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# Assessment of Carbon Footprint Associated with Electricity Consumption at Deen Dayal Upadhyaya Gorakhpur University, India

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**Research Article**

**Keywords:** Carbon footprint, Greenhouse gases, Electricity consumption, Universities, Sustainability, Scopes 2 emissions

**Posted Date:** June 30th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-10055181/v1

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**Additional Declarations:** No competing interests reported.

# Abstract

Climate change and environmental sustainability have emerged as critical global challenges, highlighting the need to quantify and manage greenhouse gas (GHGs) emissions across various sectors, including higher education institutions. Universities consume substantial amounts of electricity to support academic, research, administrative, and residential activities, making electricity-related emissions a significant component of their environmental footprint. This study assesses the carbon footprint associated with electricity consumption at Deen Dayal Upadhyaya (DDU) Gorakhpur University, Uttar Pradesh, India, with a particular focus on Scope 2 emissions generated from purchased electricity during the period 2019–2024.

The assessment was conducted using the Greenhouse Gas (GHGs) Protocol developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). Monthly electricity consumption data were obtained from electricity bills provided by the Uttar Pradesh Power Corporation Limited (UPPCL), while emission factors were sourced from the Central Electricity Authority (CEA), Government of India. Carbon emissions (CEs) were estimated by applying annual emission factors to electricity consumption data. The study also evaluated the contribution of on-campus solar photovoltaic systems in reducing grid electricity dependence and associated emissions.

The results revealed pronounced seasonal variations in electricity consumption and CEs, with peak values recorded during the summer months (May–June) due to increased cooling requirements and intensive campus operations. Lower electricity consumption was observed during winter months. A significant decline in usage of electricity and associated emissions occurred during 2020–2021 as a result of COVID-19-related restrictions, whereas a substantial increase was observed during 2023–2024 following the resumption of normal academic and administrative activities. Annual electricity consumption increased from 2,074,160 kWh in 2019 to 3,181,673 kWh in 2024, reflecting growth in the demand of energy in the campus. Solar Energy Generation contributed significantly to reducing net grid electricity consumption and CEs; however, a decline in solar energy production during 2023 increased dependence on grid electricity and resulted in higher emissions.

The findings confirm that electricity consumption represents a major source of indirect CEs within university campuses and highlight the critical role of renewable energy in mitigating environmental impacts. Expanding solar photovoltaic capacity, improving energy efficiency, adopting energy-efficient technologies, and promoting energy-conscious behavior among campus stakeholders can substantially reduce institutional carbon footprints. The study demonstrates that integrating renewable energy with effective energy management strategies is essential for sustainable campus development and climate change mitigation. The findings provide valuable insights for policymakers, university administrators, and sustainability practitioners seeking to enhance environmental performance and support the achievement of Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action).


# Introduction

In the contemporary era, sustainability is widely conceptualized through the framework of the Sustainable Development Goals (SDGs), which integrate economic, environmental, and social dimensions of development (1). Growing concerns regarding environmental degradation, resource depletion, and climate change have elevated sustainable development to a global priority since late twentieth century. International initiatives such as the Brundtland Report (1987), the Rio Declaration (1992), Agenda 21, and the Paris Agreement (2015) have consistently emphasized the necessity of balancing economic growth with environmental protection and social well-being (2).

Within higher education institutions, sustainability initiatives are commonly implemented under the concept of a “green campus,” which promotes environmentally responsible practices in teaching, research, administration, and infrastructure management. One of the most widely adopted approaches for evaluating the environmental performance of a green campus is the assessment of its carbon footprint (1). Carbon footprint analysis enables institutions to quantify greenhouse gases (GHGs) emissions associated with their activities and identify opportunities for reducing their environmental impact.

Climate change has emerged as one of the most pressing environmental challenges of the twenty-first century, posing significant threats to ecosystems, public health, economic stability, and global sustainability (3). According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the observed increase in global temperatures is primarily attributable to anthropogenic activities (4). Human-induced emissions resulting from fossil fuel combustion, industrial processes, deforestation, and rapid urbanization have substantially increased the concentration of greenhouse gases (GHGs) in the atmosphere, thereby intensifying global warming and associated climatic disruptions (4, 5). The IPCC identifies 18 GHGs with varying global warming potentials. However, under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, carbon accounting primarily focuses on six key GHGSs: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride ($SF_6$), while other gases are regulated through separate mechanisms (6). Among these, $CO_2$ remains the dominant contributor to climate change due to its large-scale release from fossil fuel-based energy generation and industrial activities. The increasing concentrations of major GHGs, particularly $CO_2$, $CH_4$, and $N_2O$, have resulted in rising global temperatures, altered precipitation patterns, glacier retreat, sea-level rise, and an increased frequency and intensity of extreme weather events (3, 7). The power generation sector is a major contributor to these emissions. Emissions from the power industry have increased by more than 300% in 2023 compared with 1990 and by 147% compared with 2005. Furthermore, emissions continued to rise in the short term, recording a 9% increase between 2022 and 2023 (8). Consequently, environmental degradation in the form of air, water, and soil pollution has intensified, adversely affecting human health, biodiversity, and economic systems.

India has experienced a substantial increase in greenhouse gas emissions over the period from 1990 to 2023 (9). Currently, India ranks as the third-largest emitter of $CO_2$ globally, accounting for approximately

7% of global $CO_2$ emissions in 2022, after China and the United States. Total national emissions during that year were estimated at around 2.7 billion tonnes of carbon dioxide equivalent ($CO_2e$). Nevertheless, India's per capita emissions remain relatively low, at approximately 1.9 tonnes per person, significantly below the global average of 4.7 tonnes (3). Despite this comparatively low per capita contribution, the country's growing population, expanding economy, and increasing energy demand underscore the importance of implementing effective emission mitigation strategies.

In this context, the concept of the carbon footprint has emerged as a valuable tool for quantifying environmental impacts. A carbon footprint is broadly defined as the total amount of GHGs emissions, both direct and indirect, generated by an activity, organization, product, or individual, expressed in terms of $CO_2e$ (10). According to the GHGSs Protocol, emissions are categorized into three scopes. Scope 1 encompasses direct emissions from owned or controlled sources; Scope 2 includes indirect emissions resulting from the consumption of purchased electricity, steam, heating, or cooling; and Scope 3 covers all other indirect emissions, including those associated with transportation, waste management, procurement, and other value-chain activities (2). The relationship between human activities and carbon emissions (CEs) became particularly evident during the COVID-19 pandemic. The World Health Organization officially declared COVID-19 a global pandemic on March 11, 2020. In response, governments worldwide implemented restrictions that significantly reduced transportation, industrial operations, and institutional activities. Educational institutions shifted from face-to-face instruction to online and distance-learning models, resulting in a marked decline in campus-related energy consumption and associated CEs. This unprecedented disruption in educational systems and societal activities led to a temporary reduction in carbon footprints across many sectors, including universities (11). The COVID-19 pandemic also introduced long-term changes in academic and administrative operations. Post-pandemic educational systems increasingly adopted hybrid and online modes of learning and administration, altering mobility patterns and resource consumption among students and staff. These transformations have demonstrated the potential of digital and flexible working arrangements to improve operational efficiency and reduce campus-related CEs (12). At the same time, the pandemic significantly affected multiple aspects of society, including healthcare, economies, and educational systems worldwide (13). In India, the nationwide lockdown and closure of schools, colleges, and universities were implemented to control the spread of the disease, further highlighting the connection between institutional activities and environmental impacts.

