Mapping Greenhouse Gas Emission Hotspots on Whiteknights Campus and Strategies for Reduction

An Environmental Management Report

Uttam Kumar Tamboli Report Environmental Management

Contents

ABSTRACT

This study included mapping of the concentration of greenhouse gases (GHGs) within the 130-hectare Whiteknights Campus of the University of Reading, with emphasis on the prevalence of Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O). To understand the significance of this problem in terms of the study area, the study draws attention to Reading town's recognition as one of the UK's most polluted areas reported by WHO in ("Families urged to walk to school as Reading revealed as one of UK's most polluted areas," no date). Additionally, findings from Kumar et al. (2023) reveal alarming statistics of premature deaths due to indoor and outdoor pollutants, highlighting the urgency of addressing this issue. The methodology involves strategic air quality sampling across the campus and utilizing Gas Chromatography for testing. Furthermore, statistical analyses confirmed elevated GHG levels both indoors and outdoors, necessitating the formulation of mitigation strategies. Among these, Carbon Capturing TiO_2 Coated Asphalt Buton, Soil Nourishment using Ash, and Green Walls emerge as viable options. The study advocates for Hydrogen Buses in Public Transport, Smart Parking Systems, halting facilities on Campus, Afforestation, and Green Roofs as additional measures to curb GHG concentrations. In conclusion, despite the visual allure of the study area, the invisible threat of GHG emissions demands immediate attention. Mitigation measures are crucial to bridge the gap between current GHG levels and global benchmarks, ensuring environmental sustainability for the Whiteknights Campus and beyond.

Introduction

Carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) are greenhouse gases (GHGs) that play a vital role in naturally maintaining the temperature of the Earth's surface. However, due to the burning of fossil fuels, the concentration of GHGs in the atmosphere has risen, leading to global climate change which calls for mitigation measures.

Considering the global perspective, the Kyoto Protocol is the international agreement under the United Nations Framework Convention on Climate Change which works to unite the world to take steps for greenhouse gas mitigation. This is prevalent because it is the reason behind serious environmental social and economic threats the world is facing today and will face in the future. (Sachica Avila, Rivera de la Ossa and Rodríguez, 2020).

This report specifically focuses on mapping greenhouse gas emission hotspots within the 130-hectare Whiteknights Campus of the University of Reading. The three primary greenhouse gases considered in this study are Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O).

The study area encompasses the picturesque Whiteknights Campus, situated at geographical coordinates 51.4406° N, 0.9471° W. Comprising beautiful parkland, a lake, woodlands, and Harris Garden, the campus holds a prominent position as one of the top-ranked UK universities in the People and Planet rankings, emphasizing ethical and environmental performance (People and Planet, 2019).

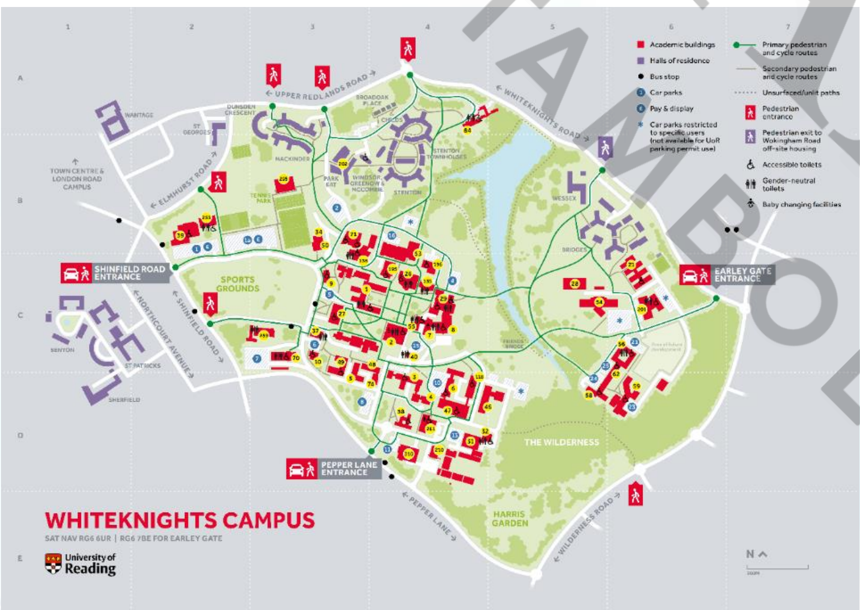


Fig-1: University of Reading Whiteknights Campus. Source: (www.reading.ac.uk, n.d.)

