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Research Article

Case Study on Role of Solar Energy in Greenhouse Gas Emissions Reduction in India

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ABSTRACT

Degradation of the environment and greenhouse gas emissions, especially of carbon dioxide, have increased issues with human health and the atmosphere. India, the world's second most populous nation, is one of the main consumers of conventional resources, which contributes to global warming. Before 2050, the growth rate is expected to expand even further, which will accelerate the expansion of industry and drive-up energy consumption. Many nations use alternative forms of renewable energy, especially solar energy, to meet their energy needs and reduce carbon emissions. Our goal in this assessment is to examine solar panel initiatives started by India, with a particular emphasis on the National Solar Mission. This paper also examines the current installed solar capacity, the 2022 solar panel plan, as well as the initiatives and results of solar panel installations in homes and businesses. A recent wave of climate efforts has set off a reduction in CO2 emissions to produce electricity. Numerous nations have been working to increase efficiency and employ renewable energy sources in order to develop and implement low carbon emission power generation systems.

Keywords: Carbon Emission, Green House Gases, Solar Energy, Renewable Energy.

INTRODUCTION

Energy is essential to the development of human society and companies. Energy is becoming more and more necessary as many technologies disciplines advance. Current projections indicate that in the ensuing decades, the world's requirement for basic energy supplies will triple [1]. While the alarming greenhouse scenario demands that pollution-free renewable sources, as opposed to fossil fuels and other resources that currently dominate the energy sector, meet the growing demand for energy, these sources have two main drawbacks: they will eventually run out of fuel and release copious amounts of carbon dioxide (CO_2) and other harmful greenhouse gases (GHG) [2], [3].

The primary cause of the rise in CO_2 emissions in developing countries like India is the massive increase in the use of traditional resources (such coal, oil, and natural gas) to meet the speed of the fast-expanding energy requirement [4]. As a result, fossil fuel-powered power plants release a lot of harmful substances into the atmosphere, such as carbon dioxide (CO_2), nitrogen oxides, and sulfur dioxide (SO_2). The global power generation sector currently generates approximately 530 g of CO_2 per kWh (gCO_2/kWh) on average [5]. The power and heat industries account for the largest portion of energy-related CO_2 emissions (42% of global emissions) [6].

India is expected to become the most populated country in the world by 2050 due to population expansion, which is connected to the country's predicted increase in net energy consumption, according to reports from the International Energy Agency (IEA) [7]. Based on these projections, there will be a greater demand for natural gas and oil in the upcoming years. To accommodate this dramatic rise in energy needs, it is estimated that the country's energy infrastructure would need to triple in size [8]. Several countries throughout the world are currently focusing their efforts on the development of renewable energy (RE) by stopping to employ conventional energy sources in order to achieve the goal of having net-zero carbon emissions by 2050 [9]. To achieve these goals, it is essential that the drawbacks of sustainable energy processing equipment be minimized in order to increase their effectiveness [10]. The Greenpeace estimate predicts that PV plants would increase nationally, accounting for 20% to 40% of India's current renewable energy sources [11].

In line with global trends, India has also resorted to renewable resources to meet its energy needs. To address energy deprivation and the detrimental effects of traditional energy sources on the atmosphere, there is currently a seismic shift away from conventional power sources and toward non-conventional ones, such as hydropower, nuclear, wind, and solar energy. In addition, there is an increase in the use of gasoline in a variety of commercial, industrial, and transportation settings [12].

The only steady and reliable power source on the planet is the sun. India is a tropical country with abundant solar power resources. Solar energy can be used to address the increasing need for energy. Because solar power is a non-vanishing, lower greenhouse gas and carbon dioxide emission, and noiseless power source, there is a lot of research focused on this field. [13] [14] [15].

PV systems have CO2 emissions that are generally much lower than those of conventional energy generation, such as that which uses coal. However, there are notable variations in the modules because of the design of the modules (traditional glass-back sheet or innovative frameless glass-glass modules) and, more importantly, because of the location of production (China, Germany, or the European Union, EU).

