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Carbon Analysis of a Multistory Commercial Building in Rajasthan

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Abstract: ***Carbon footprint assessment is an effective tool for quantifying greenhouse gas (GHG) emissions generated directly and indirectly by an organization in terms of carbon dioxide equivalent (CO_2). Measuring these emissions helps identify major emission sources, evaluate carbon reduction opportunities, and support sustainable development through effective mitigation strategies. Educational institutions, owing to their energy consumption, transportation activities, and resource utilization, have significant potential for reducing their carbon footprint and promoting low-carbon campus operations.***

This study evaluates the carbon footprint of a hostel building using the principles of ISO 14064-1:2018 and the GHG Protocol Corporate Standard. A bottom-up life cycle assessment (LCA) approach was adopted to quantify Scope 1, Scope 2, and Scope 3 emissions based on activity data and appropriate emission factors. Carbon sequestration potential of the existing tree cover was estimated using allometric equations, and suitable carbon reduction and offset measures were proposed. The total organizational carbon footprint was estimated at 51.55 tCO_2e, while inclusion of human respiration for comparative analysis increased the total to 88.99 tCO_2e. Scope 3 emissions contributed the largest share (47%), followed by Scope 1 (27%) and Scope 2 (26%). The existing tree cover provided a carbon sequestration potential of approximately 0.60 tCO_2e per year, indicating the need for additional carbon sinks.

The study further evaluated mitigation strategies including a 5kW rooftop solar photovoltaic (PV) system, biogas generation from organic waste, rainwater harvesting, rooftop vegetation, composting, energy-efficient appliances, and sustainable transportation practices. Among these, the rooftop solar PV system exhibited the highest emission reduction potential of approximately 10.9 tCO_2e per year, while the combined implementation of all proposed measures can substantially reduce the hostel's carbon footprint. The findings demonstrate that integrating renewable energy, efficient resource utilization, sustainable waste and water management, and enhanced green infrastructure can support the transition of institutional buildings toward carbon neutrality and contribute to achieving national and global sustainability goals.

Keywords: Carbon footprint, Greenhouse gas emissions, ISO 14064-1, GHG Protocol, Life cycle assessment, Carbon sequestration, Solar photovoltaic, Carbon neutrality.

I. INTRODUCTION

The construction sector is one of the major contributors to global carbon emissions due to the extensive use of energy-intensive materials and processes. With increasing concerns over climate change and environmental sustainability, it has become essential to evaluate and minimize the carbon footprint of buildings throughout their life cycle. In this context, carbon emission and assessment of buildings under real climatic conditions play a crucial role in understanding their environmental impact.

The present study focuses on the carbon emission of a recently constructed building under conditions. Carbon emission involves the systematic estimation and analysis of carbon dioxide (CO_2) emissions associated with material production, construction activities, operational energy consumption, and environmental interactions of a building. Since climatic parameters such as temperature, humidity, solar radiation, and wind significantly influence building energy demand and performance, their impact on carbon emissions must be thoroughly examined [1].

This research aims to analyze how changing conditions affect the carbon emission profile of a newly constructed building. The study considers seasonal variations and local characteristics to study building performance and associated carbon emissions. Such an approach helps in identifying critical factors contributing to higher emissions and enables the evaluation of energy-efficient and low-carbon design strategies.

This interactive chart shows the breakdown of global CO2 emissions by region. We see that until well into the 20th century, global emissions were dominated by Europe and the United States. In 1900, more than 90% of emissions were produced in Europe or the US; even by 1950, they accounted for more than 85% of emissions each year. But in recent decades this has changed significantly.

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In the second half of the 20th century, we see a significant rise in emissions in the rest of the world, particularly across Asia, and most notably, China. The US and Europe now account for less than one third of emission [2].

