ESTIMATING THE ROOFTOP SOLAR POTENTIAL OF GREATER MUMBAI

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

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BRIDGE TO INDIA

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The National Centre for Photovoltaic Research and Education (NCPRE) at IIT Bombay was launched in 2010 with funding from the Ministry of New and Renewable Energy (MNRE) of the Government of India. The broad objectives of NCPRE are to provide R&D and education support for India’s ambitious 100 GW solar mission. NCPRE has 39 faculty members and over 120 research staff across eight Departments at IIT Bombay working on various aspects of Photovoltaic. Excellent laboratory facilities have been set up which are accessible to all NCPRE researchers.

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Observer Research Foundation Mumbai

Observer Research Foundation (ORF) is a multidisciplinary public policy think tank started in New Delhi in 1990 by the late Shri R. K. Mishra, a widely respected public figure, who envisaged it to be a broad-based intellectual platform pulsating with ideas for nation-building. Beginning 2010, ORF Mumbai has been reactivated to pursue the foundation’s vision in India’s financial and business capital. It conducts research and advocacy in six broad areas: Education, Public Health, Urban Renewal, Inclusive and Sustainable Development, Youth Development and Promotion of India’s Artistic and Cultural Heritage. It is headed by Shri Sudheendra Kulkarni, a social activist and public intellectual who worked as an aide to former Prime Minister Shri Atal Bihari Vajpayee in the PMO. ORF Mumbai’s mission statement is: Ideas and Action for a Better India.

Bridge to India

Bridge to India was founded in 2008 with the objective of bringing international renewable technology and business expertise to India. The organization has grown significantly since then to become a leading consulting and knowledge services provider in the Indian renewable market and worked on numerous assignments for top-tier clients including the Indian government, GE, SunPower, AES, Fortum, Huawei, First Solar, Bosch, Tata Power Solar, Sterling & Wilson, The World Bank, IFC and The Climate Group. The organisation also produces regular market leading research and has published several thought leadership pieces shaping the growth of the renewables sector in India.

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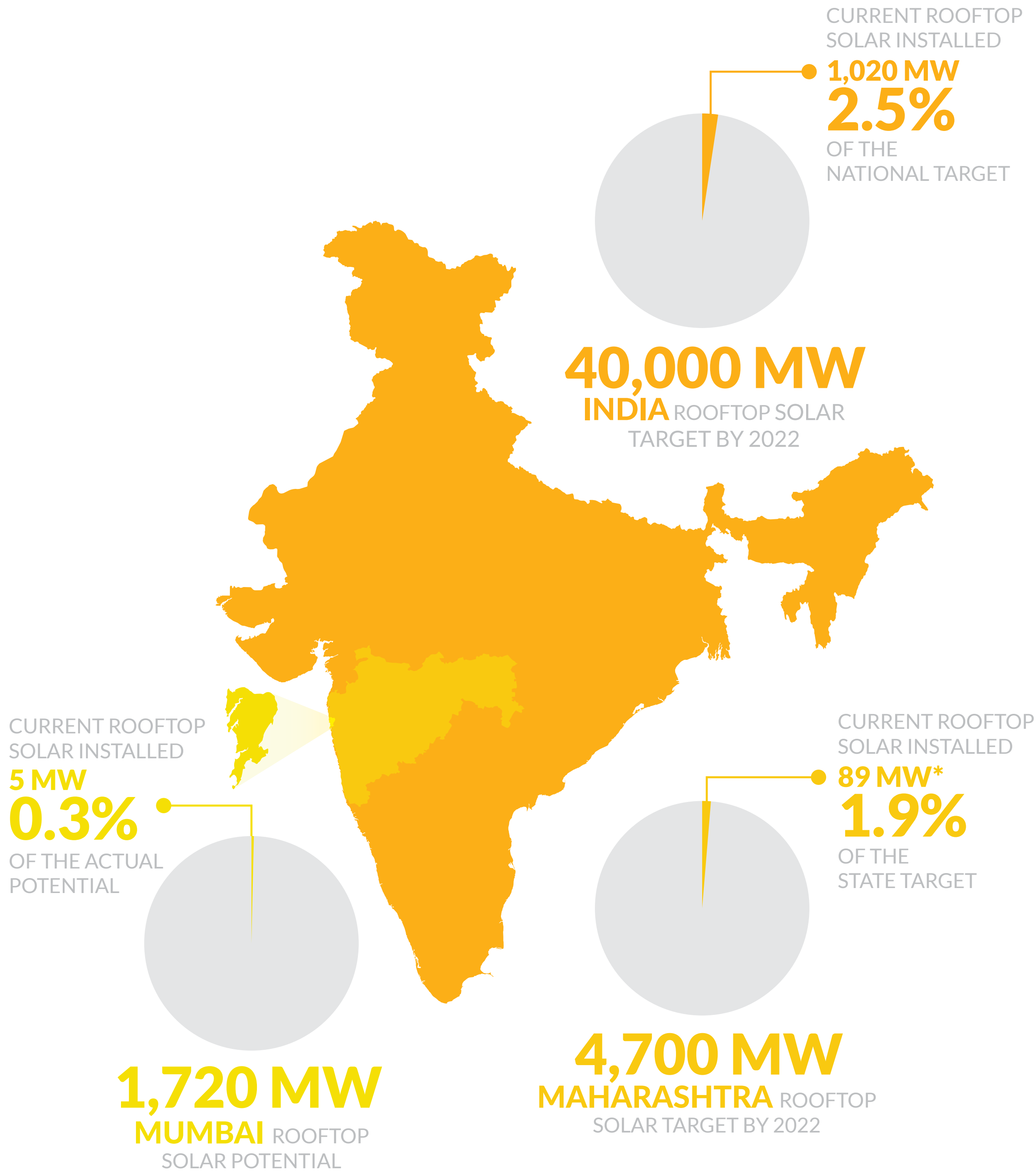
THE INDIAN **ROOFTOP SOLAR** OPPORTUNITY



Source: *MNRE Website, Bridge to India Website (As of September 2016)*
**Excluding Residential Solar Installations*

FOREWORD

Jawaharlal Nehru National Solar Mission (JNNSM) has set an ambitious target of 40 GW capacity to be achieved by the year 2022 through decentralised and roof top scale solar projects. In this context, Municipal Corporation of Greater Mumbai in collaboration with Observer Research Foundation Mumbai and other stake holders had launched a discussion, which I had the opportunity to chair, sometime in 2014 on taking up an ambitious Mumbai Solar Mission. Several aspects of establishing roof top PV installations in Mumbai were discussed at length. Estimating the roof top solar potential in Mumbai was one of them. IIT Bombay had come forward to take up this task in the right earnest. I must compliment NCPRE and CUSE of IIT Bombay and their partners, IEEE Bombay Section, Bridge to India and ORF to have systematically completed this task.

Quite apart from bringing out some key findings, the study is also an important attempt to evolve scalable methodologies for assessment of rooftop potential in our cities. Involvement of students has been an important aspect of this effort. The study has concluded that the total potential for rooftop PV installations in Greater Mumbai is around 1.72 GWp. An assessment of the load profile of the city and the expected generation profile from PV installations indicates that grid management may not be a difficult task even if the entire 1.72 GWp potential becomes a reality. The study has also identified the need to look at major load centres in the city and potential of roof top PV sources in proximity for their effective use in feeding the needs of nearest load centres. Industrial and commercial buildings offer special attraction in this context as there is a significant tariff advantage. The study does bring out potential of different categories of buildings in various wards. One can expect fuller use of available potential in commercial and industrial buildings.

Potential for decentralised generation located close to loads is one of the important feature of solar energy. Roof top installations form an important component of this mode of generation that is free from issues of land use conflict.

I do hope that this study would lead to the much-needed impetus to required actions as well as further policy evolution by concerned agencies in realising the dream of Mumbai Solar Mission.

Anil Kakodkar

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Former Chairman, Atomic Energy Commission
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ABBREVIATIONS

2D	2 Dimension
3D	3 Dimension
BEST	Brihanmumbai Electric Supply & Transport Undertaking
CGS	Central Government Employee's Society
CO_2	Carbon dioxide
C/P	Coverage area to Plot area ratio
CSV	Comma Separated Values
CUSE	Centre for Urban Science and Engineering
ELU	Existing Land Use
GIS	Geographical Information System
GW	Giga Watt (Unit of Power)
GW_p	Giga Watt peak - unit used to denote the peak power output of PV plants
HVAC	Heating Ventilation and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
IIT	Indian Institute of Technology
IMEP	Integrated Metropolitan Environmental Policy
IT	Information and Technology
JNNSM	Jawaharlal Nehru National Solar Mission
KMZ	Keyhole Mark-up Language Zipped
kW	kilo Watt (unit of power)
kW_p	kilo Watt peak – unit used to denote the peak power output of PV modules under standard test conditions
kWh	kilo Watt Hour (unit of electrical energy)

LiDAR	Light Detection And Ranging
MCGM	Municipal Corporation of Greater Mumbai
MHADA	Maharashtra Housing and Area Development Authority
MIDC	Maharashtra Industrial Development Corporation
MMRDA	Mumbai Metropolitan Region Development Authority
MNRE	Ministry of New and Renewable Energy, Government of India
MTNL	Mahanagar Telephone Nigam Ltd.
MW	Mega Watt
MW_p	Mega Watt peak - unit used to denote the peak power output of PV plants
NCPRE	National Centre for Photovoltaic Research and Education
ORF	Observer Research Foundation
PV	Photovoltaic Technology
RBI	Reserve Bank of India
RCC	Reinforced Cement Concrete
RGB	Red-Green-Blue
RMS	Root Mean Square
SAR	Solar Analysis for Revit
S/C	Shade free area to Coverage area ratio
SEEPZ	Santa Cruz Electronics Export Processing Zone
SPA	Special Planning Areas
sq. m.	square meter
TERI	The Energy and Resource Institute
UK	United Kingdom
USA	United States of America

EXECUTIVE SUMMARY

Renewable energy is being seen as a transformative solution to meet energy as well as climate challenges, both globally and nationally. There is an increasing focus on the development of solar energy in India for a variety of reasons, including our limited conventional energy reserves, their local environment and social impacts, energy security issues, energy access and tackling the challenge of climate change. Solar photovoltaics (PV) technology is emerging as an extremely attractive option, particularly with abundantly available solar resource, modular technology and zero fuel costs over 25 years of the project life.

Considering this, the Government of India, through the Jawaharlal Nehru National Solar Mission (JNNSM) has recently expressed its intent to achieve 100 GW of solar capacity in the country by 2022, of which 40 GW is expected to be achieved through decentralised and rooftop-scale solar projects. Rooftop solar PV would play a prominent role in meeting energy demands across different consumption segments. It has already achieved grid parity for commercial and industrial users and is fast becoming attractive for residential consumers as well.

As the first step towards achieving the 40 GW target we undertook a study to assess the potential of solar rooftop PV in various urban, semi-urban and rural areas to help prioritise and target several infrastructure segments for deployment of the technology. The goal of this study was to estimate the potential of solar rooftop PV for the city of Mumbai. Mumbai has an average power demand of about 3 GW, one of the highest in India.

An equally important objective of this study was to establish a quick, yet accurate, methodology to estimate the rooftop solar potential of India's urban centres. One of the biggest challenges in deploying a large capacity of rooftop solar PV system is the availability of shadow free rooftop area. Additionally, most of India's cities have witnessed unplanned urbanization in the last decade. Such unplanned urbanization shows lack of clearly demarcated areas for different usages. For instance, residential areas also cater to commercial activities (small shops that sell daily supplies); slums coexist with industries; schools and colleges weave themselves around residential complexes, etc. Managing to categorise buildings by type of usage is indeed a challenge in most Indian cities.

Satellite based assessments using open source tools such as Google Earth and Google Maps can help estimate a fairly accurate potential of rooftop solar PV area. However, since Google Maps is not capable of categorizing areas as per usage (residential, commercial, educational, etc.), the methodology adopted in this study uses a three-step approach. In the first step, we estimate, category-wise, the potential rooftop area available in Mumbai by solely relying on freely available satellite imagery (Google Maps, Google Earth, Wikimapia and WoNoBo) along with the Existing Land Use (ELU) Maps provided by the Municipal Corporation of Greater Mumbai (MCGM). In the second step, we refine these results by making site visits to carefully selected sample sites (one each in residential, commercial, industrial, etc.) and ascertain use-type. Site visits also help corroborate satellite data and check for accuracy. We found, in most cases, that satellite data varied from actual ground data by a maximum of 12%, while in most cases, the average variation was only 5%. This shows that open source tools are adequate for estimating rooftop potential of cities without the need for expensive satellite imagery or time-consuming and complicated image processing algorithms. In the third step, we further refined the estimate using 3D modelling and shading analysis of building clusters to come up with discounting factors which account for inter-building shading,

This study estimates the total rooftop solar PV potential of Greater Mumbai to be 1.72 GW with residential buildings making up nearly 1.3 GW_p or nearly 75% of the total rooftop solar PV potential in Greater Mumbai. The second largest potential is contributed by industries - 223 MW_p, followed by educational institutions - 72 MW_p and commercial buildings - 56 MW_p. Mumbai's transportation sector holds some potential with the railways (stations and offices) contributing 26 MW_p and bus depots contributing 4 MW_p.

This potential only indicates the maximum amount of solar PV installation capacity that Greater Mumbai's rooftops can accommodate. It does not take into account the adoption rate of solar rooftop systems, which is difficult to estimate, being dependent on various factors such as affordability, system price trends, electricity rates and incentives from the State and Central Government and finally policy support.

The geographic boundary of this study was Greater Mumbai which includes all areas that fall under the jurisdiction of the Municipal Corporation of Greater Mumbai (MCGM) within an expanse of 437 sq. km. This study area covers all of the 24 wards (administrative zones) that fall under the MGCM.

We hope that this report will help the government and the solar industry to tap this vast potential of rooftop solar PV in the city of Mumbai and in other urban areas of India. The study will also help policy makers in taking appropriate steps to come up with schemes helping the proliferation of rooftop solar. We believe that the methodology which we have developed can readily be adopted by various stakeholders across other cities in India so as to ensure a speedy assessment of the solar potential of India's urban centres.

CHAPTER 1

BACKGROUND

HISTORICAL DEVELOPMENT OF SOLAR PV IN MAHARASHTRA STATE

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LITERATURE REVIEW

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BACKGROUND

The solar energy sector in India has seen an exponential growth during the last five years and we expect it to grow in the same way for the next decade or so with various national and regional pro-solar policies in place. A large number of initiatives under the umbrella of JNNSM are boosting the solar PV sector in particular. The Government of India has announced a revised target of 100 GW of solar PV by 2022 out of which 40 GW has to be accomplished through decentralised grid connected rooftop systems [1]. A substantial amount of these rooftop systems are expected to come up in various urban and semi-urban centres of the country. It therefore becomes very important to estimate the potential across these urban centres, to achieve the targets prescribed by the Ministry of New and Renewable Energy (MNRE). More importantly, it becomes imperative to develop a standard methodology to estimate rooftop solar installation potential. This 'resource assessment' is the primary step in planning distributed rooftop solar power plants at a city level. A quick and reliable assessment of available rooftop areas, classified according to the existing power consumer category - residential, commercial and industrial users - can assist planning authorities to draft effective regional rooftop solar policies and devise processes for implementation. It also provides urban planners the necessary framework to develop building regulations that may mandate use of solar PV for new buildings in cities.

HISTORICAL DEVELOPMENT OF SOLAR PV IN MAHARASHTRA STATE

Maharashtra announced its latest renewable energy policy in July 2015. This policy came after seven years since the announcement of the previous renewable energy policy released in 2008.

RENEWABLE ENERGY POLICY 2015

The Policy titled *'Comprehensive Policy for Grid-connected Power Projects based on New and Renewable (Non-conventional) Energy Sources 2015'* aims at the installation of 7,500 MWp of solar power projects by 2020 [2]. Out of the 7,500 MWp capacity, 2,500 MWp is scheduled to be commissioned by the state owned generating company MAHAGENCO via a public-private partnership (PPP) mode. It is likely that MAHAGENCO will own the assets and outsource the construction of these plants to private Engineering, Procurement and Construction (EPC) companies. Ten percent of this target capacity is allotted to projects based on water bodies such as canals and lakes.

Developers and investors will own and construct the remaining 5,000 MWp. The state distribution companies (DISCOMS) shall buy the power generated from this capacity at appropriate tariff. The tariff is likely to be discovered through competitive bidding against the benchmark solar tariff as computed by the Maharashtra Electricity Regulatory Commission (MERC). Minimum project size for solar PV projects has been set to 1 MWp.

The project also allows captive solar power projects to be set up by industries, commercial establishments, etc. that have a large power requirement. Open access is also allowed, though its actual implementation has traditionally remained a challenge in Maharashtra.

The land required to construct solar power plants can be Government land / waste land / private land owned by individuals or even farmland. The policy provides for the status of deemed non-agricultural land for any farmland procured for solar PV projects.

The policy does not provide any specific targets for rooftop solar PV installations. The policy also does not include any state specific subsidies or implementation guidelines. However, the MNRE has set targets for rooftop solar PV capacity for every state and union territory in India [3], and this is shown in Table 1.1 for Maharashtra. By 2022, it is expected that 4.7 GW of solar PV will be installed on rooftops in Maharashtra, which is quite an ambitious target.

Maharashtra has a total installed capacity of 52 MWp as on December 2015 [4]. According to Bridge To India's analysis, Maharashtra is one of the most attractive states for the adoption of rooftop solar PV in India. This is largely due to the high tariffs for industrial and commercial customers.

NET METERING REGULATION FOR ROOFTOP SOLAR PV PLANTS

Although there is no specific policy support for rooftop solar PV plants in Maharashtra, the regulator has announced rooftop solar PV regulations that would provide the necessary rules and guidelines for the installations of such systems. The Maharashtra Electricity Regulatory Commission (MERC) announced the net metering regulation in September 2015 [5]. The policy titled, *'Net Metering for Roof-top Solar Photo Voltaic Systems Regulations, 2015'* is applicable to all consumers of a distribution licensee (DISCOM) who intend to set up a rooftop solar PV system of capacity less than 1 MWp. The highlights of MERC net metering policy 2015 are compiled in Table 1.2.

Table 1.1: Year wise rooftop solar PV targets for Maharashtra (2015-2022) in MWp

2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
20	565	588	704	823	940	1060
Total Capacity: 4,700 MWp						

Source: MNRE. State wise and year wise targets for installation of 40,000 MWp grid connected solar rooftop systems. [3]

Table 1.2: The highlights of MERC net metering regulation 2015

Eligible Consumer	All existing consumers of DISCOMs in Maharashtra on a first-come-first-serve basis
Eligible System Size	Less than 1 MW_p installed dc capacity; however system size cannot exceed sanctioned demand of the consumer
Penetration limits	40% of the distribution transformer capacity; beyond which a detailed load flow study shall be performed
Connected voltage in urban areas	
Voltage level	Maximum Size of Rooftop PV System
230 / 240 V (Single Phase)	< 8 kW_p
400 / 415 V (Three Phase)	> 8 kW_p and < 150 kW_p
11kV and above	150 kW_p and < 1 MW_p
Compliance Standards	
1. CEA, Technical Standards for Connectivity of the Distributed Generation Resources, 2013	
2. CEA, Measures relating to Safety and Electric Supply, 2010	
3. MERC, State Grid Code, 2006	
4. CEA, Installation and Operation of Meters, 2006, 2013	
Renewable Purchase Obligation	
• If the net-metering consumer is an obligated entity, then the quantum of energy generated shall count towards the consumer's RPO • If the net-metering consumers is NOT an obligated entity, then the quantum of energy shall count towards the DISCOM's RPO	
Commercial Settlements	
The DISCOM shall carry forward any excess energy into the next billing cycle. The DISCOM shall compensate the consumer (generator) for the excess energy at the end of the financial year at the prevailing Average Pooled Purchase Cost (APPC).	

ESTIMATING THE ROOFTOP SOLAR POTENTIAL FOR GREATER MUMBAI

Mumbai being one of the oldest cities in India has a varied urban texture throughout its expanse. The urban topologies in Mumbai vary from the colonial constructions in the south to the post liberalisation constructions in the central areas. There are planned native townships like the Parsi Colony in Dadar and there are unplanned native settlement areas like the Bhendi Bazar area near Mazgaon. Central Business Districts (CBDs) like the Bandra-Kurla Complex area and the extremely unplanned and un-engineered constructions in the chawls and slums like in Dharavi add to the diversity. Huge university campuses like the Mumbai University campus and the IIT Bombay campus can be considered as a category of urban topology by themselves. Government owned townships and constructions like that of the Railway Colonies, Navy Nagar, Indian Oil Corporation, etc. come under a different category. Even though the entire 'developed' area of whole greater Mumbai is dominated by residential buildings, there are significant areas of built up land under commercial, industrial, educational, medical and transport amenities. In short, it is an arduous task to classify Mumbai into various urban topologies and to develop a generic methodology for estimating the rooftop potential for the whole city. But if such a methodology can be developed, it can be easily adopted and replicated in any other city in India.

LITERATURE REVIEW

The Energy and Resource Institute (TERI), New Delhi, in 2009, came up with a master plan for making Chandigarh a solar city [6] . This is one of the earliest attempts in the Indian context related with the evaluation of the rooftop solar potential at a city scale. This section presents a brief review looking into various aspects of solar city projects in India and around the globe. More details of the case studies are available in Appendix I.

In India, the Ministry of New and Renewable Energy (MNRE) has launched the development of 60 solar cities across India in January 2014. The project aims at meeting at least 10% of the projected energy requirement of 60 cities in India through solar energy by the end of 5 years through deployment of renewable energy sources and energy efficiency measures in the city [7]. The goals of the solar city program are expected to be achieved by the end of 12th Five Year Plan, i.e. by 2017. The master plans for such solar cities are available from various web based sources. The solar city master plans for Mysore in Karnataka [8], Surat and Gandhinagar in Gujarat [9] [10], and for Chandigarh [6] are available from MNRE's official website. Most of the project proposal documents for various sources just refer to the annual average values of solar insolation in the city and estimate a ball park figure for power generation potential based on the insolation values. Nearly 10% samples were selected and studied for the rooftop area calculation and the values obtained from these samples were generalised. The first ever master plan report for a solar city in India, for Gandhinagar, released in 2007 [11] has taken a sample study of one sector (sector 21) among the entire 30 sectors. For the rest of the sectors, they referred to secondary data from the administrative bodies regarding the rooftop area, assumed an acceptance rate of 5% among the building owners to join the rooftop project and estimated the potential to be 14.07 MW_p.

Bridge to India had earlier released a report on the study of rooftop solar potential of Delhi city in 2013 [12]. In this report the authors had used Google Earth in identifying and estimating rooftop potential. Wikimapia was used to classify the building category. The study broadly classified the buildings and built up areas in Delhi into 3 categories – residential, commercial and industrial. The study concluded that the approximate rooftop potential from all these building categories sums up to 2 GW_p.

The second of the reports from Bridge to India assessed the rooftop solar potential of Patna using a similar methodology. It was estimated that the rooftop solar PV potential of the city of Patna was 759 MW_p [13].

There have been various solar city initiatives in various countries and attempts have been made globally and in India for quantifying the rooftop solar potential at a city scale. r-Sun, arc-GIS and 3D modelling tools have been used by various teams in quantifying the rooftop areas for various cities. Semi-automated (which requires some manual work for digitizing the rooftops areas) and fully automated image processing methods (which requires the software to be trained by experts) are widely used in this arena. A 10% representative sampling of urban textures and modelling can give rooftop estimation results with a 95% confidence level [14].

DESIRABLE FEATURES OF A METHODOLOGY FOR ASSESSING SOLAR POTENTIAL

While developing a methodology for quantifying rooftops the following criteria need to be considered:

a) Methodology should have a reasonably good accuracy and reliability. The computational errors should be bounded within reasonable limits.

b) It should be inexpensive (the use of expensive high quality satellite images and licensed image processing tools should be avoided where possible).

c) It should be fast in producing results (low calculation time).

d) The method must have the capacity to produce geo-referenced results. The GIS layers, if used as a part of rooftop area measurements should be encrypted with the latitude-longitude data, so that whenever a third party opens it on a different computer, the layers gets aligned to the original latitude-longitude.

e) It must be scalable and replicable locally and globally.

f) The methodology should be well structured, and at the same time flexible. Modifications in the process should be possible in future for improvement, depending on the local/regional aspects of the project area. [14]

For India, the methodology must in addition be able to classify buildings by type i.e. Government, Residential, Commercial, Industrial, Educational Institute, etc. This classification is as per the cities' electricity retail tariffs. This is important because the adoption rate of rooftop solar PV is a function of the electricity prices. Higher electricity prices usually mean faster adoption rates. Since retail electricity tariffs in India are non-uniform and tiered according to the categories mentioned above, it makes sense for any rooftop solar PV potential assessment methodology to use the same classification schemes. This means integrating into the process inputs such as development plans and land use maps available with local municipal corporations. Based on these insights from literature and reports, we have developed a methodology for the rooftop potential estimation of greater Mumbai, i.e. the MCGM's administrative area. The methodology has been explained in the next chapter.

CHAPTER 2

METHODOLOGY

METHODOLOGY

In this report, we propose a new methodology for quick assessment of the rooftop PV potential of urban and semi urban areas using free and online Geographic Information System (GIS) tools and crowdsourcing the manual mapping work done by the student community. This study utilizes GIS tools such as Google Earth [15] and WikiMapia [16], the existing land use maps, limited site visits, and simple statistical analysis to estimate the solar PV potential of Greater Mumbai. The methodology can be easily extended to other urban areas. The details regarding the study area and the procedures for calculating the rooftop potential are explained in this chapter.

DESCRIPTION OF STUDY AREA

The study area which is considered for the rooftop potential estimation falls under the Municipal Corporation of Greater Mumbai (MCGM) jurisdiction with an expanse of 437 sq. km. This does not include the water bodies such as rivers and creeks. However, the GIS data with MCGM says that the area under their jurisdiction is 458.16 sq. km. including the water bodies. The approximate geographical location of the study area is between 18° 53' - 19° 16' N latitudes and 72° 44' - 72° 58' E longitudes. Information from the MCGM website which includes the detailed "Draft Development Plan for Greater Mumbai 2014-2034" and the Existing Land Use (ELU) maps [17] were widely used as references while planning and executing the study activities.