CURRENT SCENARIO OF SOLAR POWER IN INDIA

At 48556.65 MW, India is the fifth-largest installed solar power (SP) capacity in the world, after China (254354.8 MW), the US (75571.7 MW), Japan (66999.949 MW), and Germany (53783 MW) (MNRE, GoI 2021; IRENA 2021). About 41001.49 MW, 6111.06 MW, and 1,444.10 MW are contributed by solar roof tops, off-grid systems, and ground-mounted solar power plants (SPPs), in that order. The Indian government is working to increase solar power capacity in order to meet the aim of 100 GW by 2022, which includes 40 GW from solar rooftops. The government has documented the enormous potential of solar energy, which is 748.99 Gwp (MNRE GoI 2020-21). The country of India is made up of 28 states and 8 Union territories (UTs), covering 3.287 million km². The highest on-grid SP installed capacity share is shared by the four states of Rajasthan (9229.8 MW), Karnataka (7483.4 MW), Gujarat (6116.85 MW), and Tamil Nadu (4757.76 MW); the lowest shares are shared by Lakshadweep (0.75 MW) and Meghalaya (0.19 MW). Rajasthan and Karnataka account for only 15-20% of the states when categorized based on installed capacity; Tamil Nadu and Gujrat (10–15%); Maharashtra, M.P., Telangana, Andhra Pradesh (510%); Uttarakhand, Haryana, Punjab, and Uttar Pradesh (1–5%); while the remaining hardy states account for less than 1% [16].

RENEWABLE ENERGY GENERATION IN INDIA

According to the Central power Authority (GoI), from June 2020 to May 2021, the whole amount of power generated came from renewable energy sources, accounting for 147678.3 MU (million units). Of the total, 41.68% (61256 MU) come from solar power alone, with wind energy (41.48%), biomass (2.18%), bagasse (7.24%), tiny hydrocarbons (6.26%), and other sources (1.17%) close behind. Karnataka had the greatest percentage of solar power output at 21.45% (13200.72 MU), with Andhra Pradesh (11.64 %), Rajasthan (17.21 %), Telangana (10.33 %), Gujarat (7.93 %), M.P. (6.83 %), Maharashtra (5.09 %), and Uttar Pradesh (3.35%) following (Ministry of Power, Government of India) [16]. With the exception of a few months when wind energy predominates, solar energy has the largest proportion throughout the majority of the year. The highest generation is seen in SR and WR, while the lowest is in ER, NER, and NR. States in the southern region together assert the highest generation, followed by those in the north and west. Despite the brief sunny days, February saw the highest generation. This may be explained by the seasonal tilt, which controls the amount of solar radiation that the Sun perceives [16].

TOP 10 CITIES IN INDIA IN TERMS OF SOLAR POWER CAPACITY

The long-term average of solar resources and their potential for power generation at a particular place can be calculated using the web-based Solar Atlas tool (Rafique et al., 2020). Solar Atlas is dependent on multiple factors, including photovoltaic power output (PV out), global horizontal incidence (GHI), diffuse horizontal incidence (DIF), direct normal incidence (DNI), and global tilted incidence (GTI). The Global Solar Atlas's simulation model-based tool was used to create a solar atlas for the top ten states in India with the highest potential for solar power. **Table 1** indicates that solar energy has a large potential in these states, as seen by the daily average values of PVout (4.40kWh/KWp), DNI (4.03KWh/m2), DIF (2.48 KWh/m2), GHI (5.28 KWh/m2), and GTI (5.64 KWh/m2) [16].

