# Solar PV Technology for Smart Cities of India

**Madhuchandrika Chattopadhyay, R. Rajavel**

***Abstract:*** ***The Smart City guidelines under "Smart Cities Mission" declared by Government of India insist 10% of the Smart City's energy requirement come from solar energy by generating electricity through solar PV rooftop installation, street lightings etc. Considering the life span of a solar PV power plant more than 20years, the study on meteorological parameters such as the latitude, ambient temperature, humidity and pollution level is necessary for choosing the right PV technology and precisely forecasting the power generation. The negative impact on environment of the unrestrained population growth has also been discussed. This study assessed five different solar photovoltaic (PV) technologies - monocrystalline silicon (mcSi), polycrystalline silicon (pcSi), amorphous silicon (aSi), copper indium gallium diselenide (CIGS), and Cadmiun Telluride (CdTe) in various smart cities located in different zones of India using PVsyst simulation software and facilitated the PV installers to plan and identify the best PV technology for a particular smart city. Thin film technologies - CIGS and CdTe has better performance ratios (PR) and capacity utilisation factor (CUF) in all six zones due to their low temperature power coefficient and ability to perform in low light or diffuse radiation condition.***

***Index Terms:*** ***Temperature, Humidity, Linke Turbidity, Population, PV technologies***

## I. INTRODUCTION

The Ministry of Urban Development, Govt. of India has announced "Smart Cities Mission" on 25th June 2015[1]. The government of India under present Prime Minister has the vision to develop 100 smart cities with emphasis on smart energy, smart waste management, smart building and sustainable environment. The Smart City guidelines under smart energy objective insist 10% of the Smart City's energy requirement come from solar energy by generating electricity through solar PV rooftop installation, street lightings etc[2]. This initiative has been driven by the price competitiveness and policy support of Government of India by announcing Capital Subsidy program for the Rooftop Solar Segment. Since the solar PV power plants are exposed to various climatic conditions for more than 20 years, the performance depends on many meteorological parameters such as the latitude, ambient temperature, relative humidity and pollution level. Thus, knowledge on the performance of PV systems under real operating conditions is necessary for choosing the right PV technology and precisely forecasting the power generation.

This research covers the study of meteorological parameters like temperature, relative humidity, pollution of all smart cities in six zones of India and their effect on the performance of solar PV power plants. The high population density is considered as contributing factor for the increase in pollution directly and increases in temperature and relative humidity indirectly. The objective of the present study is to assess the suitability of different solar PV technologies in various smart cities located in different zones of India and facilitate the PV installers to plan and identify the best PV technology for a particular smart city. Variations in solar radiation and power due to relative humidity, pollution and ambient temperature from season-to-season influence the CUF and PR of a solar PV power plant. Increase in temperature shrinks bandgap of the semiconductor and has a negative effect on open circuit voltage, as well as on power output, fill factor and efficiency. And also increases short circuit current slightly due to the increase in reverse saturation current in various solar cell technologies[3-8]. Temperature coefficients (Tc), which quantify temperature sensitivities, are important parameters for predicting PV energy production[9] and temperature power coefficient of the a-Si is 0.13%/$^{o}$C, CdTe is 0.21%/$^{o}$C, CIGS is 0.36%/$^{o}$C and c-Si is -0.45%/$^{o}$C[10]. Technology-wise, c-Si modules usually have low $V_{OC}$ and high $I_{SC}$ values while thin film modules typically have high $V_{oc}$ and low $I_{sc}$[11]. Generally, thin film cells have larger band gaps (a-Si=1.7ev, CdTe=1.5ev, CIGS=1.15ev) than crystalline cells (=1.125ev)[9,12] and for this reason, thin film modules lose less power at high temperatures than crystalline modules[10]. Humidity is another ambient parameter that refracts, reflects and diffracts the direct visible solar radiation. This dispersion effect results in deterring the reception of the direct component of solar radiation by water vapour particles present in the atmosphere[13]. Humidity alters the irradiance non-linearly and irradiance itself causes little variations in $V_{oc}$ in a non-linear manner and large variations in $I_{sc}$ linearly[14, 15]. Humidity readily affects the efficiency of the solar cells[16,17] and creates a minimal layer of water on its surface thus decreasing the efficiency by 10-20% of the total power output produced[18, 19]. The record lab module efficiency is 24.4% for mcSi and 19.9% for pcSi wafer-based technology. The highest lab efficiency in thin film technology is 19.2% for CIGS, 18.6% for CdTe solar cells and 12.3% for aSi[20]. The extraterrestrial radiation that reaches just outside the earth's atmosphere is 1367 W/m$^2$; this number is known as solar constant and relatively constant. The intensity of the extraterrestrial solar radiation traversing through the earth's atmosphere is attenuated by the various constituents of the atmosphere, namely air pollution and cloud cover. Because the variation in PV power is linear with the incoming solar radiation, the solar radiation attenuation leads to less PV output.

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The air pollution includes producing aerosols and greenhouse gas emissions in the earth's atmosphere. Human activities have a great role in producing aerosols (air pollution) that perturb the Earth's energy budget directly by scattering and absorbing radiation[21,22] and greenhouse gases that absorb and emit infrared radiation[23].

Aerosols are heterogeneous mixtures of solid or liquid particles suspended in a gaseous medium. The size of these particles can range from 0.005 to 20 µm in effective radius. The influence of these substances is crucial in the attenuation process of solar radiation because they give rise to the formation of clouds[24,25] and the most importantly affecting the amount of solar radiation reaching the earth's surface under cloudless sky conditions. Aerosols influence the solar radiation both directly and indirectly through their various sizes and thus their different optical and physical properties. When aerosols are sufficiently large in size, they scatter and absorb sunlight, and when these particles are small, they act as cloud condensation nuclei and aid in the formation of clouds[26]. On a global scale, $CO_2$, water vapour and other gases are called as greenhouse gases, which are transparent to incoming light from the Sun, but absorbs infrared energy radiated from the Earth's surface, thus delaying its loss to space and this phenomenon is known as greenhouse effect. The concentration of $CO_2$ in the atmosphere is increasing year on year as we burn fossil fuels, which enhances the natural greenhouse effect and warms the planet. The World Bank estimates, in India by the year 2014, $CO_2$ emissions have been increased by 57% from the year 2000. The motorized traffic volume in India will very nearly touch the mark of 13000 billion passenger-km in 2020-21, out of which 91.7% will be provided by the roads and the rest by railways. If there is no reduction in modal $CO_2$ intensities, $CO_2$ emission is projected to increase from 19.80 million metric tons of carbon equivalent in 2000-01 to 93.25 million metric tons of carbon equivalent in 2020-21[27]. Globally, compared to the current period (1981–2010), urban regions get warmer by about 6°C in the near future (2041–2070) and by twice this much (∽ 13 °C) at the end of the century (2071–2100). The higher the emissions, the higher urban surfaces get warmer, i.e, it indicates that urban regions are sensitive to greenhouse gas emissions[28]. The heat-generating fuel combustion machines (e.g., cars), heating, ventilation and air conditioning systems, and other anthropogenic processes affect local and large scale weather and climate processes [29]. Population growth has a negative impact on the quality of the environment. Air pollution is higher in urban areas due to the high population density and industrial activities, and particles formed as a product of the combustion of fossil fuels and construction activities are mostly present in it[30,31]. The decrease of the incoming radiation in urban areas is given that of nature and amount of pollutants. These pollutants alter the solar energy reaching the ground in two ways – by depleting the total energy and by changing proportions of direct and diffuse radiation[32,33]. The global radiation values will be lower in the cities due to highly polluted air and fine particulates induced by the very rapid growth of population. This huge increase in population is followed by a rapid increase in traffic density and industrial activity[34]. As per McKinsey Global Institute report, India's urban population is expected to increase to 590 million by 2030[35]. Ever growing population size can be treated as a surrogate variable of anthropogenic pollution. The annual mean air temperature of a city with one million or more people can be 1.8 to 5.4ºF (1 to 3ºC) warmer than its surroundings as a result increasing energy demand for cooling which puts pressure on peak urban electricity demand by 1.5 to 2 percent for every 1ºF (0.6ºC) rise[36, 37] while also increasing air pollution and greenhouse gas emissions.

