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ROOFTOP REVOLUTION:

Unleashing **Chennai's & Hyderabad's** Rooftop Potential

The solar thermal plant set up by Trans Solar Technologies, in collaboration with Holy Family Hospital, New Delhi.
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Solar Power: Photovoltaic Installation on University Roof.
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ABBREVIATIONS

AD	Accelerated Depreciation
APPC	Average Pooled Purchase Cost
CEIG	Chief Electrical Inspector to Government
CMDA	Chennai Metropolitan Development Authority
DisCom	Distribution Company
DT	Distribution Transformer
EHT	Extra High Tension Line
ESRI	Environmental Systems Research Institute
FID	Field Identity Number
FiT	Feed-in Tariff
GBI	Generation Based Incentive
GCC	Greater Chennai Corporation
GHG	Greenhouse Gas
GHMC	Greater Hyderabad Municipal Corporation
GIS	Geographical Information System
GW	Giga Watts
HT	High Tension Line
kW	Kilowatt
kWh	Kilowatt hour
MNRE	Ministry of New and Renewable Energy
MW	Mega Watts
NCPRE	National Centre for Photovoltaic Research and Education
NGA	National Geospatial-Intelligence Agency
PID	Plot Identity Number
PV	Photovoltaic
RESCO	Renewable Energy Service Company
RTPV	Rooftop Solar Photovoltaic
SRS	Stratified Random Sampling
SERC	State Electricity Regulatory Commission
TNEB	Tamil Nadu Electricity Board
TNERC	Tamil Nadu Electricity Regulatory Commission
TSERC	Telangana State Electricity Regulatory Commission
UNDP	United Nations Development Program
USGS	United States Geological Survey

PREFACE


Solar Powered Night School in India.
© Marcus Franken / Greenpeace

In the run up to the Paris climate talks in 2015, India announced a goal of having 100 GW installed solar capacity by 2022, of which 40 GW would come from rooftop solar/distributed sources. No other country at a similar position on the development ladder has such ambitious clean energy targets, and this has allowed India to justifiably lay claim to a leadership position in tackling the global climate challenge.

India remains energy-deficit, with hundreds of millions having no or inadequate access to electricity. At a time when pollutants from fossil fuels have created an air quality crisis across virtually every Indian city, the ability to generate electricity without contributing to the air pollution problem is invaluable. Solar (and wind) energy is vital to meet India's goal of ensuring electricity access to all households, without also worsening the country's air quality through fossil fuel combustion. On the climate front, if humanity is to successfully keep global temperature rise as close to 1.5°C as possible, India will have to do its part to reduce the carbon intensity of its growth, even as it works to improve the quality of life of its poor. At a time when climate change influenced weather events have exacted a devastating toll in India and across the world, the win-win benefits to constraining the growth in India's carbon emissions is clear.

Since the 100 GW solar target has been announced, utility-scale solar in India has progressed well, with costs falling and installations growing fast.

However, progress in the rooftop/distributed segment has been slow, with less than 1861[1] MW installed as of September 2017. While growth rates are high, this is from a virtually non-existent base, and at the current trajectory, India will fall far short of the 40 GW target by 2022. This is despite significant policy incentives at the national level (30% capital subsidy) and at regional levels in terms of net metering/feed in tariffs.

Achieving the rooftop solar goal is in many ways more vital than the utility-scale goal, as distributed solar offers grid resilience, avoids AT&C losses and broadens the community of direct solar beneficiaries, all critical to building the energy system of the future. Greenpeace believes that much more needs to be done to educate consumers of the benefits of going solar, to smoothen bureaucratic wrinkles standing in the way of faster solar adoption and harness the power that states and distribution companies wield in support of India's ambitious solar goals.

Towards this end, Greenpeace India is launching a multi-city programme to spread awareness among residents and small business owners of the advantages of going solar. This report's analysis of the rooftop solar potential of Hyderabad and Chennai, conducted by GERMI, is a part of this effort. We hope the results, and the methods explained in the report, help spur a faster, deeper uptake of solar rooftops by citizens across India.

[1] *http://bit.ly/2DgReWX Bridge to India*

EXECUTIVE SUMMARY

This report is an outcome of a study that aims to compute the rooftop solar PV potential of the cities of Hyderabad and Chennai, India. The report is broadly divided into four sections. Section one is an introductory section that examines the current status of RTPV deployment in both cities. It also looks at the policy framework and the regulatory background in both states of Telangana (of which Hyderabad city is the capital) and Tamil Nadu (Chennai city). A key observation in both states is that the deployment of rooftop solar PV is lackluster despite existing policies and regulations that support rooftop solar. If deployment rates do not significantly increase, it is unlikely that that India's rooftop solar PV (RTPV) deployment target of 40 GW by 2022 will be met. Hyderabad and Chennai, by virtue of being Tier 1 cities, are representative of locations in India from where most demand for RTPV solar is likely to arise.

A much more fundamental question to be asked is whether India's cities can host the 40 GW target; or quite simply, "Are there adequate roofs on which 40GW of RTPV systems can be installed?". The second section develops a methodology to estimate the rooftop PV potential of Hyderabad and Chennai. Although the methodology relies on satellite imagery and land use maps that are unique to the cities, it can easily be replicated across other cities with a few minor modifications. The methodology uses freely available tools such as Google Earth, Google Maps, Wikimapia, etc. that are open source and accessible to all with an internet connection and a computer. This would aid other groups to quickly replicate this study for their own cities.

The third section reports the results of the assessment for both cities.

Key results:

Hyderabad: The total rooftop solar potential of the city is 1.73 GW.

- Buildings in Osmania University (Annexure IV) collectively have a potential of over 5,100 kW.
- The Begumpet and Rajiv Gandhi International Airports can house PV arrays with over 700 kW capacity.
- The city's railway stations have a solar PV potential of about 3,187 kW.
- All bus depots in Hyderabad can together host nearly 3000 kW of solar.
- All metro stations can host 679 kW.

Chennai: The total rooftop solar potential of the city is 1.38 GW.

- Railway station roofs can hold 3,582 kW
- Metro station roofs can hold 1,696 kW.
- Bus Depot roofs can host approximately 938 kW of solar PV.
- The Chennai International Airport can host approximately 889 kW of rooftop solar.

The results are reported (see Annexures) across each zone (or circle) of each city and across different consumer categories such as commercial, industrial, multipurpose use, public and semi public, residential, transportation and military buildings (only in the case of Hyderabad). The aim of classifying results by zones is to help local municipalities estimate their potential and engage with citizens to accelerate the rooftop PV revolution. The category wise classification would help potential developers and EPC[2] companies target their clients quickly. For the same reason, the largest contributors to the rooftop PV potential in the transportation sector (bus depots, railways, metro stations, airport) are listed out in the annexure. We hope that this level of granularity of results will aid policy makers, the industry and advocacy groups target the relevant audience and accelerate the deployment of RTPV in India.

Is India's 40GW solar rooftop goal feasible?

Finally, in the last section we look at what these numbers mean in the larger context of India's 40 GW solar rooftop goal. We compare these numbers with other rooftop potential studies carried out for the cities of Delhi, Mumbai and Patna. We also try to draw inferences based on urban patterns . Example:, "how much rooftop PV can a city hold?". Based on a thumb rule estimate of megawatt potential of RTPV per square kilometer, we estimate the potential of all tier 1 and 2 cities of India. We gauge that all of India's tier 1 and 2 cities can host over 62 GW of RTPV. Since it would be foolhardy to assume that the entire potential is realizable in the near term owing to a host of factors such as affordability, awareness and technical feasibility, we look at current adoption rates (i.e. number of roofs that have RTPV systems). We have sampled three neighborhoods in Germany and one in San Francisco to understand how many rooftops in a given neighborhood have RTPV systems installed. Our rudimentary analysis shows that this ranges from 5-24% of all roofs that have solar PV potential. It may be assumed that India's RTPV adoption rate in the near term would be far below that of such affluent neighbourhoods. Assuming an average adoption rate of 10% over the next 5 years, we are looking at a total installed solar PV capacity of about 6 GW by 2022 or so in Tier 1 and Tier 2 cities. A significant portion of the 40 GW by 2022 distributed solar target would therefore need to come from smaller towns, rural and semi-rural locations, grid connected solar pumps and other distributed solar applications, which might necessitate other incentivising schemes.

[2] *Engineering Procurement and Construction*

Solar Energy Trainees at Work in Lebanon.
© Fadi Gedeon / Greenpeace

INTRODUCTION

Importance of Rooftop Solar PV (RTPV)

The solar PV market in countries such as Germany has been driven primarily by rooftop solar PV (RTPV) systems. India's solar energy development pathway has been quite the opposite, with the country's emphasis mainly on utility scale solar such as large MW scale solar plants and even bigger solar parks. The rooftop solar PV segment in India has somewhat struggled over the years despite adequate incentives from the Government.

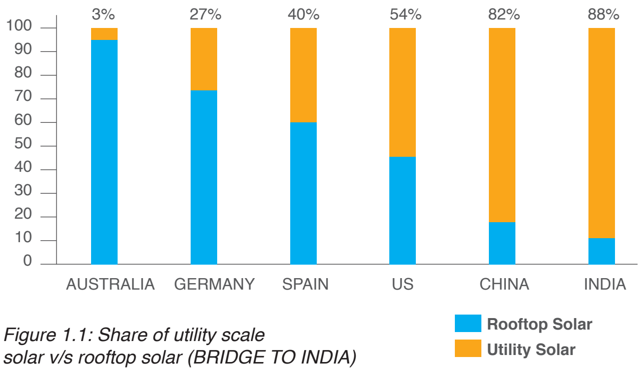


Figure 1.1: Share of utility scale solar v/s rooftop solar (BRIDGE TO INDIA)

The Ministry of New and Renewable Energy (MNRE) provides 30% of the capital cost of the RTPV systems as an upfront subsidy to the residential and educational sector. In addition some states like Gujarat provide an additional subsidy of INR 10,000 per kW (restricted to INR 20,000), while some other states like Karnataka provide attractive Feed-in Tariffs (FiT). Commercial and Industrial establishments can avail accelerated depreciation (AD) of 40% in the first year after commissioning the RTPV system. Additionally, Industrial and Commercial customers in most states are already paying higher electricity tariffs, providing a good financial incentive to meet at least a portion of their energy needs through RTPV. Despite these drivers, the uptake of RTPV in India has been rather slow (see figure below).

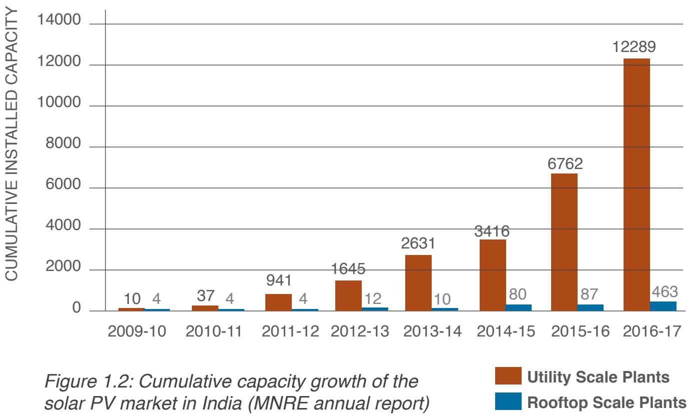


Figure 1.2: Cumulative capacity growth of the solar PV market in India (MNRE annual report)

There are broadly three reasons for the slow uptake of RTPV systems in India.

- **Capital Cost Constraints:** Despite the adequate subsidies being accorded to the residential segment, the capital cost of RTPV systems remain quite high. The cost ranges from about INR 55,000 per kW to about 70,000 per kW based on the quality of components used. For a average household of a connected load of about 3kW, this translates to INR 165,000 to INR 210,000 for the entire system. This is still beyond the reach of most families.

- **Conflict of Interest:** Every RTPV system must be permitted by the local Distribution Company (DisCom). However, installing a RTPV system will also ensure that the discoms revenue especially from some of its most bankable customers (industrial and commercial) is reduced. This represents a conflict of interest. Most DisComs delay the process, or in some cases even unofficially reject applications despite net metering regulations. In other instances, the policy provisions also limit the size of RTPV systems in order to limit the revenue loss for DisComs.

- **Customer Effort Barrier:** RTPV systems are unlike off-the-shelf power electronic equipment such as air conditioners and washing machines. They are highly customizable and site specific. This prevents equipment dealers and installers from quoting a single price per kW, which often leads to confusion among customers. Additionally, popular online retail portals do not sell ready to use rooftop solar systems, which makes a high entry barrier.

Despite these challenges, RTPV provides specific benefits to customers, discoms and the country as a whole apart from the known benefit of reducing greenhouse gas (GHG) emissions.

- **Benefit to DisCom:** Reduction in distribution and transmission losses.

  RTPV systems are located closer to the load than centralized power plants. This greatly reduces the transmission and distribution losses incurred along the grid. These losses are typically borne by the utility. Secondly, RTPV systems also help boost tail-end voltages which are prone to lag due to the length of some distribution feeders.

- **Benefit to the Customer:** Diversification of supply (energy security) and savings on power bills

  RTPV systems help customers (especially industrial and commercial customers) reduce their power bills. It also helps hedge against any future price rises. Rooftop systems when coupled with storage and/or generators also give a certain degree of security over the energy supply. This is especially true in areas that face significant power cuts.

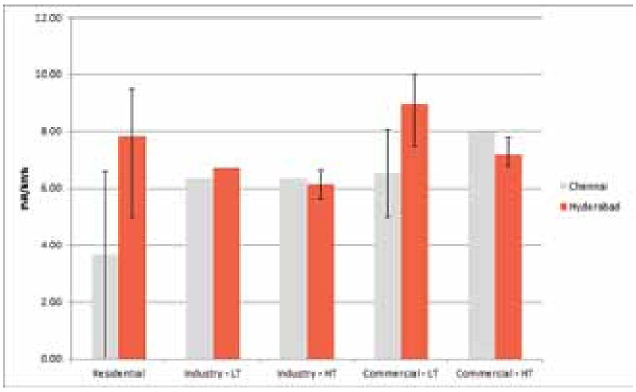


Figure 1.3: Summary of grid prices in Chennai and Hyderabad[3] [tariff orders]

- **Benefit to the Nation:** Job creation is far more significant compared to utility scale solar PV. Owning to the distributed nature of RTPV, it ensures that no single corporation or installer can corner the market. This leads to a much more distributed job generation profile across the country. Several studies have shown that the number of jobs created per MW from RTPV is 2.22 times higher than that of utility scale PV[4].

Need of the Report

Given the benefits of RTPV systems to India and the challenges being faced in deploying these systems across the country, it is important for the State and Central Governments to set time based targets. While MNRE has assigned targets to various states, there doesn't appear to be a traction and a seriousness in implementing these targets. It is equally unclear if these targets can actually be installed on the rooftops. Therefore the first exercise that needs to be carried out is a survey of the major cities of each state to ascertain whether the 40 GW rooftop solar target actually has adequate rooftops. This puts the target in context and provides a ceiling limit against which states, cities and even municipalities can plan RTPV deployments.

This report focuses on determining the rooftop solar potential of the cities of Hyderabad and Chennai. We hope that this would give policymakers precise scientific inputs that would enable realistic target setting. Further, the methodology developed in this report would help other groups assess the rooftop potential of other cities across India, which ultimately would help arrive at the rooftop potential of those cities. The report also provides a rough yard stick to assess the RTPV potential of all Tier 1 and Tier 2 cities in India.

Current RTPV Status of Hyderabad

Policy Support

The Government of Telangana announced its solar policy in 2015. Consumers are free to choose either net or gross meter for sale of power to the DISCOMs under this policy. This is an important policy clause, since it enables the adoption of third party investment (known as RESCO models).

The tariff applicable for units generated under gross metering at 11 KV and below would be average cost of service of the DISCOM as determined by Telangana State Electricity Regulatory Commission (TSERC). The tariff applicable for units under net metering would be Average Pooled Power Purchase Cost (APPC). Projects under both gross and net metering would be subject to monthly billing and settlement. However, no special FiT has been accorded to RTPV systems.

Regulatory Background

TSERC released its draft net metering regulations in 2016. The highlights of the regulation are:

- The capacity limits for rooftop based net metering range from 1kW to 1 MW
- RTPV systems of capacity greater than 75kW require special approval from the Central Electricity Inspectorate General (CEIG)
- Grid penetration limit is capped at 30% of distribution transformer capacity; which means that only 30% of all power at a transformer can come from net metered solar PV systems
- No grid connection voltages are mentioned in the regulation, which implies that the regulations mentioned in the state grid supply code shall prevail

On-ground Implementation

The implementation of net metering in Telangana is reported to be far smoother than Tamil Nadu. Both DisComs i.e. Telangana Southern Power Distribution Company Limited and Telangana Northern Power Distribution Company Limited are actively accepting and processing applications for net metering.

Current Status

The state of Telangana has a total installed rooftop solar PV capacity of 54 MW[5] by September 2017. The estimated installed RTPV capacity in Hyderabad is 34 MW (Bridge to India).

Current RTPV Status of Chennai

Policy Support

The Tamil Nadu Solar Policy was announced in 2012 and promotes the deployment of both utility scale and rooftop scale PV systems in the state. The state initially provided a Generation Based Incentive (GBI) for domestic consumers for a limited period of time until 2014, which has since then been rescinded. The policy also introduced net metering for commercial and residential establishments while conspicuously leaving out Industrial buildings - most likely to protect the interests of DisCom.

The connectivity voltages are given below[6]:

Solar PV System Size	Connection Voltage
< 10kWp	240 V
10kWp to <15 kWp	240/415V
15 kWp to < 100kWp	415 V
> 100 kWp	11kV

Table 1.1: Solar PV system connection voltages in Tamil Nadu

[3] Respective tariff orders from Telangana and Tamil Nadu
[4] CEEW-NRDC, "Filling the skill gap in india's clean energy market", february 2016. http://bit.ly/2yK7lss
[5] *http://bit.ly/2DgReWX The numbers includes both MNRE subsidized systems and unsubsidized systems.*
[6] *Tamil nadu solar energy policy 2012, Government of Tamil Nadu, http://bit.ly/1cvKbVv*

Regulatory Background

The Tamil Nadu Electricity Regulatory Commission (TNERC) officially released the order on "LT Connectivity and net metering in regard to Tamil Nadu Solar Energy Policy 2012" in 2013[7]. The highlights of the order are:

- Net metering is applicable to residential, commercial and government buildings only. Industrial consumers have been conspicuously left out.
- Electricity generated from RTPV system and injected into the licensee's grid shall be capped at 90% of the electricity consumption by the eligible consumer at the end of a settlement period. That is, no more than 90% of a consumers requirement can be met by RTPV systems.
- In the event that export of energy is greater than the import of energy, this shall be carried forward to the next billing cycle. The maximum carry forward is for a period of one year. Any excess energy at the end of the year shall be treated as void.
- Grid penetration limit is capped at 30% of distribution transformer capacity

The regulation also differs from the policy in terms of connection voltage for a particular system size (see table below). Such contradictions become bottlenecks and increases ambiguity for homeowners and investors.