The significance of this concern within the study area becomes apparent through a report published by the World Health Organization, which identifies Reading town as one of the most polluted areas in the UK ("Families urged to walk to school as Reading revealed as one of UK's most polluted areas," no date). Furthermore, the study conducted by Kumar et al. (2023) elucidates the widespread nature of this issue, affecting both indoor and outdoor environments. According to their findings, the World Health Organization reports 4.3 million and 3.7 million premature deaths annually attributed to indoor and outdoor pollutants, respectively.

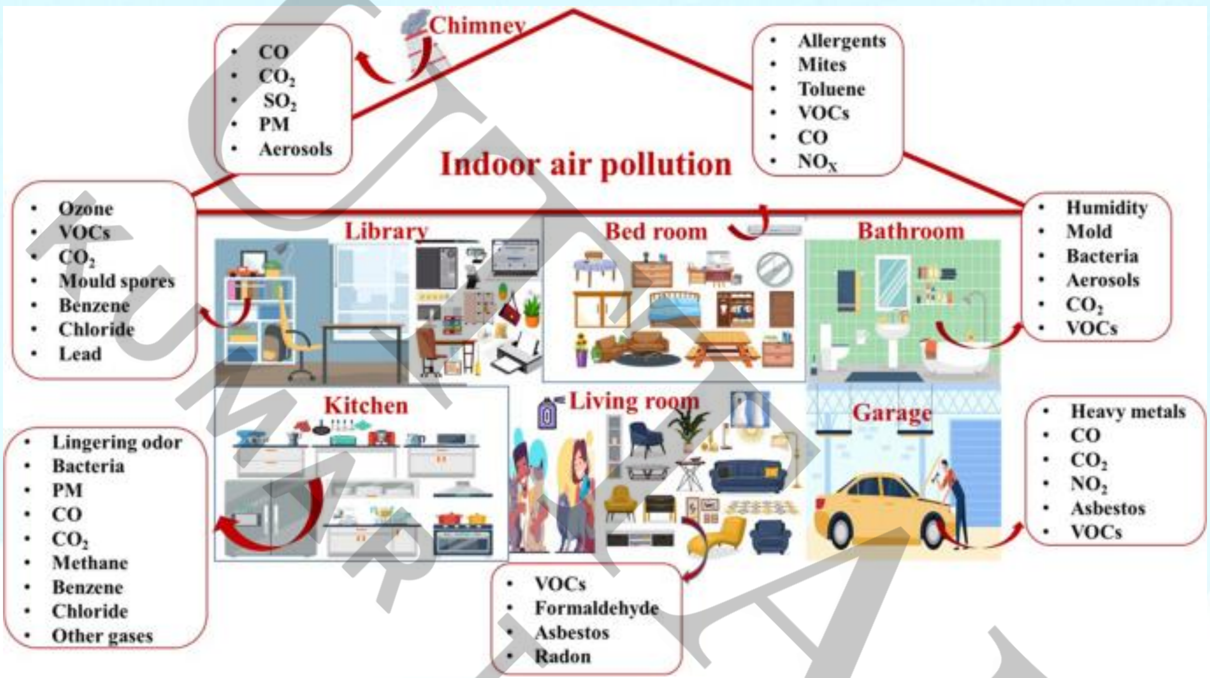


Fig-2: Graphical Illustration of types of pollutants and their sources. (Kumar *et al.*, 2023)

Hence, mapping of greenhouse gas emissions was done, and mitigation measures were proposed with the aim of improving the air quality of the study area.