The entire Greater Mumbai is divided into 24 distinct administrative areas called 'wards' which have physical boundaries. The nomenclatures of the wards are English alphabets appended with letters E, W, S, N and C which denotes their position East, West, South, North and Central respectively. The list of wards and the actual name of localities under each ward are given in Table. 2.1. Fig 2.1 shows the satellite picture and ward map of Greater Mumbai.

Table 2.1: Nomenclature of Administrative Wards in Greater Mumbai Region

Name	Name of the localities within each ward boundary
A	Navy Nagar, Geeta Nagar, Cuffe Parade, Colaba, Ballard Estate and Fountain
B	Mandvi, Umerkhadi, Pydhonie, Dana Bunder, Chinch Bunder and Mumbai Port Trust
C	Kalbadevi, Bhuleshwar, Girgaon (Part), Zaveri Bazaar, Null Bazaar and Marine Lines
D	Banganga, Malabar Hill, Peddar Road, Grant Road and Girgaon Chowpatty
E	Byculla, Agripada, Cotton Green, Kamathipura and Darukhana
F/N	Dadar - Parsi Colony, Hindu Colony and Prateeksha Nagar
F/S	Abudhaya Nagar, Parel, parts of Wadala, Sewri and Curry Road
G/N	Mahim Causeway, Dadar, Shivaji Park and Prabhadevi
G/S	Mahalaxmi, Worli Naka, Lower Parel and BDD Chawls
H/E	Bandra Kurla Complex, Vakola, Kalina University, Girgaon (Part) and Milind Subway
H/W	Palli Hills, Bandra Reclamation, Khar (West), Band Stand and Carter Road
K/E	Marol, Bamanwada, Sahar Airport, SEEPZ, Jogeshwari and Gundavali
K/W	Juhu Beach, Lokhandwala, JVPD and Versova
L	Sakinaka, Kurla, Nehru Nagar and M.H.B Colony.
M/E	Wasi Naka, Shivaji Nagar, Deonar, RCF Colony, BPCL Colony, HPCL Colony and Trombay
M/W	Chembur Station Area, Sindhi Colony and Tilaknagar
N	Ghatkopar, Rajawadi, Phirojsha Nagar (Godrej), Pant Nagar, Vidyavihar and Vikhroli
P/N	Malwani, Aksa, Malad, Orlem Colony and Inamdar Layout.
P/S	Aarey Colony Film City, Goregaon, Mindspace and Bangur Nagar
R/C	Kandivali, Mahindra & Mahindra Tractor Division and Charkop
R/N	Dahisar, Borivali and LIC Colony amongst others.
R/S	Charkop Industrial Estate, Thakur Village and Thakur Complex and Lokhandwala (Kandivali East).
S	Powai, Hiranandani, Kanjur, Nahur and Hariyali.
T	Mulund Colony, Paanch Rasta, Moto Nagar and Nirmal Nagar.

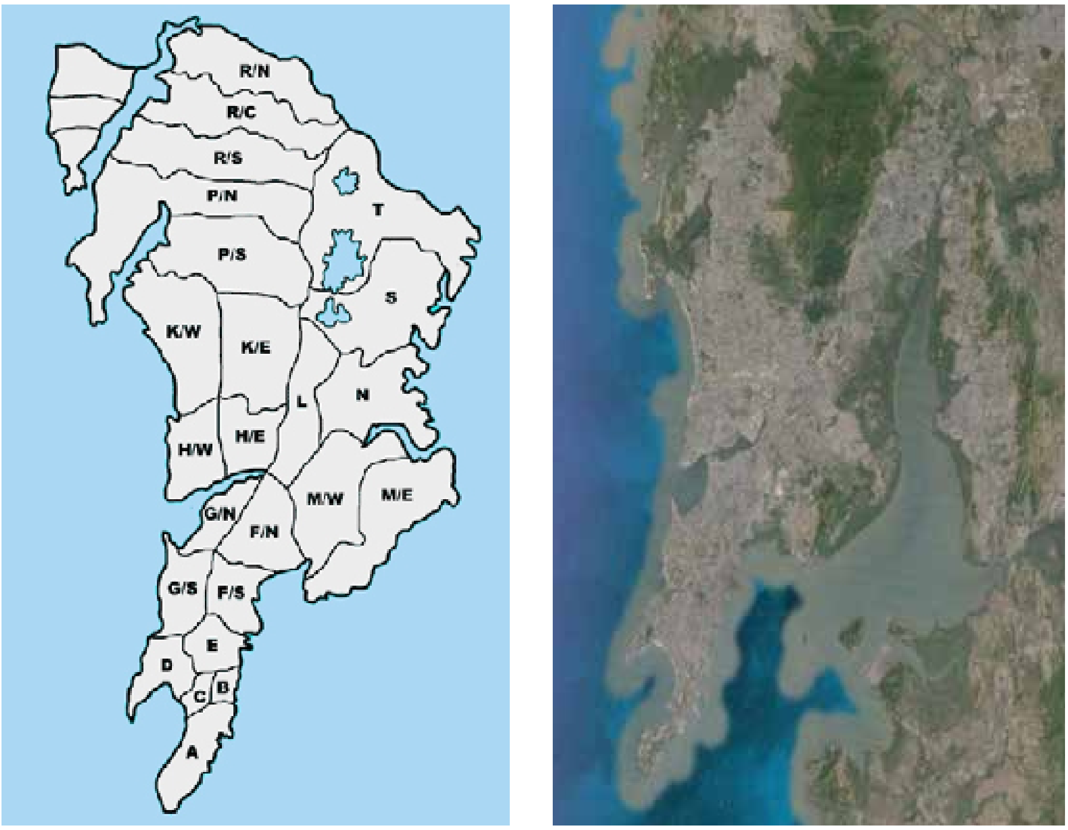


Figure 2.1: Satellite Picture of Greater Mumbai and City Map with Ward Boundaries

(Source: [15], [17])

Greater Mumbai is also divided in two broad zones, namely, the Planning Area (415.05 Ha.) and the areas under Special Planning Authorities (SPA) (43.23 Ha.). MCGM has limited authority to plan and execute infrastructure and development project under the latter areas. Special planning authorities like MMRDA (Mumbai Metropolitan Region Development Authority), SRA (Slum Rehabilitation Authority) and MIDC (Maharashtra Industrial Development Corporation) are in charge of the development of some of these SPAs. The MCGM website does not provide the ELU maps for such SPAs e.g. Back Bay Reclamation area, Bandra-Kurla Complex, Dharavi, Wadala Truck Terminal, Oshiwara Business District, SEEPZ (Santacruz Electronics Export Processing Zone), Marol Industrial Area, and Airport, which is estimated to be around 43.23 sq. km. The study area is therefore restricted to the planning area under MCGM which is around 415.05 sq.km.

EXISTING LAND USE OF MCGM PLANNING AREA

Land use classification is an integral part of any city planning process. MCGM conducted an extensive survey to gather the information of existing land use of each parcel at block level. The data was used to create the Existing Land Use Map (ELUs) 2012 on a GIS platform. Based on the ELU 2012, an assessment of the various land uses and their distribution across the various wards of the city was done across various scales – at the level of Greater Mumbai, followed by the ward level and finally the planning sector levels. The existing land use survey reveals that only 65.34% (27,117 sq. km) of the planning area of Greater Mumbai is developed, whereas 34.66% of is undeveloped. The undeveloped area includes natural areas, vacant lands, plantations and salt

Table 2.2: Distribution of developed area in Greater Mumbai Region under different primary land use categories

Category level-1	Area in Hectares	% of Total area	% of Developed area
Residential	10,327.09	24.88	38.18
Industrial	2,242.88	5.40	8.27
Commercial	911.46	2.20	3.36
Offices	360.96	0.87	1.33
Amenities (Education, Medical, and Social)	1528.06	3.68	5.63
Transport and Communication facilities	5,306.92	12.79	19.57
Public Utilities & facilities	693.43	1.67	2.56
Open Space	1,537.78	3.70	5.67
Urban villages	318.42	0.77	1.17
Primary Activity (P1, P3, P4, P5 P6,P7)*	939.22	2.26	3.46
Unclassified	1,829.77	4.41	6.75
Vacant Land (only under Construction)	1,121.97	2.70	4.14
Total	***27,117.96***	***65.33***	***100***

** Primary activities under the Developed Areas include – P1 (Fishing / Drying Yard), P3 (Dairy), P4 (Buffalo Stables), P5 (Cattle Pounds), P6 (Quarry), and, P7 (Dhobi Ghats)*

pans. Table 2.2 shows the distribution of built areas (alias developed areas) under different primary land use categories.

For further understanding and study, the primary land use categories have been subdivided into secondary and tertiary categories. For example 'Residential' category has 5 sub categories ranging from single family houses to slums. Similarly 'Educational Amenities' are divided into 'Primary Schools', 'Integrated Schools' and 'Colleges' at the second level of hierarchy and colleges are further sub-categorised into colleges, polytechnics, professional colleges, universities, civic training institutes and other educational amenities at the third level of hierarchy. Separate colour codes have been used for representing each of these categories while preparing the land use maps. The colour codes used for representing primary land use classifications is as shown in figure 2.2. Further, figure 2.3 shows the colour codes used for sub categories of residential buildings.

Existing Land Use (2012)	Colour Codes
Residential	
Commercial	
Offices	
Industrial	
Natural Areas and Open Spaces	
Education Amenities	
Medical Amenities	
Social Amenities	
Public Utilities and Facilities	
Transport and Communication Facilities	
Urban Villages	
Primary Activity	
Unclassified	
Vacant Land	

Figure 2.2: Colour coding used for primary land use categories in ELU map preparation by MCGM *(Source: [17])*

RESIDENTIAL

Main Code	Sub Code	Subject Category	Type (For Identification on Field)		RGB Color Values
R	R1	Individual Housing	R1.1	Primary Residential Zone	255 - 255 - 0
			R1C	Residential with Commercial	255 - 255 - 0 / 0 - 75 - 250
	R2	Apartments / Multifamily	R2.1	Primary Residential Zone	240, 220, 90
			R2S	Residential with Shopping	240, 220, 90 / 115 - 185 - 255
			R2C	Residential with Commercial	240, 220, 90 / 0 - 75 - 250
	R3	Government / Municipal Staff / Quarters / Housing	R3.1	Primary Residential Zone	255 - 200 - 0
			R3S	Residential with Shopping	255 - 200 - 0 / 115 - 185 - 255
	R4	Chawls	R4.1	Chawls Predominantly Residentia	214 - 153 - 0
			R4S	Chawls with Shopping	214 - 153 - 0 / 115 - 185 - 255
			R4C	Chawls with Commercial	214 - 153 - 0 / 0 - 75 - 250
			R4I	Chawls with Industry	214 - 153 - 0 / 170 - 150 - 230
	R5	Slums/ Clusters	R5.1	Slum Predominantly Residential	134 - 96 - 0
			R5C	Slum with Commercial	134 - 96 - 0 / 0 - 75 - 250
			R5I	Slum with Industrial	214 - 153 - 0 / 170 - 150 - 230

Figure 2.3: Colour coding used for Secondary Level Residential categories in ELU map preparation by MCGM *(Source: [17])*

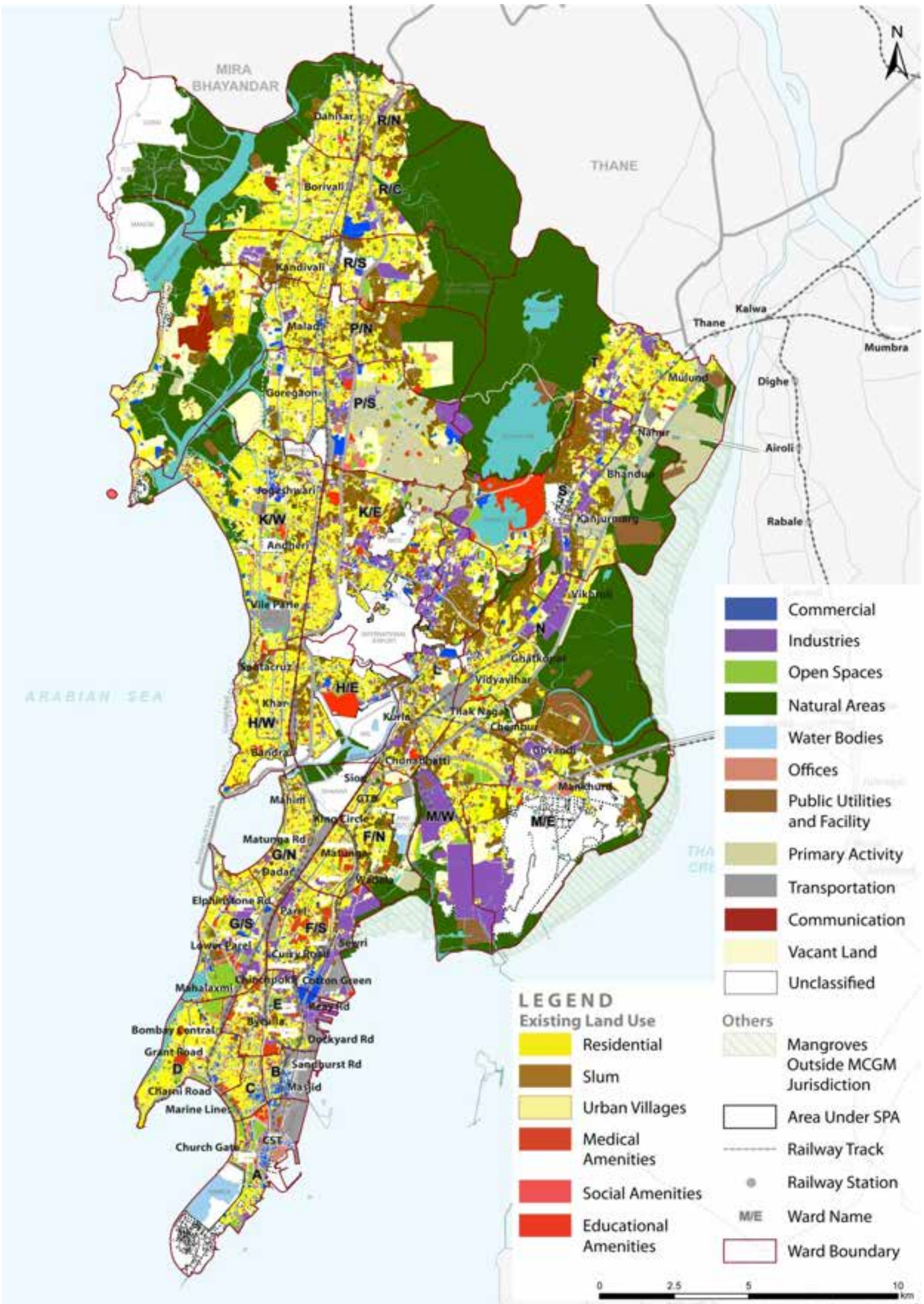


Figure 2.4: Existing Land Use map of Greater Mumbai (2012) *(Source: [17])*

Figure 2.4 shows the ELU map for entire Greater Mumbai. Based on this map and the data from the MCGM planning report, samples areas were selected for further mapping and simulation to estimate the rooftop potential of the entire city.

METHODOLOGY FOR ESTIMATING THE ROOFTOP POTENTIAL OF GREATER MUMBAI

The existing methodologies used for rooftop PV potential estimation (Appendix I) do not capture information about the existing use of the buildings (which has an implication on the electricity tariffs and acceptance rate for PV). Hence based on the insights from the review of literature on past activities, a new methodology was developed which performs a three-stage analysis for estimating the rooftop potential of urban or semi-urban areas. The *first stage* in this methodology is to perform a two-dimensional (top view) mapping of selected samples or plots in the city using Google Earth Pro tool (https://www.google.com/earth/). The mapping process includes manual sorting of the 2D top view satellite images into various buildings/plot types. Using proper sampling methods, we made sure that all categories of developed areas and buildings are represented in the mapping process. After the mapping, a rough estimate of the fraction of developed area converting to building foot print area is obtained. Then out of this 'built area' (alias 'coverage area'), the fraction contributing to shade free area suitable for PV installation is calculated. Using simple statistical extrapolation, the total rooftop solar potential of the city can be calculated. The *second stage* involves site survey of selected samples. During this site survey the actual usable rooftop areas of buildings are physically measured. This helps in calculating the 'error' in measurement or the deviation in estimated area using online tool from the actual measured physical area. Basic information about the strength of the buildings in a particular locality, perception of the people about rooftop solar programs, willingness of the people to adopt rooftop solar etc. are also covered through the on-site survey. The floor to floor heights of buildings were also measured. The site survey is conducted by a team of student volunteers, well trained in the task at hand. This has the additional benefit of exposing youngsters to the benefits and potential of solar energy. The information gained is then fed into the *third stage* which is a 3D modelling and shading analysis of building clusters from various sample areas. This helps in finding out the discounting factors to be considered while calculating the rooftop PV potential due to inter building shading, especially in densely built up areas with varying building heights. A flowchart of the methodology is shown in Fig. 2.5. The various stages of the methodology and associated tools used and the methods of execution are explained in the sections following the flowchart.

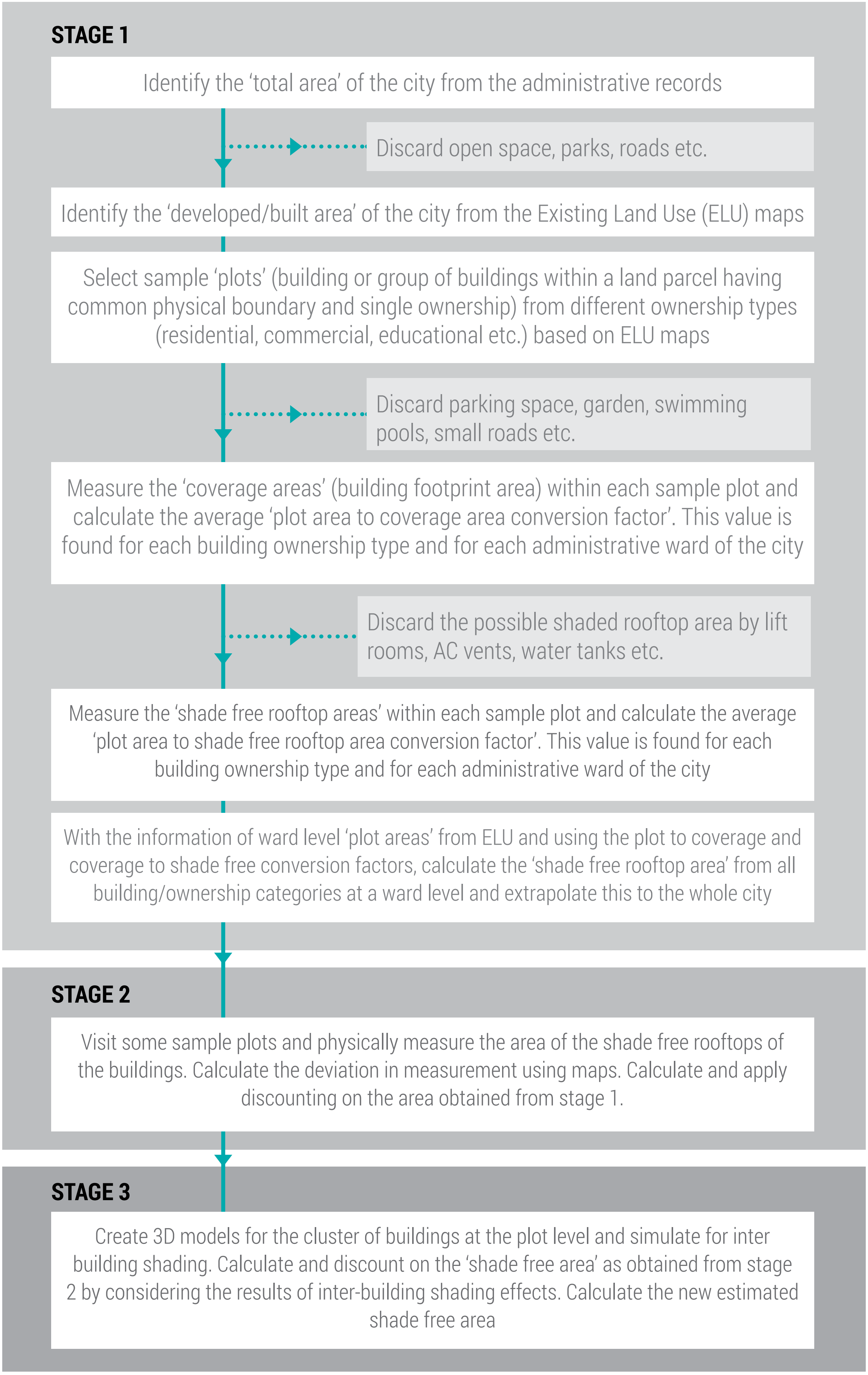


Figure 2.5: Flowchart for the rooftop estimation methodology used for Greater Mumbai

STAGE 1: SAMPLING AND MAPPING OF PLOTS ACROSS THE STUDY AREA

Since it is a laborious task to map each and every building in Greater Mumbai (or any other urban area) manually, samples that are representative of the various building categories were taken. The primary and the most challenging task was to select enough number of samples and a sampling methodology which can truly represent the whole of the city. The ward level ELU maps were used as references and it was made sure that at least 10% of the area under residential plots, and 50% area under other major land use categories were mapped in each ward. Since the land use categorisation was done in a 3 level hierarchy, the sampling method adopted was 'Stratified Random Sampling' [18]. The sampling method basically classifies the entire study area into various 'strata' based on land use category. From each stratum, samples were randomly chosen. As per the basic statistical requirement, at least 2,711 hectares (10%) of developed area need to be plotted out of the 27118 hectare built area [14] so that we can generalise the results to the entire city with 95% confidence level and 6.2% confidence interval. Based on these criteria and sampling method, enough number of samples were plotted in every administrative ward using the Google Earth Pro tool. Some of the terms used to denote certain values and used as a part of the methodology are explained below.

PLOT AREAS:

The entire bounded area identifiable in the ELU maps which is 'built/developed' and categorised under one of the sub-categories of land use are termed as plot areas. A 'plot' is usually a parcel of land having a physical boundary and having one or more buildings under single ownership (or type of ownership). Plot area includes the parking areas, gardens, pools etc. within the boundaries of a developed plot. Figure 2.6 shows, as an example, the plot area for Mumbai University campus in ward H/E mapped using Google Earth and the corresponding land use map used as reference.

COVERAGE AREAS:

This includes the 'footprint' area of the buildings which have suitable rooftops for a solar PV system installation within the plot boundary. Figure 2.7 shows, as an example, the coverage area for Jawaharlal Nehru library complex (left) of the Mumbai University and the overall coverage areas (right) plotted within the plot area.

SHADE FREE AREAS:

Shade free area is the actual area suitable for the installation of PV modules. This is the area obtained by excluding the shaded areas on the rooftop. We have to consider shading objects such as ventilation of chillers and ACs, elevator shafts, water heater systems, water tanks, etc. and exclude the rooftop area around these objects while measuring the 'shade free area'. The height of a shading object was arbitrarily considered as 4 m (which can be the maximum of floor to floor height as obtained in the literature survey [19]). If there is a shading object on the rooftop, then 4 m to its east, west and south directions were excluded while calculating the shade free areas. This is considering the maximum length of shadows obtained when the sun is at a reasonable elevation of 45° above horizon during its east-west movement and during the maximum inclination towards the north (23.5+19 = 42.5°) during seasonal north-south movement. Obvious shading from nearby trees are considered. A reasonable area is excluded from shade free

Figure 2.6: Plot area mapped using google earth and corresponding ELU map used as reference

Figure 2.7: Coverage area mapped for library complex in Mumbai University and the entire coverage areas within the plot

Figure 2.8: Shade free area of Mumbai University library

Figure 2.9: Shade free area of Tata Steel building

area if there are tall trees nearby either on the east, west or the south of the building. It has to be noted that the shading caused by adjacent tall buildings is not considered in this calculation, since the height of the adjacent building is not available from Google Earth's top views. Figure 2.8 shows the shade free areas obtained for the library complex of Mumbai University. The area marked in white colour is the shaded area due to structures on the rooftop which is discounted. For slanted roofs, the area which is obtained from the parts slanting towards south, south east or south west are considered as 'solar-suitable'. Figure 2.9 shows the shade free area obtained from Tata Steel building from ward R/C.

COVERAGE AREA TO PLOT AREA RATIO:

The ratio between the total coverage area of all buildings within the plot to the total plot area is called the 'Coverage area to Plot area ratio' or 'C/P ratio'. This allows conversion of the plot area to coverage area. For example the plot area of Mumbai University is 86,418 sq. m. and the sum of the building footprint (coverage) areas is 64,934 sq. m. Hence the C/P ratio is 0.751.

SHADE FREE AREA TO COVERAGE AREA RATIO:

After discounting the shaded areas on every rooftop within the plot, the sum of shade free areas is calculated. The ratio between the total shade free area to the total coverage area within a plot gives an indication of how much rooftop area gets translated to 'solar suitable' area. This ratio can be called as the 'Shade free area to Coverage area ratio' or 'S/C ratio'. The sum of shade free area from different buildings in Mumbai University campus plot is 63,510. This shows that almost 98% of the coverage area in the university campus contributes to area suitable for rooftop PV installation. Here we can consider the S/C ratio as 0.981.

The plot area of Mumbai University is a typical example for a large plot whereas most of the residential plots are smaller and has lesser number of buildings per plot.

Having defined the terms which will be used in this report, we now describe below the various sub-steps used in Stage 1.

USE OF GOOGLE EARTH POLYGON TOOL:

The most important tool used in the mapping is the polygon tool in Google Earth. This tool is available in the professional version of Google Earth. From January 30, 2015 onwards, they started offering free licenses on request [20]. By switching to the professional version there are two advantages. Firstly the area measurements can be now made as polygons (otherwise restricted to rectangles and squares in the normal version) and secondly there is access to high resolution imagery. Figure 2.10 shows the sequence of plotting the plot area of the Government Polytechnic, Bandra using the polygon tool.

Figure 2.10: Sequence of plotting, colour coding and area measurement by using Google Earth Polygon tool

The area of the mapped region can be measured in sq. m. or sq. km. or in any of the 8 options available in the dropdown list available with the tool. The area within the polygon can be filled with different colours (whose RGB value can be given as input) and at varying 'opacity level'. Hence the RGB values obtained from ELU maps from MCGM could be easily followed while mapping with the polygon tool.

