowered to cross subsidize and make the program more beneficial for the masses.

Therefore models having external financing from green bonds and soft loans were tested for their highest possible benefits as suggested above. The three models of each type that yielded best results were:

- Model 1 - Private RESCO (Renewable Energy Service Company)financed in aequity-debt ratio of 30:70,with financing from green bonds
- Model 2 - Government owned RESO, fully financed from green bonds
- Model 3 - Government owned RESCO, financed by soft loans

Optimization was carried out using excel sheet models, using the following conditions:

- Maturity period for Green Bondswill be 15 years with 7 % interest for a period of 10 years and 8% for the remaining 5 years. Soft loans will have a 6% simple interest and 25 year maturity.
- Project life cycle is taken as 25 years from last installation in 2033. Till final installation, the system is assumed to produce at maximum 80% rated capacity before. Post that, the capacity is going to decline at a uniform rate of 2% per annum.
- Operation and MaintenanceCost is CERC (Central Electricity Regulatory Commission) recommendedvalue of INR 700000 (CERC 2016), adjusted to INR 800000. For subsequent years the value is inflated@5% per annum.

Table 4: Possible Consumer Benefits under Various Implementation Methods

	Tax Rebate	Concession up to 500 kwh / month of total energy use (on RE component)	Concession above 500 kwh/month of total energy use (on RE component)
Model 1	9.28%**	40%	10%
Model 2	9.28%**	20%	10%
Model 3	9.28%**	50%	10%

** 5% excise duty and 4.28% surcharge

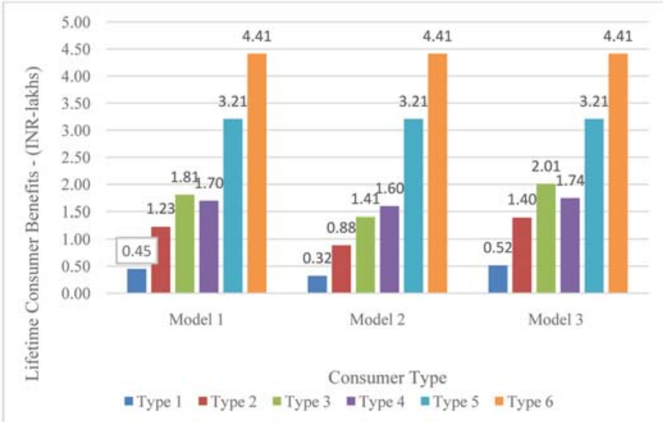

Figure8: Life Time Consumer Benefits (till 2058)

- For any financial stress beyond absorbing capacity in 5 future years, the model is assumed to have failed.
- No taxes are to be levied on the RESCO during incubation period of 25 years.

With 5 year tariff control period as per Electricity Act 2003and price projection, based on linear model for control period 2009-13(UPPCL 2009),2013-17 (UPPCL 2013) and 2017-22 (UPPCL 2017), optimized maximum concession and benefits that can be transferred to the consumers for RE use for each case are as in table 4 and figure 8

Both soft loan financing model and RESCO in a debt equity ratio of 30:70 were found to give better benefits than a government owned RESCO fully financed from green bonds and can be used for implementation of renewable energy program.

This will achieve 3 times the targets of the current Solar City Program and reduction of 1.48X10^7tonnes of CO_2e, 97500 tonnes SO_2, 110000 tonnes NO and 35000 tonnes of SPM (Suspended Particulate Matter) during the program period.

Appendix 1
Average Monthly DNI Values

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DNI –kwh/ sq m/day	3.25	6.25	6.25	5.75	4.75	4.25	2.25	2.25	4.75	4.75	3.75	3.25

Source: www.nrel.gov

Appendix 2
Power Rating of Appliances

Appliance	Rating-Watt
CFL 1	20
CFL 2	40
Bulb	100
Refrigerator (up to 200 l)	200
Refrigerator (above 200 l)	350
Geyser	2000
Pump	1000
Microwave	1000
Washing Machine	500
Cooler	150
Air Conditioner	2500
Television	200
Computer	175
Fans	75
Heating Rod	1500
Electric Iron	500
Electric Heater	2000

Appendix 3
Projected Installation Cost of PV Systems

CERC Benchmark Cost Components have been used to project future costs.