Methodology:

The following approach was followed:

Fig-3: Flow chart of Methodology

Deciding sites and number of air quality samples to be taken:

Brainstorming on different probable hotspots was done on the university campus and sites were finalized. It was made sure to consider both indoor and outdoor locations. Also, to prevent discrepancies in observation, three samples were recorded on each site and their average was considered. Following are the sites which were finalized:

a) Car Park (Outdoor)
b) Bus Stop (Outdoor)
c) Library (Indoor)
d) Grassland (Outdoor)
e) Whiteknights Lake (Outdoor)
f) Harris Garden (Outdoor)

Dividing team in groups and collecting air quality samples in sites:

Our team was divided into two groups and each group was designated with the task of collecting samples from 3 sites each. The samples were collected using Plastic Syringes. It was made sure that every three samples on the same site were recorded with a time interval of 5 minutes.

Fig 4: Collecting Air Quality Samples from different sites of the University of Reading Whiteknights Campus

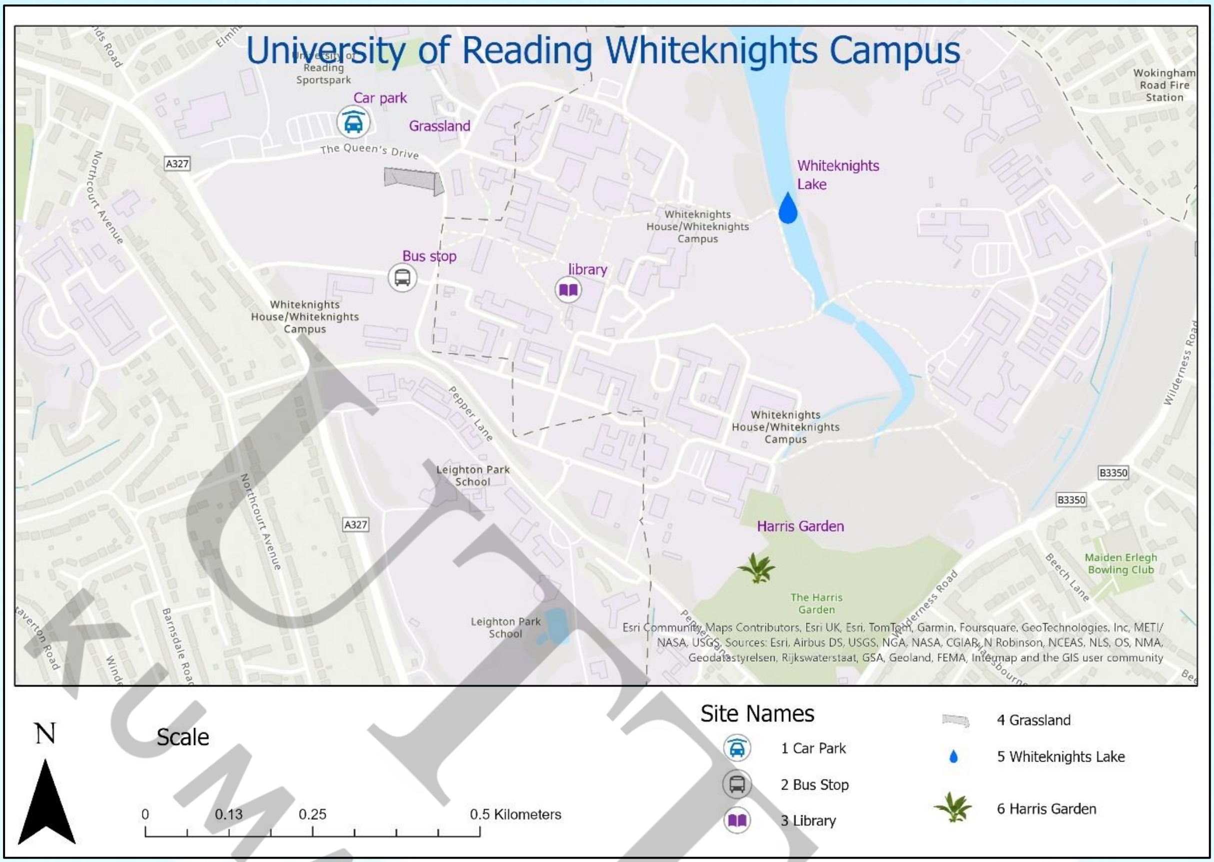


Fig 5: GIS Map of University of Reading Whiteknights Campus with Location of Air Quality Sample Sites. Note: The British National Grid Geocoordinate System was used to plot the GIS Map with the help of ArcGIS software.

Testing Air Quality Samples Using Gas Chromatography

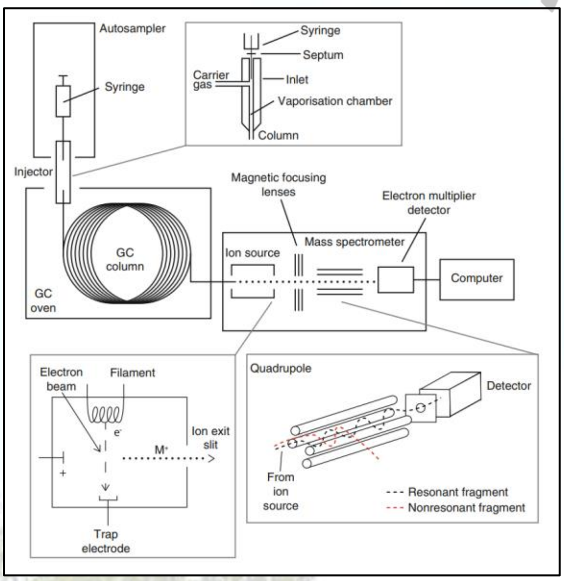


Fig 6: Typical Figure of Gas Chromatography Instrument. (Grimm, Fets and Anastasiou, 2016)