Figure 2.11 shows that Google maps overlaid with mappings with polygon tool and the actual ELU maps resemble each other closely if the mapping work is done by people with reasonable skill and dedication.

A similar procedure was followed for marking the coverage areas and the shade free areas.

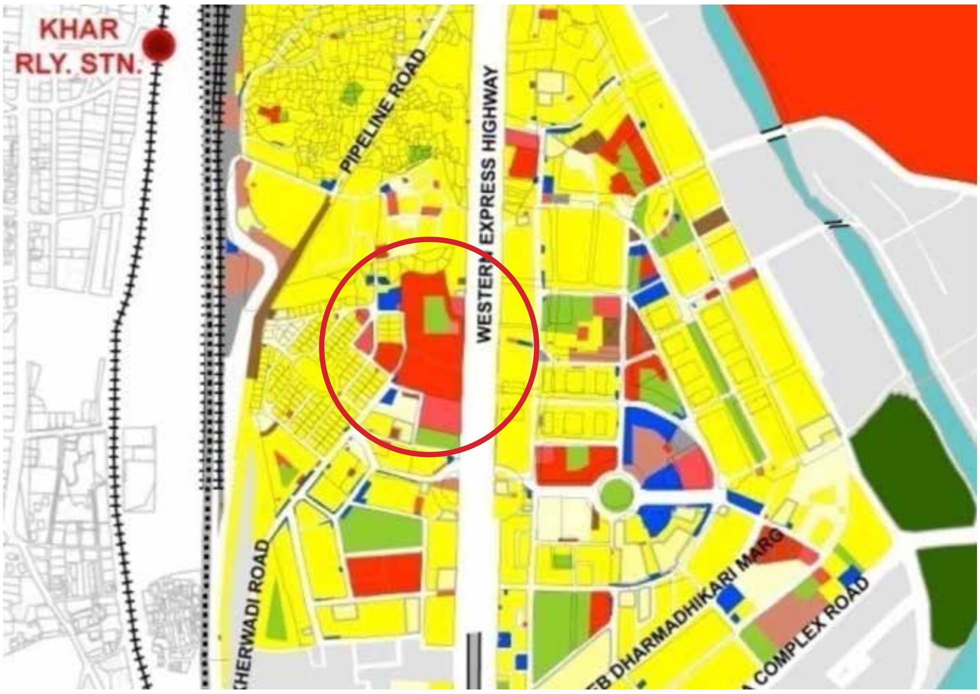


Figure 2.10: Step 1: Refer to the ELU map and identify the plot

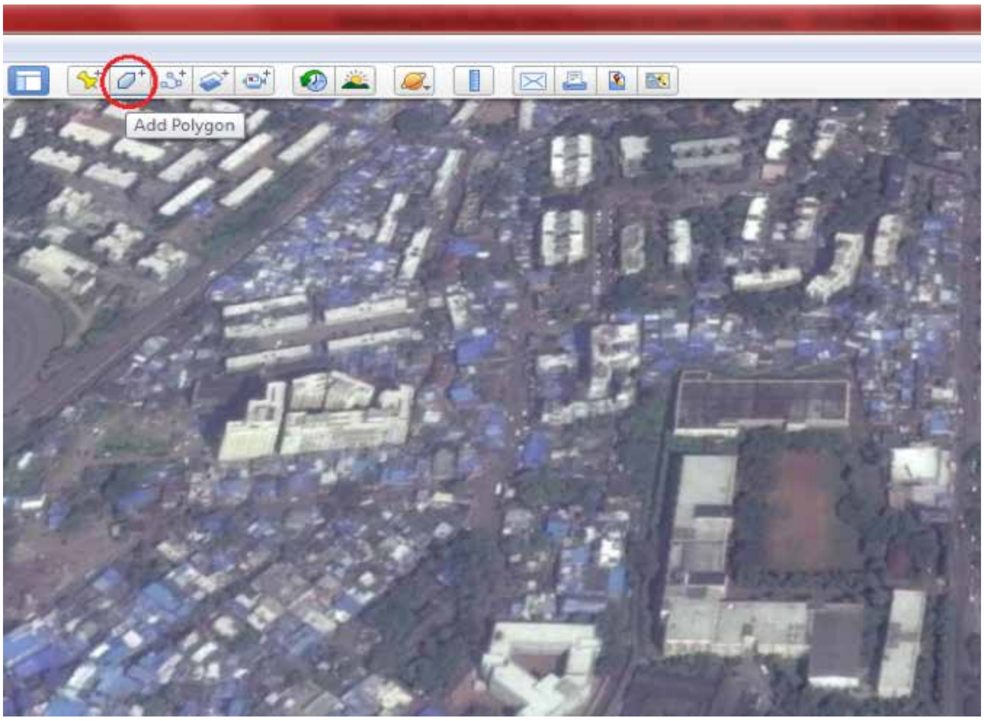


Figure 2.10: Step 2: Locate the plot in Google Earth and select the polygon tool

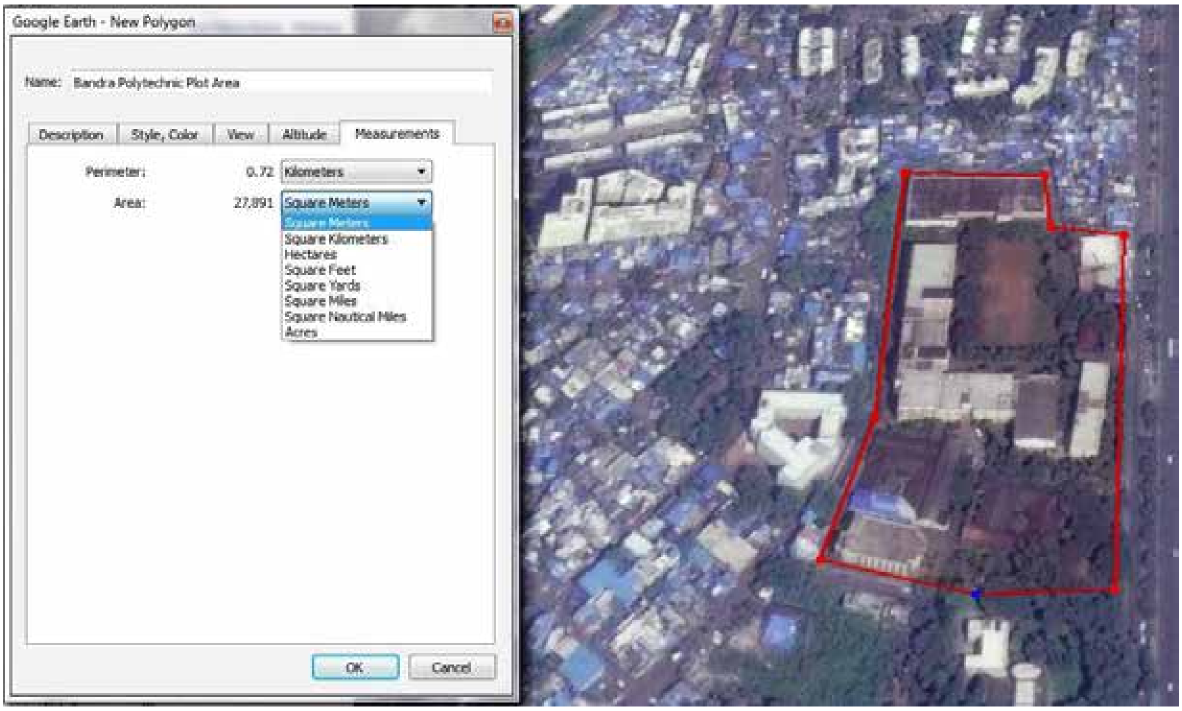


Figure 2.10: Step 3: Mapp the area by clicking on various corners of the plot and area can be measured using the 'Measurements' tab and by choosing the appropriate units

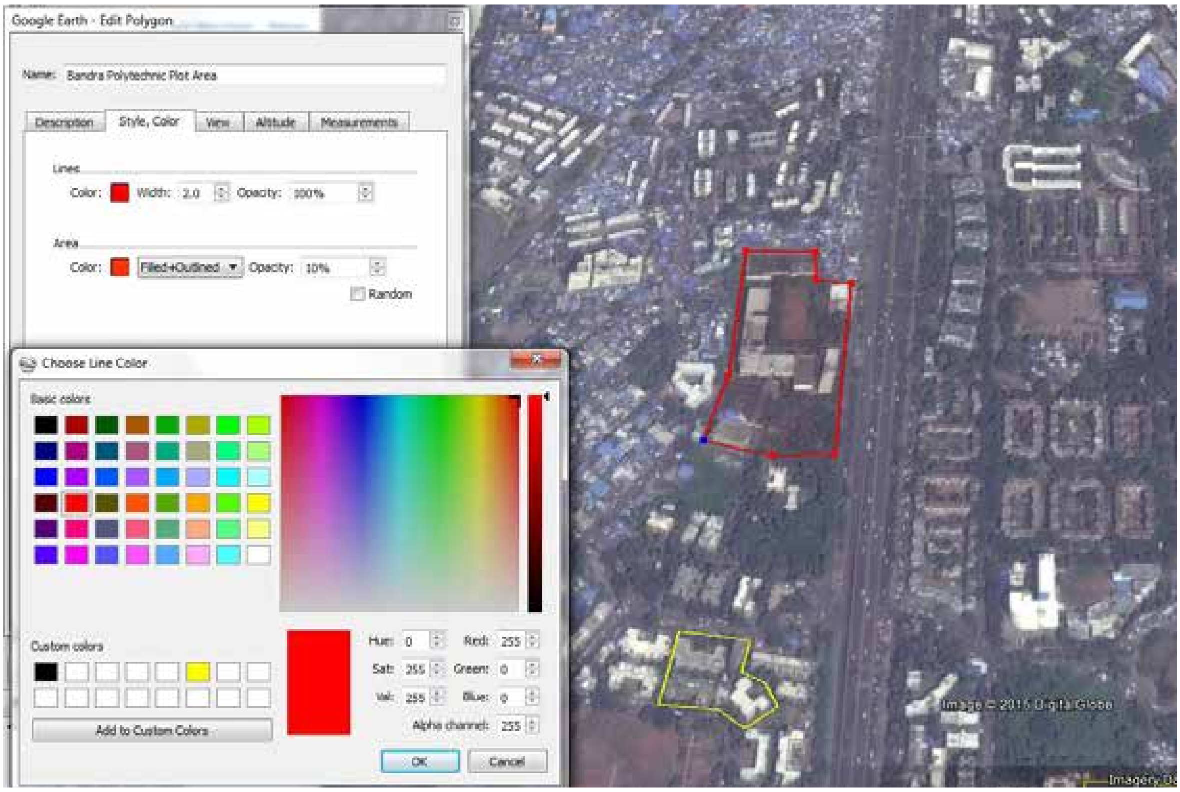


Figure 2.10: Step 4: Polygon line colour and the area fill colour can be selected from 'Style, Colour'

Figure 2.10: Sequence of plotting, colour coding and area measurement by using Google Earth Polygon tool

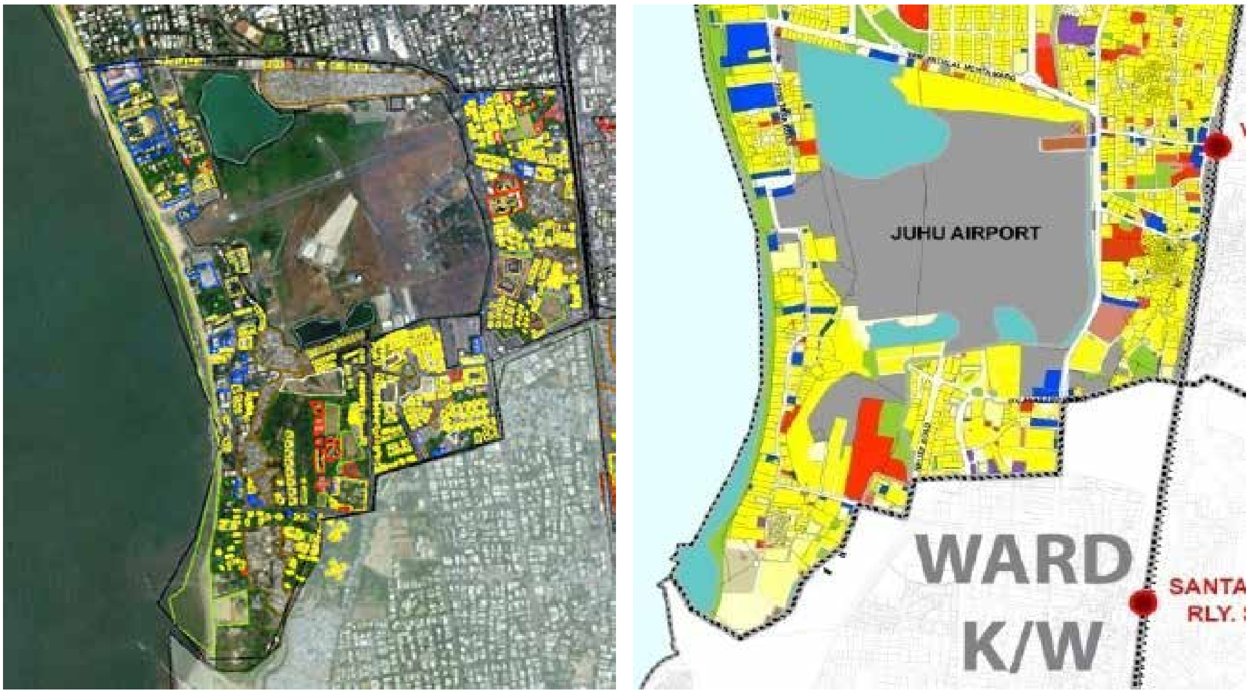


Figure 2.11: Mapping done through Google Earth and the ELU map for Juhu airport area

USE OF WIKIMAPIA PLUGIN IN GOOGLE EARTH:

Wikimapia is an open content collaborative mapping project which uses crowd sourced collection of places marked by registered users and guests to describe places in the satellite maps [21]. Wikimapia provides a plugin file which can be integrated into Google Earth Pro and can be enabled and disabled by clicking the checkbox along its side. Once enabled, the plugin overlays all the details and polygons mapped by Wikimapia users about the area being observed using the Google Earth. Figure 2.12 shows the polygons from Wikimapia overlaid for the Government Polytechnic, Bandra and its surrounding area. It can be seen that the Wikimapia plugin is enabled by clicking on the checkbox. The popup message which will be displayed on clicking the top left corner of the wiki polygons gives more information on the plots mapped. This tool is very helpful in understanding the use and type of the buildings and hence validating the information on land use obtained from MCGM's ELU maps.

USE OF 'MAP OVERLAYS' PLUGIN IN GOOGLE EARTH:

Similar to that of Wikimapia, maps from sources other than Google can be integrated on to Google Earth Pro with proper geo referencing. Plugins for map overlays for Google Earth can be obtained from various sources. One of the plugins obtained from a blog [22] gives us the freedom of overlaying maps from Open Street maps, Nokia maps, Bing maps and many other sources. Figure 2.13 shows that how Bing maps has been overlaid on Google Earth. Even if the Google maps images are not very clear for a particular locality, this overlay feature provide us the convenience to switch to any other source and use a better imagery if required.

USE OF GOOGLE SPREAD SHEET FOR DOCUMENTATION OF MAPPED DATA:

An innovative method for compiling the mapped data is proposed through this survey by the usage of Google Spreadsheets. Separate online spreadsheets were created for each administrative ward. On each of the sheets, the information regarding sample plots mapped (plot number, plot name, 2 levels of land use hierarchy) and its associated coverage area and shade free area were noted down. Figure 2.14 shows a snap shot of the compiled data for ward K/W. It can be seen that the plot areas are named and numbered in a systematic way and also categorised into primary and secondary levels of land use category. The information available from

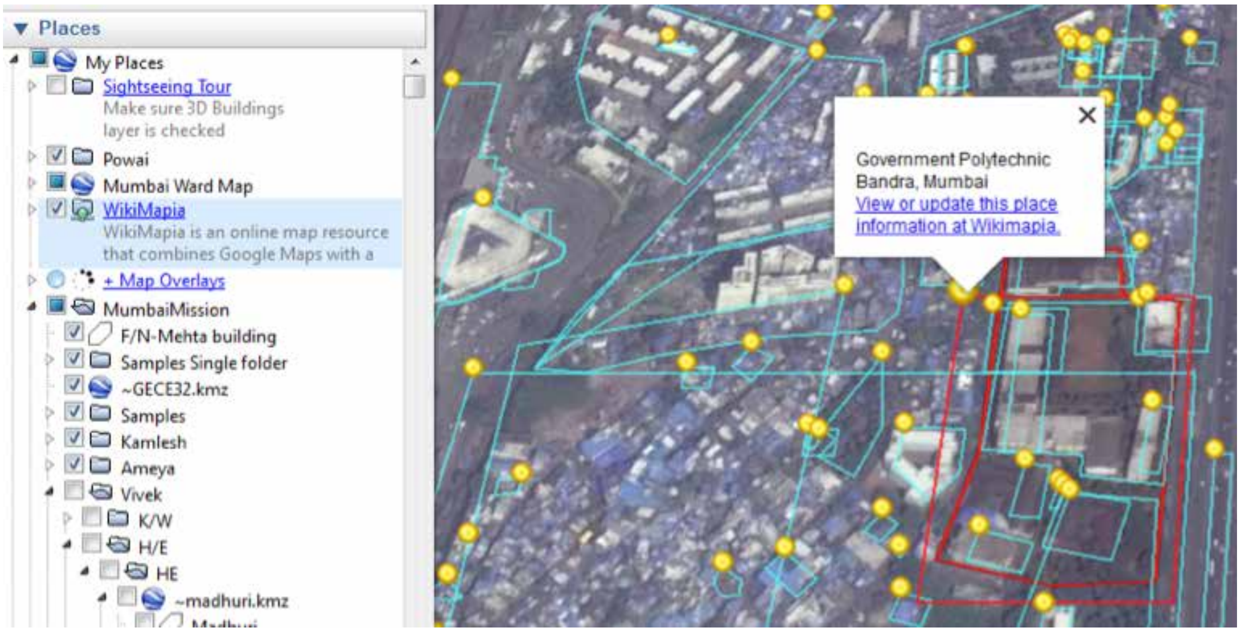


Figure 2.12: Polygons from Wikimapia overlaid on the Google Earth imagery

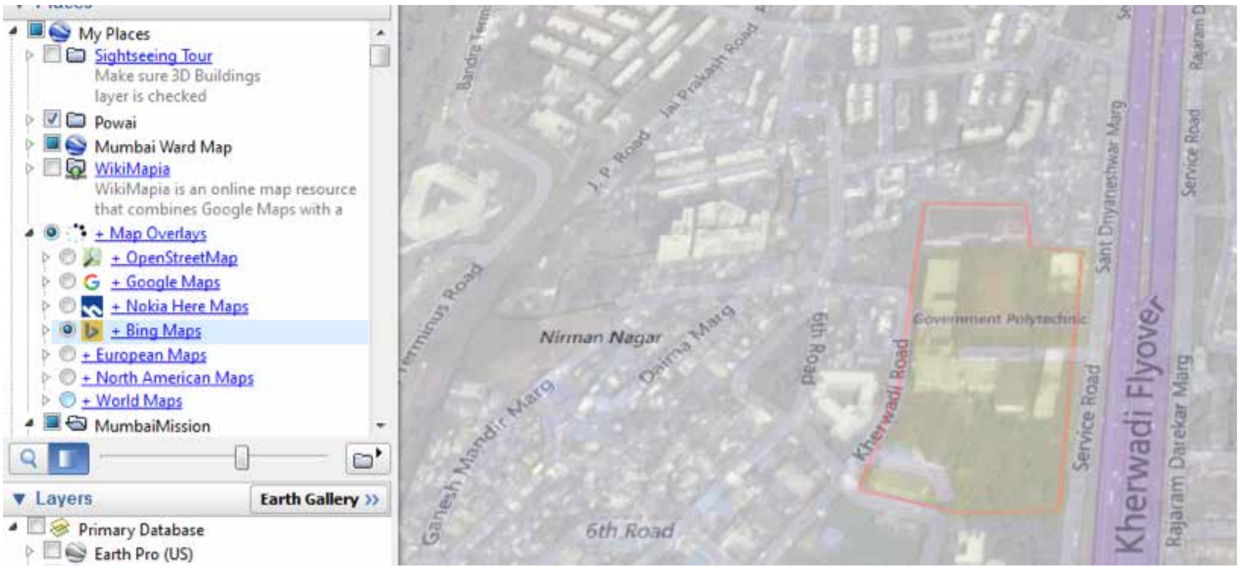


Figure 2.13: Bing maps overlaid on the Google Earth imagery using map overlay feature

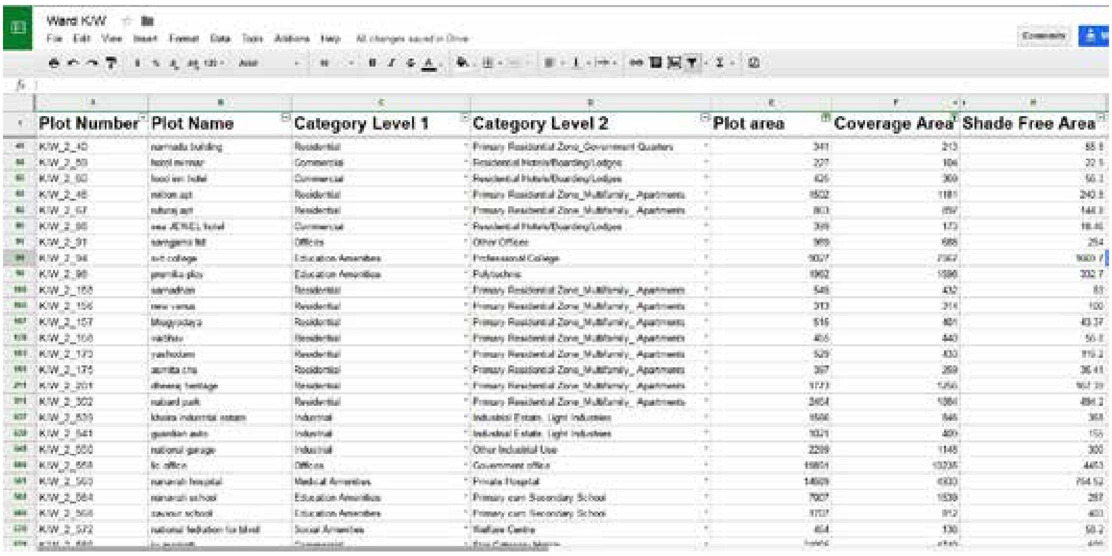


Figure 2.14: Google Spreadsheet used for organized documentation of mapped data

Wikimapia plugin is used for naming the plots and categorising them into appropriate land use types. Thus the Wikimapia plugin helps in validating the information on existing ELU maps of MCGM. The plot area, total coverage area and the shade free area under for each plot are also calculated using polygon tool and documented in the spread sheet. Server side scripting can be incorporated in Google Spreadsheets so that we can select the category level 1 from a list of options available as a dropdown list in column number 3 (Refer Figure 2.14). Based on the selection in column number 3, another dropdown list is generated automatically at column number 4 with all sub categories of selected 'base category' in column 3. This process saves a lot of time in documentation (otherwise the category name has to be manually typed into the sheet) and also brings in consistency in the data entry when several people are working on the same shared spreadsheet shared over the internet.

EXECUTION METHOD: INVOLVEMENT OF THE IEEE STUDENT COMMUNITY:

The entire process of mapping using Google Earth can be done by anyone with basic computer knowledge and some proficiency in online mapping tools. Marking out plot areas and shade free areas is a laborious task but for someone with interest towards solar energy and its utilisation, or an interest in the city's geography, this task can be exciting. Most of the methodologies mentioned in the literature review are done in a centralised manner, where the entire process and the associated knowledge generated remains confined to a limited number of people. In this project, we have tried a new 'bottom-up' approach of information and knowledge creation with regards to solar rooftop potential. The task of mapping and documentation of rooftop areas for Greater Mumbai was executed by a group of 120 undergraduate student volunteers from various engineering institutes in and around Mumbai. All of them are members of IEEE Bombay Section's student branches and had voluntarily joined this mapping effort. They were divided into teams of five, and each team was assigned the task of mapping necessary samples from one of the 24 administrative wards. IIT Bombay was the nodal agency for imparting training and education for these students, so that they could perform this task successfully. As a part of the training, a one-day workshop (Figure 2.15) was conducted in IIT Bombay campus, where the 120 students learned about the basics of solar energy, photovoltaic technology, sun paths and shading area calculation, as well as Google Earth Pro and documentation using spreadsheets. There were short lectures by experts from IIT Bombay, Bridge to India and ORF on topics like 'current energy scenario and solar photovoltaics in India', 'introduction to rooftop PV system design' and 'role of informatics in energy sector'.

One student from each team was nominated as the team leader. A total of 24 such team leaders were provided more extensive training by 6 expert mentors from IIT Bombay, ORF and Bridge to India in several sessions (Figure 2.16) for mastering the Google Earth tool. The training sessions were conducted at IIT Bombay. These leaders were responsible for further training their team members.

COMPILATION OF MAPPED DATA

The students reported their work to their mentors (the 6 mentors handled 4 teams each). Mentors had access to the Google spreadsheets in which the students updated the mapping data. The team leaders were also supposed to send the rooftops mapped in their respective wards to their mentors on a weekly basis. The rooftops (polygons) mapped in Google Earth can be

Figure 2.15: Some of the participants of 1 day workshop for IEEE volunteers who did the mapping of rooftop areas

Figure 2.16: Hands on training session on Google Earth Pro tool conducted for team leaders

exported as Keyhole Mark-up Language Zipped (KMZ) files and can be sent via email. Hence the mentors could check the accuracy of mapping and correctness of data entry in the spreadsheets.

COMPILATION OF C/P AND S/C RATIOS FOR RESIDENTIAL PLOTS

It was targeted that at least 100 plots were mapped out in every ward and the sum of the total area mapped under residential segment added up to at least 10% of the total area under residential plots in that ward. Area under chawls or slums were not considered for the mapping exercise since the buildings in this area were expected to be structurally weak and unsuitable for PV installation. Based on statistics, the minimum area to be plotted within each ward under residential category so that the results could be generalised to the entire population with 95% confidence level and 1% confidence interval was calculated [23]. The area requirement varied from ward to ward and the values were found between 9386 sq. m and 9590 sq. m. Even though the 10% area mapping target was not met in every ward, the minimum mapped area required for statistical extrapolation was met in every ward except for ward F/S. Table 2.3 shows the summary of the land area mapped across different wards under residential category.