Table.1: Solar Power Capacity In Urban Centers Of Top10 States

PVout		GHI	DNI	DIF	GTI
State	**(KWh/KWp per day)**	**KWh/m2 per day**	**KWh/m2 per day**	**KWh/m2 per day**	**KWh/m2 per day**
Rajasthan	4.766	5.487	4.820	2.329	6.129
Karnataka	4.436	5.403	4.142	2.458	5.668
Tamil Nadu	4.389	5.571	3.934	2.624	5.672
Andhra Pradesh	4.25	5.285	3.77	2.560	5.504
Telangana	4.434	5.354	4.023	2.496	5.668
Gujarat	4.658	5.542	4.867	2.273	6.033
Madhya Pradesh	4.449	5.228	4.149	2.416	5.696
Maharashtra	4.361	5.315	3.872	2.586	5.619
Uttar Pradesh	4.109	4.843	3.313	2.565	5.223
Punjab	4.153	4.795	3.446	2.511	5.27

Source: Global solar atlas generated using simulation model-based tool

MITIGATION OF CARBON EMISSIONS USING SOLAR ENERGY

A technology's carbon emission intensity, or the quantity of CO2 or CO2 equivalent released per unit of energy produced, can be used to assess how it affects the climate. Here, "CO 2 equivalent" (CO 2eq) refers to greenhouse gases that are not CO2 and are released as a result of various human activities, including the extraction of fossil fuels and agriculture. Two examples of these gases are methane and nitrous oxide. While renewable technologies like solar power emit minimal or no emissions during operation, they may produce emissions during manufacturing. In contrast, existing fossil fuel technologies have a high carbon emission intensity due to the combustion of carbon rich fuels. Therefore, by substituting more carbon-intensive sources of power and heat, solar energy can help reduce carbon emissions. The amount of carbon dioxide absorbed by the displaced energy sources, the quantity and kind of energy used in the production, installation, and operation of the solar energy system, and the displacement of conventional heat or electricity all affect how much emissions are mitigated [17].

Numerous future energy scenarios have been issued by the International Energy Agency (IEA), such as the two degree scenario (2DS), which calls for a maximum increase in global temperature of only 2°C, and the two degree scenario (2DS-hiRen), which heavily emphasizes renewable energy sources. According to the 2DS-hiRen scenario, by 2050, around one-third of renewable power, or 22% of global electricity, might come from solar energy, of which 10.4% comes from solar thermal power and 11.3% from photovoltaics.8 It is projected that solar will supply 14% of the world's power in the 2DS, while the renewable contribution is lower. Furthermore, according to IEA estimates, the 258 Gt of CO2 emissions that would need to be mitigated globally by 2050 in the 2DS scenario relative to the baseline 4DS case8 would be contributed by 12% through the usage of solar photovoltaic and concentrated thermal power. The estimated deployment level for 2050 indicates an average annual rise in capacity of about 12–14%, which is significantly slower than the growth rates observed today and in the past. Based on recent experience, these rapid growth rates seem to be both technically and financially possible. As a result, solar thermal and photovoltaic energy constitute a critical capability to attain notable reductions in emissions [17].

Numerous factors have contributed to the low degree of solar energy usage observed thus far. Solar photovoltaic technologies' high cost was historically a key barrier, but recent price reductions have made solar PV technology affordable, with the cost of additional system components acting as a ceiling. The present dominance of fossil fuels in the energy system is a result of their cheap private cost (i.e., disregarding expenses associated with climate change and atmospheric pollution) when compared to alternatives with lower carbon emissions.This advantage has been solidified through investments in and advancements of related generation and distribution technologies and infrastructure. It has also been difficult to scale up the adoption of low-carbon alternatives and attract the investment required to drive down costs and spur innovation in the absence of significant policy incentives or regulations due to the limited large-scale and commercial experience with them as well as their variable nature. If solar energy is to meet a considerably higher percentage of energy demand, even with such methods, additional energy storage or power management measures will be required [17].