Assumptions for future rate projections are:

- New technologies are going to decline at 25 % for the tariff rate control period. However, for PV Systems, the costs are not going to go below INR20/ watt and for power conditioning units, the costs are not going to go below INR5/watt. From there, there is going to be an increment at the same rate.
- Civil works are assumed to increase at the rate of 25% for control period (Source: CPWD Schedule of Rates)
- Items using metal such as Mounting Structure and Evacuation Charges are going to increase at the rate of 10% for control period. (Source: CPWD Schedule of Rates)
- Pre operative costs are assumed to decline at 25% for the tariff control period

Year	PV Units	Civil Works	Mounting Structure	Power Conditioning Units	Evacuation Charges	Pre Operative Expenses	Total Cost
2041	31.25	9.5	13.3	7.8	17.7	1.8	81
2037	25	7.6	12.1	6.3	16.1	2.4	69
2033	20	6.1	11.0	5.0	14.6	3.2	60
2029	20	4.9	10.0	5.0	13.3	4.2	57
2025	22.5	3.9	9.1	5.6	12.1	5.6	59
2021	30	3.1	8.3	7.5	11.0	7.5	67
2018	40*	2.5	7.5*	10.0*	10.0**	10.0**	80

* Source: Primary Survey
** Source: CERC

Appendix 4
Power Tariff Projections

Future Tariffs have been projected based on the linear model of average tariff increase during the previous control periods:

Year	Life Line Customers		General Customers				
	Fixed Charge	0-100 kwh	Fixed Charge	0-150 kwh	150-300 Units	300-500 kwh	500+ kwh
Projected Future Power Tariffs							
2041	100	12.0	350	13	13.5	23.8	24.9
2037	100	9.5	300	11.3	11.6	19.0	19.9
2033	100	7.5	225	9.9	10.0	15.2	15.9
2029	75	6.0	200	8.3	8.5	12.2	12.7
2025	75	4.5	150	7.0	7.3	9.7	10.2
2021	75	3.8	125	5.8	6.3	7.8	8.1
Previous Power Tariffs							
2017*	50	3	100	4.9	5.4	6.2	6.5
2013**	50	2.2	75	4	4.3	4.5	5
2009**	50	1.9	65	3.45	4	4	4

* (UPPCL 2017)
** (UPPCL 2013)
*** (UPPCL, APPROVED TARIFF FOR FINANCIAL YEAR 2009-10 2009)

Appendix 5- Survey Format

Primary Survey Format –
Domestic Electricity Demand through City Integrated PhotoVoltaic Systems for Composite Climate, in High Density States of India– Case of Aligarh

General
1) Name .... 2)Ward.................................... 3)No. of Family Members (Users of 1 electrical connection) .... 4) No. of Earning Members... 5) No. of Children Getting Education............6) No. of disabled and aged in family...................... 7) Type of your house- Flat (Apartment)/Independent) 9) Is your house owned or rented – Owned/Rented

For Independent Plot/House Owners
1) Plot Size (sq m)...........2) No. of constructed floors..........3) Terrace Area (sq mt) ....4) No. of Families living (using separate metered connections) ....

For Apartment/Flat Owners
1) Total floors in your building.................. 2) Total Terrace Area ....

During 8 hrs of sunlight, for how much time is the building shaded by adjacent buildings?.......................................

No of family members working in
1)Government...
2)Government -Contractual ....
3)Job in Private Organized (School /Factory/ Registered Firm) ....
4)Job in Pvt. Unorganized (Unregistered Firms/Construction Workers) ....
5)Self Organized Business (Registered business) ......
6)Self Unorganized Business (Unregistered Business/Shops etc) ....