Table 2.3: Area plotted under residential plots across different wards

Ward	Total Residential Area (10^4 sq. m)	Area Mapped (10^4 sq. m)	Percentage Area Plotted
A	79.09	7.33	9.26
B	41.25	7.35	17.83
C	76.65	4.02	5.24
D	351.98	23.32	6.63
E	155.87	19.08	12.24
F/N	266.47	1.97	0.74
F/S	162.31	0.21	0.13
G/N	172.11	18.64	10.83
G/S	150.51	46.53	30.91
H/E	170.31	8.78	20.24
H/W	377.04	6.85	1.82
K/E	406.49	34.47	8.48
K/W	657.95	2.35	0.36
L	228.17	35.89	15.73
M/E	256.99	25.19	9.80
M/W	258.82	7.69	2.97
N	310.36	7.85	2.53
P/N	497.89	17.91	3.60
P/S	274.38	30.15	10.99
R/N	235.28	10.58	4.50
R/C	502.43	3.52	0.70
R/S	336.72	32.33	9.60
S	225.47	24.9	11.04
T	321.57	12.77	3.97
TOTAL	**6,516.11**	**389.68**	**5.98**

Since the number of samples under each ward was truly random and selected from geographically well-distributed locations within the ward area, a simple average of the C/P and S/C ratios was calculated and this value was used as a representative ratio for further calculations. In fact, C/P and S/C ratios were calculated for every sub-category within residential plots, i.e. C/P ratio for individual houses, multifamily apartments, government quarters etc. were calculated separately for each wards. Based on ELU maps, ward-wise land use area under different residential sub-categories was compiled. Table 2.4 shows the compiled values. Similarly the C/P and S/C ratios were also compiled in similar tables (refer Tables 2.5 and 2.6). Decimal values up to 3 positions were considered significant to improve the accuracy of calculations. Then a one-to-one multiplication of cells in the three tables was executed. The final value would roughly give the expected available rooftop area available from residential plots from each ward. Since the C/P and S/C ratios were calculated separately for different wards for residential plots and at a sub classification level, manual errors while plotting and documentation would remain limited within the same ward and sub-category.

Table 2.4: Ward wise land use area under different residential sub categories

	Area under each residential land use sub category (hectare) [17]						
Ward Name	Individual Housing	Individual Housing with Commercial Space	Multifamily Apartments	Multifamily Apartments with Commercial Space	Multifamily Apartments with Shops	Government Quarters	Government Housing with Shops
A	-	-	34.38	12.22	18.27	12.45	1.77
B	-	0.04	3.30	17.73	15.48	4.05	0.65
C	-	-	12.56	32.46	30.77	0.62	0.24
D	21.90	0.04	183.44	29.50	75.96	38.55	2.59
E	1.71	0.17	60.12	27.68	32.36	32.11	1.72
F/N	3.12	0.77	113.55	26.55	40.53	79.22	2.73
F/S	0.74	-	69.03	3.55	32.18	51.77	5.04
G/N	2.45	0.04	89.21	12.75	48.40	17.83	1.43
G/S	0.98	0.10	68.84	10.52	23.82	36.63	9.62
H/E	4.42	-	96.34	2.22	28.23	38.24	0.86
H/W	31.27	0.38	260.17	16.95	51.91	16.27	0.09
K/E	9.07	0.53	275.51	12.17	84.96	23.20	1.05
K/W	51.11	6.19	452.14	31.62	96.33	19.74	0.82
L	9.01	1.70	165.76	5.26	35.02	11.18	0.24
M/E	22.75	-	102.61	1.55	23.51	106.36	0.21
M/W	40.67	0.60	147.99	8.26	21.14	38.71	1.45
N	4.17	0.13	181.99	24.04	38.87	58.44	2.72
P/N	108.30	13.34	253.98	10.77	99.85	11.57	0.08
P/S	16.26	0.05	172.96	9.27	47.11	28.73	-
R/N	5.74	0.10	140.74	6.84	69.78	11.87	0.21
R/C	107.56	2.31	263.36	19.09	98.14	11.87	0.10
R/S	26.91	8.33	200.02	12.81	72.67	15.42	0.56
S	5.26	0.04	165.14	7.68	31.87	15.43	0.05
T	22.53	2.56	203.62	17.35	52.33	23.07	0.11

Table 2.5: Average value of C/P conversion ratios under different residential sub categories across different wards

Ward Name	Individual Housing	Individual Housing with Commercial Space	Multifamily Apartments	Multifamily Apartments with Commercial Space	Multifamily Apartments with Shops	Government Quarters	Government Housing with Shops
A	-	-	0.726	0.710	0.276	0.579	--
B	-	0.459	0.576	0.961	0.268	0.596	--
C	-	-	0.520	0.562	0.285	0.607	--
D	0.628	0.554	0.462	0.414	0.319	0.643	--
E	0.795	0.365	0.618	0.414	0.251	0.601	--
F/N	0.436	0.557	0.721	0.516	0.399	0.740	--
F/S	0.618	-	0.520	0.594	0.183	0.538	--
G/N	0.517	0.576	0.441	0.476	0.349	0.520	--
G/S	0.622	0.744	0.672	0.475	0.300	0.546	--
H/E	0.351	-	0.336	0.348	0.293	0.226	--
H/W	0.560	0.490	0.432	0.543	0.275	0.497	--
K/E	0.456	0.519	0.321	0.310	0.310	0.185	--
K/W	0.544	0.500	0.615	0.392	0.293	0.108	--
L	0.399	0.538	0.307	0.478	0.375	0.251	--
M/E	0.392	-	0.419	0.497	0.497	0.495	--
M/W	0.392	0.548	0.470	0.497	0.497	0.442	--
N	0.382	0.543	0.269	0.555	0.436	0.281	--
P/N	0.562	0.602	0.399	0.307	0.488	0.328	--
P/S	0.528	0.510	0.532	0.323	0.431	0.244	--
R/N	0.410	0.692	0.366	0.458	0.516	0.571	--
R/C	0.503	0.692	0.561	0.539	0.516	0.571	--
R/S	0.554	0.692	0.332	0.290	0.344	0.437	--
S	0.472	0.530	0.553	0.776	0.448	0.096	--
T	0.596	0.606	0.507	0.689	0.689	0.304	--

Table 2.6: Average value of S/C conversion ratios under different residential sub categories across different wards

Ward Name	Individual Housing	Individual Housing with Commercial Space	Multifamily Apartments	Multifamily Apartments with Commercial Space	Multifamily Apartments with Shops	Government Quarters	Government Housing with Shops
A	-	-	0.461	0.572	0.519	0.433	--
B	-	0.420	0.656	0.597	0.518	0.574	--
C	-	-	0.307	0.716	0.520	0.512	--
D	0.418	0.449	0.599	0.335	0.523	0.327	--
E	0.709	0.390	0.636	0.861	0.516	0.776	--
F/N	0.509	0.527	0.892	0.609	0.273	0.343	--
F/S	0.627	-	0.640	0.715	0.509	0.625	--
G/N	0.602	0.527	0.539	0.476	0.354	0.500	--
G/S	0.662	0.509	0.655	0.597	0.435	0.799	--
H/E	0.924	-	0.829	0.735	0.489	0.620	--
H/W	0.648	0.839	0.559	0.898	0.575	0.872	--
K/E	0.701	0.429	0.259	0.403	0.403	0.566	--
K/W	0.648	0.429	0.518	0.622	0.489	0.544	--
L	0.531	0.478	0.618	0.637	0.447	0.471	--
M/E	0.392	-	0.601	0.623	0.623	0.495	--
M/W	0.392	0.502	0.503	0.623	0.623	0.448	--
N	0.382	0.490	0.726	0.618	0.535	0.482	--
P/N	0.520	0.634	0.459	0.389	0.455	0.641	--
P/S	0.561	0.497	0.622	0.566	0.495	0.719	--
R/N	0.884	0.439	0.893	0.439	0.435	0.606	--
R/C	0.676	0.439	0.596	0.604	0.435	0.606	--
R/S	0.572	0.312	0.252	0.211	0.277	0.604	--
S	0.425	0.492	0.816	0.773	0.495	0.478	--
T	0.468	0.565	0.554	0.593	0.593	0.601	--

COMPILATION OF C/P AND S/C RATIOS FOR NON-RESIDENTIAL PLOTS

For non-residential plots such as educational amenities, medical amenities, industries, commercial plots etc., a different approach was implemented while calculating the C/P and S/C ratios. The largest 5 plots (in terms of area) were identified visually from the ELU maps under each category and were mapped using Google Earth. In most of the cases, the cumulative area of the mapped plots went above 50% of the area under that particular land use category within that ward. Since the number of samples is limited and small, weighted averages (based on area of plot) of the C/P and S/C ratios were calculated for each land use category for each ward. These weighted average values were used in generalising the calculation of shade free area from buildings under each category under each ward. Hence, the errors in mapping are limited to the particular ward and land use category. As an example, Figure 2.17 shows the land use map of H/E ward with the top 5 educational amenities mapped. The corresponding data are compiled in Table 2.7. The weighted average values of C/P ratio and S/C ratio come out to be 0.091 and 0.964 respectively for educational amenities in ward H/E. From the ELU maps it can be found out that the total plot area under educational amenities in ward H/E is 97.58 hectare. So the total building footprint area from educational infrastructure in ward H/E can be obtained by multiplying 97.58 with 0.091 which is 88,797 square meters. Out of this 88,797 square meters, roughly 0.964 parts converts into shade free area hence the product of 88,797 with 0.964 (weighted average of S/C ratio for educational amenities in ward H/E) gives the rough estimate of shade free area or the solar potential from educational amenities in ward H/E which is 85,601 sq. m.

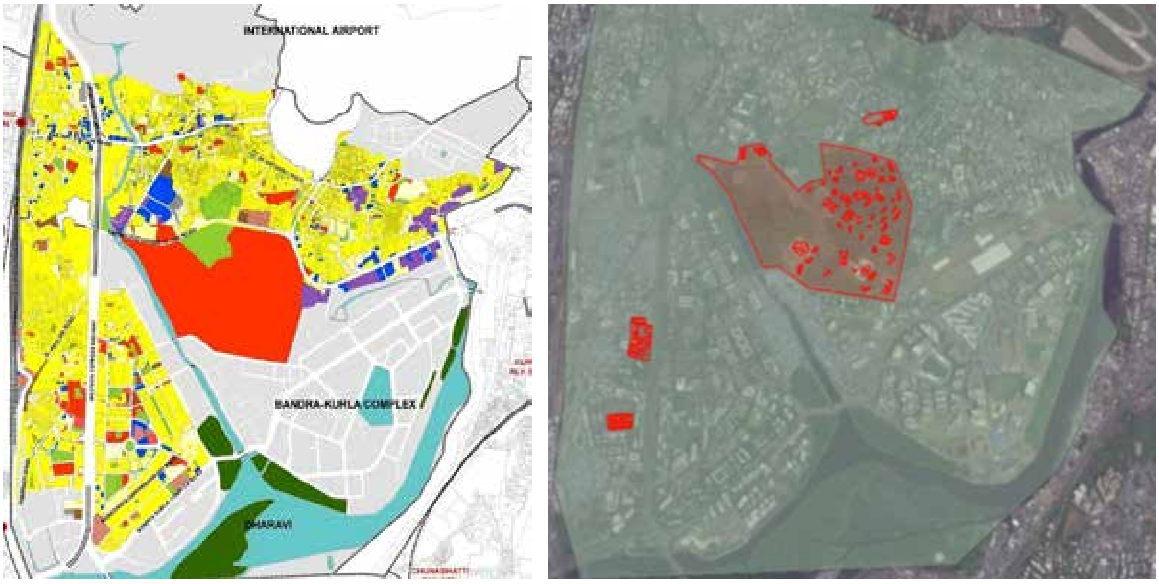


Figure 2.17: ELU map of ward H/E and the corresponding Google map with educational amenities mapped

Table 2.7: C/P and S/C ratios for largest 5 educational plots in ward H/E and the weighted average of ratios

Plot/ Institution Name	Category	Plot area (sq. m)	C/P ratio	Coverage area (sq. m)	S/C ratio	Shade free area (sq. m)
Mumbai University	University	864,128	0.075	64,934	0.978	63,510
Govt. Poly Technic Bandra	Polytechnic College	24,809	0.439	10,909	0.638	6,963
Kher Municipal School	Primary cum Sec. School	8,338	0.402	3,352	0.726	2,436

Similar to the above procedure, rooftop potential from all other major land use categories were calculated. For transport amenities i.e. for railways and BEST depots, all the railway stations, associated buildings and bus depots under MCGM area were mapped (that is, 100% sampling was done).

STAGE 2: SITE SURVEYS AND COMPARISON WITH MAPPED DATA

The second stage of the project was to identify and physically survey some of the samples plotted using GIS. Such a survey can help in several ways. Firstly, the difference between the actual rooftop area (physically measured at site) and the area obtained using GIS can be compared and the deviation in different parts of the city can be ascertained. Secondly, the general condition and structural integrity of buildings in a given area can be studied. Thirdly the perception of the people in the surveyed buildings regarding rooftop PV installations, their attitude towards government schemes and willingness to invest in solar can be understood. Another added advantage of the site survey is that the floor to floor height of buildings and rough urban morphology of the surveyed locality can be captured. This information can help in 3D sample creation of cluster of buildings, which can be used for simulation studies of inter-building shading. The 120 students who participated in the mapping process were also trained as surveyors. The team leaders were given a first-hand survey experience by the mentors in the workshop conducted at IIT Bombay. Certain protocols to be followed during the site survey were also taught – getting permission to access the rooftop, safety precautions while measuring the rooftop, etc. After the classroom session students were asked to survey different buildings in the IIT Bombay campus to do the rooftop measurements. This mock survey helped them to understand the protocol they need to follow once they actually set out to the field.

CONTENTS OF THE QUESTIONNAIRE

The survey team was given a Questionnaire to carry to the site. The questionnaire contained 5 sections, and most of the information was to be obtained from a respondent at the site.

•**Details of Surveyed Plot:** This section includes details related to Plot, such as Ward, plot name, Hierarchical classification, and the Respondent's contact details. The respondents for residential buildings were in most cases the secretary of the residential association. For shops, commercial buildings and the industries, the owners of the business used to give the answers to the question. Their contact details were collected so as to communicate with them in future for any clarification regarding the information collected.

•**Site details:** It covers details related to structural integrity of the building. Accessibility to the roof, type of roof and walls, height of shading objects on the rooftop of the building, types of shading objects etc. are also noted. The approximate height of the building itself and of surrounding buildings is also noted.

•**Electrical details:** This section ask about the utility company providing electricity supply to the company, types of loads in common areas, total connected load, tariff category, average monthly bills, time of the day at which demand peaks, nature of power backup systems used etc.

•**Views on Solar PV:** This section has questions regarding the willingness to spend on solar PV,

Figure 2.18: Sub sector created within ward A based on unique urban texture and associated sample areas

major reasons for opting/not opting PV, what can motivate them to go for solar etc.

Views on Façade PV: This section checks the interest of the respondent on façade PV and the government incentives he or she expects for adopting solar.

SELECTION OF SAMPLES TO BE SURVEYED

Samples were selected from all over the MCGM area, except from SPAs and transport facilities. The basic step of sampling was to categorise the ward areas into sub-sectors with similar building architecture and planning (urban texture). Later from each sub-sector one or two clusters of buildings were identified, preferably from different land use categories. While identifying the clusters, orientation of buildings (within that unique texture) was also considered. Figure 2.18 shows the sectors created within ward A. The polygons in white border show the extent of the area within which a common building architecture and planning exists. The yellow polygons represent the cluster of buildings identified for site survey.

Figure 2.19 shows the distribution of samples (yellow polygons) across different wards and the corresponding sector they represent. More than 300 samples were identified across entire city. According to literature, this is a type of point sampling method [24]. With the given number of samples, the results of the survey (and 3D modelling activities as explained in Stage 3) can be generalised to the entire population at a confidence interval of 9.8% (~10%) at a confidence level of 95%.

DEVIATION OF MEASURED AREA FROM ACTUAL AREA

In order to understand the error involved in the measurement of area using Google Earth, the physical measurement of the shade free area on the rooftops at some sites was done by the volunteer surveyors, as mentioned earlier. These values were compared with the value obtained using Google Earth polygon tool. The deviation of area was found out to be between -12% to +12% as shown in Table 2.8. The average value of error is around 7%. Since it was found that the deviation of area can be as high as 12%, as a conservative measure, a deviation of ±10% can be considered.

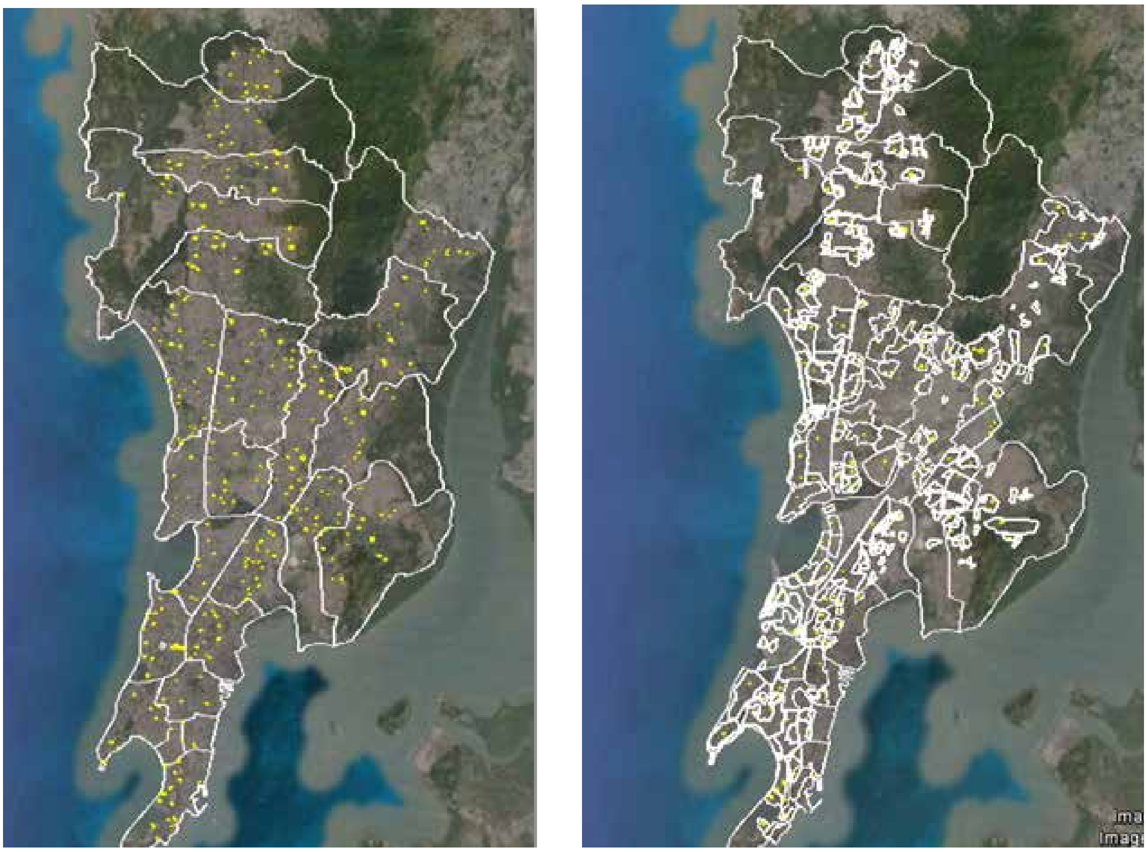


Figure 2.19: Samples selected for site survey across different wards in Greater Mumbai and the corresponding areas they represent

Table 2.8: Deviation of shade free area measured using GIS from actual area measured on site

Sample Number	Ward name	Area measured during survey (sq. m)	Area measured using Google Earth (sq. m)	Deviation from actual value (percentage)
1	A	254	272	-7
2	A	30	27	10
3	B	333	373	-12
4	B	920	855	7
5	B	900	945	-5
6	B	1264	1365	-8
7	B	189	212	-12
8	B	164	157	4
9	B	30	32	-6
10	C	530	583	-10
11	C	214	200	7
12	C	240	228	5
13	C	245	267	-9
14	C	370	399	-8
15	D	3.84	4	4

16	D	189	191	1
17	E	869	860	-1
18	K/W	50	46	7
19	K/W	45	50	-10
20	K/W	1378	1309	5
21	K/W	149	152	-2
22	K/W	145	128	12
23	K/W	5017	5318	-6
24	K/W	40	44	-11
25	K/W	63	60	4
26	N	139	128	8
27	P/N	37	41	-9
28	R/C	293	287	2
29	R/N	2850	2650	7
30	S	36	34	3
31	S	32	35	-10
32	S	32	36	-12
33	T	113	120	-6
34	T	1346	1373	-2
35	T	127	121	5

STAGE 3: 3D MODELLING AND INTER BUILDING SHADING ANALYSIS

In the previous stage, the potential rooftop area from various land use categories was calculated using just 2D mapping in Google Earth. Since this process does not consider the shading effects on a particular rooftop by adjacent buildings (as opposed to shading caused by structures on that rooftop itself), the area found thus far would be an over-estimate. To improve upon this, a 3D modelling and simulation study was done on more than 300 sample clusters of buildings across different wards. This task was performed by 26 of the volunteers from the IEEE student branches. The same sets of samples selected for the site survey were used for 3D simulation as well. 3D modelling and shading simulation was done using the licensed educational version of the software Revit developed by Autodesk Inc. [25], available at IIT Bombay.

USE OF AUTODESK'S REVIT AND SOLAR ANALYSIS PLUGIN

Revit is generally used by architects and structural engineers for Building Information Modelling (BIM). This software provides a plugin called Solar Analysis for Revit (SAR). Using this plugin, we can visualize and quantify the distribution of solar radiation on various areas (roof, wall, and floor) of a building by taking into account the shading effects from adjacent objects, such as vegetation and surrounding buildings in an urban setting.

The 3D models of the cluster of buildings were created in Google SketchUp [26]. They were imported to Revit at the actual orientation (georeferenced) and annual solar insolation on

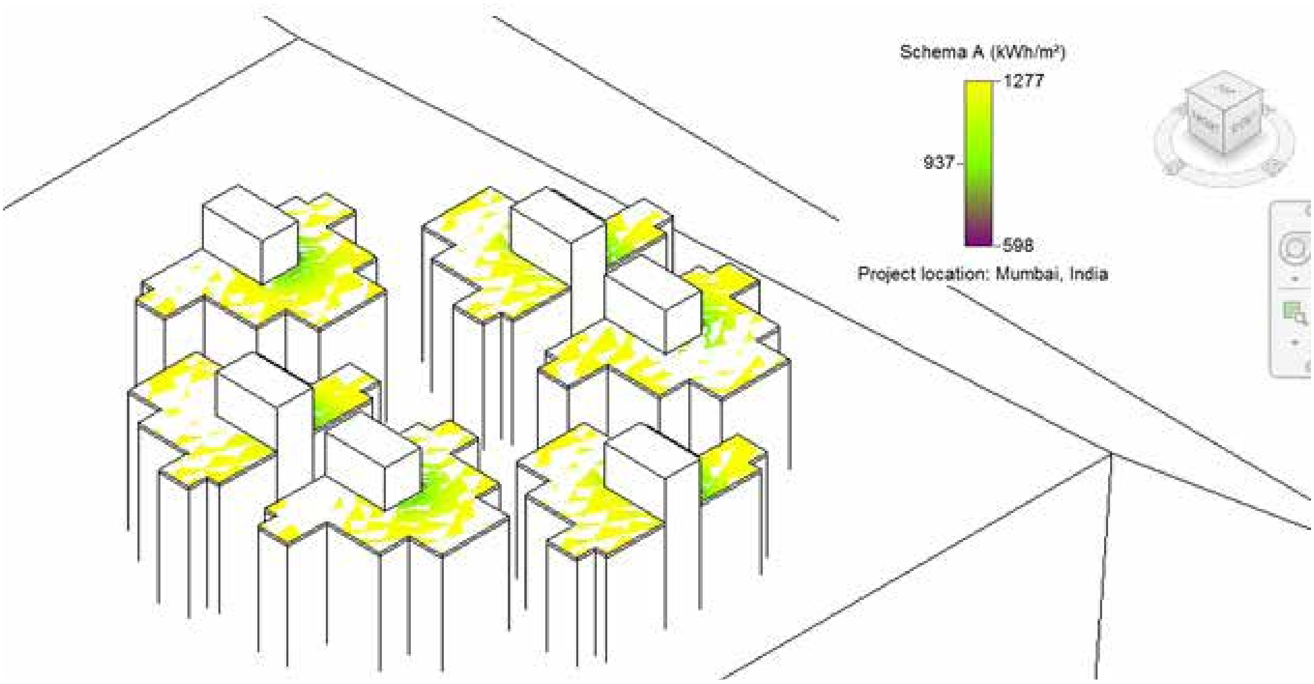


Figure 2.20: Visualisation of 3D modelling and simulation results for inter-building shading

the roof areas was calculated. Insolation values within a given time duration can be integrated over a year using this software. In this project, we have used time duration of 10 AM to 4 PM for simulation. It was assumed that during these time duration, the irradiation levels are fairly high and shadowing (if it exists) will be prominent. The software also divides the area under simulation into grids of desired units of cell area. The plugin also helps to export the simulation results into an external spreadsheet (of CSV format) which contains the information of the insolation values for each cell in the grid. In this project we have used a grid size of 1 sq. m. for simulation. After the simulation, we get a visualisation of the insolation with colour coded rooftop area (insolation values are scaled, colour coded and filled in each cell). Figure 2.32 shows the output of the simulation for a sample cluster from ward P/N. The simulation results in Mumbai shows that the insolation value for unshaded roofs is between 1200 - 1400 kWh/ sq. m. per year (integrated value of irradiation during 10 AM to 4 PM for the entire year). Hence cells with this maximum value of annual insolation can be considered as cells without much shading. By counting the number of cells with this maximum value, we can get the total shade free area for the rooftop in sq. m. (since 1 cell = 1 sq. m).

In Figure 2.20 the insolation values are scaled and colour coded between dark violet and bright yellow. Dark violet denotes an insolation value of 494 kWh/ sq. m per year. Bright yellow denotes a value of 1276 kWh/sq. m per year.