Higher education institutions play a critical role in promoting sustainability due to their influence on future generations, research activities, and community engagement. Deen Dayal Upadhyaya Gorakhpur University (DDUGU) located in Uttar Pradesh, India, is a prominent academic institution characterized by diverse activities including teaching, research, administration, and residential services. The university campus consists of academic buildings, laboratories, libraries, administrative offices, and student hostels, all of which require substantial energy inputs for daily operations. Electricity constitutes a fundamental resource supporting campus activities, including lighting, air conditioning, laboratory operations, information technology infrastructure, and administrative functions. Given India's continued

dependence on fossil fuel-based electricity generation, electricity consumption represents a major source of indirect GHGs emissions, categorized under Scope 2 emissions. Consequently, assessing the carbon footprint associated with electricity consumption is essential for understanding the environmental impact of university operations and identifying opportunities for emission reduction. Previous studies have demonstrated that energy consumption patterns in higher education institutions are closely influenced by factors such as campus size, population, infrastructure development, and operational intensity (14). As student enrolment, staff numbers, and campus facilities expand, energy demand generally increases, leading to higher CEs. Furthermore, the growing use of electrical appliances, air-conditioning systems, digital technologies, and information infrastructure has intensified electricity consumption across educational institutions (7). These trends highlight the urgent need to adopt energy-efficient technologies and encourage behavioral changes aimed at reducing energy demand.

Carbon footprint assessment serves as an important foundation for sustainability planning and policy development. By identifying major emission sources, institutions can formulate targeted mitigation strategies, including improvements in energy efficiency, adoption of renewable energy technologies, implementation of energy management systems, and promotion of sustainable consumption practices. Furthermore, carbon footprint assessments contribute directly to achieving global sustainability objectives, particularly Sustainable Development Goal 13 (Climate Action) (2).

In the context of DDUGU, a comprehensive assessment of campus CEs can provide valuable insights into the environmental consequences of institutional activities and support evidence-based decision-making for sustainability initiatives. Such an assessment can help identify opportunities for reducing electricity consumption, improving operational efficiency, and transitioning toward renewable energy sources such as solar power. Moreover, the implementation of sustainable energy practices within the university can serve as a model for other educational institutions and contribute to broader national and global climate mitigation efforts.

In conclusion, the growing urgency of climate change and the pursuit of sustainable development have made carbon footprint assessment an essential tool for understanding and managing environmental impacts. Higher education institutions, including DDUGU, possess both the responsibility and the opportunity to contribute to climate action through sustainable campus management. By focusing on electricity consumption and associated Scope 2 emissions, the present study seeks to contribute to the expanding body of knowledge on carbon footprint assessment while supporting the development of effective strategies for creating a more sustainable university campus.

## Materials and Methods

# Study Area

The present study was conducted at DDUGU, located in Gorakhpur, Uttar Pradesh, India (26.7481°N, 83.3808°E). The university is situated approximately 2 km east of the city center and lies within walking distance of the Gorakhpur railway station to the south. Established in 1957, the university campus covers an area of 190.96 acres (77.28 hectares). At the time of the study, the university comprised two campuses, eight faculties, and more than twenty academic departments. The institution served over 20,000 students and employed approximately 400 teaching staff and more than 1,500 non-teaching personnel. The campus infrastructure included around 30 buildings supplied with electricity throughout the day, encompassing academic blocks, administrative offices, research facilities, a central library, hostels, and a canteen. The diversity and scale of these facilities make the university an appropriate case study for assessing electricity-related CEs in higher education institutions.

## Greenhouse Gases Protocol

The GHGs accounting and reporting framework adopted in this study follows the *Greenhouse Gas Protocol: Corporate Accounting and Reporting Standard* developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) in 2011. This protocol is one of the most widely recognized and accepted methodologies for organizational carbon footprint assessment and provides standardized guidelines for quantifying and reporting greenhouse gas emissions covered under the Kyoto Protocol.

Carbon footprint refers to the total amount of greenhouse gas emissions, expressed as $CO_2e$, that are directly or indirectly generated by an activity, organization, product, or service throughout its life cycle. Although the IPCC identifies 18 greenhouse gases with varying global warming potentials, carbon accounting under the UNFCCC and its Kyoto Protocol primarily considers six GHGs: $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, and $SF_6$ (15).

According to the GHGs Protocol, emissions are classified into three categories:

## Scope 1 Emissions

Scope 1 emissions refer to direct GHGs emissions from sources that are owned or controlled by an organization. These emissions typically arise from the combustion of fossil fuels in boilers, furnaces, generators, turbines, and other equipment, including fuels such as kerosene and liquefied petroleum gas (LPG). Scope 1 emissions were not considered in the present study.

## Scope 2 Emissions

Scope 2 emissions comprise indirect GHGs emissions associated with the generation of purchased electricity consumed by an organization. These emissions occur at the power generation source and are attributed to the end user based on electricity consumption. Since electricity consumption represents a

major source of indirect emissions within the university, Scope 2 emissions constitute the primary focus of this study.

## Scope 3 Emissions

Scope 3 emissions include all other indirect emissions resulting from organizational activities that originate from sources neither owned nor controlled by the institution. Examples include emissions associated with student and staff commuting, paper consumption, food waste, wastewater treatment, water supply, and solid waste disposal. Scope 3 emissions were not included in the present assessment.

# Data Collection

Two types of data were required for estimating Scope 2 CEs: activity data and emission factors. Activity data consisted of electricity consumption records obtained from monthly electricity bills issued by the UPPCL. Electricity consumption was recorded in kilowatt-hours (kWh) for all university facilities within the defined organizational boundary.

Data were collected for five financial years: 2019–2020, 2020–2021, 2021–2022, 2022–2023, and 2023–2024. Monthly electricity consumption data were aggregated to estimate annual electricity usage across the campus.

The emission factors used to calculate $CO_2$ emissions for the corresponding years were 0.713, 0.703, 0.715, 0.716, 0.727, and 0.710 kg $CO_2$e/kWh for 2019, 2020, 2021, 2022, 2023, and 2024, respectively. These factors were applied to convert electricity consumption into equivalent greenhouse gas emissions.

## Emission Calculation

Scope 2 CEs resulting from electricity consumption were estimated using the following equation:

## CE = AD / EF

where:

**CE** = Carbon emissions (kg $CO_2$e)

**AD** = Activity data, represented by electricity consumption (kWh)

**EF** = Emission factor (kg $CO_2$e/kWh)

The equation was applied to monthly electricity consumption data, and the resulting emissions were aggregated to obtain annual Scope 2 CEs for DDU Gorakhpur University.