PVsyst V6.77 is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid PV systems, and includes meteonorm 7.2 and PV systems components databases, as well as general solar energy tools[38]. Studies conducted in previous papers showed that PVsyst simulation results were almost nearer to the monitored power generation data[39, 40]. The aim of this study is to choose the right PV technology and precisely forecast the power generation of every smart city using PVsyst simulation software and Weatherspark modelling system.

## II. METHODOLOGY ADOPTED

A. Classify India into six zones – east, northeast, north, west, south and Island.
B. Analyse the meteorological parameters such as ambient temperature, relative humidity and pollution level using online software:
    a. WeatherSpark weather modelling system[41].
    b. Meteonorm 7.2
C. Study the pollution level/ Linke turbidity values of six zones of India by using PVsyst V6.77 project design online software.
D. Selection of commercially used PV technologies such as mcSi, pcSi, aSi, CIGS and CdTe.
E. Analyse the energy generation output and PR from each PV technology array using simulation software and calculate CUF[42] of different types of commercially used PV technologies for all zones of India.

## III. ANALYSIS OF METEOROLOGICAL PARAMETERS

### *A. Eastern India*

The maximum ambient temperature is greater than 35ºC during April to June in all the smart cities except Namchi of Sikkim. While the maximum ambient temperatures are ≤25ºC in December and January of smart cities of Bihar and Jharkhand. But Namchi of Sikkim located in Indian Himalayan Range (IHR)[43] with an altitude of 1487m has temperatures less than 30ºC throughout the year. Nevertheless, regions with high altitude have higher performance ratios due to low temperature, such as the southern Andes, Himalaya region, and Antarctica[44,45]. The ambient temperature of smart cities of Odisha is never below 28ºC even during winter. Except for Ranchi and Rourkela, all the smart cities of Eastern India have profound humidity from June-January throughout the year which influences incoming solar radiation and is the reason for declining efficiency of a solar PV power plant during this period. The Bhubaneswar has extreme humidity for a longer period of time but winter months.

For smart cities of Bihar, the peak turbidity factor is greater than 6 during hot season-April & May due to convection currents in air because of higher temperature gradient and significant increase in dust and haze because of air pollution in the lower layers of the atmosphere which induce a more turbid atmosphere and negatively influences the power output of a solar PV plant[46, 47].

According to the World Health Organisation (WHO 2018) report[48], Muzaffarpur and Patna of state Bihar or Eastern India are the two of the fourteen most polluted cities in India. Keeping aside the monsoon season (June-September)[46], the turbidity values varied between 3 and 6 in other seasons of remaining smart cities but slightly lower in Namchi of Sikkim as it is located in the high altitude zone. The annual average global horizontal irradiance (GHI) and direct normal irradiance (DNI) is decreasing eastwards, 4.5-5 kWh/m$^2$/day and 3.5-4 kWh/m$^2$/day. Ranchi and Rourkela have somewhat higher GHI and DNI of 5-5.5 kWh/m$^2$/day and 4-4.5 kWh/m$^2$/day[49].

### *B. North Eastern India*

According to ENVIS centre on Himalayan ecology-Govt. of India[43], the Indian Himalayan Region (IHR) is spreading on 10 states (administrative regions) namely, Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, and hill regions of 2 states viz. Assam and West Bengal of Indian Republic. It contributes about 16.2% of India's total geographical area, and most of the area is covered by snow-clad peaks, glaciers of higher Himalaya, dense forest cover of mid-Himalaya. The maximum ambient temperature of all eight North-East states never increased above 33ºC even in hot season and is ≤25ºC during winter in all the regions. Shillong located at an altitude of 1436m experiences lowest ambient temperature, less than 23ºC all through the year. The humidity is greater than 70% throughout the year in all smart cities of northeastern India, except Imphal, Aizawl and Shillong where the humidity is less than 70% from February to April. Therefore the level of water vapour will invariably affect the amount of received solar irradiance at the location where the water vapour level is high. None of the smart cities of this region falls under highly polluted cities list. Guwahati and Agartala, located in the low altitude region of 50 masl and 16 masl have turbidity value between 5 and 6 in April and May. Remaining cities, positioned at high altitude region has low turbidity values; ranging 2 and 5. The Central Pollution Control Board's (Govt. of India) Impact Assessment of Jhum Cultivation on the ambient air quality shows Jhum burning areas of Manipur and Mizoram: PM$_{10}$ levels in the range 200-250 µg/m$^3$ during burning period, compared to "before burning" the background levels below 100 µg/m3. The CO levels increased from nil to 200 mg/m$^3$ during Jhum Burning. In cities like Guwahati, the Desert Research Institute and –NASA (USA) report shows that more than 400,000 vehicles ply on roads and emit excessive amounts of black carbon and other very toxic pollutants[50]. Although the whole north-eastern India experiences favourable temperature all through the year high relative humidity enlarges the size of aerosol particles, as a result, scatters solar radiation[51] leading to a reduction in power output from a solar PV power plant. The annual average global horizontal irradiance (GHI) and direct normal irradiance (DNI) values are lower in comparison to the national irradiance value, 4-5kWh/m2/day and 3-4kWh/m2/day. However, the irradiance is slightly higher in Imphal and Aizawl of around 5-5.5 kWh/m$^2$/day and 4-4.5 kWh/m$^2$/day[49].