Case Study: This case study assesses carbon emissions for an educational institute at Pune, located in Pimpri Chinchwad area. This report is based on Total energy generated, Purchased, consumed through a year, and calculation of CO2 emission. CO2 emission leads to financial savings in electricity bill and sustainable to environment. Procedural steps to carried out this practice is as follows,

PRESENT ENERGY CONSUMPTION AND CO2 EMISSION IN SPECIFIED LOCATION

The case study has been performed in Pune location at Sant Tukaram Nagar with latitude and longitude 18.62°N, 73.81°E respectively at Dr D Y Patil Institute of Technology, Pimpri,Pune. Generation of solar plant is 100Kw. Multicrystelline and monocrystelline solar panel has been used with series and parallel combination to generate specified output. Dr. D Y Patil Unitech Society's Dr D Y Patil Institute of Technology, Pimpri, Pune consumes energy in the form of Electrical energy, used for various office equipment. The total energy consumption for one year is 586324kWh. **Table. 2** explains the installed capacity of solar power plant and generation of energy through solar PV. By utilizing solar power 527.69MT CO2 emission has been reduced.

RENEWABLE ENERGY AND CO2 EMISSION

Table.2: Renewable Energy and CO2 Emission

Sr. No.	Particulars	Value	Unit
1	Installed Solar PV Plant Capacity	100	kWp
2	Energy Generated by Solar PV Plant	162489	kWh
3	Reduction in Annual CO2 Emission	527.69	MT

PROCEDURAL DIAGRAM

Fig. 1 is the procedure to calculate, CO2 emission in given specified location. The major contributor to the connected load of the institute includes LED, celling fan, BLDC fans, PC, printer, AC, lifts and other equipment. Based on load connected to the specified site total energy consumption has been calculated. The net energy consumption is 48860.33kWh. EPI (Energy Performance Index) calculated to identify how energy-efficient a building is and take steps to improve its energy performance. EPI of a building is its annual energy consumption in Kilo Watt Hours per square meter of the building. EPI is determined by

$$EPI = \frac{Annual\ Energy\ Consumption\ in\ Kwh}{Total\ Built-up\ area\ in\ m^2}$$

EPI calculation speaks about solar energy consumed and energy efficiency. Then calculation of CO2 emission is calculated. With this procedure energy generation due to solar and total reduction in CO2 emission is studied.

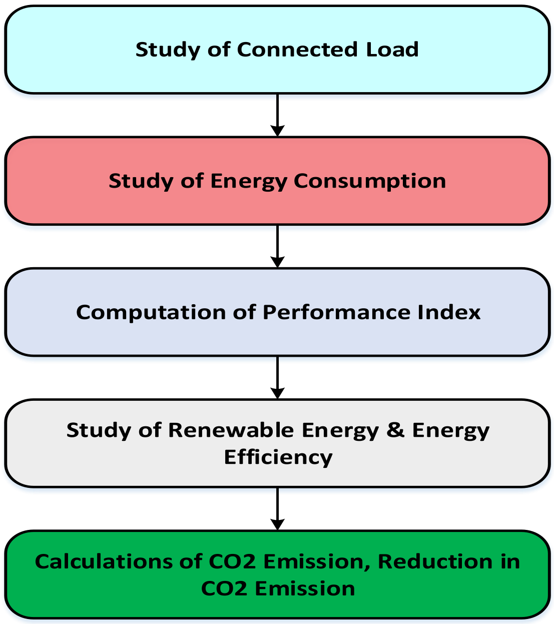

Fig. 1. Procedural Diagram

A carbon footprint is defined as the total greenhouse gas emission, emitted due to various activities. The institute uses electrical energy for various electrical gadgets. Basic computation of CO_2 emission the basic of calculation for CO_2 emission due to electrical energy is as under 1 kWh of energy releases 09 Kg of CO_2 into atmosphere.

ENERGY CONSUMPTION IN ONE YEAR

Table 3 and **Fig. 2** represents the total energy purchased from utility, solar energy generated and energy exported to the grid. This data has been collected monthly. It has been clearly visible from **Fig. 2** that generation through solar plant is more during March , April and May.