Now in order to reduce such emissions, it is firstly important to know numerous sources of these emissions and then to quantify them. Typically, any building during its life cycle i.e. during construction and operation emits carbon which can be calculated under 3 scopes as defined in GHG Protocol (World's most widely used greenhouse gas accounting standard) and to attain a "NET ZERO"it is important to have a comprehensive information about sources of these scope categories. Below is a brief description of various scopes defined by GHG Protocol:

The data for carbon emission for india and world are shown in table 1 and 2.

Table 1: Industry-wise carbon Emissions – Global vs India

Industry / Sector	Global Emissions ($GtCO_2e$/year)	India Emissions ($GtCO_2e$/year)
Electricity & Heat Production / Energy Industries	17.88	1.25
Agriculture, Forestry & Land Use	9.79	0.41
Transportation	7.61	0.3
Manufacturing & Construction	6.49	0.38
Residential & Commercial Buildings	3.35	0.3
Fugitive Emissions from Energy Production	3.09	0.07
Industrial Processes & Product Use (IPPU)	2.77	0.24
Waste Management	1.7	0.08
Other Fuel Combustion	0.53	0.01
Total	53.2	2.96

Electricity and energy industries contribute a larger share in India (42.4%) than the global average (33.6%) due to the continued reliance on coal-based power generation. Agriculture contributes a lower percentage in India (13.7%) compared to the global average (18.4%), although it remains a major source of methane emissions. Industrial processes (IPPU) contribute a higher share in India (8.1%) than globally (5.2%), reflecting rapid industrialization and growth in cement and steel production. Buildings contribute a greater share in India (10.3%) than globally (6.3%) because of increasing urbanization and energy demand in residential and commercial sectors. Waste management contributes a relatively small share in both India and the world.

Globally, the energy sector remains the largest contributor to greenhouse gas emissions, with electricity and heat production accounting for approximately 33.6% of total emissions. Agriculture, forestry, and land-use activities contribute 18.4%, followed by transportation (14.3%) and manufacturing and construction (12.2%). Buildings account for 6.3% of emissions, while industrial processes and waste management contribute 5.2% and 3.2%, respectively. These findings highlight the importance of adopting renewable energy technologies, sustainable transportation systems, energy-efficient buildings, and climate-smart agricultural practices to achieve global carbon reduction targets and support sustainable development [3].

Global greenhouse gas emissions are estimated at approximately 53.2 $GtCO_2e$ per year, whereas India's emissions are approximately 2.96 $GtCO_2e$ per year, representing about 5.6% of total global emissions. In both cases, the energy sector is the dominant contributor. However, India's emissions profile shows a greater dependence on electricity generation and building energy consumption, while the global profile exhibits relatively higher contributions from agriculture and transportation sectors.

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This comparison highlights the need for accelerated deployment of renewable energy systems, energy-efficient buildings, and sustainable industrial practices in India to achieve long-term emission reduction targets [4].

Table 2: Percentage Comparison

Industry / Sector	Global (%)	India (%)
Electricity & Heat Production / Energy Industries	33.6	42.4
Agriculture, Forestry & Land Use	18.4	13.7
Transportation	14.3	10.1
Manufacturing & Construction	12.2	12.9
Residential & Commercial Buildings	6.3	10.3
Fugitive Emissions from Energy Production	5.8	2.5
Industrial Processes & Product Use (IPPU)	5.2	8.1
Waste Management	3.2	2.6
Other Fuel Combustion	1	0.4
Total	100	100

II. GREENHOUSE GAS EMISSION SCOPES IN HOSTEL

Identifying carbon emission sources: To alleviate the harm caused by emission of greenhouse gases, it is particularly important to identify the sources of such emissions. As per GHG Emission Protocol Corporate Standards the sources are categories into 3 categories.

1) Scope 1 include the carbon emitted directly into the atmosphere. In this study, such emission is due to:

- Mobile emission: Due to the movement of the institute owned vehicles for various official tours
- Static emission: Use of fossil fuels for satisfying the cooking requirements of the institute. Cafeteria, canteen and hostel mess

2) Scope 2 include carbon emitted indirectly by the institute. Due to purchased electricity for conducting various operations within the institutes.