### *C. Northern India*

The dominant geographical features of North India are the Indus-Gangetic Plain which spans the states and union territories of Chandigarh, Delhi, Punjab, Haryana, Uttar Pradesh, the Himalayas lie in the states of Uttarakhand, Himachal Pradesh and Jammu and Kashmir and the Thar Desert lie mainly in the state of Rajasthan. The ambient temperatures of smart cities of Delhi, Haryana, Rajasthan and Uttar Pradesh rises above 35ºC from April to June. On the other hand, the temperature above 35ºC from May to July is in smart cities of Punjab and May to June in Uttarakhand. However, the temperatures are higher than 40ºC in some smart cities such as Kota, Jhansi, Allahabad, Varanasi, Agra and Chandigarh in the month of May. Almost in all the smart cities except Udaipur of Rajasthan, maximum ambient temperature drops to ≤25ºC in winter months. The Dharamshala of Himachal Pradesh located at the altitude of 1319m and falls in the Indian Himalayan Region (IHR)[43] has ambient temperatures less than 30ºC throughout the year. Excluding Faridabad, the humidity of other smart cities in Haryana and Delhi is higher than 70% both in monsoon and winter season. In the state Punjab, profound humidity greater than 70% in Ludhiana city during most part of the year except hot season and in remaining cities during monsoon and winter, whereas it is higher only in one or two months of monsoon season in Rajasthan. The smart cities of Uttar Pradesh experienced considerable humidity (>70%) only in the monsoon season and in other cities such as Saharanpur, Kanpur, Allahabad, Lucknow, Varanasi, it also extended to winter months. Except for the hot season, remaining seasons of Ludhiana, Dehradun and Chandigarh has very high humidity levels during most part of the year. As per the World Health Organisation (WHO 2018)[48], the remaining 12 most polluted cities of 14 are located in the northern part of India. The Linke turbidity values of all smart cities are lower in winter, ranging from 3 to 5; and high in summer, ranging from 5 to 7. For the post-monsoon season, turbidity values are intermediate, ranging from 3 to 6 of some cities such as Delhi, Karnal, Faridabad, Ludhiana, Amritsar and Ghaziabad where the values are higher than 6 in October because of Crop Residue Burning (CRB) in Haryana and Punjab produces 12 to 60 percent of Particulate Matter (PM) concentrations in regional atmosphere[52]. Since Delhi and Ghaziabad are positioned very near to the Punjab and Haryana are highly affected due to the thick smoke emanating from burning crops mixed with vehicular emissions doubling the amount of pollution and increasing total levels 12 times higher than WHO recommendations. These two states, Punjab and Haryana contribute to 48 per cent of the total emission due to paddy burning across India. The burning of crop residues emits traces of carbon dioxide, methane, carbon monoxide, nitrous oxide, sulphur dioxide and particulates which affect human health. It is estimated that India annually emits 1,44,719 mg of total particulate matter from open burning of stubble[53].

The potential of the atmosphere to disperse and dilute pollutants emitted into it by myriad sources depends upon various factors such as wind, vertical mixing, inversion of temperature in the vertical, etc[54]. Being located at high altitude than other stations, Dharamshala (1319 masl) and Dehradun (652 masl) are less turbid relatively.

As one advances from winter to summer months the turbidity increases for all the smart cities for the reason is the existence of dust storms in summer. For Delhi, Haryana, Punjab and Uttar Pradesh, owing to their proximity to Rajasthan’s deserts, there are dust storms and air pollution due to vehicle emissions. The air temperature and the wind speed in urban areas is usually less, foremost reason for increasing turbidity. Fossil fuel consumption and vehicular emissions along with large industrial point sources add to elevated aerosol fluxes over northern India[55]. The high turbidity value for smart cities of northern India is not a favourable factor for solar power generation as it results in dimming the solar radiation. The annual average global horizontal irradiance (GHI) and direct normal irradiance (DNI) values are slightly higher than eastern India, 5-5.5 kWh/m$^2$/day and 4-5 kWh/m$^2$/day[49].

### *D. Western India*

Western India is bounded by the Vindhya Range in the east and north and the Arabian Sea in the west. Except in January, all smart cities of Madhya Pradesh experiences the maximum ambient temperature above 25ºC throughout the year since Western India part falls in the low latitudinal region and has the high ambient temperature. Coastal smart cities – Panaji, Diu, Silvasa, Surat and Vadodara have moderate temperatures, between 28ºC-35ºC all through the year due to the very large heat capacity of water bodies. Apart from the coastal smart cities, the maximum ambient temperature of most of the smart cities in Western India is around 40ºC in the month of May. Excluding coastal cities, the humidity greater than 70% is restricted to only monsoon season in remaining cities. Lower relative humidity indicates low water vapour in the atmosphere which gives rise to high solar irradiance, thus enhances the high production of current from a solar PV power plant. The smart cities, Rajkot, Gwalior and Ujjain have high turbidity, exceeding the value 6 during May. And the remaining cities have the turbidity, ranging between 3 and 6. Coastal smart cities do have the inherent advantage of the coastal breeze influence that tends to dissipate pollution[56], accordingly reducing the turbidity of the local region. The western part of India also has the highest annual average global horizontal irradiance (GHI) and direct normal irradiance (DNI) of 5.5-6 kWh/m$^2$/day and >4.5 kWh/m$^2$/day[49] and suitable region for solar PV power generation.

### *E. Southern India*

South India is a peninsula in the shape of an inverted triangle bound by the Arabian Sea on the west, by the Bay of Bengal on the east and the Indian Ocean on the south. All the smart cities of South Indian states have maximum ambient temperatures higher than 25ºC even in winter months. Being in the low latitudinal region, south India experiences higher ambient temperatures. Coastal smart cities - Visakhapatnam, Kakinada, Mangaluru, Thiruvananthapuram, Kochi, Oulgaret, Chennai, Thanjavur and Tirunelveli have moderate temperatures, between 28ºC-35ºC all through the year due to the very large heat capacity of water bodies. During April and May, the maximum ambient temperature of Tirupati, Vellore, Warangal and Karimnagar rises above 40ºC. The operating temperature plays a central role in the photovoltaic conversion process. Coastal cities have considerable humidity in most part or almost throughout the year. When the wind blows from the seas, they bring in moisture near the land areas and increase the humidity level of the surrounding area. Remaining smart cities experiences high humidity during monsoon and post-monsoon seasons in the year and in some cities it extends to a few months of winter season. While smart cities from southern India also feature in the World Health Organisation’s (WHO 2018)[48] database of “most polluted cities” list, their relative rank with respect to their northern counterparts is much lower. None of the smart cities turbidity value in this region exceeded 6. These cities do have the inherent advantage of the coastal breeze influence that tends to dissipate pollution[56]. The potential of the atmosphere to disperse and dilute pollutants emitted into it by myriad sources depends upon various factors such as wind, vertical mixing, inversion of temperature in the vertical, etc[54]. The turbidity is intermediary, ranging between 3 and 6, hence the south India smart cities atmosphere is turbid, not highly polluted. The annual average global horizontal irradiance (GHI) and direct normal irradiance (DNI) values are very high in southern part of India, 5.5-6 KWh/m$^2$/day and >4.5 kWh/m$^2$/day[49], a favourable factor for elevated power generation from a solar PV power plant. However, Visakhapatnam and Kakinada do not fall in this irradiance range and has slightly lower irradiance values.