Figure 2.20: Visualisation of 3D modelling and simulation results for inter-building shading

When the heights of the buildings were not varying much among a cluster, the shading on the roof is mostly due to the structures in the roof of the buildings itself as shown in Figure 2.20. When there is a significant difference in the height of the buildings within a cluster, the inter building shading becomes prominent (Refer Figure 2.21, clusters from ward L and ward B, where you can see dark violet patches on the roof of buildings adjacent to tall ones, which denotes heavy shading).

USE OF WONOBO WEBSITE FOR BUILDING HEIGHT INFORMATION

While creating the 3D models for 300 odd clusters, the height information of different

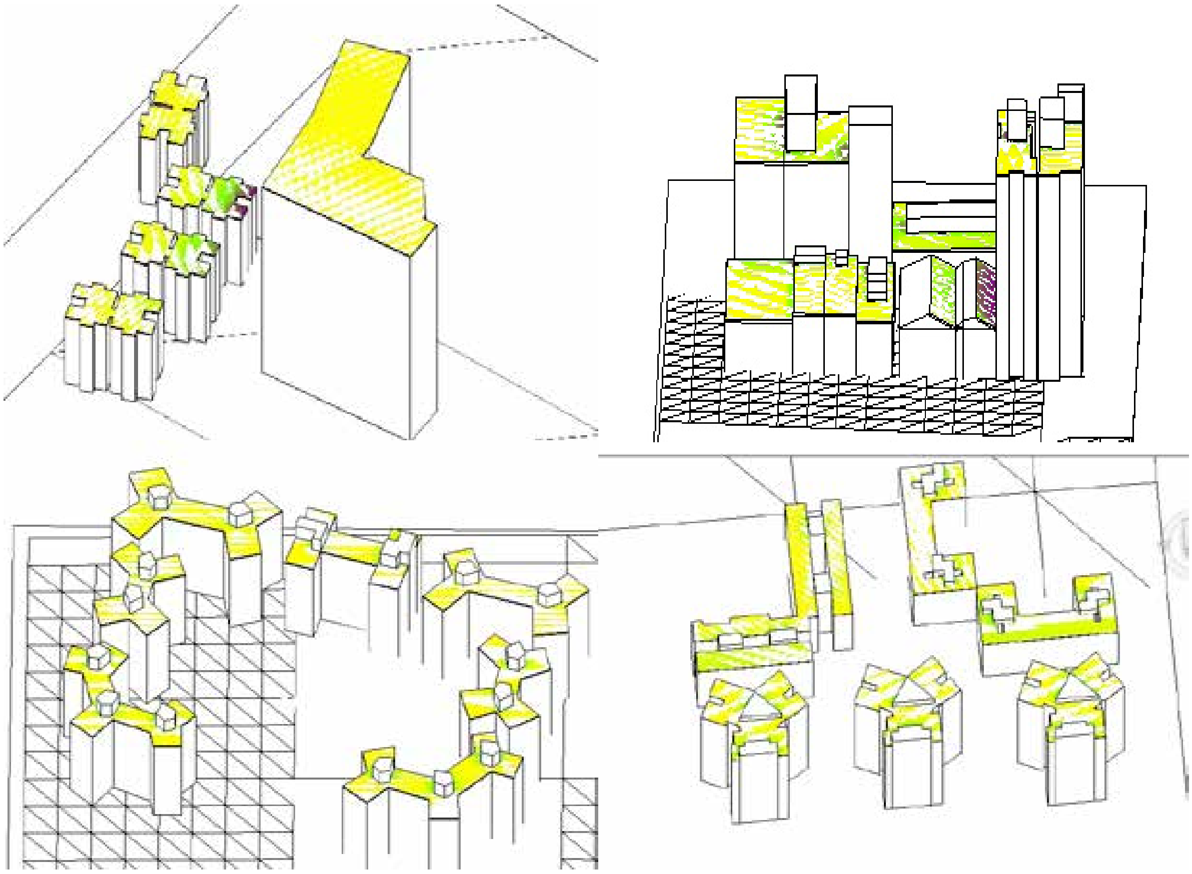


Figure 2.21: Shading analysis results for samples from wards L(top left), B(top right), E(bottom left) and R/S (bottom right)

buildings were required. Only 49 buildings were covered in the site survey and height information of the cluster of buildings around these 49 sites was used from the survey. For the remaining samples, we had to resort to a website called www.wonobo.com. The site provides street view for the entire Mumbai city. Hence, by virtually visiting the sample plot through this website, the details of each building in the cluster to be modelled were collected. Basically the number of floors on each building was multiplied by the average floor to floor height obtained in the survey for similar buildings (4 m). It is important to note that wonobo is providing street view for 16 other cities in India and they are expanding. A detailed video tutorial on how to use Google SketchUp, Wonobo, Revit and how to execute the simulation was uploaded in YouTube and shared among the students who volunteered for this exercise. The video is available in the following link: https://youtu.be/Rbwwx1yiO3U

INSOLATION ON SOUTH SLANTING ROOFS

While marking the rooftop potential of buildings with slanted roofs, we had considered only south, south west or south east facing structures. This assumption was validated using the simulation results. Figure 2.22 shows the result of a sample cluster in ward B. It can be noted that the part of the roof facing south are bright yellow in colour (which denotes 4 kWh/sq. m per day insolation) and the roofs slanting east-west are having only 2 kWh/sq. m per year insolation (hence coloured green).

DISCOUNTING FACTORS FOR VARIOUS WARDS

After 3D modelling and simulation, new deviation factors or discounting factors were developed for re-calculating the shade free rooftop area for different wards. Table 2.9 shows the deviation in shade free area measured using 2D mapping and 3D simulation for the 11 samples selected for ward F/N. The deviation percentage varies from as high as 81% in some samples to as low as 0.5% in certain other clusters. There were both positive and negative deviations in the area calculated. The effect of inter building shading in 3D simulation results in lesser rooftop area when

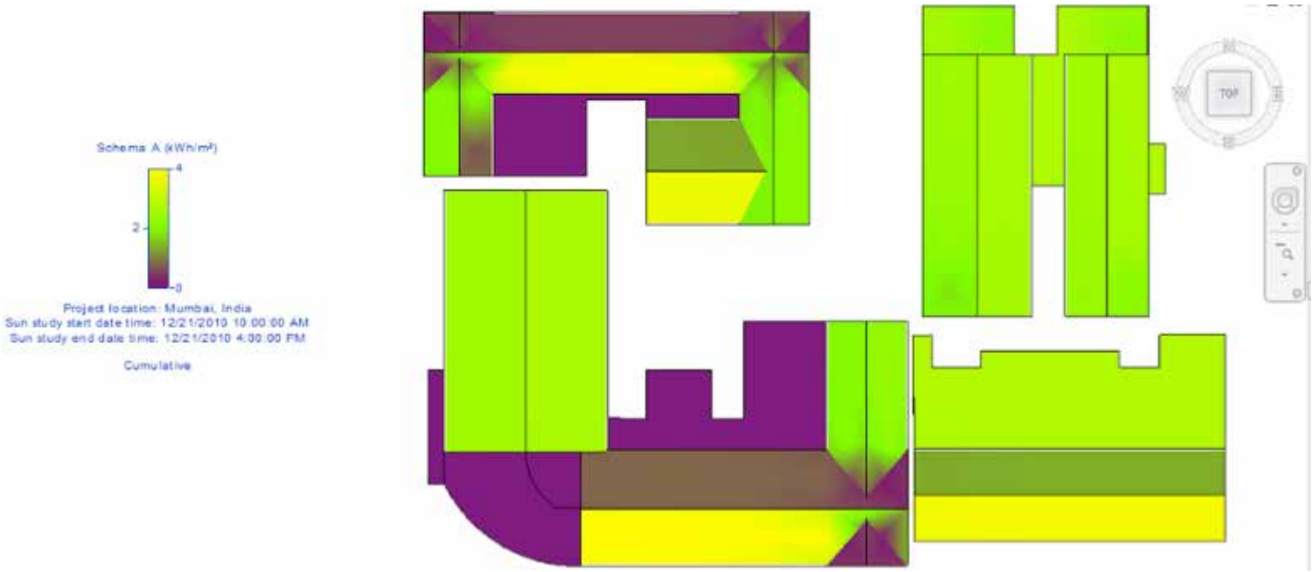


Figure 2.22: Shading analysis on sloped roofs

compared to 2D mapping. Since in 2D mapping, the effect of shading by nearby building is not obvious, we may have calculated more area as shade free (since there may not be any shading structures on its own roofs such as water tanks, exhausts etc.). But after 3D simulation, we see that the nearby buildings can cause heavy shading, resulting in big reduction in shade free area. The reason for positive deviation can be explained in two ways. Firstly, it can be due to a limitation of imagery with Google. In fact Google Earth is not providing a 'perfect top view' of the buildings; they are in 3D coordinates. Hence many times the view on the rooftop may be slightly slanted. This results in blinding of certain areas behind the shading objects or super structures on rooftop. For example, Figure 2.23 shows the images for residential complexes by 'Dosti Developers' in ward F/N. The three images were taken on three different times (dates). Hence in the first picture, the area behind the lift room is not obvious and was not calculated properly in its full extends in the shade free area. This error was captured when we explored the building virtually in Wonobo and the actual building structure was reconstructed. Secondly, the increase in the area can be due to 'conservative assumptions' used while mapping the 2D areas. Whenever the shading objects were identified on the rooftop, as much as 4 m to its east, west and north were excluded while mapping the shade free area. In reality the object may be shading within this region only for a short period of a day or for a particular season. When we actually simulate the annual insolation values, this shading may become insignificant and hence more area now qualifies for PV installation, around the shading structure.

Table 2.9: Deviation of shade free area measured using GIS from actual area measured in the field

Sample No	Area of the sector the sample represents	Percentage share of the sector in whole ward area	Shade free area from 2D mapping	Shade free area from 3D simulation	Percentage deviation in the area calculation	Weighted Standard Deviation [27]
F/N.1	1676278	50	358	244	-32	± 29.89 %
F/N.2	68463	2	877	951	+8	
F/N.3	76047	2	1116	961	-14	
F/N.4	739702	22	830	793	-4	
F/N.5	191123	6	929	906	-2	
F/N.6	74866	2	809	1078	+33	
F/N.7	163734	5	1809	3273	+81	
F/N.8	143245	4	416	313	-25	
F/N.9	9181	1	714	583	-18	
F/N.10	30907	1	859	863	-0.45	
F/N.11	185267	6	1373	1480	+8	

Figure 2.23: Variation in area calculation caused due to imperfect top view of buildings as obtained in Google Earth

Based on the deviation of area calculations for various samples, a ward level deviation percentage in the rooftop area was calculated. Square of deviation value was weighted (multiplied) by the percentage contribution of the sector represented by that sample and averaged. The square root of this number gives us the RMS value of weighted average of deviations. In the case of ward F/N, sample 1 represents a large chunk of the ward area which has a deviation of 32%. Hence the overall deviation value for the ward is more towards this value. Due to the same reason, the 81% deviation from sample number 7 is not really reflected in the final value since it represents only 5% of the total area in the ward. To sum up, the rooftop potential which we found out using extensive 2D mapping for ward F/N may vary within ±29.89% of its initial value when we consider the results of 3D mapping.

Similarly, the deviation factors for other wards were also calculated. The deviation values for all the wards are compiled in Table 2.10. For a conservative estimate, only the negative deviation values were considered for further calculations.

Table 2.10: Deviation from shade free area measured using 2D mapping and 3D simulation for all the wards

Ward Name	Weighted standard deviation in shade free area calculation
A	± 35.37 %
B	± 45.53 %
C	± 12.81 %
D	± 32.35 %
E	± 12.33 %
F/N	± 29.89 %
F/S	± 27.58 %
G/N	± 14.24 %
G/S	± 32.47 %
H/E	± 14.39 %
H/W	± 24.99 %
K/E	± 19.56 %
K/W	± 13.82 %
L	± 22.09 %
M/E	± 15.62 %
M/W	± 20.08 %
N	± 16.64 %
P/N	± 23.80 %
P/S	± 11.89 %
R/N	± 25.25 %
R/C	± 23.69 %
R/S	± 34.31 %
S	± 16.58 %
T	± 10.17 %

CHAPTER 3

CALCULATIONS AND RESULTS

This section of the report describes the final results of the rooftop potential estimation exercise. The rooftop potential in terms of installed capacity (kWp) was calculated with an assumption that the area required for installing 1 kWp of PV modules 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 this range of efficiency is 1.6m x 1 m. Hence 4 such modules would make a 1 kWp system which takes around 6.4 sq. m. At an array level on roof mounted system, we can count on another 50% area for inter array spacing. Hence the total area requirement would be 9.6 sq. m (~10 sq. m).

ROOFTOP PV POTENTIAL FOR RESIDENTIAL BUILDINGS

As already explained in Section 2.3, the total area under different residential plots was compiled on a ward by ward basis and at sub-category level as shown in Table 2.4 and later each area was multiplied with their corresponding C/P and S/C ratios. This final number is the expected shade free area after 2D mapping. The discounting factors were then applied as per the results of 3D simulation exercise. For example, the total expected shade free area from 'multifamily apartments' in ward A is 34.38 hectares (total plot area in ward A under multifamily apartments category in hectares) * 0.726 (average value of C/P ratio of entire ward A for multifamily apartment plots) * 0.461 (average value of S/C ratio of entire ward A for multifamily apartment plots) = 11.51 hectares. But out of this we need to discount 34.38% area for inter building shading. Hence the final value of shade free rooftops available in ward A under multifamily apartments category becomes 7.44 hectares. According to the assumption stated in the beginning of this chapter, 10 sq. m. area can accommodate 1 kWp solar modules. Hence the total rooftop solar potential from ward A under residential buildings of multifamily apartment sub category is 7.44 MWp. Similarly calculations and discounting was done for all other residential sub categories in every ward and the final rooftop potential in MWp is summarised in Appendix II, Table II.1.

It is very evident that the majority of the contribution comes from 'multifamily apartments' in every ward. Their total potential across Greater Mumbai comes to nearly 800 MWp. Multifamily apartments with shops (residential spaces in the upper floors and commercial on the ground floor) have a potential for installing 169 MWp. If the PV systems are installed on the rooftop which belongs to the housing society and if the electricity is sold to the shops below (who pay much higher tariffs), it can be an economically viable business model. Similarly the total potential coming out of government quarters in Mumbai is around 130 MWp. If the government launches a scheme of 100 MWp to be installed across all government quarters, it can be easily achieved. Individual housings also have a very good potential of 113 MWp. Ward wise distribution of rooftop potential shows that ward K/W has the largest residential rooftop potential with around 160 MWp. This ward is also the largest in terms of built area. The analysis also shows that the contribution from government quarters is predominant in the southern wards (island city) and contribution form 'individual housings' is almost nil in these wards. Once we move towards the northern suburbs there is a good contribution from individual houses. The total rooftop potential from entire residential areas in Greater Mumbai is expected to be 1.31 GWp.

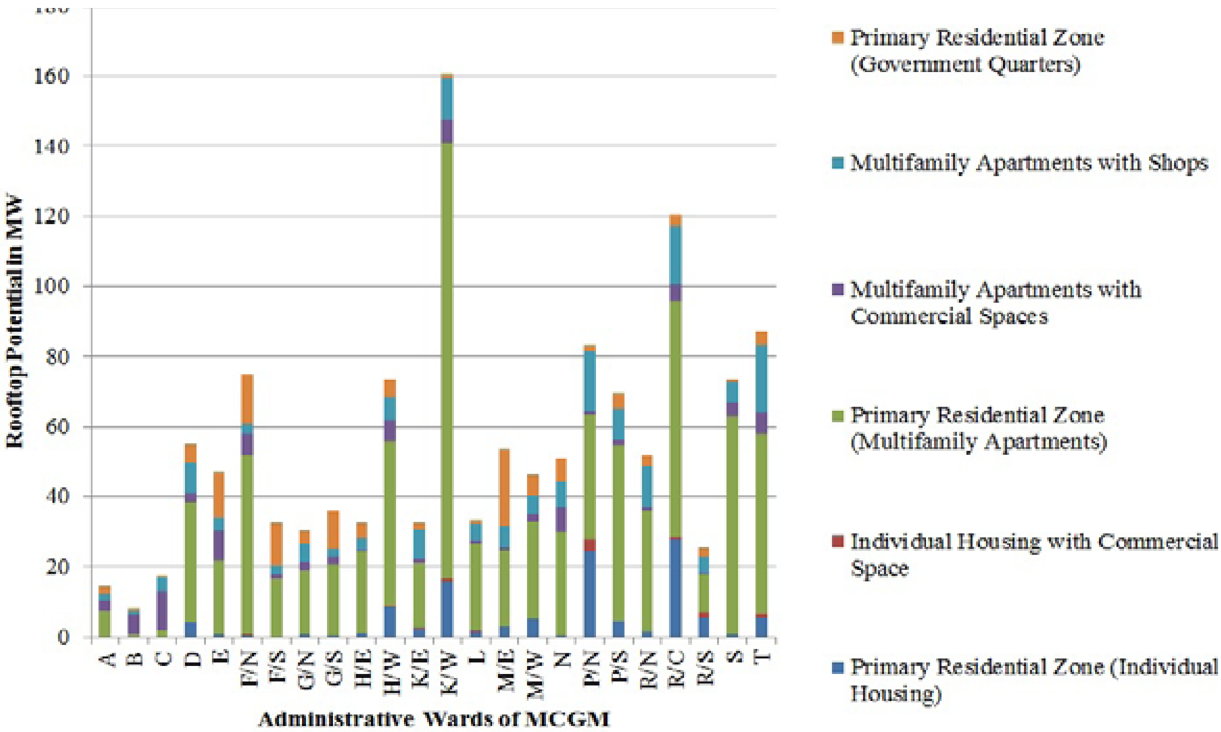


Figure 3.1: Rooftop PV installation potential from various residential building categories across 24 wards in Greater Mumbai

Figure 3.1 shows the split up of rooftop PV installation potential of residential buildings at the sub category level. The 130 MWp rooftop potential from government quarters should be a positive sign for government if they are planning big in promoting solar in Mumbai. The central railway quarters in ward D have a potential of nearly 200 kWp. The Byculla police quarters and the Judge's quarters in Mazgaon have nearly 25 kWp potential each. The residential buildings in Worli Police headquarters (Ward G/S) have a potential of nearly 1MWp. RBI colonies in wards A, R/N and G/N together contribute nearly 150 kWp. Air India colony buildings in ward H/E have a good potential of nearly 1.65 MWp. MHADA (Maharashtra Housing and Area Development Authority) colony in ward L (Chandivali) has a potential of 1.17 MWp. Similarly the new MHAD colonies in ward P/N have a potential of 810 kWp. The government can also think of a scheme where all the MHADA colonies should have rooftop solar. MTNL staff quarters in ward P/S (Goregaon) have a potential of 132 kWp. BEST officers' quarters in ward R/C (Gorai) can provide at least 25 kWp. The central government employee's society has the CGS colony in Antophil (ward F/N), the largest housing colony in Asia has 7 sectors and has a potential of around 47 MWp.

ROOFTOP PV POTENTIAL FOR EDUCATIONAL AMENITIES

Educational amenities are subcategorised into schools, colleges, universities and others (civic training institutes, special schools, polytechnics etc.) The total plot area under each sub category was compiled ward wise as shown in Appendix II, Table II.2.

Table II.3 shows the ward level weighted average of C/P ratio of top 5 samples (as explained in Section 2.3) under each sub category. Table II.4 has the corresponding S/C ratios put together. And finally after discounting for inter building shading, the final rooftop potential in kWp from each educational amenity category is given in Table 3.1.

Figure 3.2: Location map of educational amenities sampled for 2D mapping

Table 3.1: Rooftop PV installation potential from Educational Amenities across 24 wards in Greater Mumbai (kWp)

	PV Potential (*10² kWp)			
Ward Name	**Schools**	**Colleges**	**University**	**Others**
A	3.98	3.10	0.24	0.02
B	3.05	0.04	--	0.02
C	3.98	--	--	--
D	15.20	1.77	--	0.01
E	24.88	0.95	--	0.62
F/N	9.66	23.72	--	0.13
F/S	16.40	13.05	--	0.10
G/N	36.44	13.28	--	0.61
G/S	19.45	4.37	--	0.40
H/E	18.18	15.98	52.54	0.21
H/W	18.60	11.87	--	0.01
K/E	7.65	15.46	--	2.09
K/W	21.70	23.75	4.80	1.40
L	33.52	31.31	--	0.06
M/E	18.98	3.45	--	0.02
M/W	10.31	1.86	--	3.03
N	25.04	11.74	--	0.23
P/N	18.78	2.65	--	0.02
P/S	16.73	3.76	--	0.01
R/N	3.26	5.65	--	--
R/C	23.53	1.56	--	0.39
R/S	11.43	3.61	--	0.02
S	9.57	4.73	65.89	0.61
T	8.47	3.97	0.00	0.02
Total	**378.79**	**201.63**	**123.47**	**10.03**
	71.39 MWp			

Table 3.2: List of major educational institutions with relatively high rooftop PV potential identified in mapping

Institution	Administrative Ward	Rooftop Potential (kWp)
Mumbai University Fort Campus	A	125
SNDT University	A	120
Sir J.J. College Of Architecture	A	140
Imamwada School, Johar Chowk	B	125
Dongri Marathi Municipal School	B	100
Habib High School And Technical Institute	B	80
Janabhai Madhavrao Municipal Secondary School	B	150
Walsingham High School, Dariya Mahel	D	75
Manav Mandir High School, Malabar Hill	D	50
Bhavan's College And Computer Training Institute	D	55
East Byculla Municipal School	E	120
MCGM Municipal School Near Chinchpokli	E	110
Torna Sanket Prashikshan Chatrawas Hostel, Byculla	E	210
M.H Saboo Siddik College	E	150
Lokmanya Tilak Municipal Medical College	F/N	350
SIES College Of Arts Science Commerce	F/N	112
Institute Of Chemical Technology	F/N	500
VJTI College	F/N	260
Haffkine Institute for Training, Research and Testing	F/S	526
Wadia Medical College	F/S	200
Bombay Veterinary College	F/S	280
St. Paul's High School	F/S	330
Lal Bahadur Shastri Marine Institute	F/S	200
Janta High School	G/S	200
Sasmira Educational Institutions	G/S	150
National Association For The Blind	G/S	115
Watumull Institute of Electronics and Computer Science	G/S	130
Maratha High School + Ambedkar School	G/S	340
D.G. Ruparel College	G/N	500
Catering College + De Silva Technical School	G/N	250

The schools in MCGM themselves can support around 38 MWp. 20 MWp can come from the rooftops from colleges. From the buildings in University campuses, 12 MWp can be expected, out of which 6.5 MWp comes from IIT Bombay and NITIE campuses, and 5.25 MWp from Mumbai University main campus at Kalina. The total expected rooftop potential from all the educational amenities in Greater Mumbai is expected to be 71.39 MWp. Some of the educational amenities with really good rooftop potential are listed in Table 3.2.

Bombay Scottish School	G/N	270
St. Xavier Technical Institute	G/N	130
St. Michael High School	G/N	120
Mumbai University, Kalina Campus	H/E	5250
Govt. Poly Technic, Bandra	H/E	696
Kher Nagar Municipal School And Purushottam High School	H/E	244
Raheja Business School	H/E	151
Bombay College of Pharmacy	H/E	221
St. Andrew's College	H/W	228
St. Josephs Convent High School	H/W	182
BPM High School	H/W	123
Ismail Yusuf College, Jogeshwari(E)	K/E	125
St. Dominic High School	K/E	410
Sardar Patel College Of Engineering	K/W	355
Central Institute of Fisheries Education	K/W	267
SNDT Women's University, Juhu Campus	K/W	429
Shri Bhagubhai Mafatlal Polytechnic	K/W	158
Swami Vivekananda School & College	L	164
Advanced Training Institute (ATI) For Electronics & Process Instrumentation	L	633
Kohinoor Business/Management School	L	165
Holy Cross Campus	L	120
Vivekananda Education Society's Institute Of Management Studies & Research	M/W	335
Tata Institute of Social Sciences (Old Campus)	M/E	48
St. Sebastian High School & Jawahar Vidya Bhavan High School	M/E	159
Udayachal Primary School	N	288
Somaiya Vidyavihar Complex	N	504
Maneklal Mehta Municipal School	N	111
Seth Virchand Dhanji Devji National School	N	89
Ramabai Marathi Primary School, Sahakar Nagar	N	109
Indira Gandhi Institute Of Development Research	P/N	169
Oberoi International School	P/S	395

Lakshdham High School	P/S	131
Siddharthnagar Municipal School	P/S	119
Mumbai Veterinary College	P/S	828
St. Pius X College (Archdiocesan Seminary)	P/S	527
St. Joseph's Convent School	P/S	282
Don Bosco High School, Borivali	R/C	125
St. Francis D' Assisi High School Borivali (West)	R/N	130
Thakur College of Engineering and Technology	R/S	356
Thakur International School	R/S	169
Thakur Polytechnic	R/S	193
IIT Bombay	S	6250
NITIE	S	250
V.G. Vaze College of Arts Science and Commerce.	T	107
MCVC College, ITI Mulund	T	167
St. Mary's Convent High School	T	92

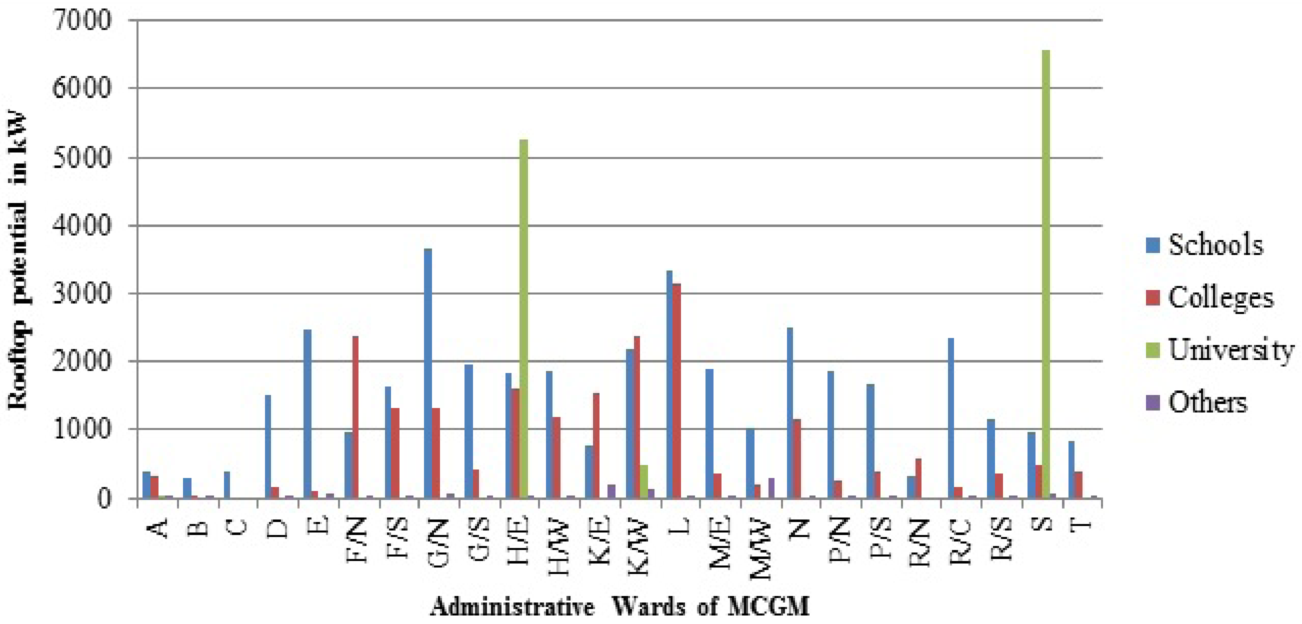


Figure 3.3: Rooftop PV installation potential from various educational buildings in Greater Mumbai

ROOFTOP PV POTENTIAL FOR INDUSTRIES

Industrial plots were classified into light industries, heavy industries and film industry. Film industry includes all the studios and processing units, which has a significant presence in Mumbai. The total plot area under each sub category was compiled from the ELU maps and is shown in Table II.5. Most of the heavy industries are concentrated around the eastern suburbs which include M/E, M/W, F/S, F/N and N wards. Most of the heavy industries in this area are related to crude oil refining. Light industrial areas are uniformly distributed across the wards but are not significantly present in the island city region (wards A to D). 5 major plots of industries available in each ward were mapped and the C/P and S/C ratios were compiled. The industrial plots which were identified and mapped in each of the wards are shown in Figure 3.4. The values are as show in Table II.6 and II.7 in Appendix II.