Net Grid was calculated by using formula:

# NGC = TEC – SEG

where:

NGC = Net grid consumption (kWh)

TEC = Total Electricity Consumption (kWh)

SEG = Solar Energy Generation (kWh)

## Results

To evaluate the potential environmental impact of conventional electricity generation, Scope 2 emissions were estimated by assuming that the electricity consumed on campus was generated entirely from thermal power plants. Emission factors published by the Central Electricity Authority (CEA), Government of India, were applied for the calculation of CEs (16). This approach enables a comparative assessment of GHGSs emissions under a fossil fuel-based electricity generation scenario and highlights the environmental benefits of integrating renewable energy sources into the energy mix.

# Monthly Electricity Consumption (kWh) from 2019 to 2024

Figure 1 illustrates the monthly electricity consumption at DDU Gorakhpur University during the period 2019–2024, revealing distinct seasonal fluctuations as well as notable inter-annual variations. Electricity consumption remained relatively low during January and increased gradually through February and March. A pronounced rise was observed from April onwards, with consumption reaching its maximum levels during May and June. This pattern reflects the increased demand for electricity during the pre-summer and peak summer months, primarily due to greater reliance on cooling systems and other energy-intensive activities. Following the peak period, electricity consumption declined slightly in July but remained comparatively high. A moderate increase was again observed during August and September, indicating sustained energy demand during the late summer and monsoon seasons. From October onward, electricity consumption exhibited a consistent downward trend, with November and December recording the lowest values, corresponding to reduced cooling requirements and lower overall energy demand during the winter season.

A comparison across the study period further indicates a gradual increase in electricity consumption in the later years, particularly during 2023 and 2024, where higher consumption levels were recorded across most months. This trend may be associated with increased campus occupancy, expansion of academic and administrative activities, and growing dependence on electrical infrastructure and equipment. In contrast, electricity consumption was noticeably lower during 2020 and 2021 compared to the other years. This reduction coincides with the COVID-19 pandemic, during which academic activities

were largely conducted through online platforms, and access to campus facilities was substantially restricted. Consequently, reduced campus occupancy and operational activities resulted in lower electricity demand. The decline in electricity consumption during this period also contributed to a corresponding reduction in CEs associated with purchased electricity. Overall, Fig. 1 demonstrates a clear seasonal pattern characterized by peak electricity consumption during the summer months and reduced demand during the winter season. The results also highlight the significant influence of the COVID-19 pandemic on campus energy consumption patterns, followed by a progressive increase in electricity demand as normal academic and administrative activities resumed in subsequent years.

# Monthly Solar energy consumption (kWh) from 2019 to 2024

Figure 2 depicts the monthly SEG at DDU Gorakhpur University from 2019 to 2024, highlighting distinct seasonal variations and inter-annual fluctuations. SEG was relatively low during January and increased progressively through February and March, corresponding to improving solar irradiance and longer daylight hours. This upward trend continued during April and reached its maximum levels in April and May reflecting the period of highest solar radiation and optimal conditions for photovoltaic energy production. Following the summer peak, SEG exhibited a slight decline in June, however, generation increased again in July. During August and September, generation levels showed moderate fluctuations while maintaining overall stability. These variations may be attributed to monsoonal weather conditions, particularly increased cloud cover and reduced solar insolation. From October onward, SEG gradually decreased, with November and December recording the lowest values of the year. This decline is consistent with shorter daylight durations and reduced solar intensity during the winter season.

Inter-annual comparisons indicate a general increase in SEG in the later years of the study period, particularly during 2023 and 2024, when higher generation levels were observed across most months. This trend suggests improvements in solar energy infrastructure, operational efficiency, and the overall utilization of renewable energy resources on campus. In contrast, comparatively lower SEG was observed during 2020 and 2021. This reduction may be associated with disruptions caused by the COVID-19 pandemic, which potentially affected system maintenance, monitoring activities, and overall operational efficiency. The restrictions imposed during this period may have indirectly influenced the performance and management of renewable energy systems, resulting in reduced energy generation. Overall, Fig. 2 demonstrates a pronounced seasonal pattern characterized by maximum SEG during the summer months and reduced output during the winter season. The results further indicate a temporary decline in generation during the COVID-19 period (2020–2021), followed by a gradual recovery and sustained increase in subsequent years. These findings highlight the significant influence of seasonal climatic conditions and institutional operational factors on the performance of campus-based solar energy systems.

# Monthly Net Grid Electricity Consumption (2019–2024)

Figure 3 illustrates the monthly net grid electricity consumption (kWh) at DDU Gorakhpur University during the period 2019–2024. The results reveal distinct seasonal variations as well as notable inter-annual differences in the university's dependence on grid-supplied electricity. At the beginning of each year, net grid electricity consumption remained relatively high during January and February, indicating greater reliance on the electricity grid to meet campus energy requirements. A decline was observed during March and April, suggesting a temporary reduction in grid dependency. However, from May onward, net grid consumption increased substantially, reaching one of its highest levels in June. This trend reflects the elevated electricity demand during the summer season, when the use of cooling systems and other energy-intensive equipment is at its maximum. Following the June peak, net grid electricity consumption decreased in July. Moderate fluctuations were observed during August and September, indicating sustained energy demand despite seasonal variations. An additional increase was recorded in October, suggesting renewed dependence on grid electricity during this period. Subsequently, net grid consumption declined during November and December, corresponding to reduced electricity demand associated with cooler weather conditions and lower energy requirements across campus facilities.

A comparison among years demonstrates that net grid electricity consumption was higher during 2023 and 2024 across most months. This increase reflects the expansion of academic, administrative, and residential activities following the resumption of normal campus operations, as well as a growing overall demand for electricity. Significantly lower net grid consumption observed during 2020 and 2021 can be attributed to when restrictions on campus access, reduced occupancy, and the widespread adoption of online teaching and administrative activities substantially decreased electricity demand and, consequently, dependence on grid electricity as this period coincides with COVID 2019 pandemic times when lockdown was imposed in the country. Negative net grid consumption values recorded in certain months and years values indicate the timeline when on-campus SEG exceeded TEC, resulting in a surplus of electricity. Such instances highlight the contribution of renewable energy systems in offsetting grid electricity demand and reducing the campus's dependence on conventional energy sources. Hence, Fig. 3 demonstrates a clear seasonal pattern in net grid electricity consumption, characterized by higher grid dependency during peak summer months and lower consumption during periods of reduced energy demand. The results further emphasize the impact of the COVID-19 pandemic on campus energy use, followed by a progressive increase in grid electricity consumption as institutional activities returned to pre-pandemic levels. The occurrence of negative net grid values also underscores the growing role of solar energy in enhancing campus energy sustainability and reducing reliance on grid-based electricity.