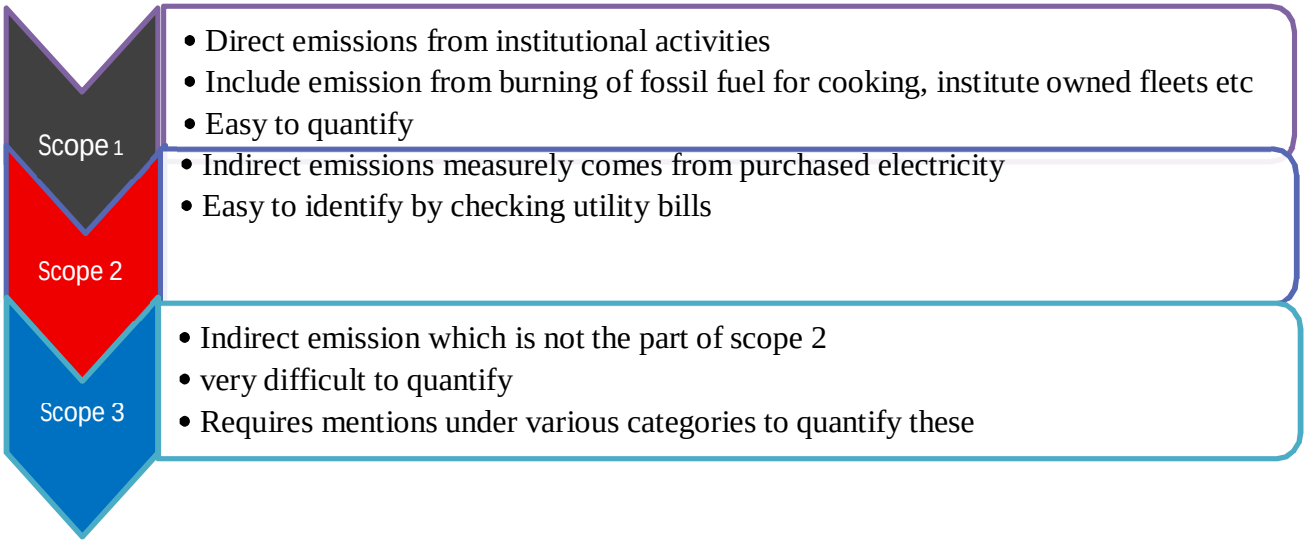
3) Scope 3 include carbon emitted indirectly by the institute such that the activities in its production are out of institute's control. These include:

- Emission due to Burning of fossil fuel due to employee commuting using their personal vehicles: staff members and students using their own vehicle to commute to institute on regular basis
- Emission due to Waste generation: A lot of waste is also generated during various course of activities which is then calculated to provide reasonably accurate data.
- Emission due to Water use: Institutional activities requiring use of water also contribute towards the emission of such carbon.
- Emission due to Purchase of goods like paper and drawing sheets etc [5].

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Figure 2: Carbon Emission Scopes