The collected air samples were then tested using Gas Chromatography which is a method of separating Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), and Methane (CH_4) from air mixtures. (See appendix-A for more details)

Data Generation, Data Extraction & Data Filtering

The readings of Gas Chromatography were compiled and using Microsoft Excel, the Standard equations were formed. These equations were then used to calculate the concentration of all three pollutants in parts per million (ppm). Apart from this, the data on the global average value of each pollutant were used as a reference and finally, the average of three samples per site for all six sites was calculated. (NOAA, 2023)

Making Hypothesis, Selecting & Performing Tests

Based on the dataset, possible tests were selected and performed, graphs were plotted, and hypotheses were prepared for the tests requiring it. Moreover, the Global Average concentration levels of all three greenhouse gases were used as a benchmark to make a comparative analysis of concentration in different sites on the campus both indoors and outdoors.

Statistical Analysis, Data Interpretation & Verifying Hypothesis

Data interpretation on the produced graphs and tests were done and efforts were made to verify the hypotheses.

Consolidating Results and Forming Conclusions on Data

The results were compiled, and conclusions were made on the data regarding the level of greenhouse gas emissions in the hotspots of the Whiteknights Campus of the University of Reading.

Researching & Strategizing Possible Mitigation Strategies

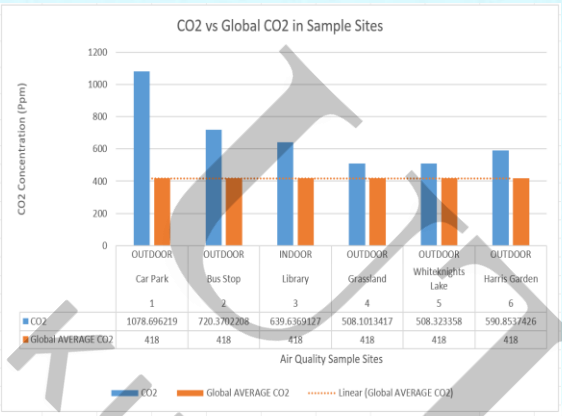
Possible Mitigation Strategies were identified using scientific research papers which could be implemented on the Whiteknights Campus.