# Monthly Carbon emissions (metric tonnes $CO_2$) from 2019 to 2024

Figure 4 illustrates the monthly CEs associated with electricity consumption at DDU Gorakhpur University during the period 2019–2024. The results reveal distinct seasonal fluctuations and inter-annual variations, reflecting changes in electricity demand, grid dependency, and renewable energy contribution

across the study period. At the beginning of each year, CEs remained at moderate levels during January and February, followed by a slight decline in March and April. This reduction corresponds to lower electricity demand and reduced reliance on grid-supplied power during these months. From May onward, emissions increased progressively, reaching one of their highest levels in June. The sharp rise during the summer season can be attributed to increased electricity consumption, particularly for cooling and other energy-intensive activities, resulting in greater dependence on grid electricity. Although emissions declined slightly in July, they remained comparatively high throughout the subsequent months. Moderate fluctuations were observed during August and September, indicating sustained energy consumption despite seasonal changes. A further increase was recorded in October, suggesting renewed growth in electricity demand. Thereafter, CEs gradually decreased during November and December, coinciding with lower energy requirements during the cooler months of the year.

Inter-annual comparisons indicate that CEs were generally higher during 2023 and 2024 than in the preceding years. This trend reflects the increasing electricity demand associated with the resumption and expansion of academic, administrative, and residential activities on campus. In contrast, emissions were substantially lower during 2020 and 2021, coinciding with the COVID-19 pandemic. Restrictions on campus operations, reduced occupancy, and the transition to online teaching significantly lowered electricity consumption and, consequently, CEs during this period. Significant, negative CE values were observed in certain months across specific years. These values occurred when SEG exceeded campus electricity consumption, resulting in a net surplus of renewable electricity. Such instances demonstrate the effectiveness of on-campus solar energy systems in offsetting grid electricity consumption and reducing the carbon footprint of university operations. Figure 4 therefore highlights a pronounced seasonal pattern in CEs, characterized by elevated emissions during the summer months and lower emissions during cooler periods. The results further demonstrate the temporary reduction in emissions during the COVID-19 period (2020–2021), followed by a gradual increase as campus activities returned to normal. The occurrence of negative emissions in some months underscores the important role of renewable energy in mitigating electricity-related greenhouse gas emissions. The annual trends in total electricity consumption, SEG, net grid electricity consumption, and CEs from 2019 to 2024 are summarized in Table 1. The results reveal considerable year-to-year variations, highlighting the dynamic relationship between campus energy demand, renewable energy generation, and associated CEs.

TEC exhibited a non-linear trend throughout the study period. A decline was observed in 2021, followed by a consistent increase in subsequent years, with the highest consumption recorded in 2024. The reduction in 2021 is likely attributable to disruptions caused by the COVID-19 pandemic, whereas the subsequent increase reflects the gradual restoration of academic, administrative, and residential activities, accompanied by growing energy demand across the university campus.

SEG remained relatively high during the initial years of the study, particularly from 2019 to 2021. However, a declining trend was observed thereafter, culminating in a substantial reduction in 2023. This decrease may be associated with operational constraints, maintenance issues, system degradation, or

unfavorable meteorological conditions affecting photovoltaic performance. Encouragingly, SEG recovered in 2024, indicating improvements in system operation and renewable energy production.

Net grid electricity consumption responded directly to changes in both total electricity demand and SEG. The lowest grid dependency was recorded in 2021, reflecting reduced campus electricity consumption combined with relatively strong solar energy contribution. Conversely, net grid electricity use increased markedly in 2023, coinciding with the decline in SEG. This pattern indicates greater reliance on conventional grid-supplied electricity when renewable energy availability decreases. A similar trend was observed for CEs. Emission levels were lowest in 2021 and increased substantially in 2023 due to the combined effects of higher electricity demand and reduced SEG. Although a slight decline was observed in 2024, CEs remained higher than those recorded during the earlier years of the study period.

The findings demonstrate a strong relationship between SEG, grid electricity consumption, and CEs. Variations in renewable energy output directly influenced the university's dependence on grid electricity, which subsequently affected its carbon footprint. Periods of reduced solar generation resulted in greater reliance on conventional electricity sources and higher GHGSs emissions, whereas increased solar energy production contributed to lower grid dependency and reduced CEs. These results underscore the importance of maintaining and expanding renewable energy infrastructure as a key strategy for reducing campus-level CEs and enhancing long-term sustainability.

# Analysis of Electricity Carbon Footprint

The electricity supply in Uttar Pradesh is derived from a combination of energy sources, including hydropower, thermal power, and renewable energy systems. At DDU Gorakhpur the analysis revealed that electricity demand at DDU Gorakhpur University was primarily met through grid-supplied electricity, with additional contributions from on-campus solar photovoltaic (PV) installations. If the TEC had been supplied exclusively through thermal power generation, the associated carbon footprint would have been 1,478.88 $tCO_2e$ in 2019, 1,540.12 $tCO_2e$ in 2020, 1,069.02 $tCO_2e$ in 2021, 1,406.30 $tCO_2e$ in 2022, 2,087.74 $tCO_2e$ in 2023, and 2,258.99 $tCO_2e$ in 2024. However, the integration of on-campus solar PV systems substantially reduced dependence on grid electricity and consequently lowered greenhouse gas emissions. Based on net grid electricity consumption after accounting for solar power generation, the corresponding carbon footprint was estimated at 887.35 $tCO_2e$ in 2019, 789.30 $tCO_2e$ in 2020, 614.17 $tCO_2e$ in 2021, 845.55 $tCO_2e$ in 2022, 1,920.22 $tCO_2e$ in 2023, and 1,613.77 $tCO_2e$ in 2024. These findings demonstrate the significant role of solar PV installations in mitigating CEs associated with campus electricity consumption, resulting in notable emission reductions across the study period (Table 1).

Table 1
Comparative Assessment of Energy consumption, SEG, Net grid unit and CEs (2019-24)

| Year | TEC | | SEC | NGC | |
|---|---|---|---|---|---|
| | (kWh) | ($tCO_2e$) | (kWh) | (kWh) | ($tCO_2e$) |
| 2019 | 2074160 | 1478.8760 | 931610 | 1142550 | 887.3531 |
| 2020 | 2190789 | 1540.1246 | 990646 | 1200143 | 789.3021 |
| 2021 | 1495134 | 1069.0208 | 841070 | 654064 | 614.1711 |
| 2022 | 1964107 | 1406.3006 | 774876 | 1189231 | 845.5494 |
| 2023 | 2871720 | 2087.7404 | 311298.8 | 2560421.2 | 1920.218 |
| 2024 | 3181673 | 2258.9885 | 908765 | 2272908 | 1613.765 |

The comparatively lower emissions recorded during 2020 and 2021 correspond to the reduction in campus activities during the COVID-19 pandemic, which resulted in lower electricity consumption. In contrast, the substantial increase observed in 2023 and 2024 reflects the resurgence of academic, administrative, and residential activities, leading to higher energy demand and associated emissions.

The marked variation in annual CEs demonstrates the strong relationship between electricity consumption patterns and GHGs emissions. Furthermore, the findings underscore the critical role of renewable energy technologies, particularly solar power, in offsetting grid electricity demand and reducing the overall carbon footprint of the university. By increasing the share of renewable energy and improving energy efficiency, higher education institutions can significantly reduce their dependence on carbon-intensive electricity sources and contribute to broader climate change mitigation efforts. The analysis highlights the environmental advantages of renewable energy adoption and emphasizes the importance of transitioning toward cleaner energy systems as part of sustainable campus development strategies.