Based on these ratios, expected shade free area from every ward from the industrial plots was calculated and later discounted for inter-building shading. The results show that the overall rooftop potential from industrial plots is around 223 MWp. Most of the industries have corrugated sheet roofs and are slanting in nature. Depending on the orientation of the slope, the solar potential varies. Table 3.3 shows the rooftop potential from industrial buildings in various wards.

Figure 3.4: Location map of Industrial plots sampled for 2D mapping

Table 3.3:Rooftop PV installation potential from Industrial buildings in Greater Mumbai (kWp)

	Rooftop Solar Potential of Industrial Buildings (*10^2 kWp)		
Ward Name	**Heavy Industry**	**Light/ Industrial Area**	**Film Industry**
A	1.72	--	--
B	--	--	--
C	--	--	--
D	4.97	4.11	1.3
E	36.39	32.98	--
F/N	5.11	24.71	--
F/S	85.76	109.12	--
G/N	--	24.21	--
G/S	--	115.3	14.34
H/E	--	14.38	1.46
H/W	2.55	--	3.24
K/E	--	176.37	--
K/W	--	86.23	2.25
L	--	231.06	5.71
M/E	34.21	96.19	--
M/W	65.37	--	--
N	157.21	125.89	--
P/N	--	54.75	--
P/S	--	143.04	19.81
R/N	--	28.79	--
R/C	13.77	30.99	--
R/S	34.06	58.61	--
S	41.37	289.11	0.06
T	31.3	25.06	--
Total	**1.72**	**--**	**--**
	223.29 MWp		

Out of the entire 223 MWp, 167 MWp potential is coming from light industries and industrial estates. Typically they are centres of large energy and power consumption. Their tariffs are also on the higher side when compared to residential users. Hence if we can convert this potential into PV installations, a reasonable share of the industrial power can be met through solar energy during day time. Some of the old mills and large manufacturing industries have immense rooftop area suitable for PV installation. Tata mills and Mahindra production plant are some examples. The list of industrial plots which were recognised in the mapping as 'with high rooftop potential' is given in Table 3.4. Figure 3.5 shows the ward wise distribution of rooftop potential from industries.

Table 3.4: List of some major industrial plots with very high rooftop PV installation potential as identified in the mapping

Industry	Administrative Ward	Rooftop Potential (kWp)
Mukesh Mill Compound	A	275
Modern Mechanical and Marine Works	B	50
Tardeo Mill Compound	D	514
Shrenuj & Co., Tardeo	D	121
Tardeo Municipal Industrial Estate	D	301
Jyoti Studio	D	143
J Karia Industrial Estate	E	207
Indian Engineering Works	E	100
Sussex Industrial Estate	E	165
Byculla Service Industrial Estate	E	207
Ajay Industrial Estate	E	86
Britania Industries	E	200
BEST Workshop, Dadar	F/N	1500
Lalwani Industrial Estate and nearby Industries	F/N	180
Sriram Industrial Estate	F/N	200
VVF Oil Company and nearby Industries	F/N	300
Antophill Godowns	F/N	1200
BPCL Sewri Terminal	F/S	925
HPCL Mazgaon	F/S	570

Tata Mills	F/S	2000
Digvijay Mills	F/S	750
Jam Mill Compound	F/S	580
Bombay Dyeing Mills	G/S	2366
Victoria Mills and Madhu Industrial Estate	G/S	275
GlaxoSmithKline Headquarters	G/S	170
Visualize PVT Ltd	G/S	228
Sun Mill Compound + Shash and Nahar Industrial Estate	G/S	2452
India United Mill	G/N	275
Hindustan Mills	G/N	390
Ruby Mills	G/N	100
New Era Mill	G/N	272
Daulat Ram Mills	G/N	215
Dani Mill Compound and nearby Industries	H/E	530
Kolivary Industrial Area	H/E	420
Chandu Studio Complex	H/E	150
Mehboob Studios	H/W	380
Y A Chunawala Industrial Estates and nearby Industries	K/E	460
Pidilite Industrial Estate	K/E	1300
JK Industries and nearby Industries	K/E	1800
Mittal Industrial Estate and nearby Industries	K/E	2500
Parle Biscuit Factory	K/E	950
Yash Raj Studio and Others	K/W	700
Vijay Laxmi Industries	K/W	1100
Golden Tobacco Company	K/W	600
Unichem Laboratories	K/W	300
C Pharma and Orison Industries	K/W	250
L&T Business Park and others	L	700
Chandivali Ice Factory and nearby Industries	L	630
Ansa Industrial Estate	L	2500
SJ Studio Chandivali	L	1000
Bindal Industrial Estate and others	L	6200
BPCL Refinery	M/W	5275
Telecom Factory - BSNL	M/E	900
Deonar Abattoir	M/E	2650

MCGM Garage	M/E	120
Valmiki Industrial Estate	N	7900
Sonal Heavy Industrial Estate and nearby Industries	P/N	3000
Film City	P/S	1800
Baban Mishra Compound and nearby Industries	P/S	1250
Pravasi Industrial Estate	P/S	3100
Sidhpura Industrial Estate and nearby Industries	P/S	1450
Tata Steel	R/C	1730
Khatau Mills	R/C	1000
Sarita Industrial Estate and others	R/N	450
Haren Textile	R/N	100
Diamond Industries (Industrial Estate)	R/N	300
National Mill Compound, Dahisar East	R/N	300
Suraj Industrial Estate and others	R/N	1685
Mahindra and Mahindra Plant	R/S	4800
Britannia Bread Factory and Others	R/S	1600
Asian Paints Ltd Bhandup and nearby Industries	S	1800
Ceat Limited Bhandup and nearby Industries	S	2750
GKW Sankey Division	S	1700
Crompton Greeves and others, Kanjurmarg	S	3800
Vitrum Glass Factory and others	S	1350
S. H. Kelkar Company	T	386
Richardson & Cruddas LTD, Mulund	T	712
Raja Industrial Premises Co-op Society	T	930
Jonson and Johnson, Mulund	T	750

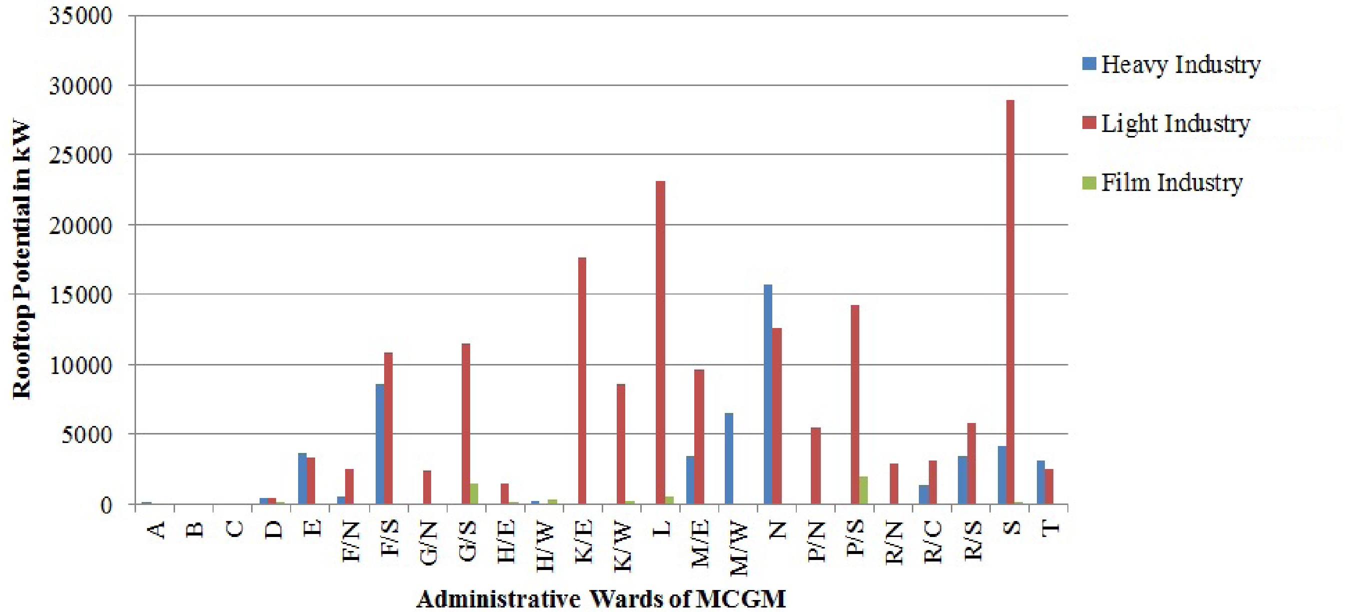


Figure 3.5: Share of different industrial buildings in total rooftop potential of industries in MCGM area

ROOFTOP PV POTENTIAL FOR COMMERCIAL BUILDINGS

In general, this category covers business and retail activities. Sub categories are markets, hotels (lodges), shopping centres, malls, warehouses and cold storages. But warehouses and cold storages were already covered along with the industrial buildings. Hence this section mainly focuses on markets, hotels, shopping centres and malls. Ward wise land use information as far as commercial buildings are concerned can be found out in Table II.8. The C/P ratios and S/C ratios from this category is compiled in Table II.9 and II.10 in Appendix II. Figure 3.6 shows the plots which were mapped under the commercial buildings category across different wards.

It was noted that the coverage to shade free conversion ratio for commercial buildings is very low when compared to previously discussed building categories. The reason is the uneven shape of rooftops of these buildings (especially malls) and most of the buildings have centralised air conditioners whose exhaust and pipes appear on the rooftops. Another shading factor is the name board of the buildings with lighting, which can cause shading on the already scarce rooftop area of such buildings. Another reason which was found during site survey was that the major hotels have converted their roofs into dining places and they use this for rooftop parties, etc.

Figure 3.6: Location map of Commercial plots sampled for 2D mapping

The total rooftop potential from commercial buildings in Greater Mumbai comes around 56 MWp. The distribution of this potential across different wards is as shown in Table 3.5. Table 3.6 has the list of major commercial buildings with good rooftop potential.

Table 3.5: Rooftop PV installation potential from Commercial buildings in Greater Mumbai (kWp)

Ward Name	Rooftop PV potential (*10^2 kWp)
A	20.20
B	11.48
C	26.26
D	24.66
E	4.78
F/N	8.26
F/S	32.21
G/N	4.20
G/S	13.19
H/E	25.37
H/W	19.31
K/E	36.72
K/W	87.66
L	87.90
M/E	15.80
M/W	12.16
N	8.54
P/N	14.18
P/S	20.75
R/N	0.00
R/C	25.11
R/S	7.16
S	39.47
T	15.65
Total	**561.02**
56.1 MWp	

Table 3.6: List of some major commercial plots with high rooftop PV installation potential as identified in the mapping

Commercial Place	Ward	Potential (kWp)
Vashani Chambers and nearby commercial spaces	A	137
Maniyar Building, Tardeo	B	116
Mulji Jetha Market	C	119
Mangaldas Market	C	232
Sopariwala Estate	D	110
City Centre Mall	D	193
Tardeo Market	D	137
Sewri Dockyards	E	357
ES&P Building	E	140
Sewree Dockyards	F/S	154
Wadia Godown	F/S	242
Godrej Workshop	F/S	145
One India Bulls Centre	G/S	119
Peninsula Corporate Park	G/S	118
K Lifestyle Mall, Worli	GS	214
Poonam Chambers	G/S	102
Kalpataru Synergy	H/E	247
Millan Mall	H/W	152
The Lalit Mumbai Hotel	K/E	154
Commercial Business Park	K/E	310
ABB Ltd.	K/W	481
JW Marriot Hotel Mumbai	K/W	128
Crystal Plaza, Office Towers & nearby Chambers	K/W	209
Phoenix Market City	L	1872
Oberoi Garden Estate	L	321
Kohinoor City Mall	L	418
Holiday Inn, Sakinaka	L	319
Mighty	M/E	107

Guru Kripa Hotel, Chembur	M/E	127
Chambers near Tatanagar, Deonar	M/E	139
R-city mall Ghatkopar	N	1097
Satyam Shopping Centre	N	122
NESCO	P/S	1194
Oberoi Mall	P/S	190
Palm Hotels & Convention Centre	P/S	180
Raghuleela Mega Mall	R/C	160
Growel's 101 Mall	R/S	151
Dreams Mall	S	151
Neptune Magnet Mall	S	433
HCC 247 Software Park	S	387
Nirmal Life Style Mall	T	168
R-Mall Mulund	T	166
Ecstasy the Mall	T	143

ROOFTOP PV POTENTIAL FOR OFFICE BUILDINGS

Offices are usually considered under 'commercial' category. However, due to their significant presence in Mumbai, they has been considered as a separate category. Offices are categorised into Municipal offices, offices belonging to centre or state, IT and IT enabled offices and others. Figure 3.7 shows the distribution of plots across different wards which were mapped for the study.

Table II.11, Appendix II shows the area under office buildings across different wards. Third and fourth columns of Table II.11 shows the C/P and S/C ratios for office plots in various wards. Finally Table 3.7 shows the rooftop PV potential of various offices after discounting the shading factors. The total potential is coming around 20 MWp. Table 3.8 has the list of major office buildings identified in this study which have more than 100 kWp potential.

Figure 3.7: Location map of Office building plots sampled for 2D mapping

Table 3.7: Rooftop potential from Office buildings from various wards

Ward Name	Potential (*10² kWp)
A	15.95
B	1.08
C	0.68
D	4.93
E	9.64
F/N	4.33
F/S	3.29
G/N	6.45
G/S	13.93
H/E	7.22
H/W	3.79
K/E	42.57
K/W	8.95
L	8.94
M/E	1.87
M/W	6.2
N	2.7
P/N	17.46
P/S	3.89
R/N	1.88
R/C	3.16
R/S	5.55
S	20.29
T	0.5
Total	**195.25**
19.53 MW	

Table 3.8: List of major office buildings with good rooftop potential as observed in mapping

Office Building	Ward	Potential in kWp
Income Tax Office (Aayakar Bhawan)	A	101
Shaikh Ali Chamber, Mahalaxmi	D	151
Directorate of Printing and Stationery	D	290
Ambevadi, Mazgaon	E	124
Turf Estate, Mahalaxmi	GS	211
MHADA / Marriage Court/ Offices	HE	103
Food And Drug Administration Office	HE	106
Trade Star	KE	183
Ahura Centre	KE	277
Skyline Icon	KE	225
LIC insurance Office	KW	593
Boomerang	L	235
Equinox Business Park	L	145
Corporate Park (Olympus Imaging India)	MW	284
Food Corporation of India Office and Warehouse, Kandivali	RC	1445
Interface, Chincholi Bunder, West Malad	PN	121
Kotak House, Goregaon East	PN	190
Infinity IT Park and nearby Offices	PN	303
Times of India - Suburban Press	RS	787
Kensington SEZ, Fullerton Office - Supreme Business Park, Purana Studio, Fairmont, Winchester	S	685
Hiranandani-Bayer House, Chemtex House, Olympia, Alpha Building and others	S	190
Nirlon Knowledge Park	PS	322

ROOFTOP PV POTENTIAL FOR MEDICAL AMENITIES

Medical amenities include dispensaries, maternity homes, hospitals and other medical services. These amenities are further classified into amenities owned by the government and private organisations. Even though the cemeteries, and burial grounds are also categorised as 'medical amenities' by MCGM (since they are under the department of health) we have not considered these lands for rooftop potential estimation. Private dispensaries, maternity homes, consulting clinics etc. forming a part of residential/commercial buildings are not captured in this study. The total installation potential form medical amenities of Greater Mumbai comes to around 15 MWp. Figure 3.8 shows the plots of medical amenities in various wards which were mapped for the study. After discounting for the inter-building shading, the rooftop potential of medical amenities is as compiled in Table 3.9. Table 3.10 has the list of major hospitals which have more than 100 kWp installation potential.

It was noted during the survey that most of the hospitals already own a solar water heater system which occupies the rooftop space and hence there is very less additional roof area available for installing PV modules.

Figure 3.8: Location map of Medical amenities' plots sampled for 2D mapping

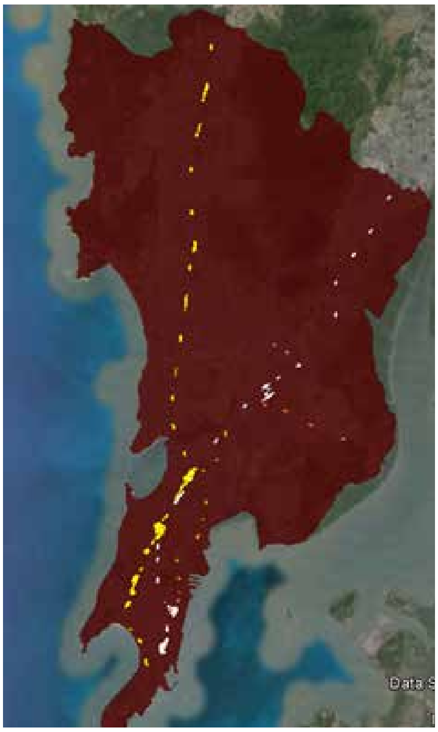
Table 3.9: Rooftop potential from medical amenities from various wards

Ward Name	Rooftop Potential (*10^2 kWp)
A	2.62
B	1.45
C	7.67
D	4.48
E	13.89
F/N	4.63
F/S	14.93
G/N	2.25
G/S	9.9
H/E	3.62
H/W	5.99
K/E	24.03
K/W	9.37
L	2.42
M/E	8.87
M/W	2.24
N	7.15
P/N	1.58
P/S	4.14
R/N	4.92
R/C	3.6
R/S	0.89
S	5.19
T	4.14
Total	**149.97**
15 MW	

Table 3.10: List of major medical amenity buildings with good rooftop potential as observed in mapping

Name of Hospital	Ward Name	Potential (kWp)	Solar water heaters installed?
Jamshedji Jeejeebhoy (JJ) Hospital and Grant Medical College Campus	E	508.9	Yes
Nair Hospital Campus	E	306.9	Yes
Lokmanya Tilak Hospital / Sion Hospital	F/N	242.2	
T B Hospital Complex	F/S	270.3	
King Edward Memorial (KEM) Hospital	F/S	441.2	
Mahatma Gandhi Hospital	F/S	237.3	
Podar Hospital	G/S	180.3	
Holy Spirit Hospital	K/E	315.3	Yes
Cooper Hospital, Juhu	K/W	177.2	
Nanavati Hospital	K/W	186.4	
Shatabdi Hospital	M/E	167.8	
Sarvodya Hospital	N	108.4	
Goderej Hospital	N	123.13	

Figure 3.9: Location map of Railway stations and associated building plots sampled mapped



ROOFTOP POTENTIAL FROM TRANSPORTATION INFRASTRUCTURE

A total of 30 stations from the Western Railway line, 20 from the Central line and 15 from the Harbour line are located in the jurisdiction area of MCGM. Hence we have restricted our studies to these stations. We have also considered the associated buildings under railways' authority which are located near to the stations. This includes the booking counters, parcel offices, garages, car-sheds, workshops etc. 12 metro stations were also investigated, but these had very less rooftop potential because of uneven rooftop structures. The location of the stations and buildings mapped out for the study can be seen in Figure 3.9.

Figure 3.9: Location map of Railway stations and associated building plots sampled mapped

Instead of calculating the C/P and S/C ratios, the actual shade free areas were plotted out for every station and associated building. While mapping, it was found that almost all the stations in the Western and Central lines have their platform roofs placed in an east-west sloping position. As mentioned in Section 2.3 (stage 3), such roofs have lesser annual yield than the roofs facing south. Hence we have envisaged an additional structure which can be erected across the apex points of two roofs, where the PV modules can be placed south facing (Refer Figure 3.10). The results from the mapping are as summarised in the Table 3.11. Table 3.12 details out the potential at the different railway stations on the 3 lines.

Figure 3.10: Rooftop area plotting done for railway station and platform roofs (CST Terminus)

Table 3.11: Rooftop PV potential for railway stations

Railway Line	Potential from RCC roofs of associated buildings (*10^2 kWp)	Potential from corrugated sheet roofs of associated buildings (*10^2 kWp)	Potential from corrugated sheet rooftops from platforms (*10^2 kWp)	Total (*10^2 kWp)
Western	15.40	127.82	48.63	191.85
Central	7.92	20.68	23.83	52.44
Harbour	0.18	0.63	8.50	9.31
Total	**25.36 MWp**			

Table 3.12: List of major railway stations with good rooftop potential as observed in mapping stations

Railway Line	Name of the Railway Station	Potential from associated buildings (kWp)	Potential from platform roofs (kWp)	Total potential (kWp)
WESTERN	Churchgate	220	764	984
	Marine Lines	27	90	117
	Grant Road	172	133	305
	Mumbai Central	229	544	773
	Mahalaxmi	0	118	118
	Lower Parel	1534	181	1715
	Elphinstone Road	14	88	101
	Parel Railway Station	0	149	149
	Dadar	284	318	602
	Matunga Road	0	119	119
	Matunga central railway workshop	4472	0	4472
	Mahim Junction	0	307	307
	Bandra	107	184	291
	Khar Road	10	335	345
	Santacruz	10	289	299
	Vile-Parle Nagar	0	262	262
	Andheri	147	387	534
	Jogeshwari	40	342	382
	Goregaon	0	148	148

WESTERN	Malad	16	204	220
	Kandivali	0	231	231
	Western Kandivali car shed	575	0	575
	Borivali	67	141	208
	Dahisar	0	295	295
CENTRAL	Mumbai CST	833	316	1149
	Sandhurst Car Shed	872	0	872
	Dadar	45	227	271
	Lokmanya Tilak Terminus	287	802	1090
	EMU Carshed	632	0	632
	Vikhroli	60	135	195
	Bhandup	0	184	184
	Nahur	2	118	120
	Mulund	16	131	146
HARBOUR	Sandhurst Road	0	133	133
	Reay Road	0	128	128

BUS DEPOTS

BEST transport service areas are divided into 4 zones: City Zone, Central Suburb Zone, Eastern Suburb Zone and Western Suburb Zone. There are 25 bus depots across these 4 zones. The depots mainly have flat roofed RCC buildings and in some depots, there are sheet-roofed buildings as well. We have mapped out the shade free area of every RCC building and the south facing roofs of the sheet-roofed buildings. The results are as shown in Table 3.13, and Fig. 3.11 shows the locations of the BEST depots.