Solar PV System Size	Connection Voltage
< 4 kW	240 V single phase OR 415 V three phase
>4 kW and <= 112 kW	415 V three phase
> 112 kW	At HT or EHT level

Table 1.2: Solar PV system connection voltages as per TNERC regulation

On-ground Implementation

The on-ground implementation of net metering in Tamil Nadu is sketchy. The Tamil Nadu Electricity Board (TNEB) recently filed a petition in TNERC of significantly overhauling the net metering regulation. The proposed amendments would adversely harm the market. It appears that TNEB is concerned of losing most of its high paying consumers.

Current Status

Tamil Nadu is a leader in the rooftop solar PV capacity with a total installed capacity of 163 MW[8]. The estimated installed RTPV capacity in Chennai is 38 MW (Bridge to India).

Photo voltaic panel installed at Elounda Sands Hotel, Crete.
© Greenpeace / Steve Morgan

[7] *TNERC. Order no. 3 dated 13.11.2013. http://bit.ly/2sWYS3t*
[8] *The numbers includes both MNRE subsidized systems and unsubsidized systems.*

METHODOLOGY IN ASSESSING RTPV POTENTIAL

This chapter describes the methodology and techniques followed in the rooftop photovoltaic (RTPV) capacity estimation for the cities of Hyderabad and Chennai. An emphasis is laid on using open source, freely available and user populated maps and Geographical Information System (GIS) software. In particular, the tools used for this study are Google Earth[9], ArcGIS[10], Wikimapia[11] and MyMap[12].

Land use maps determined by the local municipal corporations of both cities were used to classify areas of each cities into eight land use categories: residential, commercial, industrial, multipurpose, transportation, public and semi public, military and unconstructed or unfeasible lands. The land use classification data is generally not available in open source maps and therefore detailed land use maps from both Hyderabad and Chennai Municipal Corporations were used.

Greater Hyderabad

Description of Study Area

The study area selected for Hyderabad is the area under the jurisdiction of Greater Hyderabad Municipal Corporation (GHMC). The GHMC area is comprised of a total area of 625 square kilometers. The approximate geographical location of the area is in between the coordinates of 17°32' N - 17°17'N latitude and 78°19'E - 78°36'E longitude.

The area under GHMC is divided into five principal municipal zones - North, South, East, West and Central. Each of the above zones is further divided into administrative circles. There are a total of 18 circles in Hyderabad, which are further subdivided into a 150 wards. A ward represents the smallest unit of geographical abstraction for land use purposes. The figure below shows the area under GHMC, which is further classified into zones, circles and wards.

Figure 2.1: (A) Zones (B) Wards of the area under Greater Hyderabad Municipal Corporation

Figure 2.2: Circle divisions of the area under Greater Hyderabad Municipal Corporation[13]

Figure 2.3 : Layered map of GHMC jurisdiction, Osmania University and the area of available land use map (in blue color)

GIS Mapping methodology and Categorization

Identifying land use categorization is the first step in determining the RTPV potential of any city. Land use categorization is necessary in order to report potential across different consumer segments. There are eight primary land use classification that are used in this report. Residential, commercial, industrial, public and semi use, transportation, multipurpose use, military land and unconstructed space. The classification is closely allied to the categories of electricity consumers as suggested by State Electricity Regulatory Commissions (SERC). Knowing potential across specific consumer segments would aid policy makers and the industry to direct their efforts to those dedicated segments where the potential is sizable and where the uptake of RTPV systems are likely to be quickest.

In case of Hyderabad, there were no publicly available official GIS land use maps that could be used. However, there was a single land use map prepared by the Environmental Systems Research Institute (ESRI) and uploaded on the ArcGIS platform. This land use map is developed under the partnership of ESRI, MapmyIndia, United States Geological Survey (USGS) and The National Geospatial-Intelligence Agency (NGA) (see figure 2.4). The limitation of this map was that it did not cover the entire 18 circles of Greater Hyderabad and was only limited to seven inner circles of Hyderabad Municipal Corporation.

[9] *Google Earth, https://www.google.com/earth/*
[10] *ArcGIS, http://arcg.is/29DXfTY*
[11] *WikiMapia, http://bit.ly/2zQSKNa*
[12] *Google My Maps, http://bit.ly/2ePaTBI*
[13] *Greater Hyderabad Municipal Corporation, http://bit.ly/2gWpPDT*

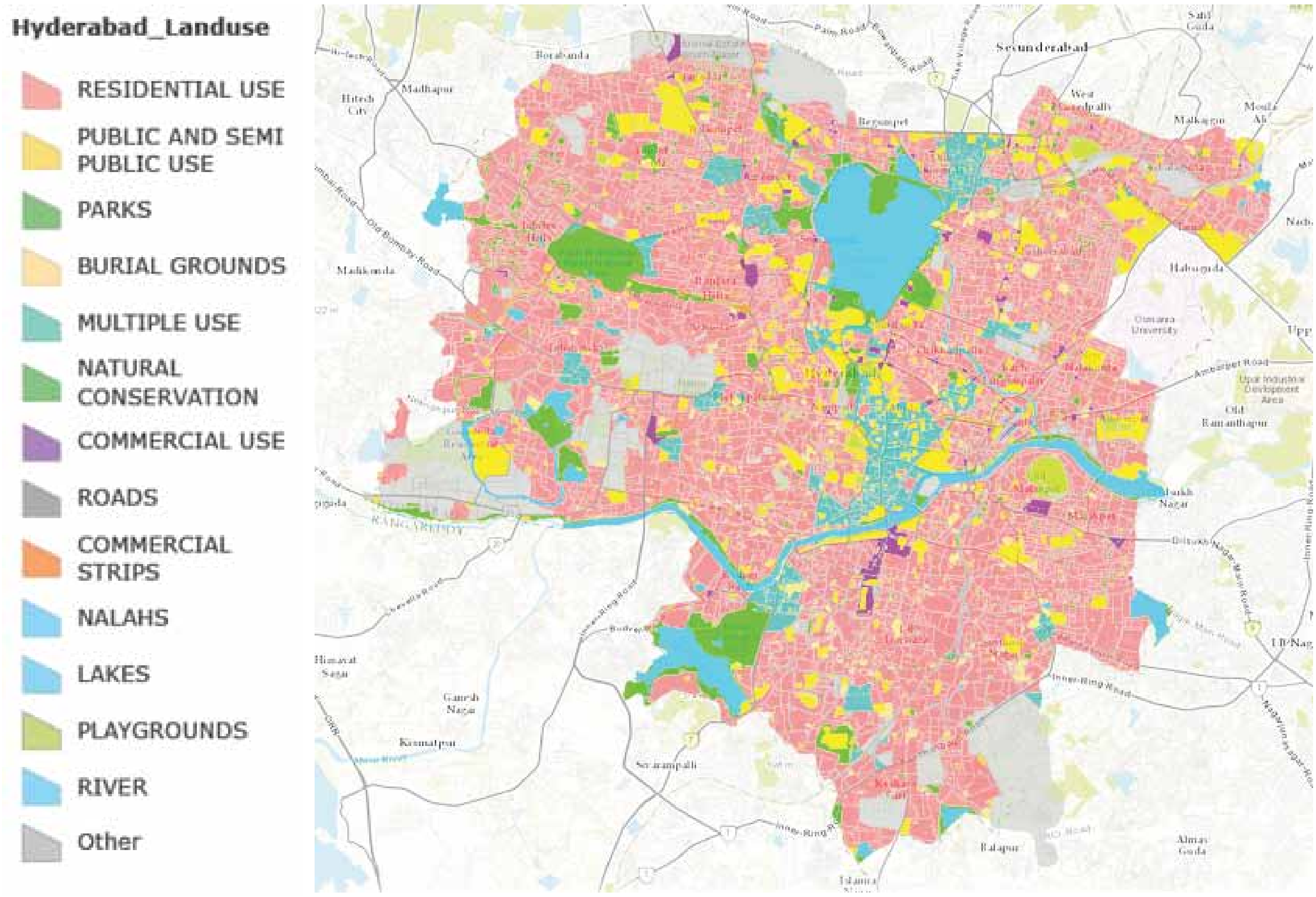


Figure 2.4: Land use maps of 7 inner circles in Hyderabad city available on ArcGIS [14]

[14] *Sainath Devi, ArcGIS, http://arcg.is/2ificVz*

Methodology used for estimation of RTPV potential of Greater Hyderabad

A four-fold approach was evolved to arrive at the RTPV potential from raw satellite imagery. The methodology is described in the image below.

STAGE 1:

LAND USE CATEGORIZATION AND MEASUREMENT OF PLOT AREAS

- Demarcation of boundaries of 18 circles & measuring total areas.
- Demarcation & measurement of individual plots within each of inner 7 circles.
- Discarding unusable areas.
- Segregation of all measured plots into land use categories across 7 circles.

STAGE 2:

SAMPLING OF SELECTED PLOTS

- Selection of samples.
- Measurement of solar feasible areas.
- Compute ratio of solar feasible area to total plot area.
- Arrive at average sampling ratios to compute solar feasible areas under 7 circles.

STAGE 3:

EXTRAPOLATION OF DATA FOR REMAINING CIRCLES

- Measurement and elimination of unconstructed areas under 11 circles.
- Compute average percentage covered area of each category using previous data from 7 circles.
- Modify the land use data and solar feasibility data based on visual assessment using labels from Google Earth/Maps/Wikimapia
- Applied sampling ratio on the constructed areas of remaining eleven circles.

STAGE 4:

CALCULATION AND RESULTS

- Calculate, categorize and analyze RTPV potential.

Stage 1: Land categorization and measurement of plot areas

Circle Boundaries

To begin with it is necessary to draw the boundaries for all 18 circles which helps one arrive at the total geographical area for each circle. This forms the basis for measurement of potential rooftop areas across the circles. These boundaries and the subsequent area measurements were made in Google Earth Pro by using GHMC jurisdiction maps as a reference.

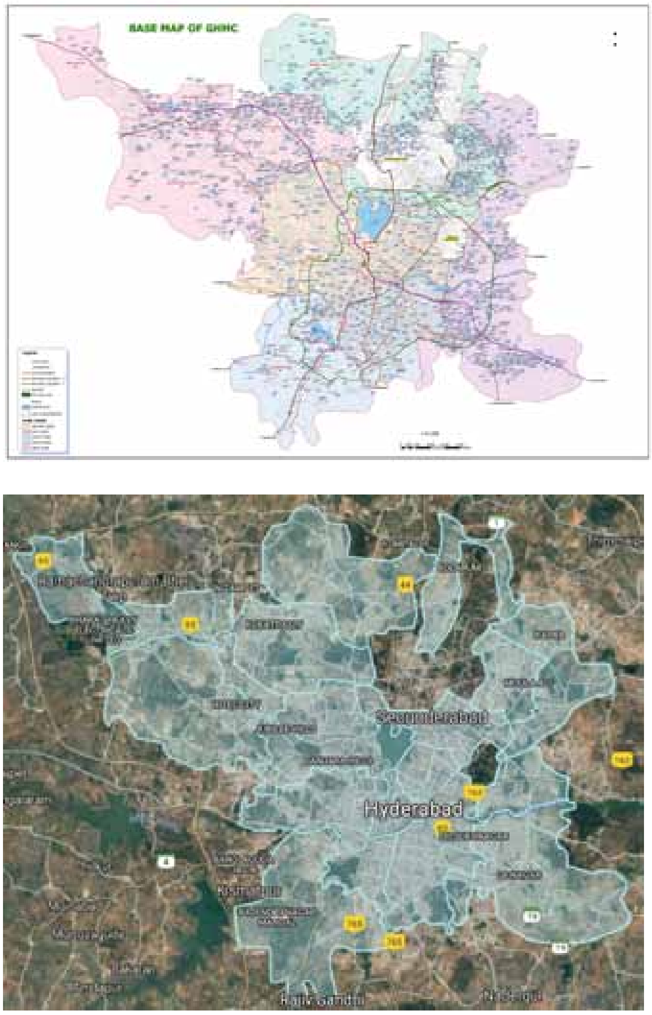


Figure 2.5: (A) Reference political map of GHMC jurisdiction[13] (B) Drawn respective GIS map

Land use segregation and plot area measurement

Having demarcated all 18 circles, the next stage is to categorize the land areas (or plots) according to various land utilization purposes. A plot in a map is a dense cluster of buildings which belongs to a same land use category. It may include open spaces within a building (i.e. garden, pool, balcony, parking space etc.) and spaces between buildings (i.e. periphery walls, trees, small streets etc.). It is therefore important to exclude these unconstructed areas in the first instance. However, the term 'unconstructed area' can be ambiguous. It can include, agricultural land and waste land where no activities are taking place. It can also mean areas that are intentionally planned as open spaces such as parks and playgrounds. It could also refer to areas within a plot that are 'unconstructed'. Examples include inter-building spaces, roads and offset from the road. In order to maintain a consistent meaning to what 'open spaces' really are, we classify them into three categories:

- **Type 1:** Plot unconstructed areas (such as compound spaces, balcony, garden, swimming pool etc.)
- **Type 2:** Planned unconstructed areas (such as roads, nalahs, small parks, playgrounds, road intersection etc.)
- **Type 3:** Open spaces (such as agricultural, reserved forests, large parks, forests, farms, lakes, burial grounds, natural conservation, recreational lands, rivers etc.)

Throughout this report, when we discount unconstructed area, then we refer to Type 3. Our aim in arriving at a usable solar feasible area is to judge 'how many feasible roofs does the city hold?'. Areas where we expect no roofs (like parks), we can safely discount away in the first instance. Once discounted, for the remaining area, we could begin to classify them into different plots.

The ArcGIS map of Hyderabad consists of a total of 8,887 number of plots across seven interior circles of the city of Hyderabad. The map in ArcGIS has a total of 22 land use categories. Not all these 22 categories are immediately relevant to the power sector consumer category classification. Therefore, these categories had to be reduced to a total of eight categories for the purpose of study. The land use categories adapted to this study are listed below.

Categories addressed by ArcGIS	Categories Taken As	Building Sets Includes
Residential	Residential	Residential colonies, bungalows, flats, apartments etc.
Commercial Commercial Strips Parking Lots	Commercial	Commercial offices, shops, markets entertainment, hotels, restaurants, resort clubs etc.
Workcentre Use	Industrial	Small/medium manufacturing facilities, refineries, production factories, power plants etc.
Public And Semi Public Use Parks Playgrounds	Public and semi public	Governments offices, schools, hospitals, religious places, tourist places, public sports facilities, public art/entertainment facilities, utility facilities etc
Railways Railway Land Bus Depot Airport	Transportation	Bus depots, railway platforms, railway offices/residences, railway/bus workshops, metro properties, airports etc.
Multipurpose use	Multipurpose use	It includes the lands, which are used by two or more previously mentioned category buildings together in random fashion.
Military lands	Military lands	Area under the boundaries of Indian armed forces. It includes their training lands, offices, residences, educational buildings, hospitals etc.
Burial Grounds Lakes Nalahs Natural Conservation Notified Heritage Buildings River Roads Other Rocks	Unconstructed/ Infeasible (type 2 and type 3)	Burial grounds, lakes, nalahs, natural conservation area, notified heritage buildings, rivers, roads and other open spaces.

Table 2.1: 22 Categories narrowed down to respective 8 categories

The measurement of the areas of 8,887 available plots was done using the online tool of ArcGIS map viewer. Using this tool one can see the whole land use maps of Hyderabad at once with its legends and description table of each plot. There are various base maps available here from which the IMAGERY base map was used in this process. The user interface of the tool is shown in the figure below.

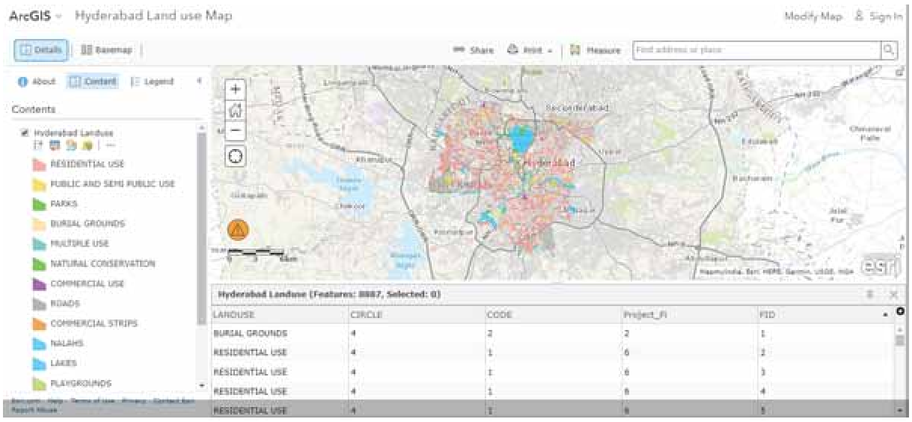


Figure 2.6: The window and tools of ArcGIS web viewer with Hyderabad land use map

However, the corresponding table within ArcGIS does not contain the individual plot areas and this data was not automatically retrievable. Therefore each plot had to be individually and manually measured with the available tools on ArcGIS map viewer. These plots could be filtered out by their circle number, Field Identity (FID)[15] as well as their land-use category using "Filter" tool as shown in the picture below.

For example, in order to find the plot with the FID number 5675, one has to go to "Filter" select FID from drop down list, select search by VALUE and enter value 5675. This procedure is described in figure 2.7. By clicking "APPLY FILTER AND ZOOM TO" the imagery will be directed to the plot under consideration.