Result

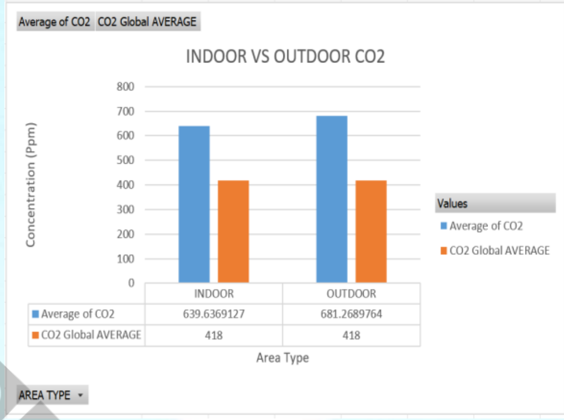
Following are the results of the statistical analysis performed on the data.

Individual Greenhouse Gas Bar Chart

CO_2



CO_2 Bar Chart concerning Sample Sites.

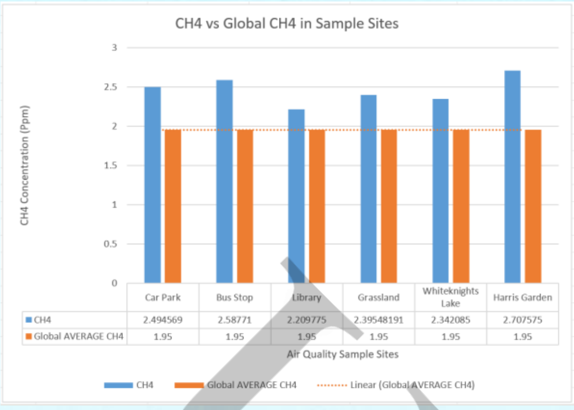


CO_2 Bar Chart concerning Area Type

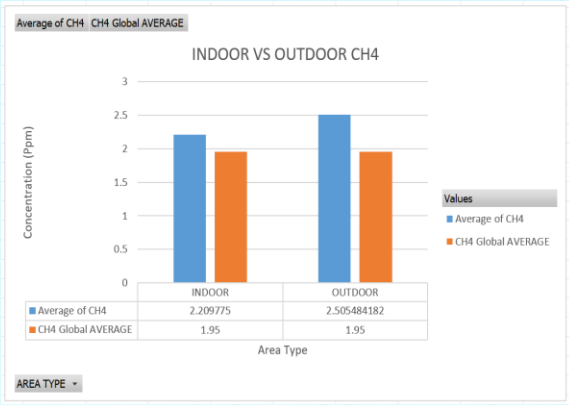
Table 1: CO_2 Bar Charts concerning sample sites and Area Type.

In Table 1, the graph on the left column shows that the Car Park has the highest level of CO_2 emissions followed by the Bus Stop. Both are outdoors and due to the presence of vehicles, the CO_2 levels are high. Interestingly, the third in line is the Library which is an indoor space. However, it is evident because the University's library is crowded with people during the weekdays. Lastly, it is important to note that the CO_2 level in the car park is more than double the concentration of the global average value whereas the average value of CO_2 concentration is similar in the Indoor vs Outdoor comparison shown on the graph on the right-side column. This indicates that CO_2 is a prevalent Greenhouse gas in both Indoor and Outdoor conditions. (Katundu, Thomas and Ntagwirumugara, 2019)

CH_4



CH_4 Bar Chart concerning Sample Sites.