# Discussion

The present study examined the carbon footprint associated with electricity consumption at (DDUGU) and evaluated its temporal variation in relation to institutional activities, energy demand, and renewable energy utilization. The findings demonstrate that CEs are strongly influenced by electricity consumption patterns, operational intensity, and seasonal variability. Periods characterized by increased academic, administrative, and residential activities corresponded with higher electricity demand and consequently greater CEs. Electricity consumption has been widely recognized as one of the principal contributors to GHGSs emissions in higher education institutions. Similar findings have been reported for the Institute Teknologi Sumatera (ITERA), where electricity consumption accounted for more than 60% of total campus emissions (17). Likewise, studies conducted across universities worldwide have consistently

identified electricity-dependent systems, including air conditioning, lighting, laboratory equipment, and information technology infrastructure, as major sources of GHGSs emissions (18). The results of the present study therefore reinforce the conclusion that effective management of electricity consumption is essential for reducing Scope 2 emissions within university campuses. The temporal variation observed in CEs further highlights the influence of institutional operational dynamics. Emission levels fluctuated in accordance with academic schedules, campus occupancy, climatic conditions, and operational requirements. During periods of intensive academic activity, electricity consumption increased due to greater utilization of classrooms, laboratories, administrative facilities, and residential infrastructure. Conversely, lower energy demand was observed during vacation periods and phases of reduced campus activity. A comparable phenomenon was documented during the COVID-19 pandemic, when restrictions on campus operations led to significant reductions in energy consumption and associated CEs (11). These findings emphasize that institutional activity levels are a critical determinant of CEs, and any disruption to normal operations can substantially alter the carbon footprint of a university campus.

The present assessment was conducted using internationally recognized carbon accounting frameworks, including the GHGSs Protocol and IPCC guidelines (2). These methodologies classify emissions into Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased electricity), and Scope 3 (other indirect emissions), thereby providing a comprehensive and standardized framework for emission accounting. The application of these methodologies enhances the transparency, consistency, and comparability of the results with those reported in similar studies. Comparable approaches have been adopted in carbon footprint assessments conducted at Gandhi Krishi Vigyana Kendra (GKVK) and Himachal Pradesh University (3, 19). The findings further support the widely accepted understanding that anthropogenic activities are the primary drivers of GHGSs emissions. Activities such as electricity consumption, transportation, fuel combustion, and waste generation contribute substantially to atmospheric $CO_2$ concentrations, the dominant greenhouse gas responsible for climate change (6). Among these activities, electricity consumption emerged as the most significant contributor to Scope 2 emissions within DDUGU. CEs are defined as the total quantity of GHGSs released directly or indirectly through human activities, expressed as $CO_2e$ (20). In the present study, emissions were estimated using activity-based data on electricity consumption in accordance with the IPCC Tier 2 methodology (15). The results revealed a substantial rebound in emissions following the COVID-19 pandemic. Total emissions increased from 614.1711 $tCO_2e$ during 2020–2021 to 1920.218 $tCO_2e$ during 2023–2024, representing more than a threefold increase. This sharp rise reflects the resumption of full-scale academic, administrative, and residential activities, accompanied by increased utilization of campus infrastructure and facilities.

Electricity consumption was identified as the dominant source of CEs at DDUGU. Electricity generation from thermal power plants relies heavily on the combustion of fossil fuels, resulting in significant $CO_2$ emissions (21). Since a substantial proportion of the electricity supplied to the university originates from conventional grid-based power generation, indirect emissions associated with purchased electricity constitute the largest component of the university's carbon footprint. Emission estimates were

calculated by multiplying electricity consumption data by the corresponding emission factors, following established IPCC guidelines (22). This methodology provides a robust and widely accepted approach for estimating electricity-related emissions. The increasing carbon footprint observed during the study period can also be attributed to the expansion of campus infrastructure and the growing intensity of institutional activities. Electricity demand is driven by the operation of lecture halls, laboratories, administrative buildings, hostels, libraries, and other campus facilities. As educational institutions expand their physical infrastructure and technological capabilities, energy demand inevitably increases, leading to higher GHGSs emissions. Similar observations have been reported in studies conducted across universities worldwide, where electricity consumption consistently emerged as the largest contributor to institutional carbon footprints (4–6, 23, 24).

The annual emission values recorded at DDUGU further illustrate the dynamic relationship between energy demand and CEs. Electricity-related emissions were estimated at 887.3531, 789.3021, 614.1711, 845.5494, 1920.218, and 1613.765 $tCO_2e$ for the years 2019, 2020, 2021, 2022, 2023, and 2024, respectively. The substantial reduction observed during 2020 and 2021 reflects the impact of pandemic-related restrictions, whereas the marked increase in subsequent years corresponds to the restoration of normal campus operations and rising energy demand. These findings demonstrate how both external factors, such as public health emergencies, and internal factors, including institutional growth and operational intensity, can significantly influence CE trends. Seasonal variability also played an important role in shaping emission patterns. During summer months, increased use of air-conditioning systems and cooling equipment resulted in higher electricity consumption and consequently greater CEs. In contrast, periods characterized by lower temperatures and reduced campus activity exhibited lower energy demand and emission levels. This seasonal influence highlights the importance of incorporating climatic and operational factors into carbon footprint assessments of higher education institutions.

The findings of this study are consistent with a growing body of international literature on university carbon footprints. Aroonsrimorakot et al. reported significant electricity-related emissions at Mahidol University, Thailand (25). Similarly, Filimonau et al. documented a 29% reduction in university CEs in the United Kingdom during the COVID-19 pandemic (26). Comparable reductions were observed in studies examining university energy consumption during pandemic-related restrictions (11). Other investigations have likewise identified electricity consumption as the dominant contributor to institutional carbon footprints, including studies conducted at Afe Babalola University (27), Sri Ramakrishna Engineering College (28), ITERA (17), Pancasila University (7), FST UNJA (12), Hasanuddin University (20), University Technology Malaysia (29), Sakarya University (11), and GKVK Campus (3). Collectively, these studies provide strong evidence that electricity consumption represents the most significant source of greenhouse gas emissions in higher education institutions worldwide.

From a mitigation perspective, reducing electricity-related emissions requires a combination of technological, operational, and behavioral interventions. Expanding solar photovoltaic installations and increasing the share of renewable energy in the campus energy portfolio can substantially reduce dependence on grid electricity and lower Scope 2 emissions. Additional measures, including the

adoption of energy-efficient appliances, LED lighting systems, smart energy management technologies, and building energy optimization strategies, can further enhance energy efficiency. Behavioral interventions aimed at encouraging energy conservation among students, faculty members, and staff also represent an effective approach to reducing overall electricity demand (4).