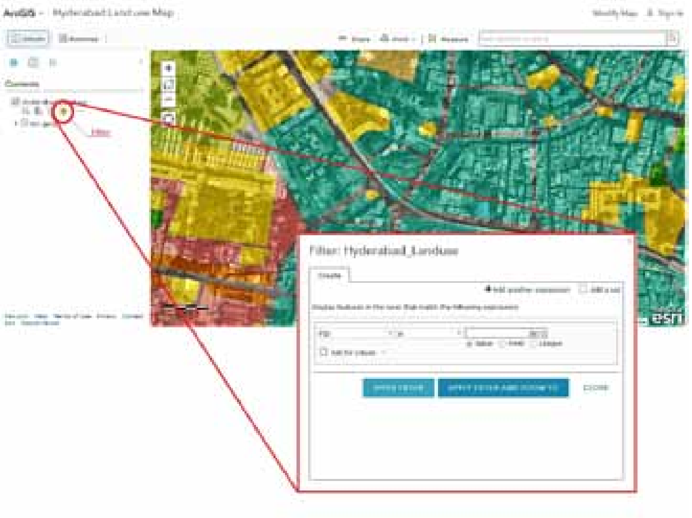


Figure 2.7: Use of filter tool to find plot in ArcGIS

[15] *A Field Identity is a unique number ascribed to each of the 8887 plots of seven inner circles of Greater Hyderabad Municipal Corporation*

Subsequently, the MEASURE tool box can be used to assess the distance, area and latitude-longitude. This area tool is used to measure the individual plot areas. The previous example of selected FID 5675 is shown in the figure 2.8 to demonstrate the boundary demarcation process.

From the figure 2.8, It is unusual to notice that the colored plot is a little shifted from the actual plot boundaries. There are numerous plots the were either shifted from their locations or their direction was tilted. Therefore the areas were measured around the actual plots.

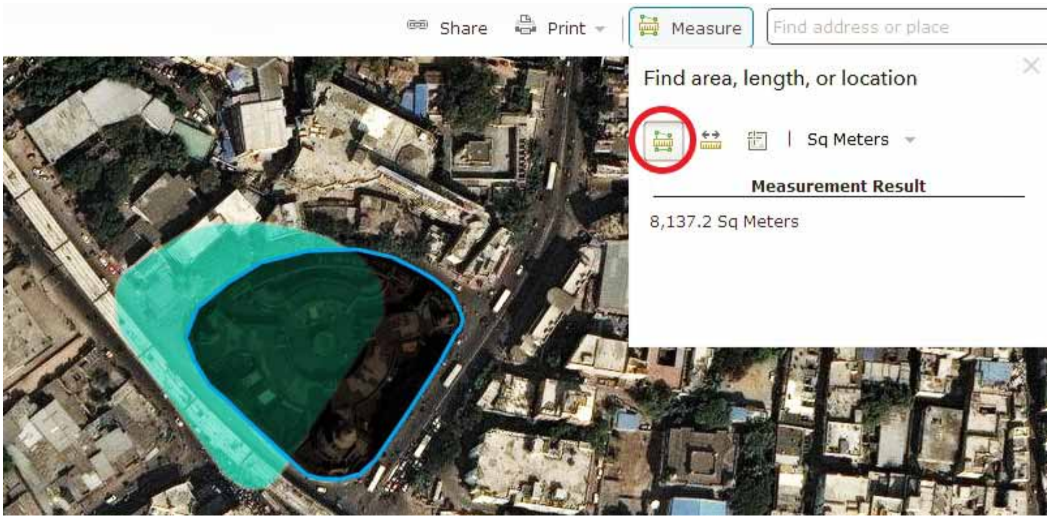


Figure 2.8: Measure tool and demarcation of polygon around the actual plot on basemap

Using the filter and measurement tools, all 8887 plots were measured and categorised. As mentioned in the previous table, there are multiple land use categories which belongs to unconstructed and/or infeasible areas. This implies that the measurement of area for these kind of plots is pointless. Therefore those plot which belongs to the categories of burial grounds, lakes, nalahs, natural conservation, notified heritage buildings, river, roads and other rocks were eliminated from the area measurement process.

The entire data of independent plots was accumulated in an excel sheet with their corresponding land use category, FID Number, plot area and circle number. The below table shows a small segment of the data sheet.

Land Use Category	FID No.	Plot Area (sq. m)	Circle No.
Residential	5670	335,770	.5
Commercial	5671	0	5
Residential	5672	11,021	5
Residential	5673	6,200	6
Commercial	5674	0	6
Multipurpose use	5675	8,137	6
Public and semi public	5676	0	6
Parks	5677	0	5
Natural Conservation	5678	0	5
Public and semi public	5679	2,300	5
Public and semi public	5680	61,510	6
Public and semi public	5681	106,358	5
Public and semi public	5682	0	6
Multipurpose use	5683	61,477	6
Public and semi public	5684	0	6
Residential	5686	646	5
Public and semi public	5687	624	5

Table 2.2: Land use categorization and classification of plots

Stage 2: Sampling of selected plots

After obtaining the geographical areas of individual plots, the next stage is to know the extent of rooftop area that is feasible for the installation of a solar PV system. Given the fact that there are millions of constructed buildings in Hyderabad, it is not physically possible to measure each of these buildings manually to obtain the shadow free area.

Stratified random sampling

To overcome this problem, stratified random sampling (SRS) is adopted which comprises of sampling specific areas of the city to arrive at the solar rooftop feasible area. The goal of the sampling process is to arrive at a ratio of solar feasible area to plot area. This ratio is referred to as the **solar feasibility ratio**.

$$\text{Solar Feasibility Ratio} = \frac{\text{Solar Feasible Area}}{\text{Plot Area}}$$

A sample plot is a part of a large cluster of many plots. A perfect sample plot is a representative plot of its category (i.e. Residential, Commercial, etc.) across the entire circle. Sample plots in each category helps one arrive at a ratio of the solar feasible area on the rooftop to the overall plot area. This helps to understand that, "how much of a particular development area is suitable for solar installation". Samples are taken across different land use categories since the built up area pattern for Commercial establishments are very different to that of say residential plots. For any particular land use category (ex: residential) most of the properties remains same as their ratios remains same. Therefore these solar feasibility ratios can be extrapolated to arrive at the total solar feasible area for the same land use category. The accuracy of the solar feasibility ratio is dependent on the the number of samples taken across the same land use category.

A data cluster is a set of data which represents similar properties within its group. From the database of plot area and land use category, we have the data of 7 land use categories from 7 circles. That means 7 plot data clusters (category-wise) can be created from each circle. Using SRS, selected samples from a circle can be used for extrapolation inside the boundaries of that corresponding circle only. It was decided to take 10% of the plots as samples from each category of each circle, restricted to maximum of 10 samples from each category of each circle. This brings to around 250 samples from all the available circles o Hyderabad. The key question though is, "are these samples adequate?". To answer this, we increased the number of samples for each category and did not observe any significant change in the solar feasibility ratio.

Solar feasible area

Taking and processing 250 individual samples requires a considerable amount of manual work. Therefore a team of 16 students was formed to perform the task of sampling. The team comprised of students from Pandit Deendayal Petroleum University in Gandhinagar, Gujarat. The students were divided into teams of two each and selected sample plots were allotted to them by respective FIDs[16]. The work is carried out online using google drive and various google sheets. The procedure followed is described below:

Procedure followed for solar feasible area measurement

01 **Search for "Hyderabad land use map ArcGIS" and open the web link from ArcGIS website.**

02 **Click on "Open in Map Viewer". A GIS map of Hyderabad will come up.**

03 **Go to "Content" > "Filter" Icon.**

04 **Search for the given sample FID number by value and apply the filter with zoom to it.**

05 **Copy the latitude and longitude of the respective plot from ArcGIS and paste it in the search bar of Google Earth.**

The previous example of FID number 5675 is shown below to represent the steps taken in obtaining the latitude-longitude of the plot from ArcGIS and reaching to the same point on Google Earth.

Figure 2.9: Obtaining the latitude and longitude from the plot in ArcGIS

Figure 2.10: Arriving at the location of the selected sample on Google Earth

Figure 2.10 shows the user interface with the dialogue box of the placemark that represents a given lat-long coordinate. The use of some the major tools on this software is demonstrated in the forthcoming parts of this report.

06 **Draw main plot boundaries:**

a) Click on "Add Polygon" button on top toolbar.

b) Go to "Style,Color" section and update it as below.

c) Line Color : White *Width: 2* *Opacity: 100%*

d) Area Color : White *Filled+Outlined* *Opacity: 0%*

e) Without Clicking ok, start plotting the boundary.

[16] *Each FID is a unique number that identifies an individual plot area of Hyderabad.*

From the points mentioned above, it can be noticed that a polygon can be customized to a very high degree. The color of the boundary line of the plots was chosen as white with a width of 2 units. The opacity of the area must be set to 0%, so that the internal polygons can be drawn easily. The formatting of boundary demarcation of the sample polygon is shown in the figure 2.11.

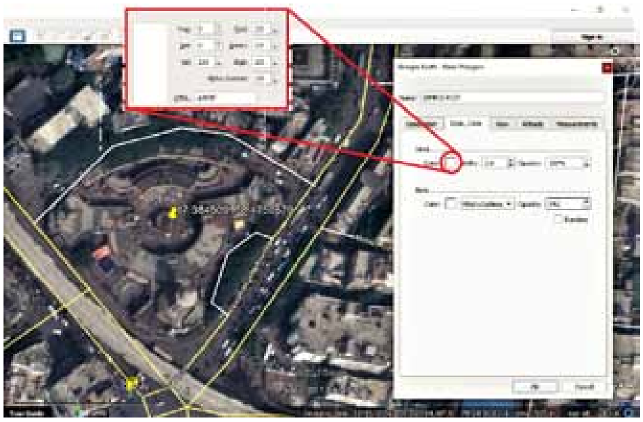


Figure 2.11: formatting of line and area color for the main plot

As the first three points of polygon are marked on the map it starts showing the area under the polygon in the measurement section of dialogue box. The area measurement unit used here is in square meters only. Once the whole boundary of the plot is marked, it shows the total area of the plot. This area is then written in the description section of the dialogue box for record and future use. The boundary demarcation and area measurement of the sample polygon is shown in the figure below.

Figure 2.12: Area measurement and accounting after main plot demarcation

07 Draw solar feasible area boundaries:

a) Click on “Add Polygon” button on top toolbar.

b) Go to “Style,Color” section and update it as below.

c) Line Color : Green (R,G,B = 0,255,0)
Width: 2 *Opacity: 100%*

d) Area Color : Green (R,G,B = 0,255,0)
Filled+Outlined *Opacity: 20%*

e) Without Clicking ok, start plotting the boundary.

f) After plotting each one of solar feasible area, Go to “properties”>“Measurements”>choose “square meters” in area and copy that value past it to “Description” section

The above steps shows the procedure to obtain solar feasible area in a sample plot. The procedure of design and measurement remains the same flow as mentioned in the step 6. But the colors and designing formats are changed to show the differences. Green color is used for the boundary lines as well as for the area fill color. Opacity is set to 20% to show the only areas on the rooftops which are feasible for installation of solar PV systems.

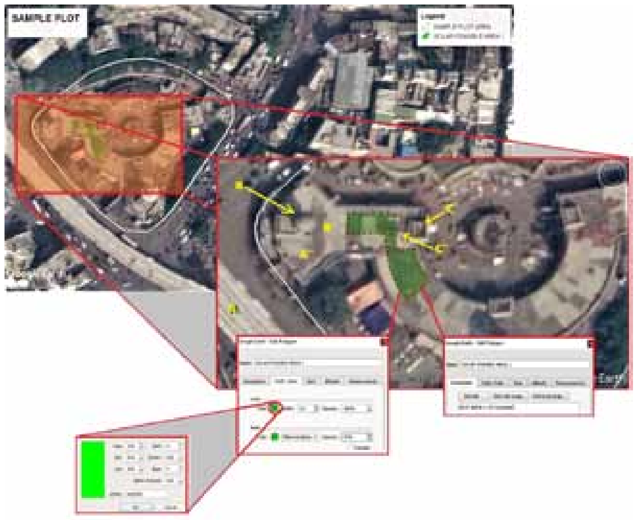


Figure 2.13: Solar feasible area measurements of sample plots

From the figure 2.13, it can be observed that a polygon drawn for the solar feasible area is selected after leaving out a considerable area that is unfeasible for solar. These are the following points considered in the process of selecting the solar feasible area:

- Keep the north direction of the basemap pointing to the top of the screen. This is done to ensure the geographical bearings are proper.
- Select one rooftop of a building at a time and have a proper look at the obstacles on/near the roof.
- Most commonly encountered obstacles are water tanks, pillars, periphery walls, staircase room, AC ducts, ventilation systems, adjacent tall buildings, towers, trees etc.
- It is important to identify the type of obstacle, so that its dimensions can be estimated. Sometimes it is hard to understand the type of the obstacle or their height using the top view of Google earth. In that case it was recommended to the team members to refer the same location and building on Wikimapia and Google maps for better understanding. It was found that the pictures of the location taken on different location may differ by their angle of shot, picture clarity and time.
- As the location of Hyderabad is in the northern hemisphere of the earth, the solar modules always faces in the south direction for optimum generation. Hence only the south face of a sloped rooftop in considered as feasible area.

- The overall intensity of solar irradiance on the north facing slope always remains lower than the south facing slope. East and west facing slope gets direct irradiance only for the half of the time from the total sun hours.

- As the sun moves from east to west (with respect to earth view), the shadow moves from west to east. The movement of the shadow goes from a little north direction due to the location of the city in northern hemisphere.

- The length of the shadow considered for a shadow analysis is upto 3 times the height of obstacle in the directions of east and west. For the north direction, a 1.5 times the height of the obstacle is usually considered. Therefore the spaces are left unconsidered for the feasibility accordingly.

A single polygon for solar feasible area is demonstrated in the figure 2.13 above. It can be observed that the there are three obstacles around that polygon, which can cast shadows on the roof. Obstacle A is the traffic over bridge passing near the building and it can cast its shadow on the A" part of the roof. Obstacle B is a tower like structure which leaves its shadow on its north and east part of the roof after the noon time. Therefore the area B" was left as unfeasible. By the same approach, obstacle C leaves its shadow on the area C". It may be noted that this is a highly conservative approach to shadow analysis. In reality some PV designers may choose to tolerate a certain amount of shadow.

Figure 2.14: The completed single solar feasible area under green polygon

The area of the polygon was noted down in the description box as shown in the figure 2.15. This description data can be referred once again from the panel in the right side of the window named 'Places'.

The method is repeated for that whole rooftop and any other buildings that may come under that plot. There were 6 different polygons drawn for the purpose:

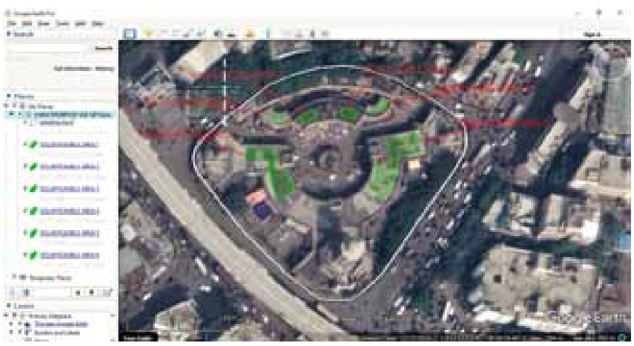


Figure 2.15: Solar feasible areas under green polygons

08 **To Save the file:**

a) See the right side of the screen for the hierarchy of your drawn plots named as "Places".

b) Right click on the parent earth file in the section. Click on "Save Place As…".

c) Save the Name of the file as below format:
<Circle Number><space><CATEGORY NAME><space><FID Number>
Example: 6 Multipurpose use 5675

09 **Upload the file into respective google drive folder of respective group.**

10 **Fill the data in the google spreadsheets named 'Sampling Results', which includes: circle number, Land use category, sample FID number, plot area, solar feasible area and feasibility ratio.**

Solar Panels in Dharnai Village in India.
© Ravi Sahani / Greenpeace

The table below shows the sampling process for circle 6 of Hyderabad. The last column named 'ratio' indicates the solar feasible ratio. The row highlighted in blue is the sample plot selected for the purpose of demonstration in this chapter i.e. FID 5675.

Circle No.	Land Use Category	Sample FID No.	Plot Area	Solar feasible Area	Ratio
6	Commercial	5628	6,806	852	0.125
		5860	2,817	431	0.153
		5988	8,406	1,521	0.181
	Industrial	5691	15,219	5,204	0.342
	Military lands	N/A	N/A	N/A	N/A
	Multipurpose use	5319	11,611	2,007	0.173
		5460	6,346	1,397	0.220
		5586	5,259	1,362	0.259
		5675	8,877	1,280	0.144
		5689	7,654	1,814	0.237
		5869	3,477	985	0.283
		5958	6,027	1,132	0.188
	Public and semi public	5233	3,197	464	0.145
		5282	6,269	604	0.096
		5346	9,609	993	0.103
		5400	7,818	926	0.118
		5525	7,903	1,219	0.154
		5561	3,500	1,090	0.311
		5657	2,630	172	0.065
		5,889	4,939	479	0.097
		5,927	3,576	313	0.088
		5,959	5,059	327	0.065
	Residential	5266	7,356	594	0.081
		5338	6,841	656	0.096
		5414	5,557	1,030	0.185
		5673	6,200	365	0.059
		5765	5,627	861	0.153
		5816	4,332	444	0.102
		5979	9,511	318	0.033
	Transportation	N/A	N/A	N/A	N/A

Table 2.3: Category wise solar feasible area data accumulation and the sample ratios of plots under circle 6

The process was repeated for all the selected samples and a sample map of Hyderabad was formed (see image below).

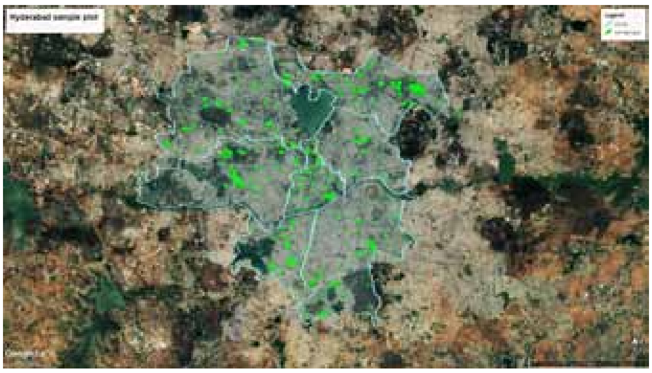


Figure 2.16: Depiction of 250 sample plots under 7 circles

Solar feasible area estimation in the seven circles

Referring to the above data table 2.4, it can be observed that the the circle number 6 has many number of samples across nearly all the available land use categories. An average solar feasibility ratio was computed from the feasibility ratios under each category. This is used as a generalized ratio for extrapolation on the remaining plots of the same category in the same circle. This calculation gives the approximate solar feasible area (category wise) of the entire circle. Repeating the process on the available data of seven circles gives us the total solar feasible area.