III. METHODOLOGY

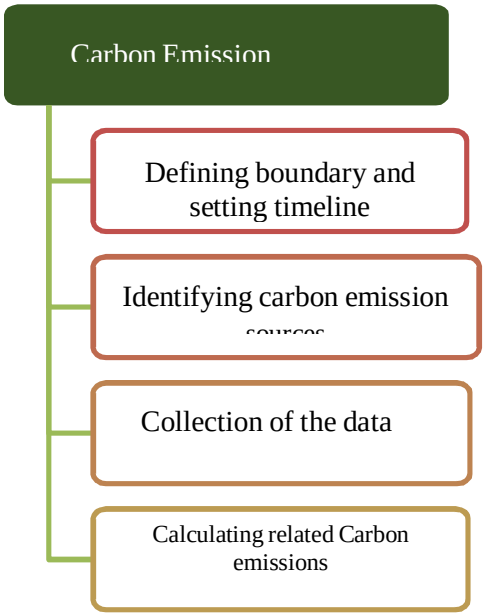


Figure 3: Flow Chart for the Carbon Emission and Carbon Sink

The methodology employed here consists of calculating first the carbon emissions using LIFE CYCLE ASSESSMENT in a bottom-up approach by following ISO 14064-1, using various conversion factors from GHG Protocol Corporate Standard, a joint initiative taken by World Resource Institutes (WRI) and World Business Council for Sustainable Development (WBCSD). The next step is then to identify several carbon sinks present within the hostel and calculating their carbon sequestration potential. Further making use of technology present today various carbon offsets may also be suggested to neutralize the carbon emissions [6].

Site and Time Period: For the given study, the selected area is the campus of Minority Department Hostel Sri Ganganagar, Rajasthan which is roughly located at an altitude of approximately 177 meters with its geographical coordinates as 29.9094°N and 73.8800°E. The study conducted here is semester-wise starting from April-Dec 24, Jan-Dec 25 and Jan-March 26. Since the place has distinct seasons with hot summers while in rain due to extremely humid area and in winter extreme cold, the energy requirements will be different for the mention season which will govern the carbon footprint. Division into these semesters will help one to understand the effect of seasonal variations on the carbon emissions of the institute.

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Collecting the data: Based on above identified sources, in inventory list is prepared which can be used in calculating the carbon emissions. Since the emission scope are very diverse, it is important to keep a check list for collecting such data.

Calculating the carbon footprint: Greenhouse gases emitted from different scopes of carbon emission are very diverse. To quantify them, it is very important to convert these emissions into some standard unit, commonly expressed in terms of carbon footprint. Carbon footprint, will thus, represent a quantitative measure of all the greenhouse gases emitted during various activities within the institution.

CO_2 equivalent = Activity x CCF* ..1)

*CCF means Carbon Conversion Factor, Activity: Following set of activities are defined , Static Emission $CO_{2\,eq}$ = LPG consumption (Kg), Mobile Emission $CO_{2\,eq}$ = Fuel Consumption (Litre), Electricity consumption, $CO_{2\,eq}$ = Unit electricity consumption (kWh), Employee Commuting using their personal vehicles, $CO_{2\,eq}$ = Fuel Consumption (Litre), Waste disposal, $CO_{2\,eq}$ = Waste Generated (Kg), Water use, $CO_{2\,eq}$ = Water Used (Liter)

Paper Consumption, $CO_{2\,eq}$ = Paper Consumed (per sheet)

Carbon Sinks and offsets: For making the institute carbon neutral several existing sinks are identified. Most common existing sink is presence of tree cover within the operational boundary of the institute. Their carbon sequestration potential is calculated by using allometric equation. Allometric equation is a set of empirical equation which provide us with non-destructive tool of calculating biomass stored in the trees [7]. Above Ground Biomass and Below Ground Biomass both are calculated by following the equation given below:

$AGB = 34.4703 - 8.0671D + 0.6589D2$ Kg ...2)

Where D is the diameter/Girth (cm) of the Tree at 1.37m height

Above equation is valid for area having rainfall less than 1500mm. With its dry tropical type climate in the area having rainfall approximately 1200mm, above equation holds good for the area under study.

Below ground mass is approximately 15% of the Above ground mass.

$BGB = AGB \times (15/100)$ Kg ...3)

Total biomass was calculated by adding both ABG and BGB.

TB= AGB+BGB (Kg) ..4)

Out of total biomass present in the tree, only 50% is stored as carbon content in the trees and its carbon equivalent was calculated by using following formula:

CO_2 (eq.) = 0.5xTotal Biomass x (44/12) ..5)

Other sinks are also identified which have the potential to reduce the carbon either directly or indirectly. The institute has a potential to install rooftop solar panels. In addition to this, various other sustainable practices can also be adopted in many activities like making use of daylight hours, using natural ventilation system, solar chimney concepts, use of double plumbing system etc [8].