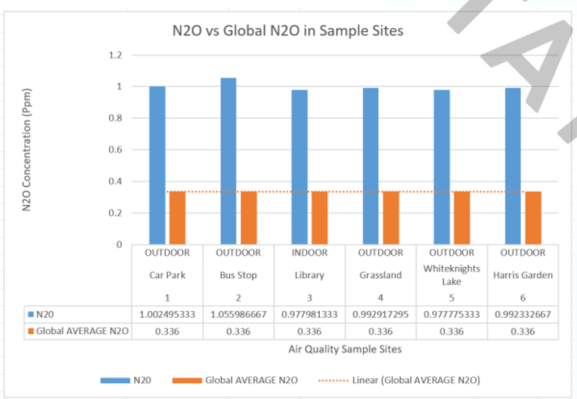


CH_4 Bar Chart concerning Area Type

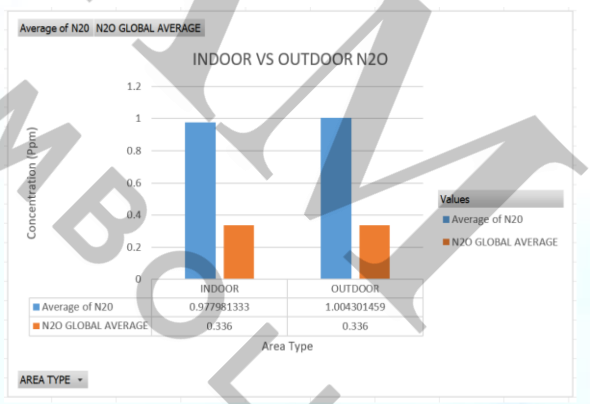
Table 2: CH_4 Bar Charts concerning sample sites and Area Type.

In Table 2, the graph on the left-side column shows that Harris Garden releases the highest amount of CH_4 (more than 0.5 ppm as compared to the global average) followed by the Bus stop, Car Park, and the rest. A probable reason can be the presence of different kinds of trees. (Turbaningsih and Mutaharah, 2022). Moreover, this can also be verified from the outdoor plot of the right-hand side graph. Also, like CO_2, CH_4 can be considered a prevalent greenhouse gas in both indoor and outdoor environments.

N_2O



N_2O Bar Chart concerning Sample Sites.



N_2O Bar Chart concerning Area Type

Table 3: N_2O Bar Charts concerning sample sites and Area Type.

From the graph in the left side column of Table 3 it is evident that unlike CH_4 and CO_2, the concentration of N_2O at all sites are similar to each other. However, from the graph on the right-hand side, it is visible that the concentration of N_2O is close to three times higher than the global average concentration level in both indoor and outdoor conditions which makes it a highly prevalent greenhouse gas in both area types which aligns with the study Garthwaite, 2020).

One Sample T-test

The data was bifurcated into two groups: Indoor and Outdoor and T Tests were conducted for all three greenhouse gases individually using SPSS Software. Following are the Hypotheses for the test:

Null Hypothesis:	There is no significant difference between the mean values of concentrations of indoor and outdoor groups.
Alternate Hypothesis	There is a significant difference between the mean values of concentrations of indoor and outdoor groups.
Significance Level:	$\alpha = 0.05$
If $p < 0.05$:	The null Hypothesis can be rejected which means that there is no significant difference in the mean values of both groups.
$p > 0.05$	The null Hypothesis cannot be rejected which means that there is a significant difference in the mean values of both groups.
Note: a) p-value and Sig. (2-tailed) signify the same thing. b) μ = Mean c) Refer Appendix for full information on the tests.	

Table 4: Hypotheses for Independent Sample T-tests.

a) For CH_4, $p < 0.05$ (0.0001), hence null hypothesis is rejected, meaning there is a significant difference between the means of concentration values for indoor and outdoor sites.
b) For CO_2, $p < 0.05$ (0.001), hence null hypothesis is rejected, meaning there is a significant difference between the means of concentration values for indoor and outdoor sites.
c) For N_2O, $p < 0.05$ (0.0001), hence null hypothesis is rejected, meaning there is a significant difference between the means of concentration values for indoor and outdoor sites.