Circle No.	Land Use Category	Total plot area (sq. m)	Percentage land covered %	Average feasibility Ratio	Solar feasible area (sq. m)
6	Commercial	104,063	2.51	0.1530	15,926
	Industrial	15219	0.37	0.3419	5,204
	Military lands	N/A	N/A	N/A	N/A
	Multipurpose use	1,774,009	42.84	0.2149	381,226
	Public and semi public	1,245,978	30.09	0.1243	154,933
	Residential	1,002,053	24.20	0.1014	101,614
	Transportation	N/A	N/A	N/A	N/A

Table 2.4: Category wise generalized ratios and solar feasible areas in circle 6

Stage 3: Extrapolation of data for remaining circles

Since the land use data was available only for seven circles of Hyderabad Municipal Corporation, but Greater Hyderabad Municipal Corporation consists of 16 circles, the land use patterns had to be extrapolated to the remaining nine circles.

Unconstructed area

At the first instance and on similar lines to the seven inner circles, it was decided to eliminate the unconstructed and infeasible land areas (type 3) from consideration. Using the GIS map developed previously, the area of individual circles was measured. The unconstructed area belongs to type 3, which includes large parks, forests, farms, lakes, burial grounds, natural conservation and rivers. These does not include the unconstructed areas of type 2 and type 1 (such as roads, nalahs, small parks, playgrounds, road intersection, garden, swimming pool, porch, compound space etc.).

Measurements of type 3 unconstructed area (without its land use map) can only be done manually. Therefore all of the visible type 3 unconstructed areas were mapped for the eleven circles individually.

Figure 2.17: Type 3 Unconstructed areas that were eliminated for the remaining 11 circles

The total measurement of type 3 unconstructed area from 11 circle arrived to be 238.37 sq. km. From the above figure 2.17, it can observed that all of the initial seven circles were located in the middle of the city. The remaining eleven circles are spread at the outskirts of hyderabad city. Moving from the middle to the outskirts of the city, construction density reduces and the sizes of unconstucted areas increases. This exercise gives the circle wise constructed areas on which the extrapolation is to be performed.

Modification in the data of land use areas and feasibility ratios

The percentage of land area that was built up (across different land use categories) was calculated earlier (refer the table 2.4 for example) in all 7 circles. A mean percentage of individual category under each of those circle gives an understanding of relative category distribution. These mean values can be used for estimation of land distribution (category-wise) in remaining circles.

Identically, the category-wise average feasibility ratio was calculated earlier for all 7 circles. Again a mean feasibility ratio of individual category under each of those circles was computed. These mean values can be used for estimation of solar feasibility ratios (category-wise) for the remaining circles.

But moving towards the outskirts of the city, the land used distribution also changes. For example the residential, public & semi public places, military lands and transportation use lands reduces. On the other side land is more used for Industrial and Commercial purposes.

A visual analysis on google earth, maps and wikimapia was conducted to make some modification in the the generalized percentage land use area distribution and the solar feasibility ratios. In general, the land use areas were either increased or decreased based on a visual inspection of the land use of the remaining circles. In case of the solar feasibility ratio, it was decreased by 10% uniformly. The 10% number came from measuring a few sample plots in the outer periphery. It was observed that the solar feasibility areas reduced due to the fact that there was much more open space within plots.

Landuse	Percentage Improvement in Average land use Area	Percentage Improvement in Average feasibility Ratio
Commercial	+10%	-10%
Industrial	+20%	-10%
Military lands	-70%	-10%
Multipurpose use	0%	-10%
Public and semi public	-8%	-10%
Residential	-15%	-10%
Transportation	-55%	-10%

Table 2.5: Category wise data modification to use it in extrapolation

Solar feasible area estimation in the eleven circles

Having modified both the land use areas and the solar feasibility ratio to account for changes in land use pattern for the outer nine circles of Hyderabad, an extrapolation was performed on the remaining nine circles. This gives the solar feasible area of individual land use categories in each circle. Using the same method, the modified solar feasibility ratio is applied to the respective category land area. This results into the final numbers of solar feasible area and therefore rooftop PV potentials across different circles and across different land use categories.

The previously calculated data of land use areas and average feasibility ratios from the inner seven circles is replaced with the new modified data respectively, which can be extrapolated on the total constructed plot areas of individual circles.

Greater Chennai

Description of Study Area

The study area considered for Chennai is the area under the jurisdiction of Greater Chennai Corporation (GCC). Prior to 2011, the city occupied an area of 174 square km which is named as Chennai Corporation. After 2011, it was expanded to include 42 local bodies which resulted in a doubling of land area. It was renamed as Greater Chennai Corporation with the total area of 426 Square km. The approximate geographical location of the area is in between geological coordinates of 13°14'N - 12°51'N latitude and 80°8'E - 80°19'E longitude.

The city under Greater Chennai Corporation (GCC) is classified into three regions named North Chennai, Central Chennai and South Chennai . The area under these regions is further divided into 15 zones, consisting of 200 wards.

The size of a zone in chennai is roughly equivalent to the size of a circle in Hyderabad and has therefore been selected equivalent to a circle in the methodology that ensues. The 15 zones under GCC does not include the area of St. Thomas Mount. But for the purpose of this study we have considered it as an individual zone. Therefore this report covers a total study area of 16 zones in the forthcoming sections.

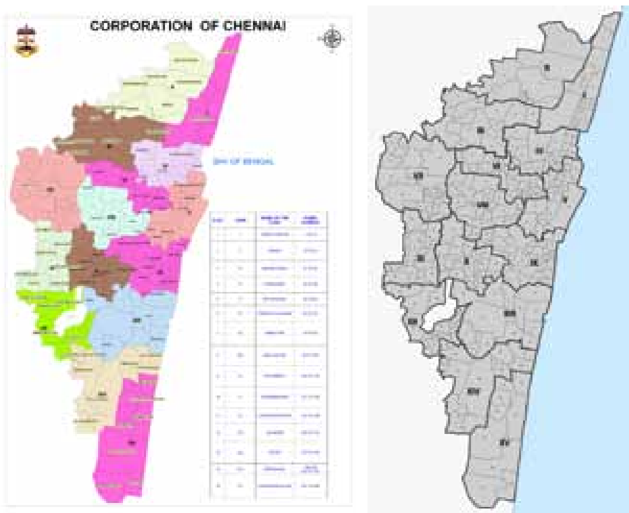
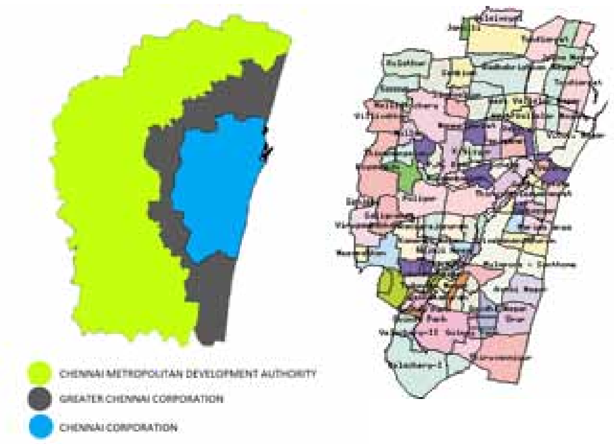


Figure 2.18: 15 zones and 150 wards under Greater Chennai Corporation[13]

[17] *Greater Chennai Corporation, http://bit.ly/2lfg599*
[18] *"More areas to come under Chennai Corporation", The Hindu, 30 December 2009. http://bit.ly/2ieuRlo*
[19] *"Expanded Chennai Corporation to be divided into 3 regions", The Hindu, 25 November 2011. http://bit.ly/2yVMWFl*
[20] *Ramakrishnan, Deepa H (20 September 2011), "Details of merged wards online soon", The Hindu. http://bit.ly/2yZOwUx*

GIS Mapping methodology and Categorization

The land use map for the city of Chennai were provided by Chennai Metropolitan Development Authority (CMDA) in PDF and JPEG formats. There are a total of 107 individual land use maps under the boundary of Chennai Corporation in CMDA jurisdiction. However, there was a need to verify if the CMDA maps in line with the boundaries of Greater Chennai Corporation (GCC) jurisdiction. GCC consists of total 16 zones including St. Thomas Mount. These 107 maps obtained from CMDA covered common land areas under CMDA and GCC. These boundaries correspond to the areas of CMDA's Chennai corporation as well as the inner 7 zones of GCC jurisdiction.



(A) (B)

Figure 2.19: (A) Layered map of CMDA and GCC jurisdictions with the common area for which land use maps were available (in blue)
(B) Common ward maps of Chennai Corporation between CMDA and GCC Jurisdiction[21].

The land use maps of remaining area under GCC were not available in a systematic format. Moreover, the external zonal boundaries of Greater Chennai as indicated by CMDA and GCC maps were not similar. However, the boundary of available 107 land use maps of Chennai Corporation was inline with the seven inner zones from the GCC map. So these maps were used as a basis for calculations and extrapolation.

Stage 1: Land Categorization and Measurement of Plot Areas

Zones boundaries

Similar to the study performed for Hyderabad, the boundaries were demarcated for all 16 zones (Including St. Thomas Mount). This gives the total area under individual zones including constructed and open spaces in it. A GIS map was created using Google Earth Pro for the above purpose considering the GCC jurisdiction map as reference.

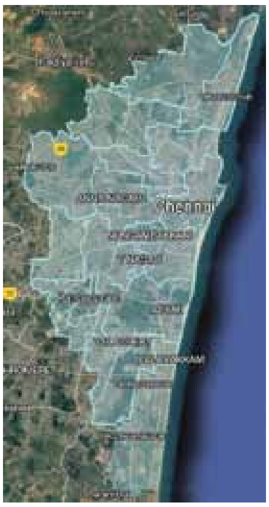


Figure 2.20: Zone wise 16 boundary demarcations (Including St. Thomas Mount) using Google Earth Pro

GIS mapping of land use maps, category segregation and measurement of individual plot areas

The first stage in the mapping process was to create a workable land use map on Google Earth. The seven available zones of Chennai had to be mapped into Google Earth. Appropriate boundaries for the seven zones were drawn using Google Earth as shown in the above figure. As mentioned earlier, the land use maps provided by CMDA are total 107 individual masterplan maps. These maps combinedly covers area of the inner 7 zones under GCC jurisdiction.

CMDA divided the land use data into total 18 land use categories. These 18 categories
were reduced to 7 categories for this study. The main purpose of doing this is to come up with only major land use categories that corresponded with the electricity regulator consumer tariff categories. Therefore the type of category was updated and new color codes were affixed as indicated in the table below.

Category given by CMDA	Category Considered	Color (R,G,B)
Commercial	Commercial	Blue (0,0,255)
Industrial Light Industrial General Industrial Special And Hazardous Industrial	Industrial	Purple (58,0,127)
Institutional	Public and semi public	Red (255,0,0)
Railways Bus Depots Airport	Transportation	Pink (255,0,255)
Mixed Residential	Multipurpose use	Green (0,255,0)
Primary Residential	Residential	Yellow (255,255,0)
Agricultural Reserved Forest Water Body Non Urban Open Space Recreational	Unconstructed/Infeasible (Type 2 and Type 3)	N/A
	If category requires to be changed	White (255,255,255)

Table 2.6: 18 Categories narrowed down to 7 categories

As an example, one of the land use map that was available in a PDF format is shown in the figure below:

Figure 2.21: CMDA land use map of Peravallur area

[21] *Chennai Metropolitan Development Authority, http://bit.ly/2z4cMqo*

Boundaries of plots under all 107 similar land use maps were demarcated, categorized and measured using Google Earth Pro. All the map files were given a Plot Identity (PID). All the data of independent plot was accumulated and segregated with their corresponding PID number, locality name, FID Number, land use category and plot area.

Some of mapped, categorized and measured data from Peruvallur area are shown in the table below for a map of PID 59:

Plot Areas of Chennai Corporation (Peravallur)				
PID No.	PID Name	FID No.	Landuse	Area
59	Peravallur	3115	Residential	79,289
59	Peravallur	3116	Residential	5,806
59	Peravallur	3117	Residential	9,665
59	Peravallur	3313	Public and semi public	3,388
59	Peravallur	3314	Public and semi public	11,536
59	Peravallur	3315	Public and semi public	1,240
59	Peravallur	3316	Public and semi public	7,676
59	Peravallur	3337	Industrial	62,487
59	Peravallur	3338	Commercial	2,433

Table 2.7: Data accumulated from the CMDA map of Peravallur area

Individual GIS files were created for all the maps. These files were merged together to create a single GIS land use map of total 6,257 plots:

Figure 2.22: Mapped and merged final land use map of Chennai corporation

Stage 2: Sampling of selected plots

Sampling methodology followed for Chennai Corporation is the similar to the method followed earlier for Hyderabad. The definition of sampling and reasons for performing this task was discussed earlier (in section 2.1.5) for Hyderabad city. The whole procedure of Stratified Random Sampling (SRS) was also described in that section. This process resulted in 160 samples from all the available zones.

Solar feasible area

According to the developed methodology a data set is required to be created for extrapolation. A total of 160 sample plots were selected for sampling. The procedure for sampling was on similar lines to that employed in Hyderabad and therefore is not repeated here.

A snapshot sampling data for the commercial category from different localities are shown in the table below:

PID No.	PID Name	FID No.	Landuse	Main Plot Area	Solar Feasible Area	Ratio	Aver-age Ratio
14	Annasalai Area Sh8	208	Commercial	4,219	217.4	5.15	
21	Azad Nagar Area	576	Commercial	3,419	191.8	5.61	
21	Azad Nagar Area	587	Commercial	5,774	369.3	6.40	
24	Chepauk	780	Commercial	5,054	1,100.2	21.77	
24	Chepauk	781	Commercial	3,142	313.7	9.98	
24	Chepauk	774	Commercial	7,618	131.6	1.73	
24	Chepauk	775	Commercial	4,109	320.6	7.80	
31	Egmore	1,166	Commercial	6,695	909.0	13.58	
38	Krishnampet	1,481	Commercial	3,992	214.0	5.36	
38	Krishnampet	1,480	Commercial	4,759	102.7	2.16	
41	Mylapore_santhome Ddp	1,611	Commercial	4,116	120.4	2.92	
47	Napier Park Ddp	1,886	Commercial	9,141	177.7	1.94	
52	Tondiarpet	2,408	Commercial	6,653	321.7	4.84	
55	Nungambakkam Ddp	2,671	Commercial	4,978	292.2	5.87	5.57
56	Nungambakkam	2,702	Commercial	5,401	164.1	3.04	
57	Perambur North Ddp	2,942	Commercial	6,309	82.8	1.31	
60	Periyamet Ddp	3,441	Commercial	3,586	224.4	6.26	
18	Ashok Nagar Ddp	337	Commercial	5,791	246.5	4.26	
64	Puliyur	3,594	Commercial	4,201	277.0	6.59	
74	Rangarajapuram	4,072	Commercial	4,643	127.9	2.75	
75	Saidapad Part 1	4,183	Commercial	6,685	72.1	1.08	
91	Kalaivannar Nagar	5,378	Commercial	3,419	193.0	5.64	
91	Kalaivannar Nagar	5,375	Commercial	5,906	436.1	7.38	
105	Jeeva Nagar	6,191	Commercial	6,729	182.3	2.71	
106	Nakkeerar Nagar	6,247	Commercial	6,209	195.3	3.15	

Table 2.8: Sample plot data of commercial category from different localities

Figure 2.23: Entire 180 sample plots under seven zones

Solar feasible area estimation in the seven zones

An average feasibility ratio was generated from the feasibility ratios under each category. This is used as a generalized ratio for extrapolation on the remaining plots of the same category in the seven zones. This calculation gives the approximate solar feasible area (according to different land use categories) under the entire seven zones

Stage 3: Extrapolation of data for remaining zones

Unconstructed area

Akin to the earlier section where the type 3 unconstructed land was discarded for our analysis, a similar process was adopted for the extrapolation process.

Using the zone wise GIS map that has been developed, the individual zonal areas were measured. The type 3 unconstructed area includes the categories of agricultural, reserved forests, water bodies, non urban, open spaces and recreational lands. These does not include the unconstructed areas of type 2 and type 1 (such as roads, nalahs, small parks, playgrounds, road intersection, garden, swimming pool, porch, compound space etc.).

Measurements of type 3 unconstructed area (without its land use map) can only be done manually. Therefore all of the major unconstructed areas were mapped for remaining nine zones individually.

Figure 2.24: Type 3 unconstructed areas under the remaining 9 zones

The total measured type 3 unconstructed area from 9 zones is 146.74 sq. meters. From the above figure 2.24, it can observed that all of the initial seven zones were located in the middle of the city. The remaining eleven zones are spread at the outskirts of Chennai city. As one moves from the central areas to the periphery of the city, the construction density reduces. Hence the sizes of unconstructed areas increases. This exercise gives the zone wise constructed plot areas on which the extrapolation is to be implemented.

Modification in the data of solar feasibility ratios

Category-wise percentage land covered area was calculated earlier for inner 7 zones. These values can be used for estimation of land distribution (category-wise) in remaining zones. Identically, a mean feasibility ratio from individual sample plots (under each category) was calculated for inner 7 zones. These mean values can be used for estimation of solar feasibility ratios (category-wise) in remaining zones.

Similar to the practice performed in case of Hyderabad, a visual analysis on google earth, maps and wikimapia was conducted, to make some modification in the the generalized solar feasibility ratios for individual categories. The reduction realized in the solar feasibility ratio was 10% of the previous solar feasibility ratio of the respective land use categories.

Solar feasible area estimation in the seven zones

Based on the modified solar feasibility ratio, the solar feasible area in sq.m. was computed for each consumer category. The RTPV potential for each zone across different land use category was computed based on this ratio.