IV. DATA COLLECTION

The campus of Govt. minority hostel Sri Ganganagar lies in the Rajsthan, where distinct seasons can be observed. By following the guidelines by GHG Protocol Corporate Standards, following data is collected under various scope categories:

1. LPG consumption	2. Electricity Bill
3. Paper consumption	4. Paper used
5. Water consumption	6. Human respiration
7. Trees count	

V. CONCLUSIONS

A detailed survey of the campus and its operational activities led to the identification of the numerous emission sources and thus helped in preparing the inventory list under the guidelines of ISO 14064-1 in bottom-up approach used in Life Cycle Analysis. The total emission under various direct and indirect sources is found to be 88995.02 kg out of which electricity consumption under scope 2 contributed nearly 47%. However, if human respiration is also to be included, the emission will go upto 37449 Kg which is more than twice of the emission identified under the categories specified by GHG Protocol Corporate Standards and is the biggest source of carbon emission identified in the institution.

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Existing carbon sink in the form of tree cover is first identified through tree census and their sequestration potential is then calculated using allometric equations. Total carbon sink provided by the tress is found to be 604.2 Kg.

Thus, considering only scope 1,2 and 3 categories, the institute is operating as a carbon neutral canpus. But since human respiration is also considered, further sinks need to be identified or suggests suggested in the form of solar rooftop panels, operational rainwater harvesting system and by adopting various green products and activities like making use of star rated appliances, efficient water and energy fittings, making use of daylight hours etc. Additionally, in order to make institute more sustainable, Carbon offset is also identified.

VI. RECOMMENDATIONS

Based on the carbon footprint assessment of the hostel, several measures are recommended to reduce greenhouse gas emissions and improve environmental sustainability.

A. Installation of Solar Rooftop Photovoltaic (PV) Systems

Electricity consumption is one of the major contributors to the overall carbon footprint of the hostel. Installation of solar rooftop photovoltaic panels can significantly reduce dependence on grid electricity generated from fossil fuels. The available rooftop area can be effectively utilized to generate clean and renewable energy, resulting in reduced Scope 2 emissions and lower electricity expenditure [9]. The hostel consumed approximately **13,292 kWh of electricity during the two-year study period**. Based on the average solar energy generation potential in Sri Ganganagar Rajasthan, a **5-kW rooftop solar photovoltaic system** would be sufficient to meet the annual electricity demand of the hostel. Such a system could generate approximately **8,000 kWh annually** and offset nearly **10.9 tCO_2e** of grid-related carbon emissions over the study period.

B. Rooftop Vegetation

Installation of rooftop vegetation over the available 4000 sq ft roof area can contribute to carbon emission reduction through direct carbon sequestration and reduced building cooling demand. Based on standard green roof performance values, the proposed system can sequester approximately 0.26 tCO_2 over the study period and reduce electricity-related emissions by about 1.09 tCO_2 through energy savings. The combined reduction potential is estimated at 1.35 tCO_2, thereby contributing to the overall sustainability and carbon mitigation objectives of the hostel building [10].

C. Plantation

Approximately 5000 sq ft of available land can be utilized for plantation of native tree species such as Neem, Peepal, Jamun, Shisham, Ber, and Mulberry. With an estimated plantation density of 30 trees, the proposed green area can sequester approximately **1.25–1.50 tCO_2 annually**, depending on species composition and growth conditions. In addition to carbon sequestration, the plantation will improve biodiversity, enhance microclimatic conditions, provide shade, and contribute to the overall environmental sustainability of the hostel campus. Therefore, increasing green cover is recommended as an effective long-term carbon mitigation strategy [11].

D. Implementation of Rainwater Harvesting Systems

The installation of a rainwater harvesting system is recommended to reduce dependence on municipal water supplies and improve water sustainability within the hostel campus. By capturing and utilizing rooftop runoff for non-potable applications such as gardening, cleaning, and toilet flushing, the demand for treated water can be significantly reduced. Based on the current water consumption pattern, the proposed system has the potential to reduce approximately **0.51 tCO_2e** during the study period through indirect savings in water treatment and distribution energy. In addition to carbon emission reduction, rainwater harvesting will enhance groundwater recharge, reduce stormwater runoff, and contribute to sustainable resource management [12].