Table.3: Energy Consumption in one year

No	Month	Energy Purchased, kWh (1)	Energy Generated, kWh (2)	Energy Exported, kWh (3)
1	Jul-22	38271	10809	865
2	Aug-22	33576	13963	1355
3	Sep-22	37848	13396	1515
4	Oct-22	25686	15691	7620
5	Nov-22	33669	15043	1525
6	Dec-22	40413	13040	465
7	Jan-23	36612	15097	1200
8	Feb-23	34416	16556	1840
9	Mar-23	38931	18234	2040
10	Apr-23	37854	19023	3680
11	May-23	47586	1865	580
12	Jun-23	42948	9772	1290
13	Total	447810	162489	23975

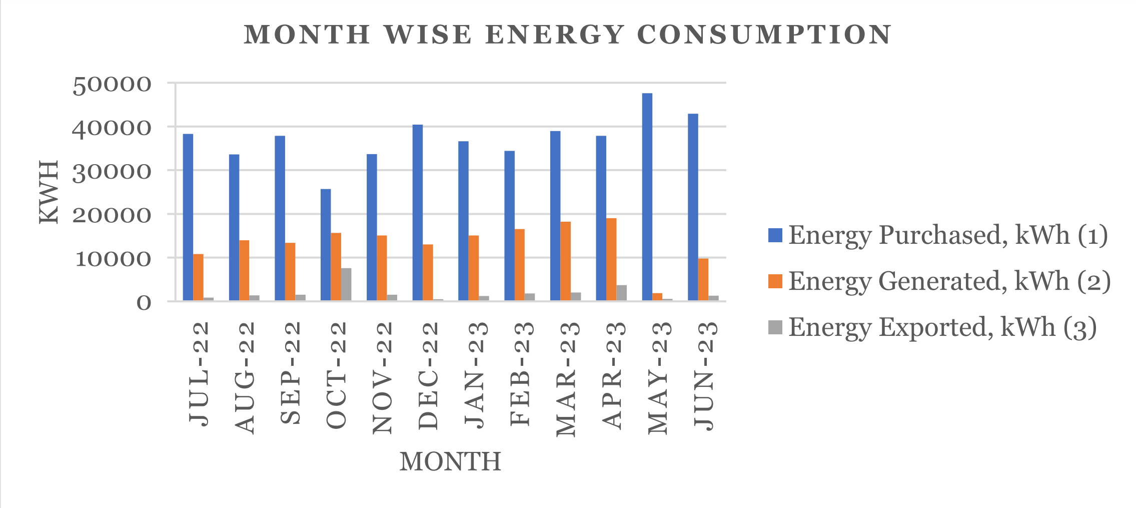

Fig. 2. Month wise Energy Consumption

It is also implicit from **table. 3**. and **Fig. 2** that the annual energy purchased is 610299 kWh which produces annually 549.26 MT CO2, and energy performance index is 28.87 kWh/m2. At the same time when grid connected 100 kW solar panel is used the annual energy purchased is 447810 kWh and CO2 emission is 403.029 MT. It clearly indicates that 146.24 MT CO2 emission reduction. The energy performance index 27.74 kWh/m2.**Table. 4** is the observation of CO2 emission in MT is 527.69. With this amount of CO2 emission over the year has adverse effect on environment. The emissions contribute to global warming and local air quality issues, potentially impacting health and the environment.

Implications and analysis of co2 emission

1. High Electricity Dependence:
   - The institute relies heavily on electricity for its operations, which has resulted in significant carbon emissions.
2. Energy Source Mix:
   - Electricity Grid: The carbon intensity of the electricity grid (i.e., how much CO_2 is emitted per unit of electricity consumed) is a key factor. If the grid relies heavily on fossil fuels (e.g., coal, natural gas), emissions will be higher. Conversely, a higher mix of renewables in the grid will reduce these emissions.
   - Renewable vs. Non-Renewable: Understanding the proportion of electricity from renewable sources versus non-renewable sources can provide insights into potential areas for improvement.
3. Potential for Energy Efficiency:
   - Infrastructure Upgrades: Investing in more energy-efficient infrastructure, such as LED lighting, high-efficiency HVAC systems, and energy-efficient appliances, can significantly reduce electricity consumption.
   - Building Improvements: Implementing better insulation, energy-efficient windows, and smart building technologies can also contribute to lower energy usage.
4. Renewable Energy Adoption:
   - On-site Generation: Installing on-site renewable energy systems like solar panels or wind turbines can offset electricity consumption from the grid.
   - Green Energy Purchasing: Purchasing electricity from green energy programs or through renewable energy certificates (RECs) can also help reduce the carbon footprint associated with electricity use.
5. Behavioral Changes:
   - Energy Conservation: Encouraging energy-saving behaviors among staff and students, such as turning off lights and equipment when not in use, can contribute to lower electricity usage.