Solar Panels in Dharnai Village in India.
© *Ravi Sahani / Greenpeace*

CALCULATIONS AND RESULTS

This section of the report describes the final results of the rooftop potential assessment study. The previous section arrived at a solar feasible area measured in sq.m. The RTPV potential in terms of installed capacity was calculated with an assumption that the area required for installing 1 kWp of photovoltaic system is 10 sq.m. This assumption considers the modules of typical efficiency values around 15%. The typical dimension of a 250 Wp multi-crystalline modules with the range of efficiency is 1.6 m x 1m. Hence 4 such modules will make a 1 kWp capacity system which takes around 6.4 sq. m. At an array level on roof mounted system, additional 50% area for inter array spacing is to be considered. Hence the total area requirement would be 9.6 sq. m (~10 sq. m).

Greater Hyderabad

Total area under each circle

The total area of Individual circles was measured manually by mapping the individual boundaries on google earth. The table 3.1, below shows the final measurements for all circles.

Circles	Total area (sq.m.)
Circle1	35,594,302
Circle2	14,907,249
Circle3	17,370,832
Circle4	31,726,988
Circle5	45,923,674
Circle6	8,786,579
Circle7	24,200,000
Uppal	17,165,093
Kapra	35,127,652
Kukatpally	43,085,469
Malkajgiri	19,421,464
Serilingapally North	28,927,140
Serilingampally South	65,453,582
Alwal	22,409,406
Patancheruvu	25,820,235
Qutubullapur	57,798,925
Rajendranagar	62,871,003
L.B. Nagar	67,861,934
Total area of Hyderabad city	624,451,527

Table 3.1: Total area (including all unconstructed areas) of individual circles

Localities under the seven circles

From the table above, it can be noticed that the first 7 circles were named by their circle numbers, but the remaining 11 circles were named by their location names. Therefore, to create a similar flow with these 7 circles, the names of their respective localities was identified. This also gives the ease of understanding the data on the maps and at the physical location.

Circles	Total area (sq.m.)
Circle1	Chandrayangutta, Charminar Saroor Nagar and Malakpet
Circle2	Jahannuma, Goshamahal and Falaknuma
Circle3	Musheerabad and Amberpet
Circle4	Mehdipatnam and Karwan
Circle5	Jubilee Hills, Khairatabad and Yousufguda
Circle6	Hill fort and ISKCON
Circle7	Begumpet and Lalaguda

Table 3.2: Name of locations under the circle

Plot areas under different categories

The data from land use map of Hyderabad (on ArcGIS) was referred to understand the land categorisation. Areas of 8887 individual plots was measured manually using the web tools of ArcGIS. The methodology for performing this task was discussed in the previous section.

Segregation of plots according to their respective category was executed to compute the total plot area of each category under 7 circles.

Land use category	Total plot area under 7 circles (sq. m.)
Commercial	2,215,699
Industrial	2,048,890
Military lands	2,951,585
Multipurpose use	8,970,829
Public and semi public	11,443,709
Residential	89,610,904
Transportation	971,462

Table 3.3: Plot areas of individual categories under first 7 circles

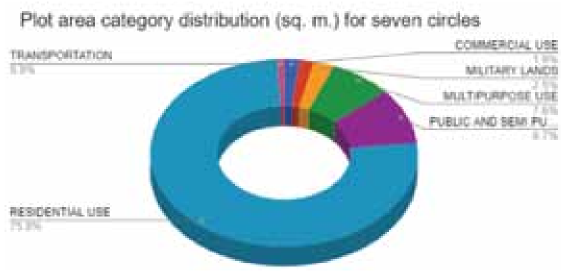


Figure 3.1: Plot area category distribution (sq. m.) for seven circles

Average solar feasibility ratios

The average solar feasibility ratio was computed based on SRS methodology outlines in the previous chapter. The results of the average solar feasibility ratios is tabulated below.

Landuse	Land Use[22] %	Average solar feasibility ratio
Commercial	1.87	0.1030
Industrial	1.74	0.1195
Military lands	2.51	0.0144
Multipurpose use	7.81	0.1036
Public and semi public	10.01	0.0751
Residential	79.22	0.0714
Transportation	1.04	0.0691

Table 3.4: Average land use area % and average feasibility ratio

[22] *Land Use % indicates the amount of sq.km covered by a particular land use category (ex: Commercial) divided by the total land area of the city (minus open spaces).*

Next, these the solar feasible area under the seven circles only is reported as a percentage of the total area (figure 3.2).

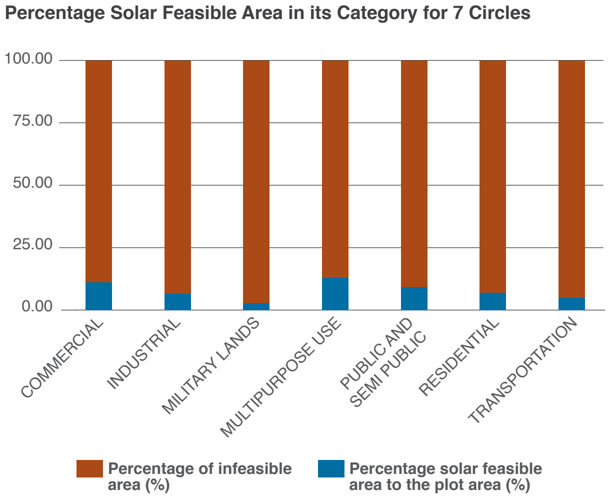


Figure 3.2: Share of solar feasible and infeasible areas (in %) for each category in Hyderabad.

RTPV potential under 7 circles

The RTPV potential across the seven inner circles of Hyderabad are listed below.

Circle No.	Solar RTPV Potential (MW)
Circle 1	102.22
Circle 2	266.64
Circle 3	90.01
Circle 4	41.85
Circle 5	52.44
Circle 6	65.89
Circle 7	46.15

Table 3.5: Solar RTPV potential of 7 circles

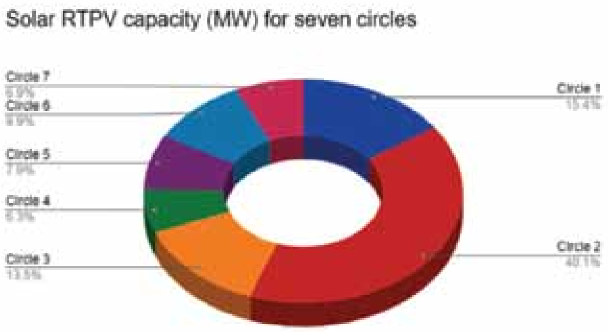


Figure 3.3: Share of solar RTPV potential (in %) for seven circles of Hyderabad

Unconstructed area measurements for remaining 11 circles (type 3)

The utilization of previous data for extrapolation can be done on the remaining eleven circles. But as mentioned in methodology, the type 3 unconstructed land in first seven circles was eliminated. Therefore it is imperative to filter-out type 3 unconstructed land area from the total area of these 11 circles.

The task was performed on Google Earth pro by mapping those plots manually in 11 circles. These plots either do not have construction on it or the solar feasibility in impossible due to obstructions.

Circles	Total area (sq.m.)	Unconstructed area (type 3) (sq.m.)	Plot area (sq.m.)	Percentage Plot Area (%)
Uppal	17,165,093	6,665,468	10,499,625	38.83
Kapra	35,127,652	13,328,659	21,798,993	37.94
Kukatpally	43,085,469	17,954,897	25,130,572	41.67
Malkajgiri	19,421,464	4,489,587	14,931,877	23.12
Serilingapally North	28,927,140	11,287,568	17,639,572	39.02
Serilingampally South	65,453,582	39,187,954	26,265,628	59.87
Alwal	22,409,406	9,578,769	12,830,637	42.74
Patancheruvu	25,820,235	18,198,547	7,621,688	70.48
Qutubullapur	57,798,925	29,635,478	28,163,447	51.27
Rajendranagar	62,871,003	35,587,659	27,283,344	56.60
L.B. Nagar	67,861,934	21,658,769	46,203,165	31.92

Table 3.6: Unconstructed (type 3) area measurements of 11 circles

Extrapolation of data for the remaining 11 circles

It was mentioned earlier that, in the measurements of external 11 circles, the larger open spaces of type 3 were eliminated from the total area under their boundaries. There for the area of type 2 unconstructed areas was not eliminated from it.

However, the available GIS Map from the inner 7 circle excludes unconstructed area of type 2 and type 3 both. In order to overcome this, the unconstructed area (type 2 + type 3) can be calculated by finding the difference between total area under these circles and the sum of plot areas. This results in 33.78% of the total area as unconstructed (type 2 + type 3) area. By a visual analysis, it was inferred that around 17.8% part comes from type 3 (large) unconstructed areas. Therefore the remaining 15% unconstructed area belongs to type 2 category.

To perform extrapolation, we need to reform the data of area from inner circles symmetrical to the data of external circles. That means it must include the area of type 2 unconstructed areas (15%) in its boundaries at the time of extrapolation.

It was described earlier that, as moving towards the outskirts of the city, the land used distribution also changes. For example the residential, public & semi public places, military lands and transportation use lands reduces. On the other side land is more used for industrial and commercial purposes. A visual analysis with the labels on google earth, maps and wikimapia is used to make some modification in the the generalized percentage land use area of each category. Similarly the generalized solar feasibility ratios for individual categories were also modified. These data updation is mentioned in the forthcoming section of this report.

Landuse	Average land use area (%)	Percentage Refinement	Modified Average land use (%)	Percentage Refinement	Modified feasibility ratio
Commercial	1.59	+10%	1.75	-10%	0.082
Industrial	1.47	+20%	1.77	-10%	0.096
Military lands	2.12	-70%	0.64	-10%	0.012
Multipurpose use	6.45	0%	6.45	-10%	0.083
Public and semi public	8.23	-8%	7.57	-10%	0.060
Residential	64.43	-15%	54.77	-10%	0.057
Transportation	0.70	-55%	0.31	-10%	0.055

Table 3.7: Data refinements for extrapolation in 11 circles

In figure 3.4 and 3.5 below, the comparative modification in the data can be observed. The percentage land use area increases for the plots of industrial and commercial establishments. It reduces for the plots of public and semi public, residential, transportation and military lands. The percentage land use area does not change much for the plot categories of multipurpose use.

Data Modification in Land Use area for Extrapolation

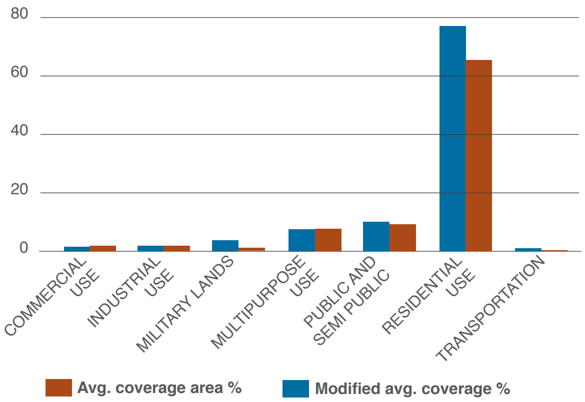


Figure 3.4: Data modifications in land use areas for extrapolation

Besides this, the construction density reduces toward the outskirts of the city. Therefore the distance between the nearby buildings also increases. It was observed that the plots area increases by a larger ratio then the increment in solar feasible area. This results in a reduction in the solar feasibility ratio. Therefore, the refinements in solar feasibility ratio is considered to be 90% of the average solar feasibility ratio (calculated earlier with 7 circles) for each category.

Data Modification in Feasibility ratios for Extrapolation

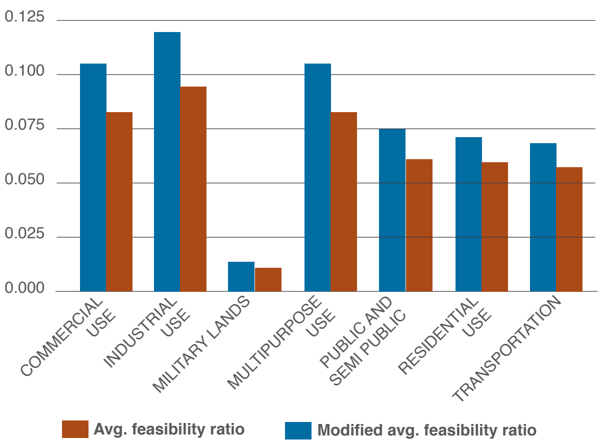


Figure 3.5: Data modifications In feasibility ratios for extrapolation

RTPV potential of Greater Hyderabad under GHMC jurisdiction

The modified data of percentage land use area and feasibility ratios is directly extrapolated on the construction area of 11 circles individually. This extrapolation results into the approximate RTPV potential of each and every categories under these circles. The table 3.8, below shows the final capacities for all 18 circles by their land use categories.

RTPV potential of each category in every circle (MW)								
	Comm-ercial	Indu-strial	Military lands	Multi-purpose	Public and semi public	Resi-dential	Transp-ortation	Total Solar RTPV Potential (MW)
Circle 1	2.12	0.15	4.10	3.35	4.49	87.77	0.24	102.22
Circle 2	10.05	1.61	N/A	37.94	26.40	190.12	0.53	266.64
Circle 3	3.07	5.82	N/A	3.25	5.34	72.21	0.32	90.01
Circle 4	0.47	0.04	0.06	1.90	3.25	36.10	0.03	41.85
Circle 5	3.99	5.36	N/A	8.54	7.59	26.62	0.35	52.44
Circle 6	1.59	0.52	N/A	38.12	15.49	10.16	N/A	65.89
Circle 7	0.64	0.56	N/A	10.76	6.80	24.23	3.17	46.15
Uppal	1.52	1.77	0.08	5.62	4.78	32.84	0.18	46.79
Kapra	3.15	3.68	0.16	11.66	9.92	68.18	0.38	97.14
Kukatpally	3.63	4.25	0.18	13.44	11.44	78.61	0.44	111.98
Malkajgiri	2.16	2.52	0.11	7.99	6.80	46.71	0.26	66.54
Serilingam-pally North	2.55	2.98	0.13	9.43	8.03	55.17	0.31	78.60
Serilingam-pally South	3.79	4.44	0.19	14.05	11.95	82.16	0.46	117.04
Alwal	1.85	2.17	0.09	6.86	5.84	40.13	0.22	57.17
Pa-tancheruvu	1.10	1.29	0.06	4.08	3.47	23.84	0.13	33.96
Qutubul-lapur	4.07	4.76	0.21	15.06	12.82	88.09	0.49	125.50
Rajen-dranagar	3.94	4.61	0.20	14.59	12.42	85.34	0.47	121.57
L.B. Nagar	6.67	7.81	0.34	24.71	21.03	144.52	0.80	205.88
Total	56.35	54.34	5.92	231.34	177.85	1192.80	8.77	-
Grand Total	**1,727**							

Table 3.8: RTPV potential of each category In every circle (MW)

A comparative analysis of RTPV potential between different categories (under all 18 circles) is shown in the donut chart below. The total potential of GHMC is 1.73 GW. The highest potential comes from the residential sector, which contributes nearly 69.1% to the overall potential of the city. However, residential rooftops tend to be small and the market is highly fragmented. Transportation and military lands have the lowest RTPV potentials in comparison to the other land use categories. Although the percentage is smaller, these buildings have considerable potential and easy to implement with large capacities.

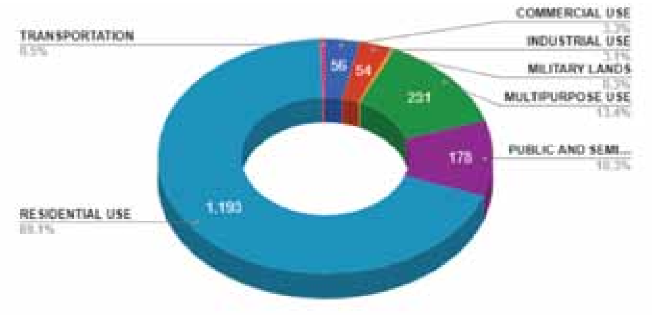


Figure 3.6: RTPV potential distribution under different categories for whole greater Hyderabad under GHMC

A comparative analysis of RTPV potential between different circles (of all 7 categories) is shown in the stacked bar chart below. The highest potential of around 267 MW is possible for the rooftops under circle 2 (Chandrayangutta, Charminar Saroor Nagar and Malakpet) and 206 MW under circle L.B. Nagar. This is owing to the larger geographical areas. This much of substantial RTPV potential is because of numerous buildings which belongs under the categories of residential, multipurpose and public & semi public use. Same categories are the reason behind lowest RTPV potential in Circle 4 and Patancheruvu (Around 42 MW and 34 MW capacities respectively).

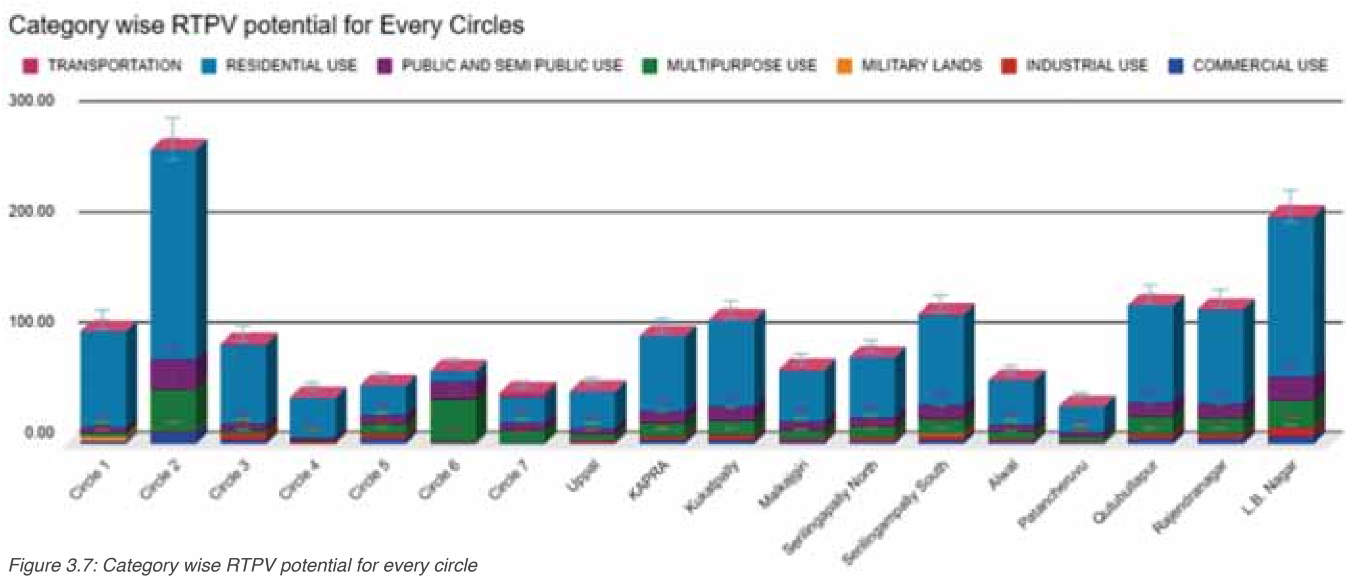


Figure 3.7: Category wise RTPV potential for every circle

Greater Chennai

Total area under each zone

The total area of individual zones was measured manually by mapping the individual boundaries on google earth. The table 3.9, below shows the final measurements for all zones.