Both statistical tests indicate that the concentration of greenhouse gases exceeds global average levels and is present in both indoor and outdoor sites at the Whiteknights Campus of the University of Reading. Consequently, there is a need for mitigation strategies to decrease these concentrations.

Discussion

Following are some prevalent mitigation measures which can be implemented in the study area:

Carbon Capturing TiO_2 Coated Asphalt Buton:

The authors of the paper (Muzakkar *et al.*, 2020) have come up with a remarkable TiO2 Coated Asphalt Buton which is capable of adsorbing greenhouse gas emissions (such as Carbon Dioxide, Carbon monoxide and other hydrocarbons) from motor vehicles.

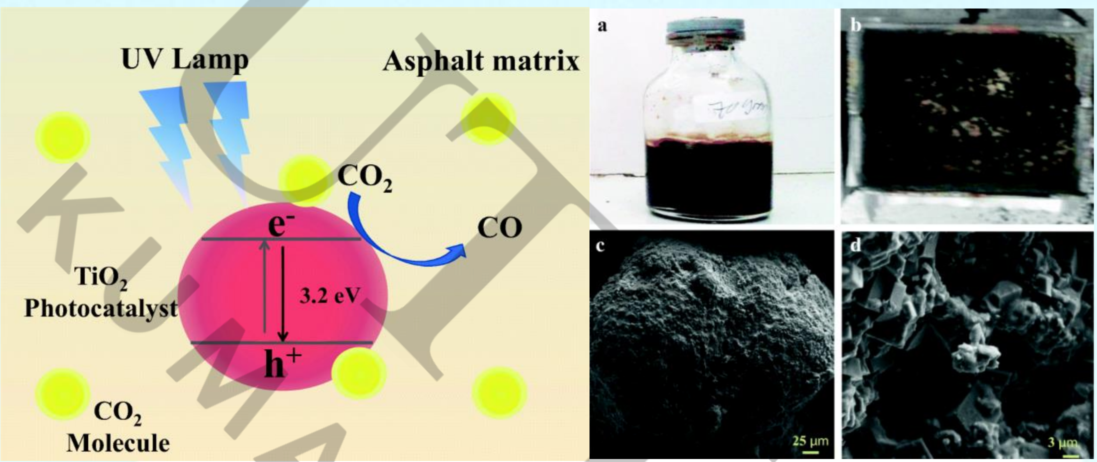


Fig 7: Working Illustration and specimen of TiO2 Coated Asphalt Buton

If this coating is applied to surfaces near car parks, bus stops and various other locations of the campus where the movement of vehicles takes place, then greenhouse gas mitigation can be executed. The coating is capable of adsorbing 600-1500 ppm of gas particles in an exposure time of 90 seconds.

Soil Nourishment using Ash.

The study (Heo and Hong, 2019) has discovered that ash (produced as a byproduct from coal combustion) when added to soil harmlessly improves aeration, increases pH, inert Nitrogen content and nutrient retention capacity of the soil. This helps in greenhouse gas mitigation by facilitating CO_2 sequestration. Hence this practice if performed in areas Harris Garden, Grassland and other locations of the study area then greenhouse gas mitigation can be facilitated.