- Awareness Programs: Implementing awareness programs to educate about energy conservation can be beneficial.

Table.4: CO_2 Emissions in one year

No	Month	CO_2 Emissions, MT
1	Jul-22	43.39
2	Aug-22	41.57
3	Sep-22	44.76
4	Oct-22	30.38
5	Nov-22	42.47
6	Dec-22	47.69
7	Jan-23	45.46
8	Feb-23	44.22
9	Mar-23	49.61
10	Apr-23	47.88
11	May-23	43.98
12	Jun-23	46.29
13	Total	527.69

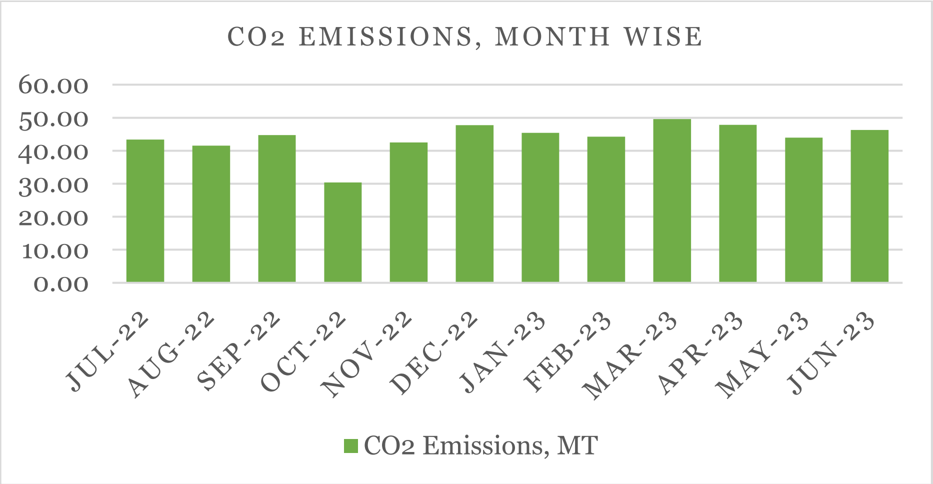

Fig. 3. Month wise CO_2 Emission

Month wise CO_2 Emission depicts in **fig .3**. and mothwise reduction in CO_2 Emission shown in **fig. 4** Focusing on reducing the 527 MT of CO_2 emissions from electricity consumption involves improving energy efficiency, adopting renewable energy, encouraging energy-saving behaviors, and continuously monitoring progress. **Table. 5** provides data of CO_2 reduction due to installation of solar panel of 100Wp.

Table.5: CO_2 Reduction in CO_2 Emission in one year

No	Month	Reduction in CO_2 Emission
1	Jul-22	9.7281
2	Aug-22	12.5667
3	Sep-22	12.0564
4	Oct-22	14.1219
5	Nov-22	13.5387
6	Dec-22	11.736
7	Jan-23	13.5873