Furthermore, universities have a strategic role in advancing sustainability and climate action. Aligning campus operations with global sustainability frameworks, including the SDGs and Nationally Determined Contributions (NDCs), can strengthen institutional commitments to environmental stewardship (3). Through the integration of sustainability principles into teaching, research, and campus management, higher education institutions can contribute significantly to climate change mitigation while serving as living laboratories for sustainable development.

The findings of the present study are consistent with existing literature and confirm that electricity consumption is the principal driver of Scope 2 emissions at university campuses. The results provide a strong foundation for the development of evidence-based carbon management strategies and highlight the importance of renewable energy adoption, energy efficiency improvements, and sustainable operational practices in achieving low-carbon and environmentally sustainable campus systems (30, 31).

# Conclusion

This study provides a comprehensive assessment of electricity consumption, solar consumption, net grid consumption dependency, and associated CEs at DDUGU during the period 2019–2024. The findings demonstrate the critical role of renewable energy integration, particularly solar photovoltaic systems, in reducing dependence on grid-supplied electricity and mitigating electricity-related CEs. The results reveal a strong inverse relationship between SEG and NGC. Periods characterized by higher solar energy production were associated with lower grid dependency and reduced CEs, confirming the effectiveness of solar energy as a sustainable alternative to conventional electricity sources. In several months, SEG exceeded campus electricity demand, resulting in negative net grid consumption and corresponding negative CE values. These observations highlight the potential of decentralized renewable energy systems to substantially offset GHGSs emissions and contribute to long-term carbon reduction objectives. The study also demonstrates that campus energy consumption and CEs are highly influenced by operational and behavioral factors. The significant reduction in electricity consumption and emissions observed during the COVID-19 pandemic reflects the direct impact of reduced campus occupancy and institutional activities on energy demand. However, the subsequent increase in electricity consumption and CEs following the resumption of normal academic and administrative operations indicates that temporary reductions in emissions are unlikely to be sustained without long-term structural and technological interventions.

An important finding of the study is the sensitivity of CEs to fluctuations in SEG. The substantial decline in solar power production observed in 2023 resulted in increased reliance on grid electricity and a corresponding rise in CEs, partially offsetting the environmental benefits achieved in previous years. This

emphasizes that the effectiveness of renewable energy systems depends not only on installed capacity but also on system reliability, regular maintenance, and efficient operational management. Seasonal variability was found to significantly influence SEG and overall energy performance. Peak solar production occurred during periods of high solar irradiance, whereas reduced generation was observed during less favorable climatic conditions. These variations highlight the need for complementary measures such as energy storage technologies, hybrid renewable energy systems, and demand-side management strategies to enhance energy security and ensure a stable supply of low-carbon electricity throughout the year.

Furthermore, the continuous increase in electricity demand during the post-pandemic period presents a potential challenge to achieving long-term sustainability goals. Although solar energy contributed substantially to reducing grid dependency and CEs, growing energy demand may diminish these benefits if appropriate energy management measures are not implemented. Therefore, renewable energy deployment should be complemented by energy efficiency improvements, sustainable building practices, and responsible energy-use behavior across the university community. Hence, the findings demonstrate that solar energy integration represents an effective pathway for reducing Scope 2 CEs and improving campus sustainability. However, maximizing these benefits requires a holistic approach that combines renewable energy expansion, energy-efficient technologies, effective system maintenance, and sustainable consumption practices. Such an integrated strategy will not only enhance the environmental performance of higher education institutions but also contribute to broader climate change mitigation efforts and the achievement of SDGs. The study further emphasizes the importance of accurately accounting for the carbon reduction benefits of SEG. Precise estimation of avoided emissions through renewable electricity production is essential for evaluating the true environmental impact of sustainability initiatives and for supporting evidence-based decision-making in institutional energy planning and carbon management.

## Abbreviations

UPPCL
Uttar Pradesh Power Corporation Limited
SDGs
Sustainable Development Goals
GHGs
Greenhouse Gases
IPCC
Intergovernmental Panel on Climate Change
UNFCCC
United Nations Framework Convention on Climate Change
$CO_2$
Carbon Dioxide

$CH_4$
Methane
$N_2O$
Nitrous Oxide
HFCs
Hydrofluorocarbons
PFCs
Perfluorocarbons
$SF_6$
Sulphur Hexafluoride
$CO_2e$
Carbon Dioxide Equivalent
DDUGU
Deen Dayal Upadhyaya Gorakhpur University
kWh
Kilowatt-Hours
CEs
Carbon emissions
AD
Activity data
EF
Emission factor
NGC
Net grid consumption
TEC
Total Electricity Consumption
SEG
Solar Energy Generation
CEA
Central Electricity Authority
PV
Solar Photovoltaic

# Declarations

### Data Availability

Data were collected from Engineering and Maintenance section of DDU Gorakhpur University.

### Author contributions

V.B.K and N.S. conceived the idea, collected data and were involved in writing the manuscript. **Funding**

No funding was used for this research paper.

**Declaration of competing interest**

The authors declare that they have no known competing interests.

**Clinical Trail Number:** Not Applicable

**Consent to Publish declaration:** Not Applicable

**Ethics declaration:** Not Applicable

**Consent to Participate declaration:** Not Applicable

**Acknowledgements**

We sincerely acknowledge the authorities of DDU Gorakhpur University, for providing the data and necessary facilities.