### *F. Island*

Lakshadweep is a group of islands in the Laccadive Sea, 200 to 440 km (120 to 270 miles) off the south-western coast of India. Kavaratti serves as the capital of the Union Territory. Andaman and Nicobar comprise two island groups, the Andaman Islands and the Nicobar Islands, separated by the 10°N parallel, with the Andamans to the north of this latitude, and the Nicobars to the south (or by 179 km). The Andaman Sea lies to the east and the Bay of Bengal to the west. The territory's capital is the city of Port Blair. Coastal areas Kavaratti and Port Blair positioned in the low latitudinal region have the moderate temperature between 27ºC-32ºC throughout the year due to the very large heat capacity of water bodies. When the wind blows from the sea or ocean, they bring in moisture near the land areas and increase the humidity level of the surrounding region. The humidity is significantly higher all through the year in both the cities. Linke turbidity is between 3 and 5, which specifies that the atmosphere is turbid due to high humidity. The vehicular and ship services in these regions are the source of air pollution which is in the limit as prescribed by the Central Pollution Control Board, Govt. of India[57]. The coastal breeze from the Sea be able to disperse pollution is the reason behind less turbidity in the atmosphere. According to National Institute of Wind Energy-Govt. of India, the annual average global horizontal irradiance (GHI) and direct normal irradiance (DNI) of Port Blair are 4.43 kWh/m$^2$/day & 2.42 kWh/m$^2$/day and Kavaratti is not known.

## IV. RESULTS AND DISCUSSION

The different PV module technologies have different performance characteristics due to their structure and material used. The commercially available PV module technologies are between the crystalline and thin film technologies.

Mono-crystalline silicon (mcSi) and Poly-crystalline silicon (pcSi) belong to the crystalline technologies (cSi) while amorphous silicon (aSi), cadmium telluride (CdTe) and copper indium selenide (CIGS) belong to the thin film technologies. In general, the most expensive and the most efficient PV cells till now is the mono-crystalline silicon due to their complex production steps involved in the manufacturing process, whereas, multi-crystalline PV cell is relatively cheaper. Moreover, thin film modules arrive with low cost since very less material used for manufacturing has better efficiency and are now produced commercially.

The performance and pre-feasibility analysis of different solar PV technologies are carried out using PVsyst software tool are discussed in this section. Table I to VI shows the performance ratio and capacity utilisation factors of five different PV technologies for various smart cities of all six zones of India. The PR of a solar PV power plant decreases with increase in temperature. Generally, PR decreases with latitude because of high temperature and increases with altitude due to low temperature. The CUF is proportional to energy generation from an SPV power plant which in turn depends on global solar insolation. The solar insolation is negatively influenced by the amount of humidity and turbidity present in the atmosphere at a location. These two parameters are calculated for every smart city to identify the suitable solar PV technology for that city.

Table I and II illustrates that eventhough, the average maximum ambient temperature of eastern and north eastern zones is not more than 35°C, the high humidity during monsoon, post-monsoon and winter played a negative role in yielding higher capacity utilisation factor. However, the PR values of these zones are relatively higher than other zones. Table IV and V explains that the western part and southern part of India located in descending latitudinal zone has lower PR than the northern zone due to relatively increasing temperature. On the whole, the CUF values of all six zones varied between 17.5 to 22.5. Higher the CUF lower will be the cost of electricity generation. The tables also clarify that thin film technologies – CIGS and CdTe have better performance ratios and capacity utilisation factor due to their low temperature power coefficient and ability to perform in low light or diffuse radiation condition. Thin film cells absorb visible light with short and medium wavelengths better than crystalline cells[58]. Thin film efficiency might increase at low incident angles of the sunlight and/or high air mass values while crystalline efficiency drops[59]. For a-Si modules, the light-induced degradation effect, known as the Wronski effect, causes an initial performance decrease during their operation, and then they are stabilized. In addition, reversible degradation occurs during winter, but the high temperatures reverse this in summer (seasonal annealing effect). Hence, the efficiency of the a-Si fluctuates during the year and can be particularly high during summer [58].

**Table I: Eastern India**

| S. No | Smart City | Performance Ratio (PR) | | | | | Capacity Utilisation Factor (CUF) % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mcSi | pcSi | aSi | CIGS | CdTe | mcSi | pcSi | aSi | CIGS | CdTe |
| 1 | Bihar - Muzaffarpur | 0.82 | 0.82 | 0.77 | 0.83 | 0.86 | 17.9 | 17.9 | 16.84 | 18.53 | 18.56 |
| 2 | Bihar - Bhagalpur | 0.82 | 0.82 | 0.78 | 0.87 | 0.86 | 18.94 | 18.94 | 17.94 | 19.63 | 19.68 |
| 3 | Bihar - Biharsharif | 0.82 | 0.82 | 0.78 | 0.86 | 0.86 | 18.56 | 18.58 | 17.58 | 19.22 | 19.27 |
| 4 | Bihar - Patna | 0.82 | 0.83 | 0.78 | 0.86 | 0.86 | 17.21 | 17.24 | 17 | 18.65 | 18.7 |
| 5 | Jharkhand - Ranchi | 0.83 | 0.83 | 0.8 | 0.85 | 0.86 | 19.75 | 19.75 | 18.97 | 20.25 | 20.48 |
| 6 | Sikkim - Namchi | 0.85 | 0.85 | 0.8 | 0.87 | 0.88 | 17.12 | 17.15 | 16.14 | 17.4 | 17.6 |
| 7 | Odisha-Bhubaneshwar | 0.82 | 0.82 | 0.78 | 0.85 | 0.86 | 18.06 | 18.07 | 17.12 | 18.69 | 18.74 |
| 8 | Odisha - Rourkela | 0.82 | 0.82 | 0.78 | 0.85 | 0.86 | 19.47 | 19.5 | 18.68 | 20 | 20.25 |