8	Feb-23	14.9004
9	Mar-23	16.4106
10	Apr-23	17.1207
11	May-23	1.6785
12	Jun-23	8.7948
13	Total	146.2401

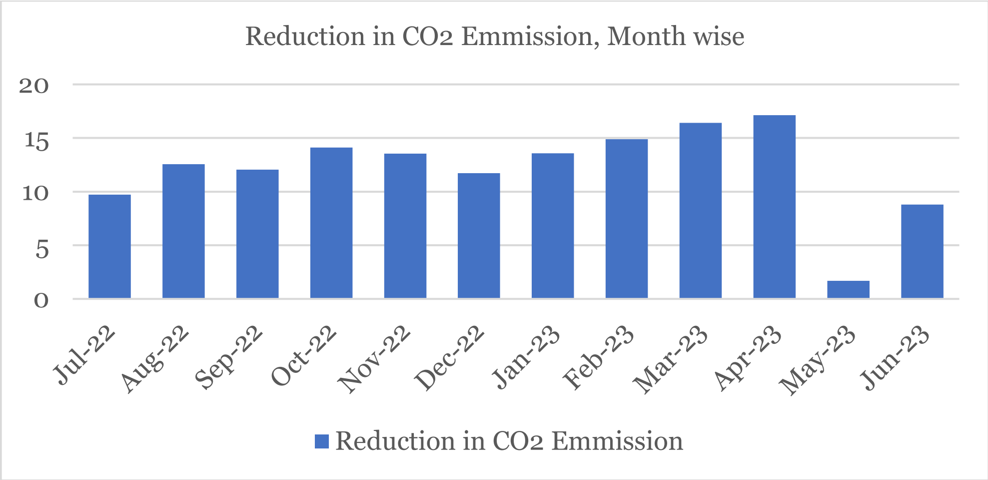

Fig. 4. Month wise Reduction in CO2 Emission

QUANTITATIVE ANALYSIS

Initial CO_2 Emissions from Electricity Consumption: 527 MT

CO_2 Emissions Reduction Achieved: 146.2401 MT

New Total CO_2 Emissions: 380.7599 MT

Implications and significance

Calculation:

Percentage Reduction=$\left(\frac{Reduction}{initial\ Emission}\right)$×100=$\left(\frac{146.2401}{527}\right) \times 100 = 27.75\%$

Significance: A reduction of approximately 27.75% in CO_2 emissions is substantial and indicates effective measures have been implemented to decrease electricity consumption or switch to less carbon-intensive energy sources.

Environmental Impact:

- **Climate Change Mitigation**: Reducing 146.2401 MT of CO_2 emissions contributes to mitigating climate change by lowering the institute's greenhouse gas footprint.
- **Local Environmental Benefits**: This reduction can also have positive local environmental impacts, such as improved air quality.

Energy Efficiency Improvements:

- **Investments in Technology**: This reduction likely results from investments in energy-efficient technologies and practices, such as LED lighting, efficient HVAC systems, and better insulation.
- **Operational Changes**: Implementation of energy conservation practices and behavior changes among staff and students.

Renewable Energy Adoption:

- **On-Site Generation**: Possible installation of on-site renewable energy systems like solar panels or wind turbines.

- **Green Energy Purchases**: Increased purchasing of green energy or renewable energy certificates (RECs).

Cost Savings:

- **Reduced Energy Bills**: Lower electricity consumption typically leads to significant cost savings on energy bills, which can be reinvested in further sustainability initiatives.

Compliance and Reputation:

- **Regulatory Compliance**: Helps in meeting local, national, or international regulatory requirements related to carbon emissions.
- **Enhanced Reputation**: Demonstrates the institute's commitment to sustainability, potentially enhancing its reputation among stakeholders, including students, staff, and the local community.

CONCLUSION

The need for alternative, more environmentally friendly ways to produce electricity, such as solar panels, has increased over the past few generations due to issues like carbon dioxide emissions, energy pricing, and the global energy crisis. A total of 63.30 GW of solar power have been deployed nationwide as of December 31, 2022, according to an MNRE report. This comprises 2.22 GW of off-grid solar, 8.08 GW of rooftop solar, and 53 GW of ground-mounted solar. Furthermore, a capacity of approximately 51.13 GW is now being implemented, and another 31.4 GW is during the tendering process. During this Financial Year (FY) 2022–2023, solar power plants with a capacity of about 15 GW are anticipated to go online.

This paper is a case study of an educational institute located in Pune, an overall CO_2 emission statistic through 100 KW solar panel. This report provides a roadmap for future development and engagement in renewable energy programs in India, particularly in Pune, for the government, business community, stakeholders, international and regional donors, regulators, and scientists.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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