E. Bio Gas Plant Implantation

Installation of a small-scale biogas plant is recommended for the effective management of biodegradable waste generated from hostel mess activities. The organic waste can be converted into biogas, which can partially replace LPG used for cooking purposes. In addition to reducing fossil fuel consumption, the biogas plant will prevent methane emissions associated with conventional waste disposal practices. Based on the current waste generation rate, the proposed system has the potential to reduce approximately **3.39 tCO_2e** during the study period. Furthermore, the digestate produced from the biogas plant can be utilized as an organic fertilizer for campus landscaping and plantation activities, thereby promoting a circular and sustainable waste management system [13].

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F. Adoption of Energy-Efficient Appliances

The hostel should replace conventional electrical equipment with Bureau of Energy Efficiency (BEE) star-rated appliances. Energy-efficient fans, water based cooling linke ducting, refrigerators, pumps, and lighting systems consume less electricity while providing the same level of performance, thereby reducing energy consumption and associated carbon emissions.

G. Installation of Water-Efficient Fixtures

Water-saving fixtures such as low-flow taps, dual-flush toilets, sensor-based faucets, and efficient shower systems should be installed throughout the hostel premises. These measures can substantially reduce water consumption and the associated indirect carbon emissions[14].

H. Maximizing Utilization of Daylight

The hostel management should encourage the effective use of natural daylight by keeping windows unobstructed and adopting appropriate interior layouts. Reduced dependence on artificial lighting during daytime hours can lead to significant energy savings.

I. Waste Reduction and Composting Practices

Organic waste generated from hostel mess facilities should be segregated and processed through composting. Compost produced can be utilized for landscaping and plantation activities within the campus, reducing landfill emissions and promoting sustainable waste management [15].

J. No Vehicle Zone

Once the campus fully developed with above recommendations. The campus may be declared as no vehicle Zone.

The adoption of the above recommendations can significantly reduce the carbon footprint of the hostel while improving resource efficiency and environmental sustainability. The integration of renewable energy systems, water conservation measures, energy-efficient technologies, and enhanced green infrastructure can support the institution's long-term goal of achieving a low-carbon and environmentally responsible campus. The total carbon emission potential is shown in table 3.