**Table II: North Eastern India**

| S. No | Smart City | Performance Ratio (PR) | | | | | Capacity Utilisation Factor (CUF) % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mcSi | pcSi | aSi | CIGS | CdTe | mcSi | pcSi | aSi | CIGS | CdTe |
| 9 | Assam - Guwahati | 0.83 | 0.83 | 0.78 | 0.86 | 0.87 | 19.11 | 19.13 | 18.04 | 19.73 | 19.82 |
| 10 | Arunachal Pradesh - Pasighat | 0.84 | 0.84 | 0.78 | 0.87 | 0.87 | 15.57 | 15.6 | 14.38 | 16 | 16.03 |
| 11 | Manipur - Imphal | 0.84 | 0.84 | 0.8 | 0.87 | 0.87 | 18.11 | 18.13 | 17.03 | 18.63 | 18.72 |
| 12 | Nagaland - Kohima | 0.86 | 0.86 | 0.8 | 0.88 | 0.88 | 18.07 | 18.08 | 16.87 | 18.5 | 18.56 |
| 13 | Mizoram - Aizawl | 0.84 | 0.84 | 0.8 | 0.87 | 0.87 | 21.19 | 21.19 | 20.11 | 21.8 | 22 |
| 14 | Meghalaya - Shillong | 0.84 | 0.84 | 0.8 | 0.87 | 0.87 | 17.6 | 17.62 | 16.62 | 18.1 | 18.17 |
| 15 | Tripura - Agartala | 0.83 | 0.83 | 0.78 | 0.86 | 0.86 | 19.31 | 19.33 | 18.31 | 20 | 20.04 |

## Table III: Northern India

| S. No | Smart City | Performance Ratio (PR) | | | | | Capacity Utilisation Factor (CUF) % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mcSi | pcSi | aSi | CIGS | CdTe | mcSi | pcSi | aSi | CIGS | CdTe |
| 16 | Delhi - Delhi | 0.82 | 0.82 | 0.79 | 0.85 | 0.86 | 21.55 | 21.75 | 20.8 | 22.17 | 22.44 |
| 17 | Haryana - Karnal | 0.83 | 0.83 | 0.78 | 0.85 | 0.86 | 20.04 | 20.05 | 19.06 | 20.59 | 20.8 |
| 18 | Haryana - Faridabad | 0.83 | 0.83 | 0.78 | 0.86 | 0.86 | 19.63 | 19.65 | 18.58 | 20.32 | 20.39 |
| 19 | Himachal Pradesh - Dharamshala | 0.84 | 0.84 | 0.8 | 0.87 | 0.87 | 20.39 | 20.41 | 19.3 | 21 | 21.07 |
| 20 | Punjab - Ludhiana | 0.83 | 0.83 | 0.78 | 0.86 | 0.86 | 18.56 | 18.6 | 17.44 | 19.18 | 19.24 |
| 21 | Punjab - Jalandhar | 0.83 | 0.83 | 0.78 | 0.86 | 0.86 | 18.54 | 18.57 | 17.44 | 19.18 | 19.22 |
| 22 | Punjab - Amritsar | 0.83 | 0.83 | 0.78 | 0.86 | 0.86 | 18.54 | 18.56 | 17.4 | 19.18 | 19.27 |
| 23 | Rajasthan - Jaipur | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 20.87 | 20.9 | 20.11 | 21.69 | 21.78 |
| 24 | Rajasthan - Udaipur | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 21.48 | 21.48 | 20.87 | 22.33 | 22.42 |
| 25 | Rajasthan - Ajmer | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 21.14 | 21.14 | 20.41 | 22 | 22.05 |
| 26 | Rajasthan - Kota | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 20.39 | 20.39 | 19.57 | 21.14 | 21.23 |
| 27 | Uttar Pradesh - Moradabad | 0.82 | 0.82 | 0.78 | 0.86 | 0.86 | 20.1 | 20.11 | 19.13 | 20.82 | 20.9 |
| 28 | Uttar Pradesh - Aligarh | 0.82 | 0.82 | 0.78 | 0.86 | 0.86 | 19.5 | 19.53 | 18.5 | 20.2 | 20.26 |
| 29 | Uttar Pradesh - Saharanpur | 0.83 | 0.83 | 0.79 | 0.86 | 0.86 | 20.7 | 20.72 | 19.68 | 21.41 | 21.51 |
| 30 | Uttar Pradesh - Bareilly | 0.82 | 0.82 | 0.78 | 0.85 | 0.86 | 19.84 | 19.86 | 18.86 | 20.55 | 20.62 |
| 31 | Uttar Pradesh - Jhansi | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.82 | 19.82 | 19 | 20.55 | 20.62 |
| 32 | Uttar Pradesh - Kanpur | 0.82 | 0.82 | 0.78 | 0.86 | 0.86 | 19.25 | 19.27 | 18.26 | 19.31 | 20 |
| 33 | Uttar Pradesh - Allahabad | 0.82 | 0.82 | 0.78 | 0.86 | 0.86 | 18.81 | 18.83 | 17.83 | 19.5 | 19.54 |
| 34 | Uttar Pradesh - Lucknow | 0.82 | 0.83 | 0.78 | 0.86 | 0.86 | 19.2 | 19.22 | 18.26 | 19.88 | 19.95 |
| 35 | Uttar Pradesh - Varanasi | 0.82 | 0.82 | 0.78 | 0.86 | 0.86 | 18.58 | 18.61 | 17.58 | 19.25 | 19.3 |
| 36 | Uttar Pradesh - Ghaziabad | 0.82 | 0.82 | 0.79 | 0.85 | 0.86 | 21.48 | 21.5 | 20.62 | 22.28 | 22.37 |
| 37 | Uttar Pradesh - Agra | 0.82 | 0.82 | 0.78 | 0.85 | 0.86 | 19.54 | 19.57 | 18.58 | 20.25 | 20.32 |
| 38 | Uttar Pradesh - Rampur | 0.82 | 0.82 | 0.78 | 0.86 | 0.86 | 20.22 | 20.25 | 19.27 | 21 | 21.05 |
| 39 | Uttarakhand - Dehradun | 0.83 | 0.83 | 0.8 | 0.86 | 0.87 | 22 | 22 | 21 | 22.72 | 22.83 |
| 40 | Chandigarh - Chandigarh | 0.83 | 0.83 | 0.79 | 0.86 | 0.86 | 20.16 | 20.18 | 19.11 | 20.85 | 20.91 |