Family Income Group (INR)

<5000		25000-35000	
5000-10000		35000-50000	
10000-15000		50000-75000	
15000-25000		75000-100000	
		100000+	

Renewable Program Preference
1)What type of renewable energy system would you prefer? Individual/Community
2)Interest in investment? Yes/ No 3)If invested, return period expected...................years
4)Do you expect government to take initiative in investment? Yes/No
5)If you make investment what method of subsidy will you prefer? Capital subsidy (government gives lump sum concession) / Tax Credit (you make investment and government gives tax concession).
6)If governments provides fixed electricity price for ten years with renewable energy (Government is investing), and also increases price for now (10-20%) will you prefer this mode of renewable energy promotion? Yes/No/Can't Say
How much should be the increase in price 10%, 20%, 30%?

Electricity Use Details:
Write no of Equipment used in each cell by hours of use

General Demand

	Hot Weather								Cold Weather								Intermediate Weather								
	CFl (<20 WATT)	CFl (20-40 WATT)	FAN	FRIDGE (<200L)	FRIDGE (>350 L)	COOLER	AIR CONDITIONER		CFl (<20 WATT)	CFl (20-40 WATT)	FAN	FRIDGE (<200L)	FRIDGE (>350 L)	COOLER	AIR CONDITIONER		CFl (<20 WATT)	CFl (20-40 WATT)	FAN	FRIDGE (<200L)	FRIDGE (>350 L)	COOLER	AIR CONDITIONER		TV
11pm-06 am																									
06-09 am																									
09am-12 pm																									
12-3 pm																									
3-6pm																									
6-11pm																									

Other Demand write no of equipment used and hours of use (e.g (2) (7 am, 9 pm)					
Washing Machine( )		Geyser /Water rod (tick)( )		Submersible Pump	
Heater (1000 watt)( )		Micro Wave ( )		Clothing Iron	
Heater (2000 watt)( )		Computer/Laptop ( )		Cooking -Microwave etc	

Conclusions

The Indian Solar City Programthat is largely dependent upon on-field solar PVinstallations can have better approach towards sustainable development by opting for renewable energy through cities. For Uttar Pradesh, the domestic sector of cities within itself is capable of producing 30% or more of its current or future demand through solar PV within cities; hence rather than opting for the current 10% emission cut, solar cities should target 30% emission cut for cities. For Bihar this can yield either better production to demand ratio or improvement of energy consumption which is low as compared to Uttar Pradesh. Low RE availability during peak demand is likely to lead to failure of RE through standalone systems. Existing approach of end user participation in financing cannot yield a targeted result and therefore RESCO financing models should be used.

Installation of PV system on roof should be exempted from bye laws. As per Uttar Pradesh Renewable Energy Policy 2017, no building permission is required and similar laws exist in other states; however in practical conditions such structures should be exempted to a maximum of one storey height (only for obstructed cases) which is going to boost renewable energy capability and allow equal opportunity to people facing obstruction from nearby buildings. For future development, laws need to protect installed systems from obstruction and rules for costs arising out of modifications, for installed systems being affected from nearby construction.

The methodology adopted can be followed in general for developing nations where resources are scarce, cities are unplanned, and lack of awareness and funding a common problem; in new technological implementation. For targeted implementation, the methodology will yield values of investment (self-financed or external) and possibility of targets that can be achieved if emission cut-down is to be had by renewable implementation. For energy scarce countries with high population densities, the method will be helpful in one strategizing one-time investment through foreign aid and help solve power shortage.

For further refining, similar studies may be conducted for different types of cities. The conclusion drawn may act as rules for similar cities and are most likely to yield better results than existing programs. The method can further be strengthened by refining urban areas into higher density based systems with definite class intervals and formulating general specification of each type of urban area for renewable plan implementation. For assessment of urban form impact, other parameters such building heights, storey and built to un-built ratio can be used for establishing the relationship between urban form and production capacity. Orientation of structures and public spaces are other aspects that can be analyzed for optimization.

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