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# Figures

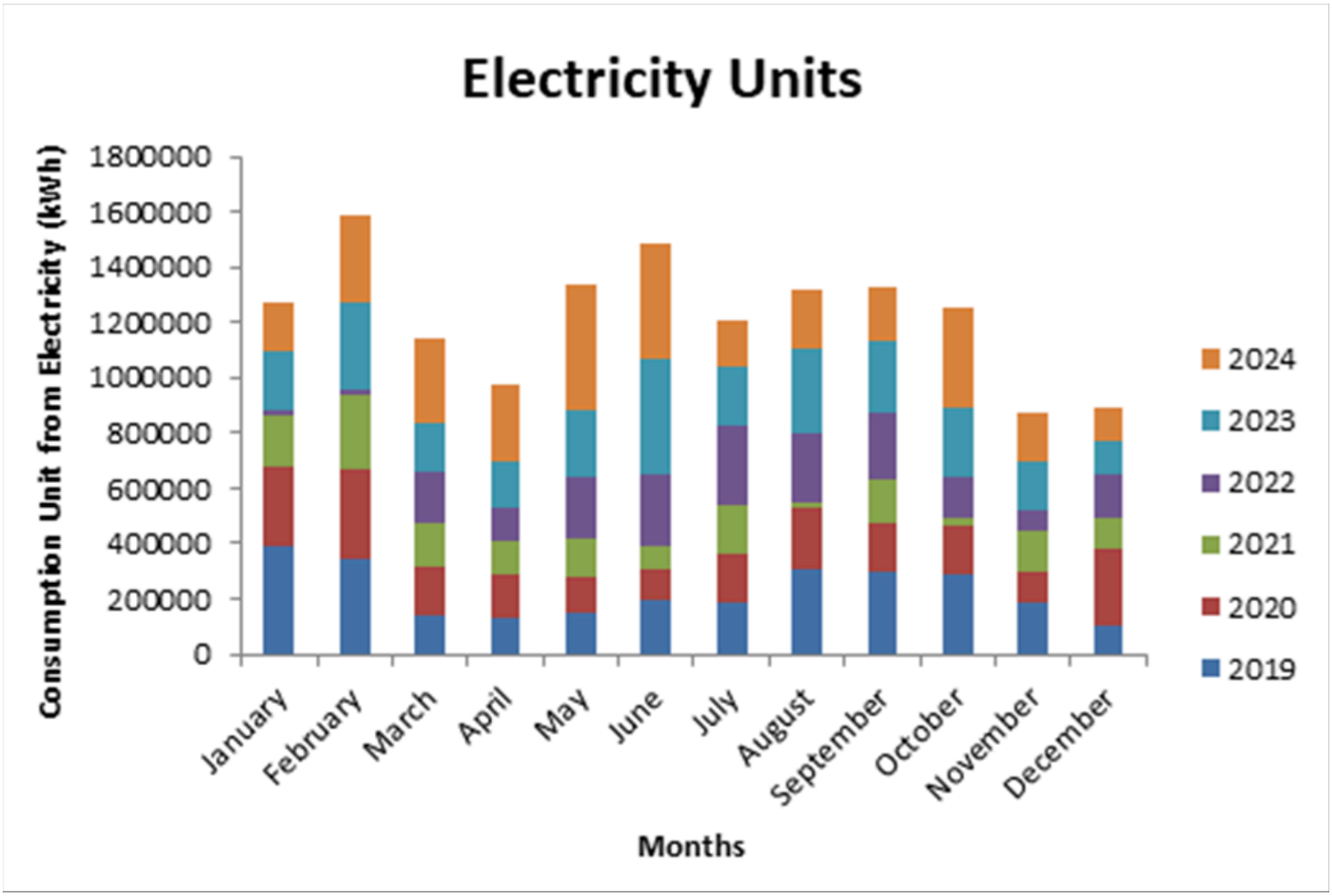



**Figure 1**

**MonthlyElectricity Consumption (kWh) from 2019 to 2024**

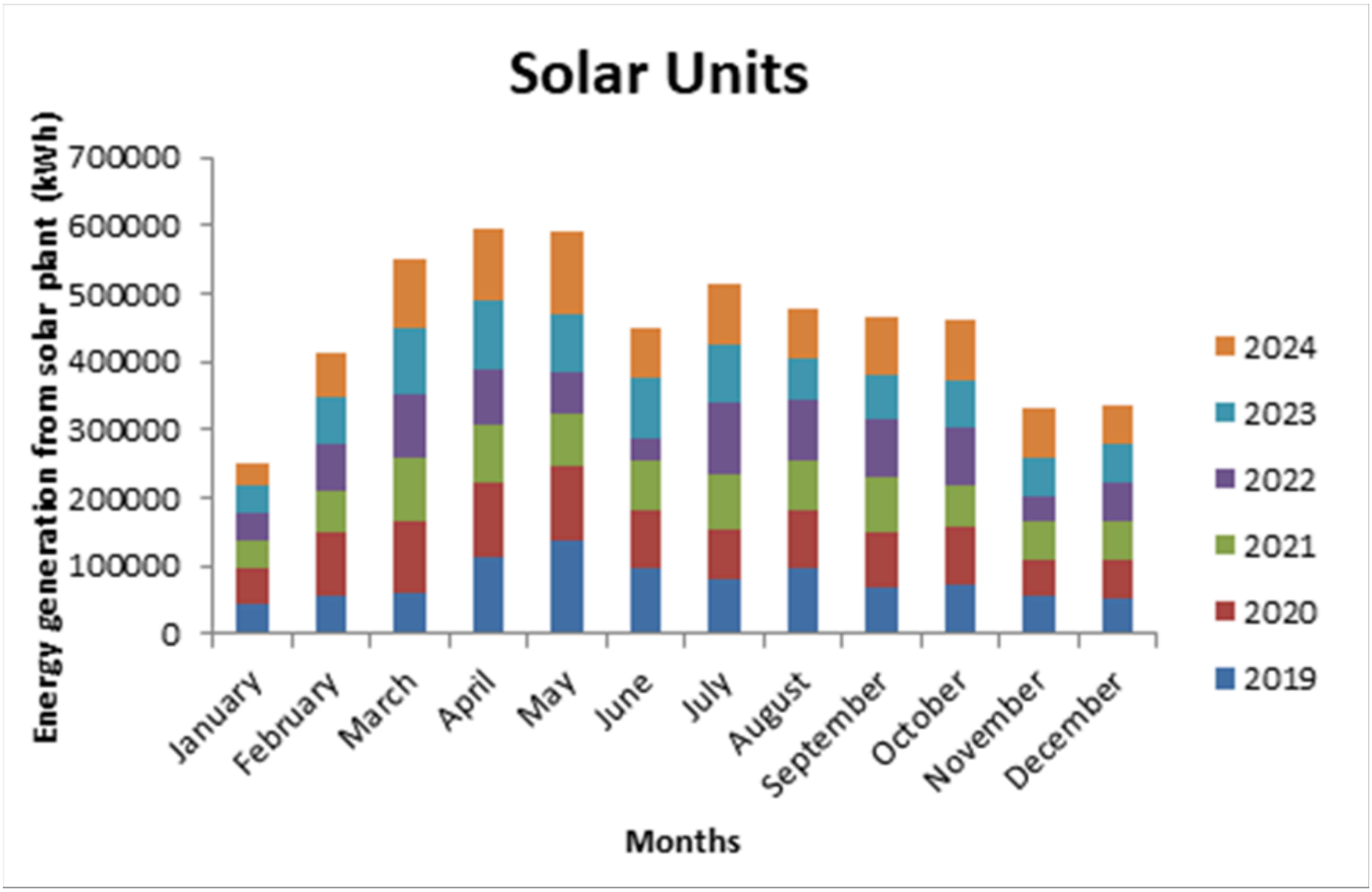



Figure 2