## Table IV: Western India

| S. No | Smart City | Performance Ratio (PR) | | | | | Capacity Utilisation Factor (CUF) % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mcSi | pcSi | aSi | CIGS | CdTe | mcSi | pcSi | aSi | CIGS | CdTe |
| 41 | Chhattisgarh - Raipur | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19 | 19 | 18.15 | 19.68 | 19.75 |
| 42 | Chhattisgarh - Bilaspur | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.36 | 19.36 | 18.51 | 20.1 | 20.19 |
| 43 | Goa - Panaji | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.06 | 19.08 | 18.26 | 19.75 | 19.82 |
| 44 | Daman & Diu - Diu | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 21.05 | 21.07 | 20.25 | 22.07 | 22 |
| 45 | Dadra & Nagar Haveli-Silvasa | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 19.27 | 19.3 | 18.42 | 20 | 20.04 |
| 46 | Gujarat - Gandhinagar | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 19.63 | 19.66 | 18.88 | 20.41 | 20.48 |
| 47 | Gujarat - Surat | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 21.2 | 21.2 | 20.55 | 22.03 | 22.11 |
| 48 | Gujarat - Vadodara | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 21 | 21 | 20.32 | 21.83 | 22 |
| 49 | Gujarat - Rajkot | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 21.61 | 21.62 | 21 | 22.51 | 22.6 |
| 50 | Gujarat - Ahmadabad | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 19.7 | 19.73 | 19 | 20.48 | 20.55 |
| 51 | Gujarat - Dahod | 0.81 | 0.81 | 0.79 | 0.84 | 0.85 | 21.51 | 21.51 | 21 | 22.37 | 22.47 |
| 52 | Madhya Pradesh-Bhopal | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.77 | 19.78 | 19 | 20.55 | 20.57 |
| 53 | Madhya Pradesh-Indore | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 21 | 21 | 20.25 | 21.71 | 21.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 54 | Madhya Pradesh-Gwalior | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.75 | 19.76 | 18.86 | 20.48 | 20.55 |
| 55 | Madhya Pradesh-Jabalpur | 0.82 | 0.82 | 0.78 | 0.85 | 0.86 | 19.77 | 19.8 | 19 | 20.5 | 20.57 |
| 56 | Madhya Pradesh-Satna | 0.82 | 0.82 | 0.78 | 0.85 | 0.86 | 19.63 | 19.66 | 18.72 | 20.34 | 20.41 |
| 57 | Madhya Pradesh-Ujjain | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 20.78 | 20.78 | 20.1 | 21.57 | 21.64 |
| 58 | Madhya Pradesh-Sagar | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.84 | 19.86 | 19.06 | 20.57 | 20.64 |
| 59 | Maharashtra-Thane | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 18.74 | 18.77 | 17.88 | 19.45 | 19.5 |
| 60 | Maharashtra-Kalyan Dombivali | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 18.79 | 18.81 | 17.9 | 19.47 | 19.54 |
| 61 | Maharashtra-Nashik | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 19.82 | 19.82 | 19.11 | 20.57 | 20.63 |
| 62 | Maharashtra-Amravati | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.25 | 19.25 | 18.45 | 20 | 20.02 |
| 63 | Maharashtra-Solapur | 0.81 | 0.81 | 0.78 | 0.84 | 0.85 | 19.22 | 19.25 | 18.56 | 20 | 20.02 |
| 64 | Maharashtra-Nagpur | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 19 | 19.02 | 18.23 | 19.7 | 19.77 |
| 65 | Maharashtra-Pune | 0.82 | 0.82 | 0.79 | 0.85 | 0.85 | 21 | 21 | 20.23 | 21.71 | 21.8 |
| 66 | Maharashtra-Aurangabad | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 19.52 | 19.52 | 18.79 | 20.25 | 20.32 |

### Table V: Southern India

| S. No | Smart City | Performance Ratio (PR) | | | | | Capacity Utilisation Factor (CUF) % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mcSi | pcSi | aSi | CIGS | CdTe | mcSi | pcSi | aSi | CIGS | CdTe |
| 67 | Andhra Pradesh-Vizag | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19 | 19 | 18.03 | 19.66 | 19.72 |
| 68 | Andhra Pradesh-Kakinada | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 18.04 | 18.08 | 17.9 | 18.7 | 18.74 |
| 69 | Andhra Pradesh-Tirupati | 0.81 | 0.81 | 0.76 | 0.85 | 0.85 | 18.61 | 18.56 | 17.58 | 19.3 | 19.34 |
| 70 | Karnataka-Mangaluru | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.13 | 19.13 | 18.29 | 19.82 | 19.86 |
| 71 | Karnataka-Belagavi | 0.82 | 0.82 | 0.8 | 0.85 | 0.86 | 19.57 | 19.59 | 18.81 | 20.25 | 20.34 |
| 72 | Karnataka-Shivamogga | 0.82 | 0.82 | 0.79 | 0.85 | 0.85 | 20.1 | 20.1 | 19.36 | 20.82 | 20.9 |
| 73 | Karnataka-Hubbali Dharwad | 0.82 | 0.82 | 0.79 | 0.85 | 0.85 | 19.7 | 19.73 | 19 | 20.41 | 20.48 |
| 74 | Karnataka-Tumakuru | 0.82 | 0.82 | 0.79 | 0.85 | 0.86 | 20.64 | 20.64 | 19.86 | 21.37 | 21.46 |
| 75 | Karnataka-Davanagere | 0.82 | 0.82 | 0.79 | 0.85 | 0.85 | 20.14 | 20.14 | 19.41 | 20.87 | 21 |
| 76 | Karnataka-Bengaluru | 0.82 | 0.82 | 0.8 | 0.85 | 0.86 | 20.55 | 20.55 | 19. | 21.26 | 21.35 |
| 77 | Kerala-Thiruvananthapuram | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.3 | 19.31 | 18.45 | 20 | 20.04 |
| 78 | Kerala-Kochi | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 18.79 | 18.81 | 18 | 19.47 | 19.52 |
| 79 | Puducherry-Oulgaret | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 18.77 | 18.79 | 18 | 19.47 | 19.52 |
| 80 | Tamilnadu-Vellore | 0.81 | 0.82 | 0.78 | 0.85 | 0.85 | 19.11 | 19.13 | 18.29 | 19.8 | 19.86 |
| 81 | Tamilnadu-Madurai | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 19.63 | 19.63 | 18.9 | 20.36 | 20.43 |
| 82 | Tamilnadu-Chennai | 0.81 | 0.81 | 0.76 | 0.85 | 0.85 | 18.77 | 18.8 | 17.74 | 19.47 | 19.52 |
| 83 | Tamilnadu-Coimbatore | 0.81 | 0.82 | 0.78 | 0.85 | 0.85 | 19.9 | 19.61 | 18.83 | 20.32 | 20.36 |
| 84 | Tamilnadu-Tiruchirapalli | 0.81 | 0.81 | 0.78 | 0.84 | 0.84 | 19.13 | 19.18 | 18.42 | 19.9 | 19.93 |
| 85 | Tamilnadu-Salem | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 19.93 | 20 | 19.22 | 20.68 | 20.78 |
| 86 | Tamilnadu-Erode | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 20 | 20 | 19.27 | 20.57 | 20.8 |
| 87 | Tamilnadu-Tiruppur | 0.81 | 0.81 | 0.79 | 0.85 | 0.85 | 20.23 | 20.23 | 19.5 | 21 | 21.05 |
| 88 | Tamilnadu-Dindigul | 0.81 | 0.81 | 0.78 | 0.84 | 0.85 | 19.68 | 19.7 | 19 | 20.55 | 20.55 |
| 89 | Tamilnadu-Thanjavur | 0.81 | 0.81 | 0.78 | 0.84 | 0.84 | 19 | 19 | 18.17 | 19.66 | 19.7 |
| 90 | Tamilnadu-Tirunelveli | 0.82 | 0.82 | 0.78 | 0.85 | 0.85 | 19.04 | 19.04 | 18.2 | 19.73 | 19.77 |
| 91 | Telangana-Warangal | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 18.9 | 18.9 | 18.08 | 19.59 | 19.66 |
| 92 | Telangana-Karimnagar | 0.81 | 0.81 | 0.78 | 0.85 | 0.85 | 19.1 | 19.1 | 18.29 | 19.8 | 19.86 |