Zones	Total area (sq.m.)
Zone 1	24,007,262
Zone 2	40,558,486
Zone 3	33,208,755
Zone 4	20,771,637
Zone 5	22,056,821
Zone 6	17,029,093
Zone 7	38,666,459
Zone 8	25,316,556
Zone 9	25,326,587
Zone 10	22,411,557
Zone 11	20,580,089
Zone 12	21,291,947
Zone 13	40,402,387
Zone 14	36,247,052
Zone 15	44,049,110
Zone 16	5,270,125
Total area of Greater Chennai	**437,193,923**

Table 3.9: Total area (inclusive of all unconstructed areas) of individual zones

Plot areas under different categories

The data from land use map of Chennai corporation was referred to understand the land categorisation. Areas of 6257 individual plots was measured manually using the GIS tools of Google Earth . The methodology for performing this task was discussed in the previous sections. Segregation of plots according to their respective category was carried out to compute the total plot area of each category under 7 zones.

Land use category	Total plot area under 7 zones (sq. m.)
Commercial	7,901,166
Industrial	10,144,153
Military lands	24,532,653
Public and semi public	26,984,049
Residential	63,459,211
Transportation	4,844,393

Table 3.10: Plot areas of individual categories under first 7 zones

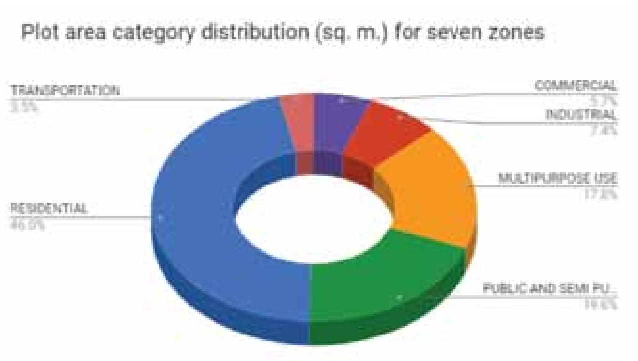


Figure 3.8: Plot area category distribution (sq. m.) for seven zones

Average solar feasibility ratios

The average solar feasibility ratio was generated from the plots of the same land use category.

Landuse	Average land use area %	Average feasibility ratio
Commercial	4.51	5.57
Industrial	5.79	8.89
Multipurpose use	14.01	7.15
Public and semi public	15.40	5.83
Residential	36.23	5.85
Transportation	2.77	6.97
Open Space	21.3	-

Table 3.11: Average land use area % and average feasibility ratio

Implementation of the average feasibility ratio give the total solar feasible area for each category. These results shows the solar feasible area under the inner seven zones only. The figure 3.9, below shows the size comparison of solar feasible area to the infeasible areas under each category.

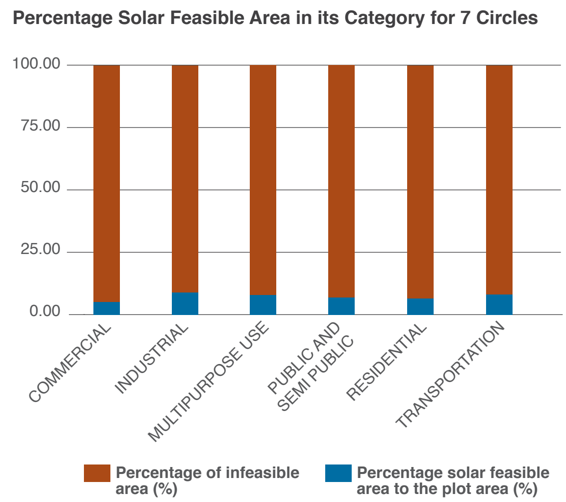


Figure 3.9: Part of solar feasible and infeasible areas (in %) for each category

RTPV potential under 7 zones

Using the consideration of 10 sq. m. for 1 kWp system capacity, the RTPV potential of Chennai is calculated and reported below.

Zones	Solar RTPV Potential (MW)
Zone 4	93.07
Zone 5	98.83
Zone 6	76
Zone 8	146.45
Zone 9	113.44
Zone 10	100.42
Zone 13	181.04

Table 3.12: Solar RTPV potential of inner 7 zones

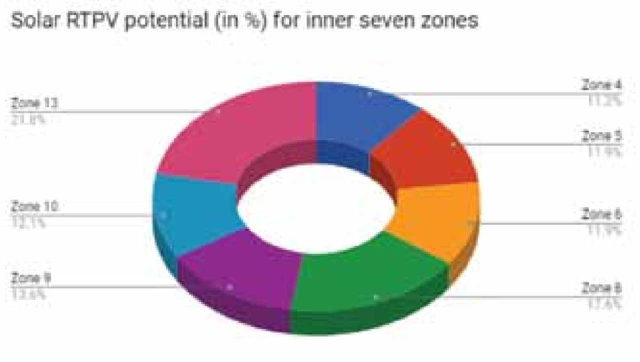


Figure 3.10: Part of solar RTPV potential (in %) for seven zones

Unconstructed area measurements for remaining 9 zones (type 3)

Utilization of previous data for extrapolation can be done on the remaining nine zones. But as suggested earlier in the methodology, the type 3 unconstructed land in first seven zones was eliminated. Quite similarly, unconstructed land area (type 3) was eliminated from the total area of these zones. This exercise of elimination was performed on Google Earth by mapping those plots manually in each of the 9 zones.

Zones	Total Area (sq. m)[23]	Plot Area (sq. m)	Open Space (sq. m)	Percentage Plot Area (%)
1	24,007,262	9,605,559	14,401,703	40.01
2	40,558,486	4,365,107	36,193,379	10.76
3	33,208,755	12,755,747	20,453,008	38.41
7	38,666,459	28,581,686	10,084,773	73.92
11	20,580,089	16,617,709	3,962,380	80.75
12	21,291,947	11,073,092	10,218,855	52.01
14	36,247,052	19,534,179	16,712,873	53.89
15	44,049,110	13,556,450	30,492,660	30.78
16	5,270,125	1,050,193	4,219,932	19.93

Table 3.13: Measured unconstructed (type 3) and constructed area form 9 zones

Extrapolation of data for 9 zones

It was mentioned earlier that, in the measurements of external 9 zones, the larger open spaces of type 3 were eliminated from the total area under their boundaries. So the area of type 2 unconstructed areas was not eliminated from it.

But the available areas from inner 7 zone excludes unconstructed area of type 2 and type 3 both. Therefore, the unconstructed area (type 2 + type 3) can be calculated by finding the difference between total area under these zones and the summation of plot areas. This results 21.3% of the total area is unconstructed (type 2 + type 3) area. By a visual analysis, it was inferred that around 11% part comes from type 3 (large) unconstructed areas. Therefore remaining 10% unconstructed area belongs to type 2 category.

To perform extrapolation, we need to reform the data of area from inner zones symmetrical to the data of external zones. That means it must include the area of type 2 unconstructed areas (10%) in its boundaries at the time of extrapolation.

[23] *Zone Area = Plot Area + Open Spaces*

However, in the case of Greater Chennai Corporation, the land use distribution behavior for the outer city was very different compared to Hyderabad. The land utilization pattern for outer zones remained almost similar to the inner zones. This is due to the larger expansion of the city in all directions towards the mainland areas.

A visual analysis with the labels on Google Earth, Google Maps and Wikimapia was used to make some modification in the the generalized percentage covered area of each category. Similar to the study of Hyderabad, the generalized solar feasibility ratios for individual categories were also reduced by 10%.

Landuse	Average land use area (%)	Modified Average land use (%)	Average feasibility ratio	Modified feasibility ratio
Commercial	4.51	5.16	5.57	5.01
Industrial	5.79	6.62	8.89	8.00
Multipurpose use	14.01	16.02	7.15	6.43
Public and semi public	15.40	17.62	5.83	5.25
Residential	36.23	41.43	5.85	5.27
Transportation	2.77	3.16	6.97	6.27
Open space	21.3	10.00	-	-

Table 3.14: Data refinements for extrapolation in 9 zones

RTPV potential of Greater Chennai corporation under GCC jurisdiction

The modified data of percentage land use area and feasibility ratios is directly extrapolated on the construction area of 9 zones. This extrapolation results into the approximate RTPV potential of each and every categories under these zones. The table 3.15, below shows the final capacities for all 16 zones by their land use categories.

RTPV potential of each category in every zone (MW)						
	Comm-ercial	Indu-strial	Multi-purpose	Public and semi public	Resi-dential	Transp-ortation
Zone 1	2.48	5.08	9.89	8.87	20.96	1.90
Zone 2	1.13	2.31	4.50	4.03	9.53	0.87
Zone 3	3.30	6.76	13.14	11.79	27.84	2.53
Zone 4	4.70	9.62	18.72	16.79	39.65	3.60
Zone 5	4.99	10.22	19.88	17.83	42.10	3.83
Zone 6	3.85	7.89	15.35	13.76	32.50	2.95
Zone 7	7.39	15.14	29.45	26.41	62.38	5.67
Zone 8	5.73	11.73	22.81	20.46	48.32	4.39
Zone 9	5.73	11.73	22.82	20.47	48.34	4.39
Zone 10	5.07	10.38	20.20	18.11	42.78	3.89
Zone 11	4.30	8.80	17.12	15.36	36.27	3.30
Zone 12	2.86	5.87	11.41	10.23	24.17	2.20
Zone 13	9.14	18.71	36.41	32.65	77.11	7.01
Zone 14	5.05	10.35	20.13	18.05	42.63	3.88
Zone 15	3.51	7.18	13.97	12.53	29.59	2.69
Zone 16	0.27	0.56	1.08	0.97	2.29	0.21
Total	69.49	142.32	276.89	248.32	586.46	53.31
Grand Total	**1,377**					

Table 3.15: RTPV potential of each category In every zone (MW)

A comparative analysis of RTPV potential between different categories (under all 16 zones) is shown in the donut chart below. The total RTPV potential of Greater Chennai Corporation is 1.38 GW. The maximum potential is from the residential rooftop segment, which occupies nearly 46%.

Transport, commercial and industrial rooftop have the least RTPV potentials compared to the other land use categories. Although the overall number is small, the few roofs that do exist tend to be large and can accomodate significantly larger potential as compared to the residential roofs.

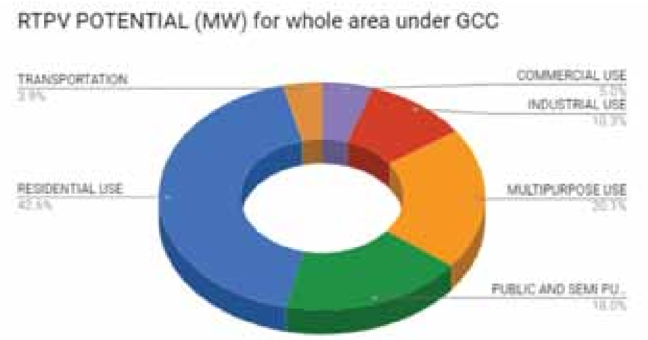


Figure 3.11: RTPV potential distribution under different categories for whole greater Chennai under GCC

A comparative analysis of RTPV potential between different zones (of all 6 categories) is shown in the stacked bar chart below. The highest potential of 181 MW is for the rooftops under zone 13 and 146 MW under zone 7. This is because of these zones have the largest geographical area and the largest spread of buildings under the categories of residential, multipurpose and public & semi public use. Conversely, the lack of buildings in the categories mentioned above result if low RTPV potentials in zone 16 and zone 9 which have 5.4 MW and 22.4 MW capacities respectively.

RTPV Potential of Major Buildings in Transportation Category

Indian railways has committed to install 1 GW of solar power capacity by 2020. It includes the utilization of their existing assets such as railway platforms, railway buildings, workshops and trains for RTPV systems and railway lands for ground mounted systems. Indian railways intends to fulfill 10% of the total electricity demand from renewable energy[24]. In another development, United Nations Development Program (UNDP) and Indian railways (IR) are now targeting an installation capacity of 5 GW by 2025 and are open to attracting private investment24.

These targets are highly ambitious, and one small step in reaching this target would be to identify rooftop spaces available on all its stations, buildings and even open lands. In order to apply our work for this specific purpose, we have analyzed all transportation facilities in Hyderabad and Chennai (see table below). Another reason for doing this, is the Government of India's intention to shift to electric transportation.

City	Name	Capacity (Kw)
Greater Hyderabad	Bus Depot	2,949
	Railway Station	3,187
	Metro Station	680
	Airport	714
	Total	7,530
Greater Chennai Corporation	Bus Depot	938
	Railway Station	3,582
	Metro Station	1,696
	Airport	889
	Total	7,105

Table 3.16: RTPV potential of transportation buildings in Greater Hyderabad and Greater Chennai Corporation

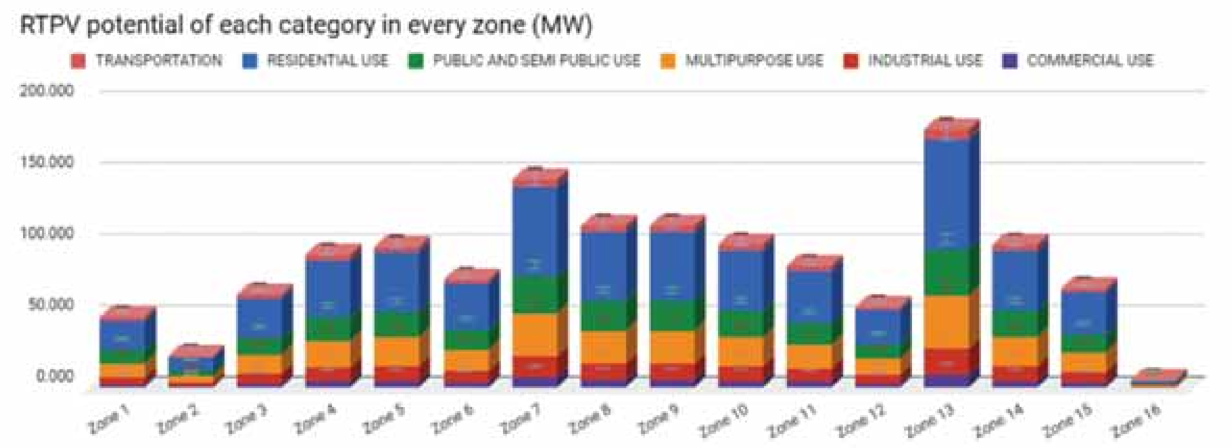


Figure 3.12: Category wise RTPV potential for every zone

Conclusion and Analysis of Results

Our assessment shows that the RTPV potential for the city of Hyderabad is 1.73 GW and 1.38 GW for Chennai. These results appear to be in line with earlier assessments done for the cities of New Delhi[25], Mumbai[26] and for Patna[27]. One way to understand and compare this data would be to look at the RTPV potential over the geographic spread of the city;

[24] *Indian Railways, UNDP, "Powering Indian Railways 5 GW by 2025", http://bit.ly/2gAh7HJ*
[25] *Tobias Engelmeier, Mohit Anand, Jasmeet Khurana, Prateek Goel, Tanya Loond, BRIDGE TO INDIA, GREENPEACE, June 2013. http://bit.ly/2lFeZDt*
[26] *Akhilesh Magal, Ameya Pimpalkhare, Prof. Anil Kottantharayil, Prof. Prachi Krithi, Prachi Jadhav, Santhosh Jois, Prof. Vinit Kotak, Vivek Kuthanazhi, Bridge to India, NCPRE (IIT-B), Observer Research Foundation, IEEE Bombay Section, Centre for Urban Science & Engineering (IIT-B), "Estimating Rooftop Solar Potential of Greater Mumbai", November 2016. http://bit.ly/2z2Su0W*
[27] *Tobias Engelmeier, Jasmeet Khurana, Prateek Goel, Karan Raj Chaudri, Mudit Jain, Tanya Loond, Ankita Jyoti, BRIDGE TO INDIA, GREENPEACE October 2014. http://bit.ly/2im6U1Z*

that is, to arrive at an average MW/sq.km for most tier 1 and tier 2 cities in India. This metric, although not entirely accurate gives us a back-of-the-envelope method of arriving at the RTPV potentials of major tier 1 and 2 cities in India.

India has set itself a target of achieving 40 GW of rooftop solar installations by 2022. The key question here is whether India's cities have adequate rooftops that capable of hosting this potential (assuming that 100% of all rooftops do host RTPV systems). Based on our and earlier studies of RTPV potential assessment, we can attempt to compute the total RTPV potential of tier 1 and 2 cities in India. Given reasons of affordability and awareness, we can assume that most of the demand for RTPV systems will come from Tier 1 and 2 cities and not smaller cities, at least in the near term.

City	Potential (in MW)	Land Area (in km2)	Solar PV Potential per unit Area MW/km2
New Delhi	2,000	1,230	1.62
Mumbai	1,720	603.4	2.85
Patna	759	297.9	2.54
Hyderabad	1,727	640	2.70
Chennai	1,385	437	3.15

Table 3.17: RTPV potential in per square km. area of mentioned cities[25 26 27]

Study of RTPV adoption rates Internationally

India has 8 Tier 1 cities and 88 Tier 2 cities as per official Government statistics (see annexure VII for complete list)[28]. In the previous data table, the RTPV potential of four tier 1 cities was mentioned. From this data, the potential distribution of RTPV across the city in per sq. km. area can be computed. On an average, this RTPV potential per square kilometer came up to approximately 2.58 MW/sq.km. for tier 1 cities. Although the RTPV potential for tier 2 cities was not studied previously in an extensive manner, the same potential (in MW/ sq. km.) is taken for further studies. This is highly optimistic approximation nevertheless helps us arrive at an estimate in the absence of concrete data.