**Monthly Solar energy generation (kWh) from 2019 to 2024**

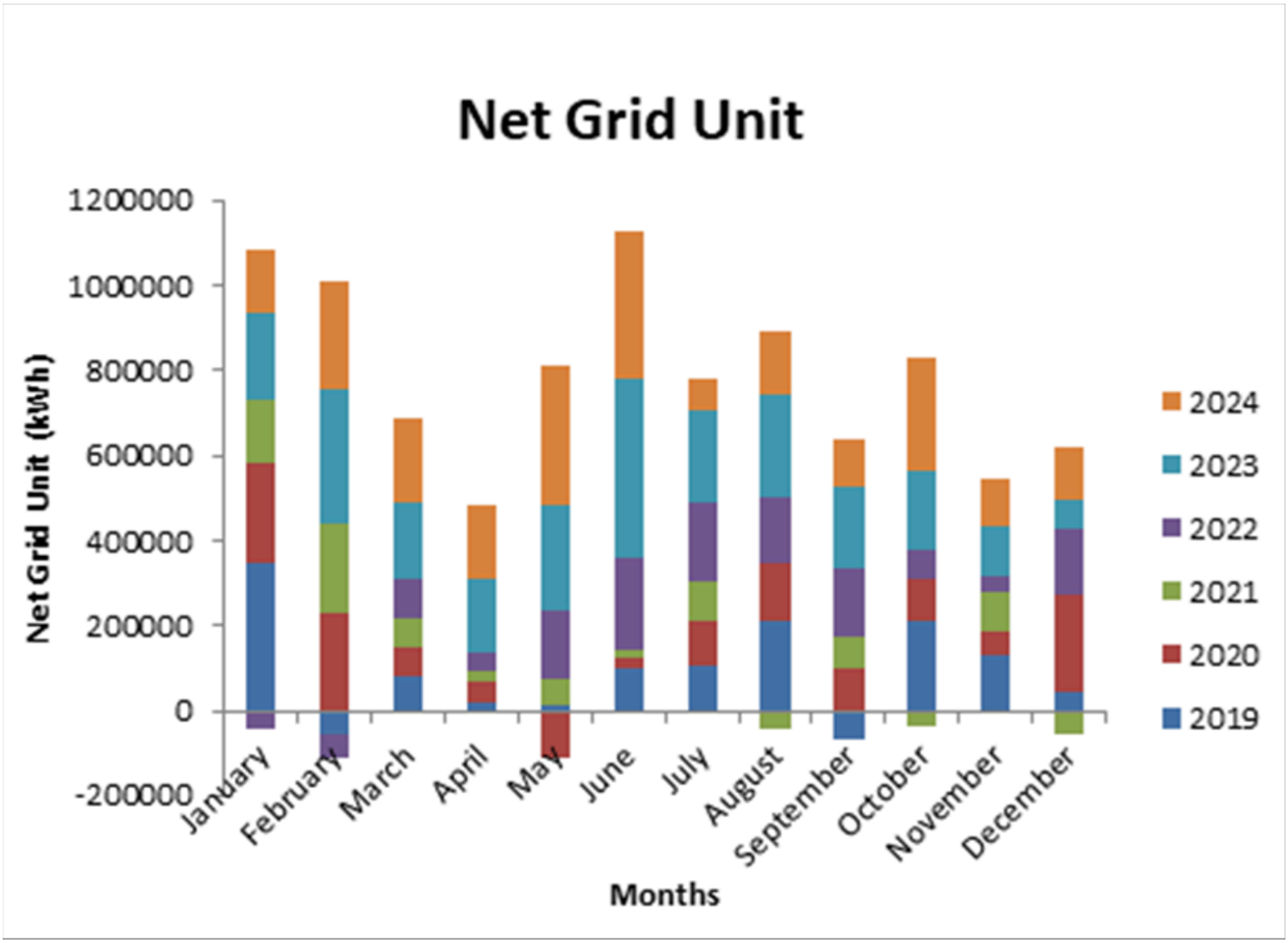



**Figure 3**

**Monthly Net Grid Electricity Consumption (2019–2024)**

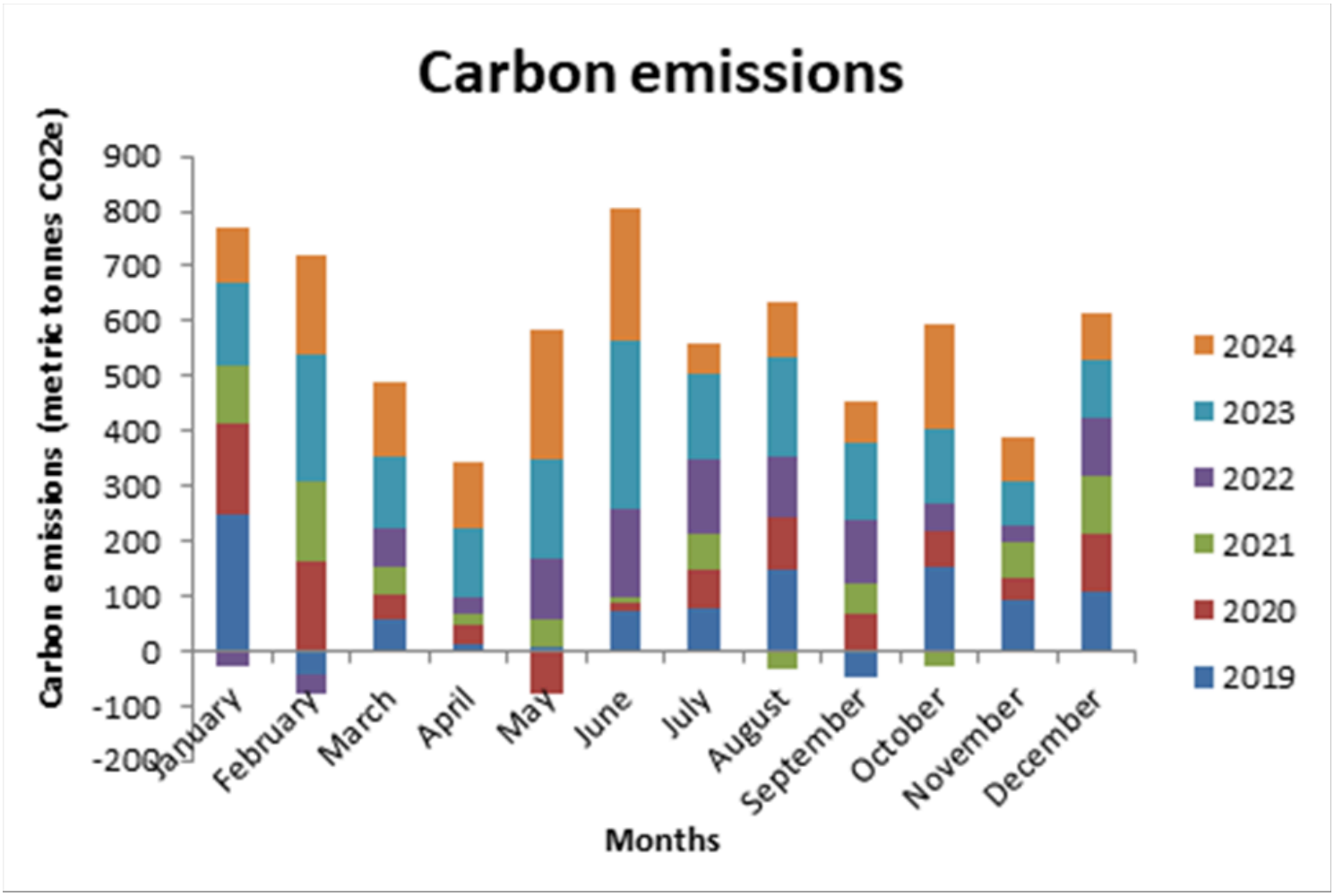



**Figure 4**

**Monthly Carbon emissions (metric tonnes $CO_2$) from 2019 to 2024**