### Table VI: Island

| S. No | Smart City | Performance Ratio (PR) | | | | | Capacity Utilisation Factor (CUF) % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mcSi | pcSi | aSi | CIGS | CdTe | mcSi | pcSi | aSi | CIGS | CdTe |
| 93 | Lakshadweep-Kavaratti | 0.81 | 0.82 | 0.78 | 0.85 | 0.85 | 18.58 | 18.61 | 17.72 | 19.27 | 19.31 |
| 94 | Andaman & Nicobar-Port Blair | 0.82 | 0.82 | 0.78 | 0.85 | 0.86 | 17.03 | 17.05 | 16.5 | 17.58 | 17.62 |

## V. CONCLUSION

The study analysed meteorological parameters like temperature, relative humidity, pollution of all smart cities in six zones of India and their effect on the performance of different solar PV technologies using PVsyst simulation software. The global radiation values will be lower and mean air temperature will be higher in the cities than surroundings due to highly polluted air and demand for energy induced by the rapid growth of population.

However, thin film technologies - CIGS and CdTe has better performance ratios and capacity utilisation factor in all six zones due to their low temperature power coefficient and ability to perform in low light or diffuse radiation condition.

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## REFERENCES

1. Ministry of Housing and Urban Affairs, Government of India. www.moud.gov.in/cms/smart-cities.php.
2. Workshop on smart city mission. *Solar Energy Applications in smart cities.* 22nd February, 2016. Ministry of New and Renewable Energy, Government of India.
3. Subhash Chander, A. Purohit , Anshu Sharma, S.P. Nehra, M.S. Dhaka. Impact of temperature on performance of series and parallel connected mono-crystalline silicon solar cells. *Energy Reports* (2015)1; 175–180.
4. Rajiv Dubey, Pranjal Batra, Shashwata Chattopadhyay, Anil Kottantharayil, Brij M. Arora, K. L. Narasimhan and Juzer Vasi. Measurement of temperature coefficient of photovoltaic modules in field and comparison with laboratory measurements. *Photovoltaic Specialist Conference (PVSC), IEEE 42nd* (2015) Page(s):1 – 5.
5. Priyanka Singh, N.M.Ravindra. Temperature dependence of solarcell performance-an analysis. *Solar Energy Materials & Solar Cells* (2012)101; 36–45.
6. Tuka Al Hanai, Rehab Bani Hashim, Lana El Chaar, Lisa Ann Lamont. Environmental effects on a grid connected 900 W photovoltaic thin-film amorphous silicon system. *Renewable Energy* (2011) 36, 2615-2622.
7. Furkan Dinçer, Mehmet Emin Meral. Critical factors that affecting efficiency of solar cells. *Smart Grid and Renewable Energy* (2010), 1, 47-50.
8. E. Radziemska. The effect of temperature on the power drop in crystalline silicon solar cells. *Renewable Energy* (2003)28; 1–12.
9. Olivier Dupr´e, Rodolphe Vaillon, and Martin A. Green. Experimental assessment of temperature coefficient theories for silicon solar cells. *IEEE Journal of photovoltaics* (2016), Vol. 6, No. 1.
10. A.Virtuani, D. Pavanello, and G. Friesen. Overview of temperature coefficients of different thin film photovoltaic technologies. *25th European Photovoltaic Solar Energy Conference and Exhibition / 5th World Conference on Photovoltaic Energy Conversion*, (2010)6-10, Valencia, Spain.
11. Stein, J. Sutterlüti, J. Ransome, S. Hansen, C. & King, B. Outdoor PV Performance evaluation of three different models: single-diode, SAPM and loss factor model. *28th EU PVSEC. Paris France* 92013), 30 September-4 October.
12. Chetan Singh Solanki (2013). *Solar photovoltaics – fundamentals, technologies and applications,* second edition (PHI learning private limited) ppno.: 16-19.
13. Gwandu, B.A..L. and Creasey, D.J. Humidity: A factor in the appropriate positioning of a photovoltaic power station. *Renewable Energy* (1995), Vol. 6, No. 3, pp. 313-316.
14. Stultz, J.W., Wen, L.C. Thermal performance testing and analysis of photovoltaic modules in natural sunlight. *LSA Task Report* (1977)5101-31.
15. Zainuddin, H., Shaari, S., Omar, A. M., Zain, Z. M., Soumin, J., Surat, Z. Alam, S. Preliminary investigations on the effect of humidity on the reception of visible solar radiation and the effect of humidity and wind speed on PV module output. *American Institute of Physics* (2010) 978-0-7354-0797-8/10.55-58.
16. Abdullahi, S. Ayegba, Musa Abdul and Adejoh Joshua. Impacts of relative humidity and mean air temperature on global solar radiations of Ikeja, Lagos, Nigeria. *International Journal of Scientific and Research Publications* (2017) Volume 7, Issue 2, 315-319.
17. Mekhilef, S., Saidur, R., & Kamalisarvestani, M. Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. *Renewable and Sustainable Energy Reviews* (2012) 16(5), 2920–2925.
18. Evans, D.L., Florschuetz, L.W. Cost studies on terrestrial photovoltaic power systems with sunlight concentration. *Solar Energy* (1977)19, 255–262.
19. Manoj Kumar Panjwani, Dr. Ghous Bukshsh Narejo. Effect of humidity on the efficiency of solar cell (photovoltaic). *International Journal of Engineering Research and General Science* (2014) Vol 2, Issue 4, 499-503.
20. Martin A. Green, Yoshihiro Hishikawa, Ewan D. Dunlop, Dean H. Levi, Jochen Hohl-Ebinger, Anita W.Y. Ho Baillie. Solar cell efficiency tables (version 51). *Prog Photovolt Res Appl.* (2018) 26:3–12.
21. Ramanathan, V., Ramana, M. V., Roberts, G., Kim, D., Corrigan, C., Chung, C., & Winker, D. Warming trends in Asia amplified by brown cloud solar absorption. *Nature* (2007), 448(7153), 575–578.
22. Bohren, C.F., Huffman, D.R. Absorption and scattering of light by Small particles. *John Wiley & Sons, New York* (1983), 531 pp.; 65.
23. V. Ramanathan, Y. Feng. Air pollution, greenhouse gases and climate change: Global and regional perspectives. *Atmospheric Environment* (2009)43; 37–50.
24. Tapakis R, Charalambides AG. Enhanced values of global irradiance due to the presence of clouds in Eastern Mediterranean. *Renew Energy* (2014); 62:459–67.
25. Kaufman, Y. J. and Ilan Koren. Smoke and pollution aerosol effect on cloud cover. *Science* (2006), 313(5787), 655–658.
26. Eltbaakh, Y. A., Ruslan, M. H., Alghoul, M. A., Othman, M. Y., Sopian, K., & Razykov, T. M. Solar attenuation by aerosols: An overview. *Renewable and Sustainable Energy Reviews* (2012), 16(6), 4264–4276.
27. Sanjay Kumar Singh. *$CO_2$ emissions from passenger transport in India: 1950-51 to 2020-21.* http://www.ebtc.eu/pdf/CO2_Emissions_from_Passenger_Transport_in_India_1950-51_to_2020-21.pdf.
28. Gemechu Fanta Garuma, Jean-Pierre Blanchet, Éric Girard, Martin Leduc. Urban surface effects on current and future climate. *Urban Climate* (2018)24,121–138.
29. Landsberg H. E. (1981). In The Urban Climate, p. 275, *International Geophysics Series* (1981), Vol. 28. Academic Press, New York.
30. Zeki Ahmed Darwish, Hussein A. Kazem, K. Sopian, M. A. Al-Goul, Hussain Alawadhi. Effect of dust pollutant type on photovoltaic performance. *Renewable and Sustainable Energy Reviews* (2015) 41, 735–744.
31. Wei Tian, Yiping Wang, Jianbo Ren, Li Zhu. Effect of urban climate on building integrated photovoltaics performance. *Energy Conversion and Management* (2007)48, 1–8.
32. Amir Shahsavari, Morteza Akbari. Potential of solar energy in developing countries for reducing energy-related emissions. *Renewable and Sustainable Energy Reviews* (2018)90, 275–291.
33. Peter Huszár, Jan Karlický, Michal Belda, Tomáš Halenka, Petr Pišoft. The impact of urban canopy meteorological forcing on summer photochemistry. *Atmospheric Environment* (2018) 176, 209–228.
34. S.M. Robaa. Urban–rural solar radiation loss in the atmosphere of Greater Cairo region, Egypt. *Energy Conversion and Management* (2009) 50;194–202.
35. McKinsey Global Institute (2010). *India's urban awakening: building inclusive cities, sustaining economic growth*. Pages: 1-229.
36. Climate Protection Partnership Division in the U.S. (2008). *Reducing urban heat Islands: compendium of strategies.* Pages: 1-19.
37. Hashem Akbari. Energy saving potentials and air quality benefits of urban heat island mitigation. *Lawrence Berkeley National Laboratory*. Publication Date: 2005-08-23.
38. PVsyst photovoltaic software. https://www.pvsyst.com/