Annexure-VII includes the approximate areas of all the listed tier 1 and tier 2 cities. Therefore it can be said that, using the potential of 2.58 MW/sq. km on the cumulative areas for all these cities (23,996.30 sq. km) the theoretically possible RTPV potential is 62 GW.

While this may sound like good news, that India's cities can in fact host the 40 GW target, it does not consider adoption factors. We looked at Germany, a country that has one of the highest adoption rate of solar rooftop systems in the world. Most of Germany's 42 GW of solar power capacity comes from rooftop solar installations[29 30]. From the figure 3.13 below, it can be observed the Federal State of Bavaria has the highest potential in per sq. km. area. Some random samples from localities in the city of Munich (capital of Bavaria) were taken to understand how many roofs in any given locality have RTPV systems installed on them. Similarly, two more samples from the cities of Passau and Los Angeles (USA) were taken as samples for this study.

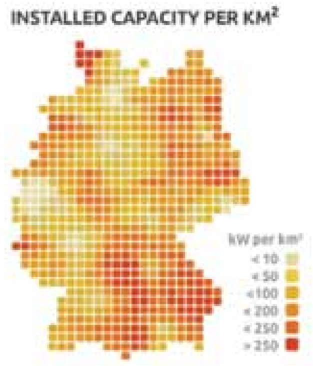


Figure 3.13: Installed capacity per km2 in Germany with highest capacity in southern state of Bavaria

The table below shows and tabulates the data:

Sample Localities	Area (sq.m.)	Number of households	Households with RTPV Systems	RTPV adoption rate (%)
Locality-1, Munich (Germany)	250	268	37	13.80
Locality-2, Munich (Germany)	250	249	38	15.26
Locality-3, Passau (Germany)	250	232	56	24.13
Locality-3, Los Angeles, (USA)	250	289	16	5.5

Table 3.18: RTPV adoption rates in the sample localities of Munich, Passau and Los Angeles

Policy Implications

Based on the above assessment, the adoption rate of RTPV systems from Germany and USA range between 5% to 25%. If we assume an adoption rate[31] of 10% for India by 2022, we arrive at a total potential of 10% of 62 GW or 6.2 GW. This number is clearly well below the 40 GW target set by the Government of India. This calls for reflection on the way ahead for India's distributed solar targets.

While RTPV needs to be strongly pushed and hurdles on approvals and subsidy mechanisms have to be eliminated, it is also worth considering other options to meet the distributed solar targets.

Clearly relying only on Tier 1 and 2 cities will be insufficient - are there other incentives that can be brought into play to promote installations in smaller towns? These are also the locations that usually suffer the worst in terms of 'load shedding' or rolling blackouts.

Another option is the inclusion of 'Field-top Solar' i.e. grid-connected solar PV agricultural pumps. Agriculture consumes roughly 23% of India's power and is the single highest consumer category[32]. It is also a highly subsidized sector and India's power distribution companies are forced to cross subsidize power for these consumers, which results in ever increasing tariffs for Commercial and Industrial consumers. Field-top solar installations can dilute the quantum of power required to be supplied to the farm sector and could eventually turn around the financial state of India's discoms. By giving the farmer a financial incentive (via net metering) to limit consumption of generated power, this system could also mitigate the threat of over-extraction of groundwater.

[28] *Ministry of Finance, Govt. of India. http://bit.ly/2z3aXKz*
[29] *Fraunhofer ISE. Energy Charts. Installed Capacity. http://bit.ly/2AP9bxR*
[30] *Strom Report. https://1-stromvergleich.com/strom-report/*
[31] *Adoption rate is defined as number of rooftops that have actually installed RTPV systems*
[32] *Amit Bhandari, "How Agriculture Consumes 23% Of India's Electricity & Picks 7% Of Tab", Indiaspend, February 2014. http://bit.ly/1n37Fan*

Woman Cleaning Solar Panels in Nightschool of Barefoot College in Tilonia/Rajasthan.
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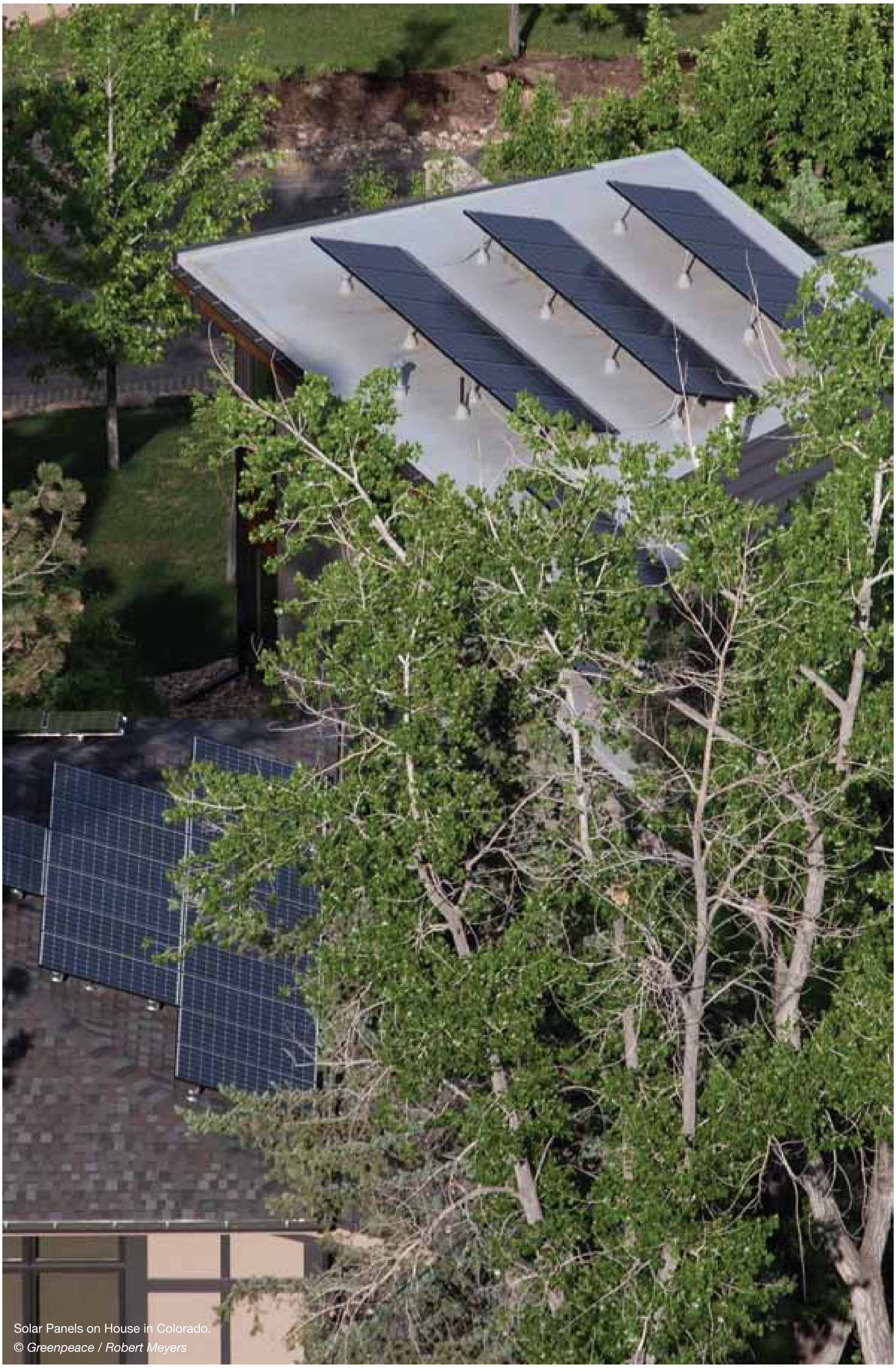

Solar Panels on House in Colorado.
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ANNEXURES

Annexure - I : RTPV Potential of Inner Seven Circles of Greater Hyderabad

Circle No.	Land use category	Total plot area (sq. m.)	Average feasibility Ratio	Solar feasible area (sq. m.)	Solar capacity (MW)	Percentage land covered %	Solar capacity (Circle wise)
1	Commercial	386,965	0.0549	21,233	2.12	1.42	102.22
	Industrial	12,693	0.1184	1,502	0.15	0.05	
	Military lands	2,908,818	0.0141	41,011	4.10	10.67	
	Multipurpose use	527,638	0.0634	33,463	3.35	1.93	
	Public and semi public	1,260,458	0.0356	44,898	4.49	4.62	
	Residential	21,962,460	0.0400	877,686	87.77	80.53	
	Transportation	213,303	0.0111	2,371	0.24	0.78	
2	Commercial	320,213	0.3139	100,506	10.05	2.69	266.64
	Industrial	93,700	0.1716	16,077	1.61	0.79	
	Military lands	N/A	N/A	N/A	N/A	N/A	
	Multipurpose use	1,949,217	0.1947	379,417	37.94	16.40	
	Public and semi public	1,223,429	0.2158	263,955	26.40	10.29	
	Residential	8,277,921	0.2297	1,901,185	190.12	69.65	
	Transportation	20,857	0.2539	5,296	0.53	0.18	
3	Commercial	383,643	0.0801	30,714	3.07	3.07	90.01
	Industrial	594,019	0.0980	58,206	5.82	4.75	
	Military lands	N/A	N/A	N/A	N/A	N/A	
	Multipurpose use	348,675	0.0931	32,475	3.25	2.79	
	Public and semi public	718,679	0.0744	53,442	5.34	5.75	
	Residential	10,369,253	0.0696	722,074	72.21	82.98	
	Transportation	81,285	0.0397	3,231	0.32	0.65	
4	Commercial	187,801	0.0250	4,695	0.47	1.15	41.85
	Industrial	20,635	0.0186	383	0.04	0.13	
	Military lands	42,767	0.0147	631	0.06	0.26	
	Multipurpose use	468,311	0.0407	19,039	1.90	2.86	
	Public and semi public	1,270,572	0.0256	32,497	3.25	7.75	
	Residential	14,382,652	0.0251	360,954	36.10	87.77	
	Transportation	14,750	0.0210	310	0.03	0.09	
5	Commercial	615,644	0.0648	39,893	3.99	2.05	52.44
	Industrial	1,182,465	0.0453	53,561	5.36	3.93	
	Military lands	N/A	N/A	N/A	N/A	N/A	
	Multipurpose use	2,661,909	0.0321	85,368	8.54	8.85	
	Public and semi public	2,788,712	0.0272	75,912	7.59	9.27	
	Residential	22,714,969	0.0117	266,209	26.62	75.49	
	Transportation	126,223	0.0274	3,453	0.35	0.42	
6	Commercial	104,063	0.1530	15,926	1.59	2.51	65.89
	Industrial	15219	0.3419	5,204	0.52	0.37	
	Military lands	N/A	N/A	N/A	N/A	N/A	
	Multipurpose use	1,774,009	0.2149	381,226	38.12	42.84	
	Public and semi public	1,245,978	0.1243	154,933	15.49	30.09	
	Residential	1,002,053	0.1014	101,614	10.16	24.20	
	Transportation	N/A	N/A	N/A	N/A	N/A	
7	Commercial	217,370	0.0293	6,375	0.64	1.36	46.15
	Industrial	130,159	0.0428	5,576	0.56	0.82	
	Military lands	N/A	N/A	N/A	N/A	N/A	
	Multipurpose use	1,241,070	0.0867	107,565	10.76	7.79	
	Public and semi public	2,935,881	0.0232	67,992	6.80	18.42	
	Residential	10,901,596	0.0222	242,344	24.23	68.39	
	Transportation	515,044	0.0615	31,662	3.17	3.23	

Annexure - II : RTPV Potential of Eleven Circles in Hyderabad

Circle No.	Land use category	Total plot area (sq. m.)	Average feasibility Ratio	Solar feasible area (sq. m.)	RTPV Potential capacity (MW)	RTPV Potential (Circle wise)
Uppal	Commercial	216,477	0.0824	17,837	1.78	57.23
	Industrial	219,095	0.0956	20,947	2.09	
	Military lands	78,914	0.0115	911	0.09	
	Multipurpose use	819,726	0.0829	67,967	6.80	
	Public and semi public	966,473	0.0601	58,103	5.81	
	Residential	7,070,133	0.0571	403,781	40.38	
	Transportation	49,159	0.0553	2,718	0.27	
KAPRA	Commercial	449,443	0.0824	37,033	3.70	118.81
	Industrial	454,878	0.0956	43,489	4.35	
	Military lands	163,839	0.0115	1,890	0.19	
	Multipurpose use	1,701,890	0.0829	141,111	14.11	
	Public and semi public	2,006,562	0.0601	120,631	12.06	
	Residential	14,678,789	0.0571	838,319	83.83	
	Transportation	102,063	0.0553	5,642	0.56	
Kukatpally	Commercial	518,132	0.0824	42,692	4.27	136.97
	Industrial	524,398	0.0956	50,136	5.01	
	Military lands	188,879	0.0115	2,179	0.22	
	Multipurpose use	1,961,993	0.0829	162,678	16.27	
	Public and semi public	2,313,228	0.0601	139,067	13.91	
	Residential	16,922,175	0.0571	966,440	96.64	
	Transportation	117,662	0.0553	6,505	0.65	
Malkajgiri	Commercial	307,859	0.0824	25,367	2.54	81.38
	Industrial	311,582	0.0956	29,789	2.98	
	Military lands	112,227	0.0115	1,295	0.13	
	Multipurpose use	1,165,761	0.0829	96,659	9.67	
	Public and semi public	1,374,455	0.0601	82,630	8.26	
	Residential	10,054,679	0.0571	574,232	57.42	
	Transportation	69,911	0.0553	3,865	0.39	
Serilingapally North	Commercial	363,685	0.0824	29,966	3.00	96.14
	Industrial	368,084	0.0956	35,191	3.52	
	Military lands	132,578	0.0115	1,530	0.15	
	Multipurpose use	1,377,156	0.0829	114,186	11.42	
	Public and semi public	1,623,694	0.0601	97,614	9.76	
	Residential	11,877,960	0.0571	678,361	67.84	
	Transportation	82,589	0.0553	4,566	0.46	
Serilingapally South	Commercial	541,534	0.0824	44,621	4.46	143.16
	Industrial	548,083	0.0956	52,400	5.24	
	Military lands	197,410	0.0115	2,278	0.23	
	Multipurpose use	2,050,609	0.0829	170,025	17.00	
	Public and semi public	2,417,708	0.0601	145,349	14.53	
	Residential	17,686,487	0.0571	1,010,091	101.01	
	Transportation	122,976	0.0553	6,799	0.68	
Alwal	Commercial	264,537	0.0824	21,797	2.18	69.93
	Industrial	267,736	0.0956	25,597	2.56	
	Military lands	96,434	0.0115	1,113	0.11	
	Multipurpose use	1,001,713	0.0829	83,057	8.31	
	Public and semi public	1,181,039	0.0601	71,002	7.10	
	Residential	8,639,767	0.0571	493,425	49.34	
	Transportation	60,073	0.0553	3,321	0.33	

Circle No.	Land use category	Total plot area (sq. m.)	Average feasibility Ratio	Solar feasible area (sq. m.)	RTPV Potential capacity (MW)	RTPV Potential (Circle wise)
Patancheruvu	Commercial	157,141	0.0824	12,948	1.29	41.54
	Industrial	159,041	0.0956	15,205	1.52	
	Military lands	57,284	0.0115	661	0.07	
	Multipurpose use	595,040	0.0829	49,337	4.93	
	Public and semi public	701,564	0.0601	42,177	4.22	
	Residential	5,132,217	0.0571	293,105	29.31	
	Transportation	35,685	0.0553	1,973	0.20	
Qutubullapur	Commercial	580,662	0.0824	47,845	4.78	153.50
	Industrial	587,684	0.0956	56,187	5.62	
	Military lands	211,674	0.0115	2,442	0.24	
	Multipurpose use	2,198,776	0.0829	182,310	18.23	
	Public and semi public	2,592,399	0.0601	155,851	15.59	
	Residential	18,964,422	0.0571	1,083,075	108.31	
	Transportation	131,861	0.0553	7,290	0.73	
Rajendranagar	Commercial	562,517	0.0824	46,349	4.63	148.70
	Industrial	569,319	0.0956	54,431	5.44	
	Military lands	205,059	0.0115	2,366	0.24	
	Multipurpose use	2,130,064	0.0829	176,613	17.66	
	Public and semi public	2,511,387	0.0601	150,980	15.10	
	Residential	18,371,787	0.0571	1,049,229	104.92	
	Transportation	127,741	0.0553	7,062	0.71	
L.B. Nagar	Commercial	952,598	0.0824	78,491	7.85	251.82
	Industrial	964,118	0.0956	92,176	9.22	
	Military lands	347,259	0.0115	4,007	0.40	
	Multipurpose use	3,607,172	0.0829	299,087	29.91	
	Public and semi public	4,252,926	0.0601	255,679	25.57	
	Residential	31,111,828	0.0571	1,776,824	177.68	
	Transportation	216,324	0.0553	11,959	1.20	

Annexure - III : RTPV Potential of Transportation in Greater Hyderabad

Bus depot	
Name	**Capacity (kW)**
Hayathnagar Bus Depot Ii	76.70
Nagole Depot	1,825.80
Uppal Bus	71.10
Tsrtc Zonal Workshop	703.79
Mahatma Gandhi Bus Station	139.56
Central Bus Station	132.20
Total	**2,949.15**

Railway Station	
Name	**Capacity (kW)**
Jamia Osmania Mmts	23.52
Feth Nagar	22.30
Sanjeevaiah Park	26.50
Necklace Road	25.04
Yakutpura	67.89
Nature Cure Hospital	27.90
Bharatnagar	49.40
Container Corporation Of India	1,703.40
Dabirpura Mmts Station	23.60
Kachiguda Railway Station	564.48
Hafizpeta Mmts Station	33.60
Malakpet	28.07
Nampally Railway Station	591.76
Total	**3,187.46**

Metro Station	
Name	**Capacity (kW)**
Miyapur Metro Railway Station(Nrs)	98.90
Jntu Metro Station	116.26
Hyderabad Metro Train Depot	54.8
Lakdikapul Metro Station	74.2
Hyderabad Metro Rail-e.S.I.Station	80.88
Erragadda Metro Station	91.27
Nagole Metro Station	17.24
S R Nagar Metro Station	15.3
Bharat Nagar, Subway Station	0
Kphb Colony Metro Station	106.55
Kukatpally Metro Station	13.28
Habsiguda Metro Station	2.39
Uppal Metro	8.52
Total	**679.59**