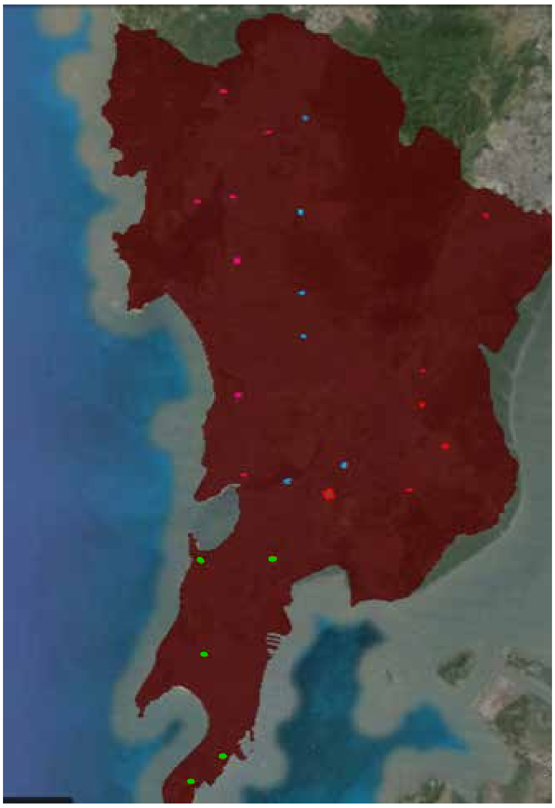


Figure 3.11: Location map of BEST depots mapped under each of their operational zone

Table 3.13: List of all bus depots and their rooftop potential as observed in mapping

No.	Zone	Name of Depot	Potential from flat roofs of RCC buildings (kWp)	Potential from south facing slanted roofs (kWp)
1	City Zone	Colaba	95	60
2		Backbay	34	0
3		Central	111	0
4		Worli	55	9
5		Wadala	234	35
6	Central Suburb Zone	Marol	30	19
7		Dharavi	207	0
8		Magathane	171	0
9		Dindoshi	259	0
10		Majas	153	0
11		Kurla ST stand & Depot	165	0
12	Western Suburb Zone	Bandra	149	15
13		Santacruz	211	5
14		Goregoan	182	10
15		Oshiwara	212	22
16		Poisar	64	18
17		Gorai	232	8
18		Malwani	205	10
19		Malad	45	14
20	Eastern Suburb Zone	Anik	89	603
21		Deonar	99	7
22		Shivaji Nagar	207	0
23		Ghatkopar	145	0
24		Vikhroli	39	15
25		Mulund	151	0
	Total		**3544**	**850**
		4.39 MWp		

ROOFTOP PV POTENTIAL OF GREATER MUMBAI: THE OVERALL PICTURE

We can now consider the entire rooftop potential coming from various building types and land use categories. The contribution from residential buildings is certainly dominating. Nearly 1.31 GWp can be installed on the roofs of residential buildings. The next highest contribution is from industries, which come to 223 MWp. Of this, mills, primary manufacturing factories and other heavy industries together contribute nearly 51 MWp and the rest of the small industries and industrial estates spread all over the city contribute almost 167 MWp. Educational institutions can accommodate another 71 MWp PV modules on their rooftops, among which the big university campuses like IIT Bombay and Mumbai University contribute up to 10 to 12 MWp. The rooftop areas from the commercial buildings are not so promising for rooftop PV installations though their cumulative potential is around 56 MWp. Nearly 20 MWp installations can happen in the roofs of office buildings and 15 MWp from various hospitals and medical amenities. Most of the hospitals surveyed already have installed solar water heaters on their roofs which leave less space for PV installations. The railways have good rooftop potential on their associated buildings near the stations whereas the platform roofs are not so optimal for PV installation. The cumulative installation from the assets of the railways, within the boundaries of MCGM was found to be 25.4 MWp. BEST bus depots have large shade-free flat rooftops over their 25 locations and they can accommodate 4.4 MWp solar installations. Adding up the figures, the total rooftop PV potential for Greater Mumbai comes to around 1.72 GWp. Table 3.14 summarises the rooftop potential from various building categories.

Table 3.14: Summary of rooftop PV potential from various building categories in Greater Mumbai

Building Category	Rooftop Potential (MWp)
Residential Buildings	1310
Industries	223
Educational Amenities	71
Commercial Buildings	56
Office Buildings	20
Hospitals and Medical Amenities	15
Railways	25
Bus Depots	4
Total	1724

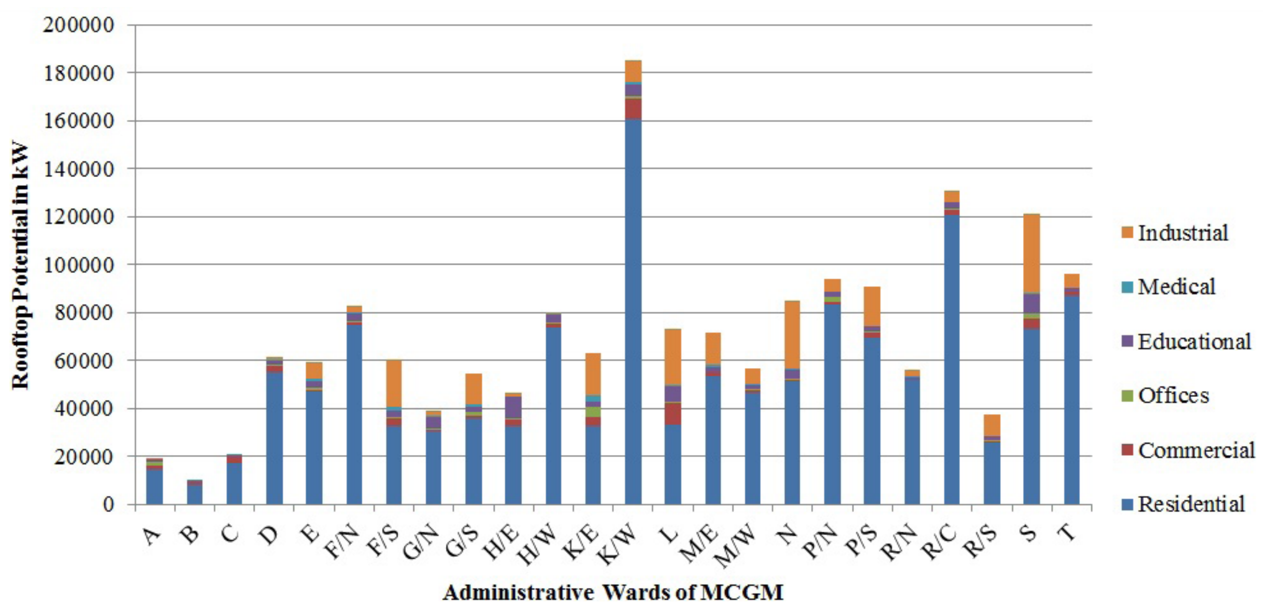


Figure 3.12 shows the potential of various categories ward-wise, and Fig. 3.13, gives a pie-chart distribution of the different categories, which again emphasizes the primacy of the residential category.

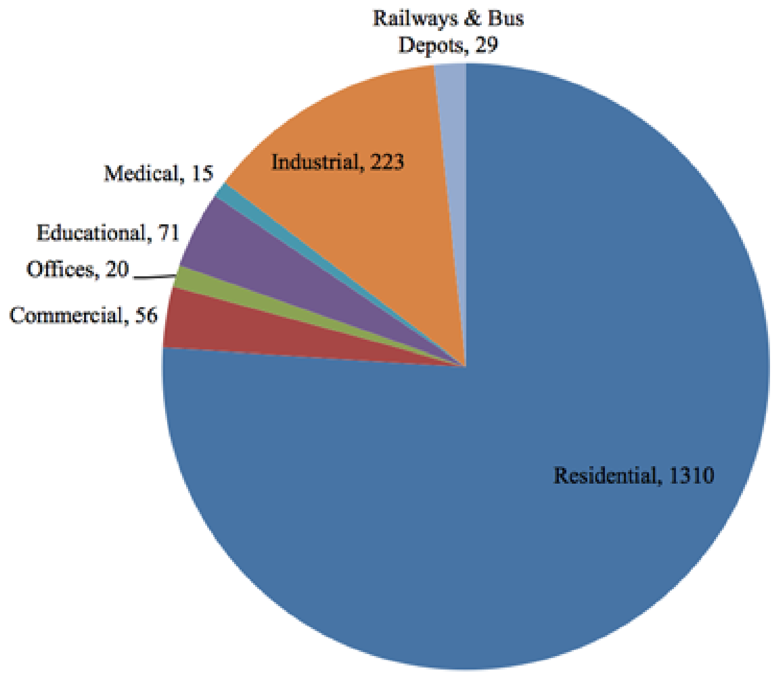


Figure 3.13: Distribution of rooftop PV potential in MWp across different building categories

Figure 3.14: Some of the sites visited for rooftop measurement and questionnaire survey

RESULTS OF THE QUESTIONNAIRE SURVEY

In section 2.3, stage 2, the site surveys executed by the students was explained in detail. This was part of the methodology to evaluate the accuracy of measurements using Google Earth and also a mean to understand the public awareness and acceptability towards rooftop PV programs. Even though 300 samples were selected for site visit, due to practical difficulties, only 49 of them could actually be covered. The non-availability of permission to access the rooftop restricted us from surveying many commercial buildings, government offices and quarters. But the results of the survey shows that the difference in the area measured using Google Earth and the area measured physically on-site during survey shows only a deviation within ± 10%. This finding was already discussed in section 2.3 stage 2. In this section the results from the questions regarding the structural details of the buildings, perceptions of the people regarding rooftop PV and their acceptance towards the technology and government policies are discussed. Figure 3.14 shows some of the locations which were actually surveyed on the field.

Figure 3.15 shows the distribution of different building categories visited during site survey Mostly residential buildings were covered in the survey followed by educational amenities and

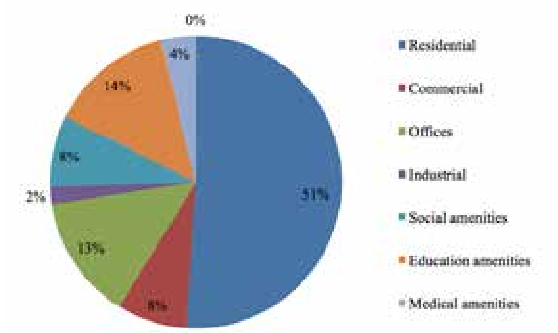


Figure 3.15: Category of buildings visited for rooftop measurement and questionnaire survey

offices. Hence the perceptions of the respondents in this survey can be considered to be mainly that of residential building owners.

ACCESSIBILITY TO ROOFTOPS

Figure 3.16 show that 76% of the buildings surveyed had proper and easy access to the rooftops. This is a positive sign as far as the scope of rooftop PV installation is considered.

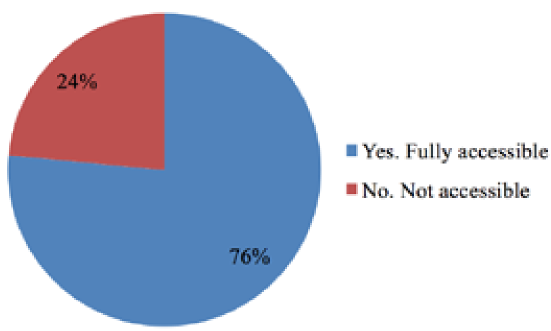


Figure 3.16: Accessibility to rooftops surveyed

FLOOR TO FLOOR HEIGHT OF THE BUILDINGS, OVERHEAD TANKS

The average value of floor to floor height of buildings was close to 4 m and the average height of shading objects such as overhead water tanks was found close to 3.5 m.

TYPE OF ROOFS

Figure 3.17 shows that a majority of the buildings have sloped roofs or have truss works and sheets on the rooftop. For the area measurement, the surveyors measured the base area of the floor just beneath the roof and multiplied this with a factor (according to the slope of the roofs). This indicates the need for engineering designs which can be used for tiled roofs and corrugated sheets.

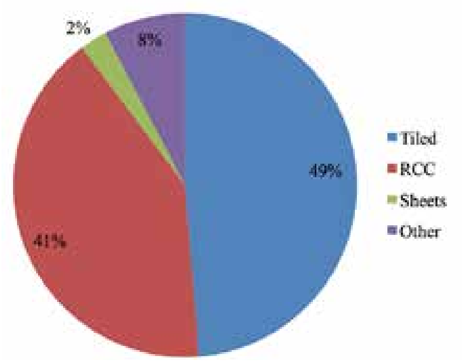


Figure 3.17: Types of rooftops available in surveyed buildings

WHETHER THE BUILDING HAS SEPARATE ELECTRICITY METER FOR COMMON AREA LOADS

Most of the residential buildings have separate meter for common area loads. Some of the office spaces and commercial centres do not have separate meters. Figure 3.18 shows the response for this question among various survey locations

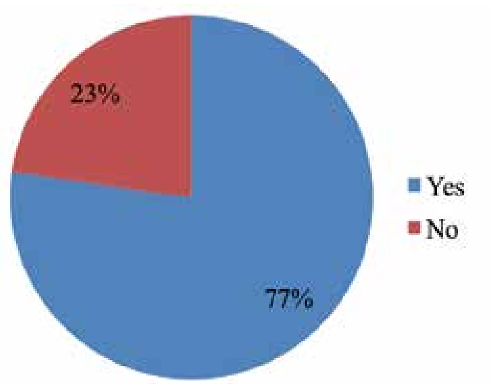


Figure 3.18: Availability of separate meters for common area lighting and other loads

TYPE OF LOADS IN COMMON AREAS

Most of the respondents said that the common load area includes lighting loads, elevators and water pumps. But there are certain buildings which have telecom towers and other loads in their common billing category (Fig. 3.19).

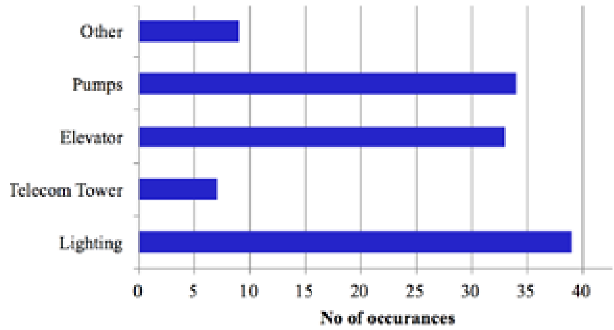


Figure 3.19: Types of loads in common area billing for the buildings

LOAD PROFILE OF THE BUILDINGS

According to the responses in the survey, the load profile of the residential buildings either remains constant throughout the day or peaks during 6 PM to 10 PM. The responses from the commercial and office spaces shows that their loads generally peak during 12 PM to 6 PM. .

WHETHER RESPONDENTS ARE WILLING TO SPEND ON SOLAR POWER FOR THEIR HOME

Around 37% respondents are ready to install rooftop PV if the government provides financial support. But about 37% are not interested in PV. This may be due to lack of awareness or knowledge. Figure 3.20 shows the kind of responses obtained from different people regarding their willingness to spend for PV systems for their home.

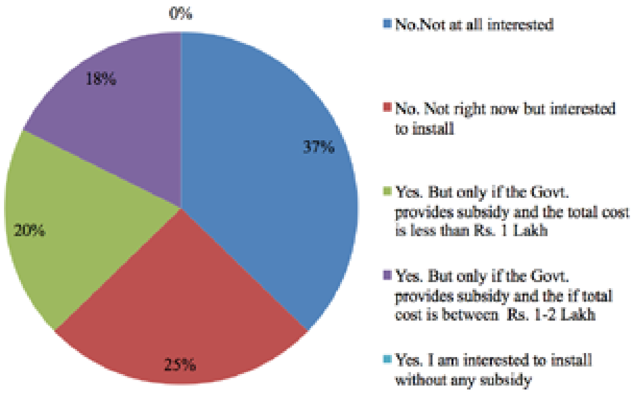


Figure 3.20: Willingness to pay for rooftop solar – perspective of the domestic consumers

IF YES, THEN MAIN REASON FOR OPTING SOLAR POWER

Survey results shows that residential buildings are mainly going for solar because to support a 'green' cause and to save their bills in common area lighting. Commercial buildings, hospitals and offices consider solar energy as a cheaper alternative for diesel generator. Figure 3.21 shows the responses obtained in the survey regarding the motivation for adopting solar.

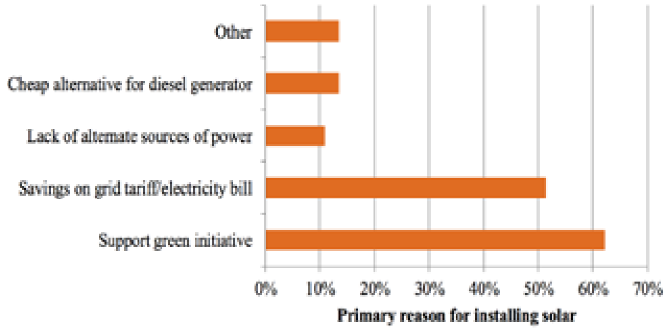


Figure 3.21: Reasons for adopting solar rooftop PV systems

IF NO, THEN IN YOUR OPINION WHICH OF THE FOLLOWING WAS THE REASON FOR NOT OPTING SOLAR POWER?

The major reason that the people are not adopting rooftop PV is their lack of awareness about the technology itself and the benefits of using rooftop PV power. High upfront investment and lack of control over roof space area are the other reasons stated by the respondents. Figure 3.22 shows the response from the people regarding their reasons for unwillingness to adopt PV.

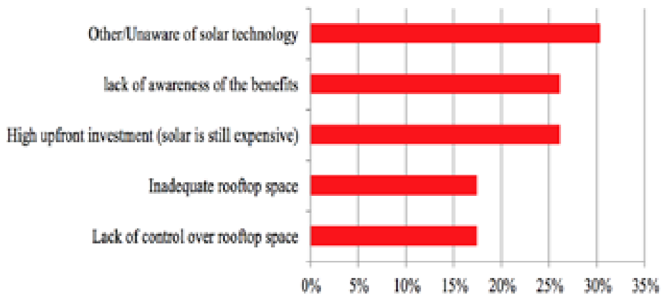


Figure 3.22: Reasons for not adopting solar rooftop PV systems

IN YOUR OPINION, WHICH OF THE FOLLOWING WOULD BE MOST SUITED TO MAKE PEOPLE CHOOSE SOLAR POWER FOR THEIR HOMES?

Most of the people think that providing easy finance options can push more people to adopt solar. Figure 3.23 show that almost 51% people believes that the best way to promote solar among domestic users is to provide them access to easy finance.

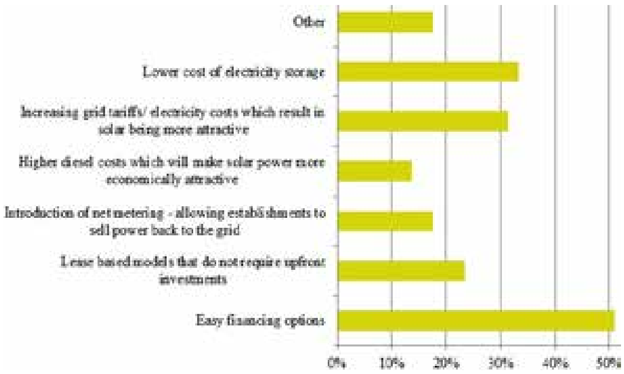


Figure 3.23: Reasons for not adopting solar rooftop PV systems

IN YOUR OPINION, WHICH OF THE FOLLOWING WOULD BE KEY DRIVERS TO ENCOURAGE RESIDENTIAL CONSUMERS TO CHOOSE SOLAR FOR BACK-UP POWER?

In another response from the survey in residential buildings, it is understood that ease of installation, minimum maintenance and the possibility of revenue generation (or bill savings) are the most attractive features or key drivers of rooftop solar systems. Figure 3.24 shows the response from the survey about the perception of people regarding key drivers to encourage solar power at residential level.

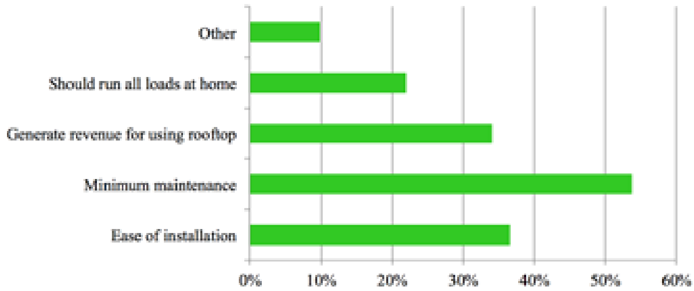


Figure 3.24: Key drivers for solar rooftop PV systems in residential segment

ARE YOU INTERESTED IN USING SOLAR PANELS ON THE BUILDINGS ENVELOPE APART FROM ROOF?

Survey results shows that most of the people are not interested in façade PV installation mainly because it would affect the aesthetics of the building. Figure 3.25 shows that while most respondents were not keen on installing PV modules on facades, 35% showed interest in exploring other possibilities of installing solar.

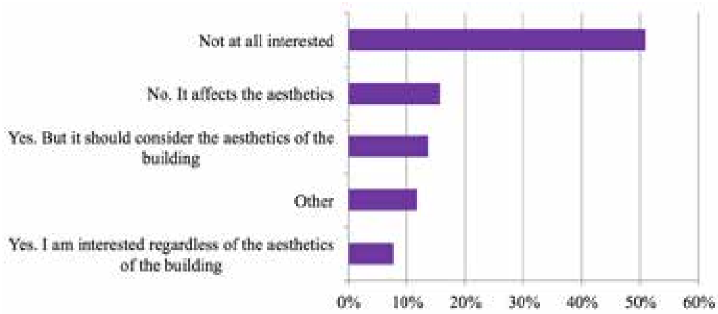


Figure 3.25: Interest in façade PV installation

PRELIMINARY STUDY ON THE LOAD PROFILE OF MUMBAI AND IMPACT OF GRID INTEGRATION OF PV SYSTEMS

In order to study the impact of grid integration of such a huge capacity of PV in a distributed manner, a simulation study was done in PVSyst software [28]. The software predicts the power generation from a PV system in detail using the historic weather data and insolation values for a place. We have assumed two levels of grid penetration of PV. Firstly, we assume that the entire 1.72 GWp potential would be realised and gets connected into the grid. In the second case, we assume that at least 20% of the identified potential i.e. 344 MWp gets realised and injects power into the grid.

CASE 1: 1.72 GWP INTEGRATED INTO THE GRID

To make the study realistic, the entire 1.72 GWp is assumed to be distributed in various rooftops at various azimuth angles (deviation angle from true south direction), keeping the tilt angle same at 20°. The simulation study was done with 7 sets of 245 MWp blocks with azimuth angles -45°, -32°, -19°, 0°,+19°, +32°, +45°. This arrangement, in a way represents the installation of modules in different azimuths in different rooftops. The power generation results were compared with the historic demand profile of Mumbai city, obtained from Maharashtra State Load Despatch Centre (MSLDC) [29]. Figure 3.26 shows the two sets of plots, one for load and other for generation. The curves were plotted for different months of the year. The load curves generally have four major sections. The morning ramp up at around 10.00 hrs, the day peak at around 13.00 hrs, evening peak at around 20.00 hrs and the night minimum at 5.00 hrs. The PV generation follows a 'bell curve' which peaks at around 13.00 hrs. The ramping up of PV power generation during morning 8.00 to 11.00 hrs is matching very much with the ramping up of load during that time. Again, the PV generation peaks during the day peak at around 13.00 hrs. Hence integrating PV into the grid seems to be beneficial for the utility companies in handling the morning peak.

Further a resultant load on the conventional sources was estimated by subtracting the PV power produced from the total load. Figure 3.27 shows that the resultant load on conventional generation centres will now be devoid of the morning peak if we integrate 1.72 GWp PV into the energy mix.

It is also important to note that the so called 'duck curve problem' (high ramping rate of demand soon after the PV generation declines during the evening hours. Ramping rates were as high as 13000 MW

in 3 hours [30]) which was seen in many of the cities with high PV penetration (like California) are not expected to happen in Mumbai. Even with the maximum expected PV penetration of 1.72 GWp. The maximum ramping rates are predicted to be in the range of 600-675 MW in 3 hours.

CASE 2: 344 MWP INTEGRATED INTO THE GRID

Realising the entire 1.72 GW PV potential may not be a practical scenario. So let us consider a scenario wherein 344 MW (i.e. 20% of the maximum estimated potential) is realised in the next 2 years. The demand itself is growing at a rate of 5 to 7% per year [29]. The load curves and the generation curve form 344 MW is expected to be as shown in Figure 3.28.

Now with this level of PV penetration, the resultant load curves over various months in Mumbai are expected to be as in Figure 3.29. In this scenario, the ramp rates are even better and expected to be around 500 – 530 MW in three hours.

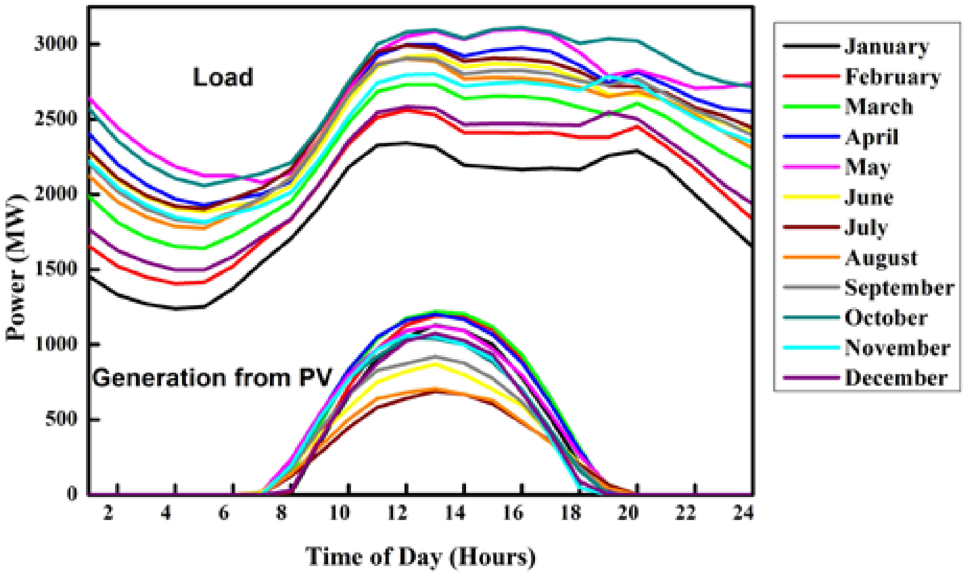


Figure 3.26: Daily load profile and PV generation profile for Mumbai for different months.

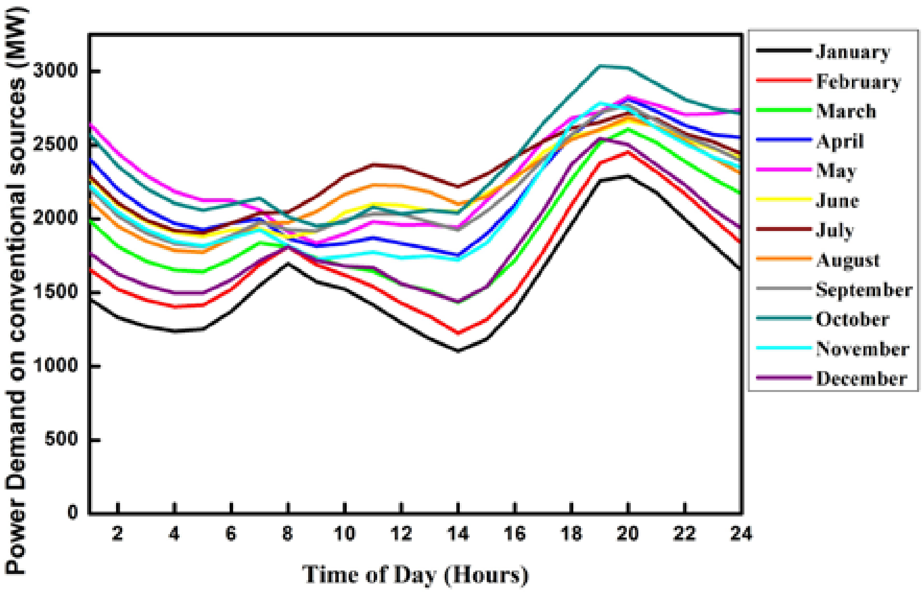


Figure 3.27: Daily load profile on conventional sources expected in Mumbai after the grid integration of 1.72 GWp PV

Hence this exercise concludes that the stability of grid may not be affected much due to the time varying nature of power integrated from rooftop PV installations even up to the levels of 1.72 GWp. This can be easily absorbed into the grid which has a morning peak load of 2.3 to 3.2 GW. Also this study shows that the utilities can find PV helpful in managing their day time ramping rates and peak loads. Since the peak demand in Mumbai continues till late evenings (18.00 – 20.00 hours) and the contribution from PV is not much expected during this time, the utilities will have to definitely maintain their existing generation assets, so as to meet this load during 'non-solar' hours.