39. B. Shiva Kumar, K. Sudhakar. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy Reports* 1 (2015) 184–192.
40. Sreenath Sukumaran, K. Sudhakar. Fully solar powered airport: A case study of Cochin International airport. *Journal of Air Transport Management* 62 (2017) 176e188
41. Weatherspark. https://weatherspark.com/about
42. Madhuchandrika Chattopadhyay and R Rajavel. *A comparative study on performance of a grid connected solar PV system installed in the urban, rural and coastal region of India*. 2nd International Conference on Inventive Systems and Control (ICISC). IEEE Xplore: 28 June 2018. pp. 131-135.
43. Indian Himalayan States, ENVIS Centre on Himalayan Ecology. G.B. Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD). Ministry of Environment, Forest & Climate Change, Govt of India. http://gbpihedenvis.nic.in/ihr.html
44. Swapnil Dubey, Jatin Narotam Sarvaiya, Bharath Seshadri. Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the World-a review. *Energy Procedia* (2013)33; 311 – 321.
45. Kotaro Kawajiri, Takashi Oozeki, Yutaka Genchi. Effect of temperature on PV potential in the World. *Environ. Sci. Technol.* (2011) 45, 9030–9035.
46. Laxmi Narain and S.N. Garg. Estimation of Linke turbidity factors for different regions of India. Int. J. *Environment and Waste Management* (2013), Vol. 12, No. 1, 52-64.
47. W. E. Alnaser and N. S. Awadalla. The Linke turbidity factor and Ängstrom coefficient in humid climate of Bahrain. *Earth, Moon and Planets* (1995) 70: 61-74.
48. *WHO Global Urban Ambient Air Pollution Database (update 2018).*World Health Organisation. http://www.indiaenvironmentportal.org.in/content/454533/who-global-urban-ambient-air-pollution-database-update-2018/
49. National Renewable Energy Laboratory. U.S Department of Energy. India Solar Resource Maps and Data. https://www.nrel.gov/international/ra_india.html. 26.09.2018
50. *Concern over poor air quality and traffic congestion in north east cities; action must gather momentum* (2013). Centre for Science and Environment. https://www.cseindia.org/concern-over-poor-air-quality-and-traffic-congestion-in-north-east-cities-action-must-gather-momentum-4964.
51. Xuexi Tie, Junji Cao. Aerosol pollution in China: Present and future impact on environment. *Particuology* (2009) 7 (2009) 426–431.
52. Polash Mukerjee and Subhojit Goswami (2016). *Delhi air pollution: Identifying perpetrators and fixing responsibility*. Down to Earth. https://www.downtoearth.org.in/news/air/delhi-air-pollution-identifying-perpetrators-and-fixing-responsibility-56240.
53. Usman Nasim (2015). *Paddy fields burning: Smog shrouds national capital.* Down to Earth. https://www.downtoearth.org.in/news/air/burning-paddy-fields-deteriorate-air-quality-in-delhi-51687.
54. D. V. Viswanadham, K. R. Santosh. Air pollution potential over South India. *Kluwer Academic Publishers* (1989) Volume 48, Issue 3, pp 299–313.
55. M. Shekar Reddy, Chandra Venkataraman. Inventory of aerosol and sulphur dioxide emissions from India: I-Fossil fuel combustion. *Atmospheric Environment* (2002)36, 677–697.
56. Tanushree Ganguly (2018). *Understanding North India's pollution crisis.* Down to Earth. https://www.downtoearth.org.in/blog/air/understanding-north-india-s-pollution-crisis-60426.
57. M. Vasanthy, R. Velmurugan and Babu Rajendran. Ambient air quality scenario at Port Blair, Andaman Island. *Nature Environment and Pollution Technology* (2007)Vol. 6 No. 3 pp. 437-441.
58. The German Energy Society (2008). *Planning and Installing Photovoltaic Systems-A Guide for Installers, Architectures and Engineers.* 2nd end. London: Earthscan.
59. Ransome, S. (2010). *The present status of kWh/kWp measurements and modelling*. 5th World PV Conference. Valencia Spain, 6-10 September, 2010.

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