Airport	
Name	**Capacity (kW)**
Begumpet Airport	42.82
Rajiv Gandhi International Airport	671.48
Total	**714.30**
Grand Total	**7,530.50**

Solar Power for Greenpeace Office Brazil.
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Annexure - IV : RTPV Potential of Buildings in Osmania University

Osmania University	
Name	**Capacity (kW)**
Sri Sathya Sai Vidya Vihar - High School	64.38
Department Of Biochemistry - University Department	24.57
The Hyderabad Public School	29.50
Department Of Zoology - University Department	84.51
Landscape Garden - Botanical Garden	9.27
Dept. Of Physics, University College Of Science,Osmania University	55.42
Institute Of Public Enterprise	25.30
Osmania University Centre For International Programmes	92.26
Maneru Hostel	169.72
Prof. G. Ram Reddy Centre For Distance Education	157.47
Mekaster Auditorium	13.80
Arts College	166.00
Press	4.58
Shishu Ranjani (Day Childcare)	4.05
Center Exploration Of Geophysics	6.80
Sports Hostel	27.58
University College Of Technology	224.61
Building Near Staff Quarter	11.84
Science And Humanities Block	52.40
Department Of Biomedical Engineering	11.31
University Of Foreign Relation Office O.U	2.12
Osmania University Building Division	1.16
NERTU	18.70
E.C.E Department	33.02
C Ramchand Girls High School	6.82
Andhra Mahila Sabha Arts And Science	36.81
Andhra Mahila Sabha School Of Informatics	15.43
Osmania University Engineering Library	16.90
Pg Admission Block	7.45
Computer Science Engineering Department	37.32
Placement Office Ouce	18.97
Swarnamukhi Hostel	11.23
Ganga Hostel	16.67
TSRTC Hospital	44.30
Aradhana Theatre	28.70
Hyderabad Metropolitan Authority	230.70
Osmania Saraswathi And Hanuman Temple	24.36
Ouccbm,Hyderabad,India	3.25
Ouccbm,Hyderabad,India	15.20
College Of Commerce And Business Management,Osmania University	53.19
Auditorium,Ouccbm,Hyderabad,India	31.50
Examination Branch Osmania University	23.54
College Of Commerce And Business Management,Osmania University	33.12
Osmania University Library	145.73
Osmania University Administrative Building	76.45
Main Tech Hostel	6.86
Masjid E Osmania	4.90
Staff Quarters	9.67
Department Of Genetics	72.99
Centre For Plant Molecular Biology	56.30
Microbiology Main Building	17.08
Kinnera Hostel	114.10
Engineering Workshop	82.00
Osmania College Of University	171.39
Department Of Electrical Engineering	9.08

Osmania University	
Name	**Capacity (kW)**
E.E.E Department	18.48
Global Care Poly Clinics, Hearing Aid & Speech Therapy Clinic	46.53
ITPC Office	14.83
Ladies Hostel Osmania University	63.37
Nizam College Ladies Hostel	43.30
Girls Hostel, Osmania University	137.26
Telangana State Archives & Research Institute	61.01
State Archives	88.40
Model High School	48.60
Tagore International Guest House	3.64
Amrita Pritam International Hostel for Women	34.21
Basheer Hostel Osmania University	65.87
Dooradarshan Kendra (TV Studio)	44.85
Ramanthapur TV tower	20.43
JSPS Government Homeopathic Medical College	117.98
Central Forensic Science Laboratory	158.99
Advanced Training Institute for Electronics and Process Instrumentation	121.20
The Hyderabad Public School	106.51
Academic Staff College	53.57
DTDC Osmania University Campus	43.11
C.Ramchand Girls High School	19.62
Application Submission Counter	6.97
Exam Branch OU	69.56
Ladies Hostel Complex	49.66
District Post Graduate Colleges	13.10
Osmania University Administrative Building	2.52
Administrative Block, Efl University	48.17
Educational Multimedia Research Center	11.00
Ramesh Mohan Library	9.34
Institute Of Advanced Study In Education	56.29
Basheer Hostel,Osmania University	10.97
Osmania University 220 Kv Substation Building	11.35
Amar Maternity Hospital	25.65
Arts College Osmania University	346.75
Astronomy Department	54.71
Krishnavenu Boys Hostel	53.35
Osmania University Boys Hostel	55.48
University Health Centre	30.17
Sanskrit Academy	18.62
Osmania University Police Station	10.20
Department Of Applied Geochemistry,Osmania University	9.71
Department Of Geology,Osmania University	47.98
Kaveri Hostel	30.46
Yamuna Hostel(New Pg Hostel)	15.04
Dr.B.R.Ambedkar Hostel	26.69
University College Of Science,Osmania University	50.40
Osmania University Staff Club	43.04
Total	**5,131.31 kW**

Annexure - V : RTPV Potential of Inner Seven Zones of Chennai

Zone	Land use category	Total plot area (sq. m.)	Average feasibility Ratio	Solar feasible area (sq. m.)	RTPV Potential capacity (MW)	RTPV Potential (Zone wise)
1	Commercial	495,450.58	5.01	24,843.50	2.48	49.22
	Industrial	636,099.34	8.00	50,877.79	5.09	
	Multipurpose use	1,538,344.75	6.43	98,984.48	9.90	
	Public and semi public use	1,692,062.05	5.25	88,769.53	8.88	
	Residential	3,979,273.83	5.27	209,648.29	20.96	
	Transportation	303,772.55	6.27	19,060.21	1.91	
	Open Space	15,362,258.90	0	0.00	0.00	
2	Commercial	225,150.33	5.01	11,289.77	1.13	22.37
	Industrial	289,066.12	8.00	23,120.67	2.31	
	Multipurpose use	699,078.46	6.43	44,982.06	4.50	
	Public and semi public use	768,933.06	5.25	40,340.02	4.03	
	Residential	1,808,323.29	5.27	95,271.62	9.53	
	Transportation	138,045.03	6.27	8,661.64	0.87	
	Open Space	36,629,889.70	0	0.00	0.00	
3	Commercial	657,935.92	5.01	32,991.04	3.30	65.36
	Industrial	844,711.10	8.00	67,563.40	6.76	
	Multipurpose Use	2,042,852.10	6.43	131,446.90	13.14	
	Public and semi public use	2,246,981.71	5.25	117,881.91	11.79	
	Residential	5,284,295.29	5.27	278,403.42	27.84	
	Transportation	403,396.18	6.27	25,311.10	2.53	
	Open Space	21,728,582.70	0	0.00	0.00	
4	Commercial	936,925.02	5.01	46,980.46	4.70	93.07
	Industrial	1,202,899.77	8.00	96,212.77	9.62	
	Multipurpose use	2,909,096.77	6.43	187,185.23	18.72	
	Public and semi public use	3,199,784.86	5.25	167,868.19	16.79	
	Residential	7,525,031.47	5.27	396,456.74	39.65	
	Transportation	574,451.04	6.27	36,043.93	3.60	
	Open Space	4,423,448.07	0	0.00	0.00	
5	Commercial	994,894.51	5.01	49,887.24	4.99	98.83
	Industrial	1,277,325.66	8.00	102,165.65	10.22	
	Multipurpose Use	3,089,088.58	6.43	198,766.77	19.88	
	Public And Semi Public Use	3,397,762.14	5.25	178,254.54	17.83	
	Residential	7,990,620.68	5.27	420,986.34	42.10	
	Transportation	609,993.51	6.27	38,274.05	3.83	
	Open Space	4,697,135.92	0	0.00	0.00	
6	Commercial	768,113.91	5.01	38,515.73	3.85	76.30
	Industrial	986,166.48	8.00	78,877.57	7.89	
	Multipurpose Use	2,384,948.26	6.43	153,459.00	15.35	
	Public and semi public use	2,623,261.42	5.25	137,622.42	13.76	
	Residential	6,169,203.74	5.27	325,024.88	32.50	
	Transportation	470,948.93	6.27	29,549.69	2.95	
	Open Space	3,626,450.27	0	0.00	0.00	
7	Commercial	1,474,231.01	5.01	73,922.73	7.39	146.45
	Industrial	1,892,736.46	8.00	151,388.69	15.14	
	Multipurpose Use	4,577,400.08	6.43	294,531.87	29.45	
	Public and semi public use	5,034,791.42	5.25	264,136.92	26.41	
	Residential	11,840,472.28	5.27	623,816.01	62.38	
	Transportation	903,886.14	6.27	56,714.34	5.67	
	Open Space	12,942,941.60	0	0.00	0.00	

Zone	Land use category	Total plot area (sq. m.)	Average feasibility Ratio	Solar feasible area (sq. m.)	RTPV Potential capacity (MW)	RTPV Potential (Zone wise)
8	Commercial	1,141,928.05	5.01	57,259.98	5.73	113.44
	Industrial	1,466,099.16	8.00	117,264.52	11.73	
	Multipurpose use	3,545,619.02	6.43	228,142.13	22.81	
	Public and semi public use	3,899,910.85	5.25	204,598.43	20.46	
	Residential	9,171,539.08	5.27	483,203.10	48.32	
	Transportation	700,143.27	6.27	43,930.49	4.39	
	Open Space	5,391,316.57	0	0.00	0.00	
9	Commercial	1,142,380.50	5.01	57,282.67	5.73	113.48
	Industrial	1,466,680.06	8.00	117,310.98	11.73	
	Multipurpose use	3,547,023.88	6.43	228,232.52	22.82	
	Public and semi public use	3,901,456.08	5.25	204,679.50	20.47	
	Residential	9,175,173.06	5.27	483,394.55	48.34	
	Transportation	700,420.69	6.27	43,947.90	4.39	
	Open Space	5,393,452.73	0	0.00	0.00	
10	Commercial	1,010,895.22	5.01	50,689.57	5.07	100.42
	Industrial	1,297,868.67	8.00	103,808.77	10.38	
	Multipurpose Use	3,138,769.86	6.43	201,963.50	20.20	
	Public and semi public use	3,452,407.76	5.25	181,121.37	18.11	
	Residential	8,119,132.43	5.27	427,756.99	42.78	
	Transportation	619,803.93	6.27	38,889.60	3.89	
	Open Space	4,772,679.14	0	0.00	0.00	
11	Commercial	857,134.25	5.01	42,979.50	4.30	85.15
	Industrial	1,100,457.95	8.00	88,019.06	8.80	
	Multipurpose use	2,661,351.14	6.43	171,244.09	17.12	
	Public and semi public use	2,927,283.53	5.25	153,572.13	15.36	
	Residential	6,884,181.81	5.27	362,693.54	36.27	
	Transportation	525,529.42	6.27	32,974.35	3.30	
	Open Space	5,624,150.90	0	0.00	0.00	
12	Commercial	571,145.30	5.01	28,639.08	2.86	56.74
	Industrial	733,282.32	8.00	58,650.88	5.87	
	Multipurpose Use	1,773,372.37	6.43	114,107.28	11.41	
	Public And Semi Public Use	1,950,574.53	5.25	102,331.70	10.23	
	Residential	4,587,225.50	5.27	241,678.26	24.17	
	Transportation	350,182.78	6.27	21,972.22	2.20	
	Open Space	11,326,164.20	0	0.00	0.00	
13	Commercial	1,822,389.22	5.01	91,380.51	9.14	181.04
	Industrial	2,339,730.00	8.00	187,141.03	18.71	
	Multipurpose Use	5,658,410.72	6.43	364,089.27	36.41	
	Public and semi public use	6,223,820.78	5.25	326,516.17	32.65	
	Residential	14,636,748.83	5.27	771,138.01	77.11	
	Transportation	1,117,350.22	6.27	70,108.15	7.01	
	Open Space	8,603,937.22	0	0.00	0.00	
14	Commercial	1,007,564.51	5.01	50,522.56	5.05	100.09
	Industrial	1,293,592.44	8.00	103,466.74	10.35	
	Multipurpose Use	3128428.20	6.43	201298.07	20.13	
	Public and semi public use	3441032.73	5.25	180524.61	18.05	
	Residential	8092381.43	5.27	426347.61	42.63	
	Transportation	617761.79	6.27	38761.47	3.88	
	Open Space	18666290.90	0	0.00	0.00	

Zone	Land use category	Total plot area (sq. m.)	Average feasibility Ratio	Solar feasible area (sq. m.)	RTPV Potential capacity (MW)	RTPV Potential (Zone wise)
15	Commercial	699235.83	5.01	35061.96	3.51	69.46
	Industrial	897735.26	8.00	71804.48	7.18	
	Multipurpose use	2171085.90	6.43	139698.07	13.97	
	Public and semi public use	2388029.11	5.25	125281.58	12.53	
	Residential	5616000.77	5.27	295879.34	29.59	
	Transportation	428718.14	6.27	26899.92	2.69	
	Open Space	31848305.00	0	0.00	0.00	
16	Commercial	54168.50	5.01	2716.18	0.27	5.38
	Industrial	69545.88	8.00	5562.56	0.56	
	Multipurpose use	168189.99	6.43	10822.15	1.08	
	Public and semi public use	184996.18	5.25	9705.33	0.97	
	Residential	435061.15	5.27	22921.22	2.29	
	Transportation	33212.00	6.27	2083.89	0.21	
	Open Space	4324951.30	0	0.00	0.00	

The solar thermal plant set up by Trans Solar Technologies, in collaboration with Holy Family Hospital, New Delhi.
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Annexure - VI : RTPV Potential of Transportation Sector in Greater Chennai Corporation

Bus depot

Name	Capacity (kW)
Thiruvanmiyur Bus Terminus	74
Alandur Bus Depot	8
Vadapalani Bus Depot	135
Tollgate Bus Terminus	146
Madhavaram	68
Ayanavaram Bus Depot	142
West Tambaram Bus Depot	54
Anna Nagar West Bus Depot	80
Vyasarpadi Mtc Bus Depot	9
Thiruverkadu Bus Depot	142
Pallavaram Bus Depot	42
Mint Bus Terminus	16
Saidapet Bus Depot	22
Total	**938**

Railway station

Name	Capacity (kW)
Ambattur Railway Station	40
Nungambakkam Railway Station	88
Mambalam	115
Chennai Chetpet	126
Chennai Beach	635
Tirusulam	176
Perungulattur	37
Chromepet	174
Chennai Fort	198
Chennai Central	215
Kotturpuram	79
Light House	168
Chennai Park	159
Minambakkam	189
Mandaveli	188
Tiruvanmiyur	530
Thirumayilai	74
Villivakkam	90
Guiyde	302
Total	**3,582**

Metro station

Name	Capacity (kW)
Ekkattuthangal Metro Station	36
Ashok Nagar	265
Arumbakkam Metro Station	70
Meenambakkam Metro	66
CMBT Metro Station	135
Little Mount Metro Station	209
Alandur Metro Train Station	143
Chennai Airport Metro	214
Perungudi MRTS Station	235
Guindy	87
Taramani	202
Koyambedu	34
Total	**1,696**

Airport

Name	Capacity (kW)
Chennai International Airport	889
Grand Total	**7,106**

Annexure - VII : List of tier 1 and tier 2 cities with geographical area

Classification of city	City	Area (Sq km)	Capacity (MW)
Tier 1	Hyderabad	650.0	1,960.00
	Delhi	1,484.0	2,000.00
	Ahmedabad	464.0	1229.60
	Bengaluru	709.0	1878.85
	Greater Mumbai	603.0	1,720.00
	Pune	700.0	1855.00
	Chennai	426.0	1,378.00
	Kolkata	185.0	490.25
Tier 2	Vijaywada	61.9	163.98
	Warangal	406.9	1,078.29
	Greater Visakhapatnam	540.0	1,431.00
	Guntur	168.4	446.26
	Nellore	48.4	128.23
	Guwahati	215.0	569.75
	Patna	297.9	789.44
	Chandigarh	114.0	302.10
	Durg-Bhilai Nagar	182+314	1,314.40
	Raipur	226.0	598.90
	Rajkot	170.0	450.50
	Jamnagar	128.4	340.26
	Bhavnagar	108.3	287.00
	Vadodara	225.0	596.25
	Surat	326.5	865.23
	Faridabad	742.9	1,968.69
	Gurugram	732.0	1,939.80
	Srinagar	294.0	779.10
	Jammu	167.0	442.55
	Jamshedpur	209.0	553.85
	Dhanbad*	104	276
	Ranchi	175	463
	Bokaro steel city	183	484
	Belgaum	94	249
	Hubli-dharwad	404	1,070
	Mangalore	132	350
	Mysore	152	402
	Gulbarga	147	389
	Kozhikode	177	469
	Kochi	94	251
	Thiruvananthapuram	214	567
	Thrissur	101	268
	Malappuram*	35	93
	Kannur*	7	19
	Kollam	73	193
	Gwalior	780	2,067
	Indore	389	1,032
	Bhopal	285	757
	Jabalpur	367	972
	Ujjain	152	402
	Amravati	121	322

Classification of city	City	Area (Sq km)	Capacity (MW)
	Nagpur	217	576
	Aurangabad	139	368
	Nashik	300	795
	Bhiwandi	150	397
	Solapur	180	478
	Kolhapur	345	914
	Vasai-virar city	380	1,007
	Malegaon*	35	94
	Nanded-waghala*	52	138
	Sangli*	49	129
	Cuttack	398	1,054
	Bhubaneswar	135	357
	Raurkela	200	530
	Amritsar*	135	357
	Jalandhar*	153	405
	Ludhiana	310	821
	Puducherry	562	1,489
	Bikaner	155	410
	Jaipur	111	296
	Jodhpur	78	208
	Kota	527	1,396
	Ajmer*	133	353
	Salem	91	242
	Tirupur	159	422
	Coimbatore	246	654
	Tiruchirappalli	167	443
	Madurai	148	392
	Erode	109	290
	Dehradun	300	795
	Moradabad*	94	250
	Meerut	141	376
	Ghaziabad	133	353
	Aligarh*	102	271
	Agra	188	499
	Bareilly	235	622
	Lucknow*	319	845
	Kanpur	403	1,069
	Allahabad	70	186
	Gorakhpur*	2	5
	Varanasi	82	217
	Saharanpur*	56	149
	Noida	203	537
	Firozabad*	27	71
	Jhansi*	136	362
	Asansol	326	865
	Siliguri	260.0	689
	Durgapur	154	408
		TOTAL (MW)	**62,266**

***Approximate area**

Solar Panels on Greenpeace New Zealand Office.
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Photovoltaic Panels on Subway Station in Seoul.
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