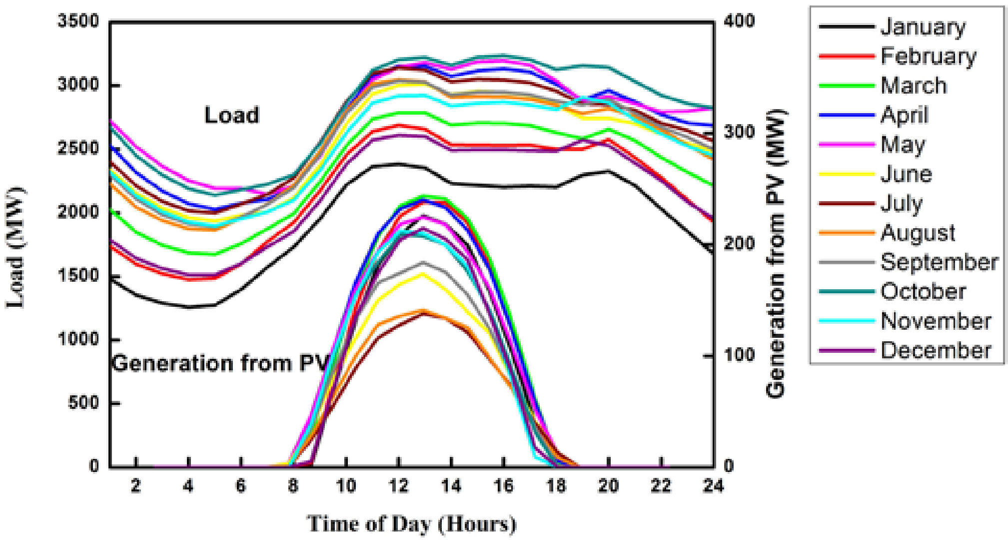


Figure 3.28: Daily load profile for Mumbai predicted for 2018 and predicted PV generation profile from 344 MWp for different months.

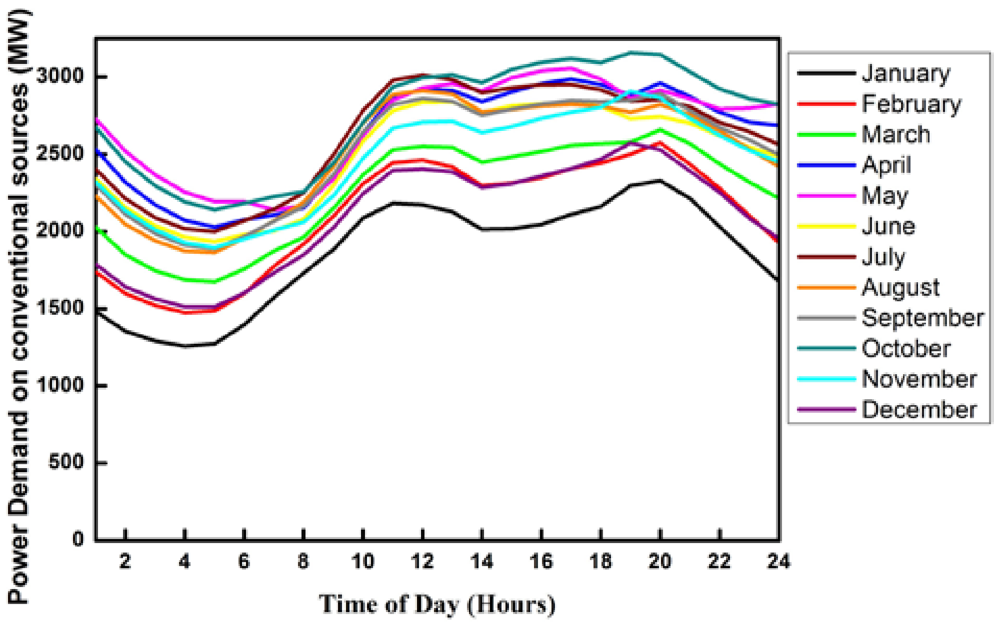


Figure 3.29: Daily load profile on conventional sources expected in Mumbai in 2018, after the grid integration of 344 MWp PV

CHAPTER 4

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS AND FUTURE WORK

The objective of this project was to predict an indicative figure for the rooftop PV installation potential for Greater Mumbai. It was also, importantly, an attempt to develop a new and scalable methodology for assessment of rooftop potential through crowd sourcing the entire mapping and surveying activities from the student community. The methodology developed here is very applicable to all urban places in India, and can provide a framework for assessing the locations required for the proposed 40 GW rooftop target. The study also envisaged generating information in such a way that it can give a clear idea to the local governments to plan large scale rooftop PV projects in their town or city. For this reason, the information was created based on the city planning maps and development reports from the local government (the municipal corporation). Other than the web based (GIS) area calculations, the students were also engaged in site surveys and physical area measurements of rooftops of selected sites to corroborate their findings using maps, which provided empirical checks. Further, through these surveys, the perception of the people (building owners) was also studied, which is important information for the planning and success of rooftop PV schemes. Finally, the use of a well-trained cadre of students as a part of the methodology had the important benefit of generating large scale awareness and interest about rooftop PV among the students, and through them, to the larger community and the public.

The entire activities for rooftop assessment ranged from mapping and identification of the 'use' of the buildings to shade free area calculations using Google Earth and other free online maps sources. Later the 3D modelling and inter-building shading simulation studies improved the quality of the work. Instead of 3D modelling of large areas, the methodology resorted to random sampling and 2D mapping of plot areas selected in a hierarchical way (based on land use information) and later simulation of 3D models of small clusters (point sampling) of buildings which can be representatives for regional urban texture. Hence this methodology can be termed as a 'rapid hierarchical mapping of rooftop areas followed by 3D simulation of point samples'. This method was found effective in generating information quickly at a macro level. In this study, the entire work was done by a team of 120 students from 12 Engineering College under the mentorship of research scholars from IIT Bombay. Together they plotted out 3117 hectares of land which comes to around 11.5% of the total developed area of Greater Mumbai. In fact if we discount for the areas under roads and other transport infrastructure not relevant for rooftop estimation studies and the unqualified land areas such as slums and open spaces (which are still considered under 'developed area') the area covered is as much as 25% of the 'qualified' plot areas.

The study concluded that the total rooftop PV installation potential for Greater Mumbai is around 1.72 GWp. The residential buildings have a major share of nearly 1.3 GWp followed by industries (223 MWp), educational amenities (72 MWp), commercial buildings (56 MWp), office buildings (20 MWp) and hospitals (15 MWp). The railways can produce 25.5 MWp power from the rooftops available from their platforms and associated buildings in the stations within MCGM boundaries. The 25 bus depots across MCGM can have another 4.4 MWp on their rooftops. We were also able to identify some of the major structures under each category which have a potential of more than 100 kWp and have listed these in this report. Further technical study needs to be done from a grid integration point of view of rooftop systems from such a huge available shade free areas across the city.

A preliminary study on the load profile of the city and the expected generation profile from PV installations was done. The results show that even if the entire 1.72 GWp potential is realised into installations, grid management may not be a difficult task. One of the problems faced by the utility companies in cities with high PV penetration is the inability to handle high ramping rates in loads during late evenings. In the case of Mumbai, even with high values of PV penetrations (of the order of 1.72 GW), the ramping rates are expected to remain within 200 to 225 MW an hour, which are within the manageable limits. A good amount of PV penetration into the grid can also help the utilities in managing the morning peak demand and ramp rates. The study shows that the typical load curve for Mumbai has a ramping rate of 250-325 MW per hour during the morning peak hours and reaches a morning peak load of around 3000 MW at 11.00 hours. The generation from the PV plants also follow a similar ramping rate and reaches the maximum at around 12.00 hours. Hence the incremental demand on the grid can be largely met by PV and the generation scheduling from the conventional sources becomes easier.

Now that we could identify and point out the potential sources, a study on the points of sinks (major load centres of electrical power) can make the picture clear on how effectively can the rooftops be utilised. If there can be any matching between the load centres and the rooftop availability across various wards, then it can lead to effective designing of rooftop PV systems feeding the needs of nearest load centres. Such a study needs the support of the utility companies.

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Ophelia Trelawney
Piyush Arjun Sawant
Pooja P Wani
Prajjwal Talwaray
Pranav Kulkarni
Pranay Sharma
Praveen P Padhy
Priyanka Gauda
Priyanka Ojha
Priyanka Padwal
Puja Gupta
Rishabh Chowdhary
Roma D. Hambar
Rudhra Pillai
Sameer Shaikh
Sarath Menon
Sarvesh Pimpalkar
Saurabh Soni
Shaun Mendes
Shiba Singh
Shubham Sharma
Shweta Balkrishna Khedekar
Sneh Dhiren Chheda
Snehal Bende
Snehal Uttamrao Kale
Sooraj Dinesan
Suman Deb
Supriya Singh
Suraj More
Suyog Pathare
Swati Pal
Swati Sundar
Tanish Kotyanbar
Tanvi Kalan
Uday Hanuman Varma
Uday Yadav
Vishakha Singh
Yash L Gada

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APPENDIX I:

REVIEW OF SOLAR CITY PROJECTS AND ROOFTOP POTENTIAL ESTIMATION METHODS

In this Appendix, we give some selected examples of urban solar PV projects and methods used to estimate the PV potential.

In terms of assessing and quantifying rooftop solar potential, various methodologies have been adopted. A team from the University of Zaragoza, Spain have developed a rooftop solar potential estimation method using statistically representative stratified-sample of vectorial GIS maps of urban areas [14]. They have proposed a three level hierarchical methodology in which first the physical potential (how much solar energy is incident on the area) of the area is considered followed by geographical potential (out of the total geographical area, how much area can be considered for deployment of solar energy harnessing equipments) and technical potential (considers the technical capability of the equipments and their performance in converting solar energy to electrical energy). They have also proposed the possibility of including 2 more levels namely social potential and economic potential to make this study more complete. The study uses the 'built up area' values obtained from local administration's land cover database as a base value and uses coefficients and indices such as void coefficient – to account for voids and recesses within the built area, shadowing coefficients – to account for shadowing caused by neighbouring buildings, objects and roof configuration itself etc. and facility coefficient – for discounting area used for other usages like aerials, HVAC equipment etc. The study was done at the scale of smallest administrative level or the municipality and then later aggregated the information to the main administrative divisions and finally to the national level.

The important aspect to be considered is the size of the area to be studied. Robinson [31] has done a shading analysis for the whole city of Matthaeus, Switzerland by using digital 3 dimensional model of the city. Another technical repot by Raphaël Compagnon, submitted to the European commission of Non-Nuclear Energy program in 2000 also has done the 3D modelling and simulation of urban texture [32]. But this method may not be feasible if the study area is quite large and the population and building density is huge and varied. Nguyen and Pearce from Queen's University, Canada have presented a methodology to evaluate the solar yield and hence identification of ideal lands for large scale solar farms using open source GIS tools. [33]. But when it comes to the case of rooftop area quantification, the same team has published a paper in 2010 which explains the use of hand digitised roof print area (marking the boundaries of the building rooftops manually, on a computer software) and Feature Analyst (FA) tool in ArcGIS [34]. They have followed the geographical units similar to Izquierdo et al. i.e 'municipalities' as the basic building blocks for analysis. They have taken 10 representative samples out of the 109 census sub-divisions, and digitised the rooftops using image recognition program. Again the two of them have improved their methodology and presented a new approach to incorporate the shading losses as well in the rooftop potential estimation. Their paper published in 2012 used Digital Surface Models (DSMs) for the urban texture which was reconstructed from LiDAR data [35].

Another similar study using LiDAR data was done for the city of Lisbon, Portugal in 2011. The paper explains the method of first-approximation estimation of the PV potential of an urban area without the need for a full 3D analysis [36]. Another comprehensive study on rooftop solar potential calculation was done by Amado and Poggi from the University of Lisbon [37]. They have introduced the concept of 'Solar Urban Planning' by modelling an ideal urban scenario with optimal orientation and form for every building to generate maximum electricity from rooftop and façade PV installation.

APPENDIX II:

PLOT AREAS, COVERAGE AREAS AND SHADE FREE AREAS OF DIFFERENT CATEGORIES OF PLOTS

Table II.1: Rooftop PV installation potential from various residential building categories across 24 wards in Greater Mumbai

Rooftop solar installation potential under each residential building sub category across different wards (MW_p)							
Ward Name	**Individual Housing**	**Individual Housing with Commercial Space**	**Multifamily Apartments**	**Multifamily Apartments with Commercial Space**	**Multifamily Apartments with Shops**	**Government Quarters**	**Total**
A	0.00	0.00	7.44	3.21	1.69	2.02	14.35
B	0.00	0.00	0.68	5.54	1.17	0.75	8.15
C	0.00	0.00	1.75	11.40	3.97	0.17	17.29
D	3.89	0.01	34.36	2.77	8.56	5.48	55.07
E	0.85	0.02	20.72	8.65	3.67	13.12	47.04
F/N	0.49	0.16	51.22	5.85	3.09	14.08	74.88
F/S	0.21	0.00	16.63	1.09	2.18	12.62	32.73
G/N	0.66	0.01	18.16	2.48	5.13	3.98	30.41
G/S	0.27	0.03	20.45	2.01	2.10	10.79	35.65
H/E	1.23	0.00	22.98	0.49	3.46	4.58	32.72
H/W	8.52	0.12	47.18	6.20	6.16	5.29	73.46
K/E	2.33	0.10	18.46	1.22	8.54	1.96	32.60
K/W	15.54	1.14	124.13	6.65	11.88	1.00	160.35
L	1.49	0.34	24.54	1.25	4.57	1.03	33.21
M/E	2.96	0.00	21.83	0.41	6.14	22.03	53.37
M/W	5.00	0.13	27.94	2.04	5.23	6.12	46.47
N	0.51	0.03	29.62	6.86	7.55	6.59	51.17
P/N	24.12	3.88	35.41	0.98	16.89	1.86	83.14
P/S	4.24	0.01	50.41	1.50	8.85	4.45	69.45
R/N	1.56	0.02	34.34	1.03	11.72	3.07	51.75
R/C	27.92	0.54	67.20	4.74	16.83	3.14	120.36
R/S	5.60	1.18	10.97	0.52	4.55	2.68	25.50
S	0.88	0.01	62.18	3.84	5.89	0.59	73.39
T	5.65	0.79	51.32	6.37	19.21	3.78	87.12
Total	**113.92**	**8.52**	**799.92**	**87.10**	**169.03**	**131.18**	**1309.63**

Table II.2: Ward wise land use area under different educational amenities

Area under educational amenity sub categories across different wards (hectare)					
Ward Name	**Schools**	**Colleges**	**University**	**Others**	**Total**
A	5.87	11.33	2.81	0.08	20.09
B	2.93	0.17	--	0.07	3.17
C	2.73	--	--	--	2.73
D	15.87	1.88	--	0.08	17.83
E	16.71	0.72	--	0.91	18.34
F/N	19.21	20.47	--	0.17	39.85
F/S	8.97	17.65	--	0.14	26.76
G/N	9.93	7.72	--	0.64	18.29
G/S	6.44	3.66	--	0.82	10.92
H/E	7.27	6.52	83.51	0.28	97.58
H/W	17.91	4.55	--	0.01	22.47
K/E	22.54	23.84	--	3.68	50.06
K/W	30.42	18.5	5.92	3.63	58.47
L	15.38	19.43	--	0.08	34.89
M/E	13.54	9.62	--	0.14	23.3
M/W	11.63	2.38	--	2.55	16.56
N	16.41	8.52	--	0.32	25.25
P/N	17.7	15.23	--	0.09	33.02
P/S	15	17.85	--	0.14	32.99
R/N	6.23	7.04	--	--	13.27
R/C	14.33	1.74	--	3.99	20.06
R/S	13.52	2.86	--	0.09	16.47
S	11.34	54.38	164.7	1.97	232.39
T	11.05	6.45	--	0.08	17.58

Table II.3: Average value of C/P ratios under different educational amenity sub categories in different wards

Ward Name	Schools	Colleges	University	Others
A	0.671	0.507	0.257	0.443
B	0.519	0.507	--	0.432
C	0.593	--	--	--
D	0.402	0.619	--	0.211
E	0.452	0.393	--	0.422
F/N	0.379	0.449	--	0.364
F/S	0.293	0.192	--	0.393
G/N	0.595	0.276	--	0.364
G/S	0.528	0.254	--	0.348
H/E	0.402	0.376	0.075	0.301
H/W	0.391	0.398	--	0.337
K/E	0.169	0.286	--	0.321
K/W	0.252	0.449	0.321	0.165
L	0.476	0.862	--	0.245
M/E	0.34	0.479	--	0.145
M/W	0.301	0.479	--	0.318
N	0.428	0.407	--	0.212
P/N	0.435	0.105	--	0.162
P/S	0.356	0.126	--	0.188
R/N	0.395	0.352	--	--
R/C	0.477	0.360	--	0.245
R/S	0.454	0.445	--	0.204
S	0.413	0.045	0.119	0.106
T	0.331	0.284	--	0.181

Table II.4: Average value of S/C ratios under different educational amenity sub categories in different wards

Ward Name	Schools	Colleges	University	Others
A	0.156	0.084	0.052	0.098
B	0.369	0.084	--	0.141
C	0.282	--	--	--
D	0.352	0.225	--	0.092
E	0.375	0.384	--	0.184
F/N	0.189	0.368	--	0.304
F/S	0.863	0.532	--	0.244
G/N	0.719	0.728	--	0.304
G/S	0.848	0.695	--	0.206
H/E	0.727	0.762	0.978	0.293
H/W	0.354	0.874	--	0.280
K/E	0.249	0.282	--	0.220
K/W	0.328	0.332	0.293	0.271
L	0.588	0.240	--	0.379
M/E	0.489	0.089	--	0.145
M/W	0.368	0.204	--	0.466
N	0.428	0.407	--	0.410
P/N	0.320	0.218	--	0.205
P/S	0.356	0.190	--	0.061
R/N	0.177	0.305	--	--
R/C	0.451	0.326	--	0.052
R/S	0.283	0.431	--	0.128
S	0.245	0.233	0.403	0.353
T	0.258	0.241	--	0.160

Table II.5: Distribution of plot areas under different industrial land use categories

	Total plot area under industrial use (hectare)		
Ward Name	**Heavy Industry**	**Light/ Industrial Area**	**Film Industry**
A	5.36	--	0.21
B	--	0.03	--
C	--	0.19	--
D	8.40	1.70	2.01
E	50.27	58.16	--
F/N	2.11	10.32	--
F/S	118.59	61.26	0.85
G/N	--	22.85	0.03
G/S	--	87.93	7.67
H/E	--	14.71	1.01
H/W	0.84	--	1.80
K/E	--	129.03	5.11
K/W	--	29.12	1.71
L	--	176.02	3.73
M/E	215.15	49.09	--
M/W	399.80	21.79	1.46
N	109.52	44.16	0
P/N	--	30.10	5.08
P/S	--	74.60	58.67
R/N	--	14.80	0.41
R/C	9.54	17.24	--
R/S	39.13	45.31	0.19
S	31.08	179.52	4.31
T	72.20	32.06	--

Table II.6: C/P ratios for industrial plots

	Coverage to Plot Area Ratios		
Ward Name	**Heavy Industry**	**Light/ Industrial Area**	**Film Industry**
A	0.192	--	--
B	--	--	--
C	--	--	--
D	0.252	0.758	0.722
E	0.726	0.299	--
F/N	0.571	0.478	--
F/S	0.438	0.778	--
G/N	--	0.545	--
G/S	--	0.432	0.643
H/E	--	0.375	0.681
H/W	0.589	0.000	0.328
K/E	--	0.409	0.000
K/W	--	0.570	0.431
L	--	0.248	0.426
M/E	0.063	0.314	--
M/W	0.084	0.000	--
N	0.494	0.469	--
P/N	--	0.313	--
P/S	--	0.399	0.117
R/N	--	0.402	--
R/C	0.415	0.343	--
R/S	0.397	0.439	--
S	0.462	0.445	0.004
T	0.320	0.248	--

Table II.7: Shade free to Coverage area ratios for industrial plots

	Shade Free to Coverage Area Ratios		
Ward Name	**Heavy Industry**	**Light/ Industrial Area**	**Film Industry**
A	0.260	--	--
B	--	--	--
C	--	--	--
D	0.347	0.471	0.133
E	0.114	0.217	--
F/N	0.605	0.715	--
F/S	0.228	0.316	--
G/N	--	0.227	--
G/S	--	0.449	0.431
H/E	--	0.305	0.248
H/W	0.687	--	0.733
K/E	0.000	0.415	--
K/W	--	0.603	0.353
L	--	0.679	0.461
M/E	0.299	0.739	--
M/W	0.243	--	--
N	0.349	0.729	--
P/N	--	0.762	--
P/S	--	0.545	0.328
R/N	--	0.647	--
R/C	0.456	0.687	--
R/S	0.334	0.449	--
S	0.345	0.434	0.406
T	0.151	0.351	--

Table II.8: Distribution of land used for developing commercial buildings across different wards

Ward Name	Area (hectare)
A	47.78
B	30.22
C	27.38
D	34.04
E	47.72
F/N	9.58
F/S	50.06
G/N	13.33
G/S	42.10
H/E	21.71
H/W	30.00
K/E	57.24
K/W	74.04
L	52.63
M/E	8.28
M/W	25.71
N	20.04
P/N	69.90
P/S	82.59
R/N	7.19
R/C	66.94
R/S	16.23
S	46.89
T	22.30

Table II.9: Coverage to Plot area ratios for commercial plots

Ward Name	Coverage to Plot Area Ratio
A	0.598
B	0.730
C	0.898
D	0.608
E	0.416
F/N	0.511
F/S	0.602
G/N	0.733
G/S	0.521
H/E	0.721
H/W	0.392
K/E	0.370
K/W	0.482
L	0.730
M/E	0.561
M/W	0.412
N	0.591
P/N	0.304
P/S	0.299
R/N	0.399
R/C	0.403
R/S	0.441
S	0.641
T	0.526

Table II.10: Shade free to Coverage area ratios for commercial plots

Ward Name	Shade free to Coverage Area Ratio
A	0.109
B	0.096
C	0.123
D	0.176
E	0.027
F/N	0.240
F/S	0.148
G/N	0.050
G/S	0.089
H/E	0.189
H/W	0.219
K/E	0.215
K/W	0.285
L	0.294
M/E	0.403
M/W	0.144
N	0.087
P/N	0.087
P/S	0.095
R/N	--
R/C	0.122
R/S	0.152
S	0.157
T	0.149

Table II.11: Total plot areas, C/P ratio and S/C ratios for plots occupied by office buildings

Ward Name	Total plot area under Offices (hectare)	Coverage to Plot Area Ratio	Shade free to Coverage Area Ratio
A	52.61	0.489	0.096
B	1.20	0.360	0.460
C	1.32	0.629	0.094
D	12.81	0.353	0.161
E	15.60	0.418	0.168
F/N	9.19	0.249	0.270
F/S	9.40	0.531	0.091
G/N	4.53	0.602	0.276
G/S	27.79	0.384	0.193
H/E	9.37	0.367	0.245
H/W	5.12	0.567	0.174
K/E	43.10	0.466	0.263
K/W	14.54	0.314	0.227
L	7.69	0.535	0.279
M/E	3.93	0.350	0.161
M/W	10.42	0.260	0.286
N	5.11	0.418	0.151
P/N	25.89	0.373	0.238
P/S	35.00	0.276	0.046
R/N	7.72	0.349	0.093
R/C	12.71	0.349	0.093
R/S	9.94	0.322	0.264
S	26.49	0.358	0.256
T	8.69	0.166	0.039

Table II.12: Total plot areas, C/P ratio and S/C ratios and expected shade free area for plots occupied by medical amenities

Ward Name	Total plot area (hectare)	Coverage to Plot Area Ratio	Shade free to Coverage Area Ratio	Expected total shade free area (10^3 sq. m)
A	10.92	0.453	0.082	4.06
B	2.24	0.767	0.155	2.66
C	5.40	0.723	0.225	8.79
D	32.24	0.359	0.057	6.63
E	46.06	0.248	0.139	15.84
F/N	18.28	0.231	0.156	6.60
F/S	41.86	0.315	0.156	20.61
G/N	5.69	0.386	0.119	2.62
G/S	19.42	0.257	0.294	14.66
H/E	2.76	0.522	0.293	4.23
H/W	9.65	0.419	0.197	7.98
K/E	16.44	0.321	0.566	29.88
K/W	20.37	0.276	0.193	10.87
L	7.54	0.56	0.057	2.42
M/E	9.89	0.373	0.285	10.51
M/W	5.60	0.274	0.183	2.81
N	10.31	0.333	0.250	8.57
P/N	10.73	0.077	0.252	2.08
P/S	8.32	0.173	0.325	4.69
R/N	4.90	0.47	0.286	6.58
R/C	5.93	0.305	0.261	4.72
R/S	4.09	0.141	0.236	1.36
S	7.89	0.173	0.455	6.22
T	10.22	0.205	0.220	4.61

As a part of its 'Green Campus' initiative, the Indian Institute of Technology Bombay (IIT Bombay), has installed a 1MWp (1 MW peak photovoltaic power) distributed rooftop Solar Photovoltaic Power Plant on its academic buildings. The Solar Power Plant was inaugurated on January 28, 2014 by Dr. Satish Agnihotri, Secretary, Ministry of New & Renewable Energy, Government of India, in the presence of Prof. Devang V. Khakhar, Director, IIT Bombay, at the institute campus.

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