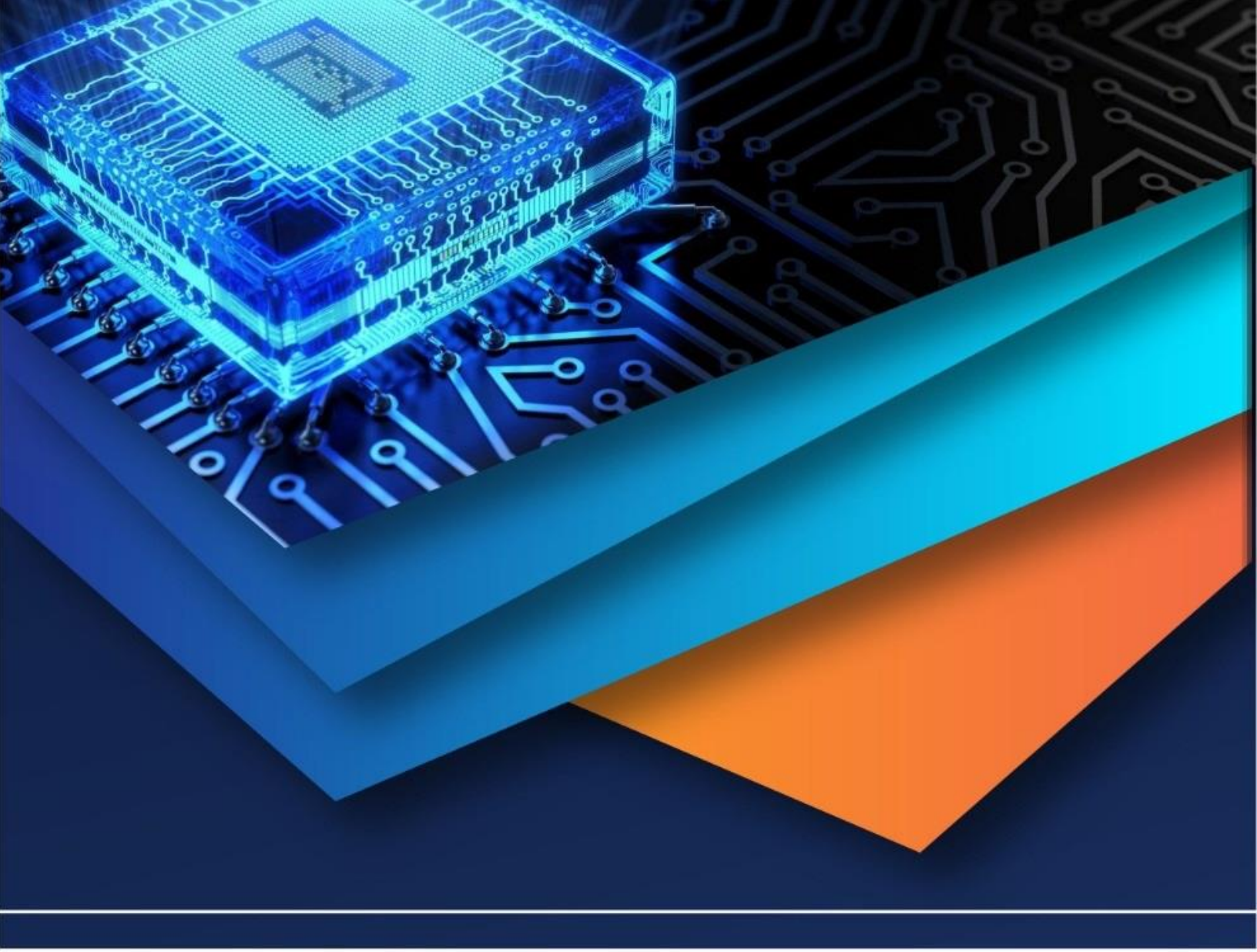
Table 3: Scope-wise Carbon Emissions and Potential Reduction Measures

Scope	Emission Source	Existing Emissions (tCO_2e/yr)	Suggested Mitigation Measure	Carbon Reduction (tCO_2e/yr)	Carbon Emission from Mitigation	Effective Potential Reduction (tCO_2e/yr)
Scope 1	LPG Consumption	13.76	Biogas Plant (Organic Waste to Energy)	0.39	0.05 (one-time construction)	0.34
			Energy-efficient cooking practices	0.2	Negligible	0.2
Scope 2	Electricity Consumption	13.29	5 kW Solar Rooftop PV System	10.9	2.20 (one-time manufacturing & installation)	8.70 (Year 1) / 10.90 thereafter
			Rooftop Vegetation (Cooling Effect)	1.09	0.10 (annual maintenance)	0.99
Scope 3	Employee Commuting	22.18	Carpooling, Cycling & Public Transport	2.00–4.00	Negligible	2.00–4.00
	Paper Consumption	0.02	Digital Documentation	0.01	Negligible	0.01
	Waste Disposal	4.28	Biogas Plant & Composting	3	0.10 (operation & maintenance)	2.9
	Water Consumption	1.01	Rainwater Harvesting System	0.51	0.08 (construction and maintenance)	0.43
Other	Human Respiration	37.45	Not practically reducible	–	–	–
Carbon Sink	Existing Trees	−0.99	Additional Plantation (3000 sq ft)	1.25–1.50	0.05 (planting and irrigation)	1.20–1.45
			Rooftop Vegetation	0.26	0.02 (maintenance)	0.24

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