Green walls, Living Walls, Potted Plants

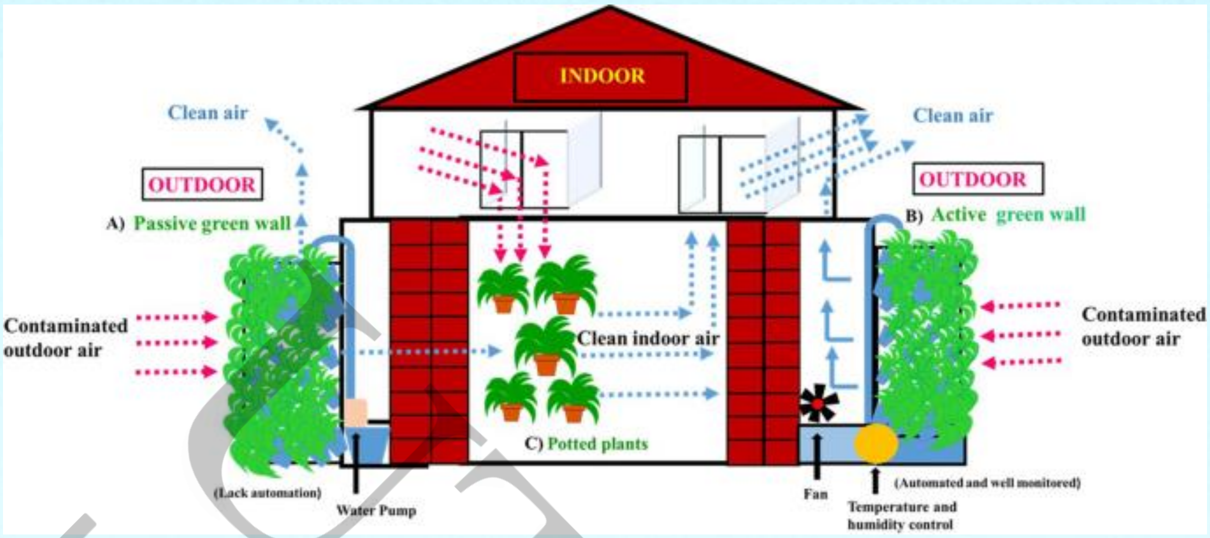


Fig 8: Illustration of Plant-based solution in Greenhouse gas mitigation. (Kumar *et al.*, 2023)

The paper (Kumar *et al.*, 2023) has discussed remarkable measures for mitigating greenhouse gases in both indoor and outdoor conditions using a plant-based approach. The authors have proposed green walls, living walls and potted plants as cost-effective environmentally friendly and effective measures which can be implemented in indoor locations such as the library and different outdoor locations of the study area.

Hydrogen Buses in Public Transport:

Hydrogen Buses are more environmentally friendly and cause even lower emissions as compared to Electric Buses. Moreover, vehicles which use a mixture of natural gas and hydrogen as fuel give efficient performance (Neacsa *et al.*, 2023). These buses are introduced in London (Pioneering Zero-Emissions Transport: Hydrogen Buses in London, no date). As buses are a prevalent mode of transportation in and across the study area, if the same buses can also be brought in Reading town then the greenhouse gas emissions of both Reading Town and Whiteknights Campus of University of Reading can be reduced.

Smart Parking System

The Whiteknights Campus is huge due to which many vehicle owners get lost on the campus or have problems getting a parking lot near the building they want to go. This leads to unnecessary wandering which causes greenhouse gas emissions. This can be avoided with the implementation of a smart parking system (Ramaswamy, 2016). This can help the drivers in getting to the nearest parking lot to their desired building along with its availability.

Halting facility on Campus:

The implication of greenhouse gas reduction resonates strongly with the Transport Sector (Hughes, 1991). This is evident in our study area as well. When visitors come to campus, they don't have anywhere to go hence they generally wait in their vehicle in the parking lot. Due to this, standing emissions take place. This can be solved by setting up a room/ halting facility on campus which the visitors can book and stay there instead of burning fuel on the parking lot. This way, a significant amount of greenhouse gas mitigation can be achieved as 100% of the electricity of the University of Whiteknights campus comes from renewable sources (Our campus - University of Reading, no date).

Afforestation

Afforestation increases the capability of an area to act as a carbon sink. (Iagomarsino, Mazza and Elio Agnelli, 2015). Hence if the studied locations including but not limited to car parks, bus stops, grasslands etc., can be surrounded by more fast-growing trees, then it will be helpful in the mitigation of greenhouse gases.

Green Roofs

The paper (Assimakopoulos *et al.*, 2020) vitalized the potential of green roofs to reduce the temperature of the building, providing an urban heat island mitigation effect and also reducing greenhouse gas emissions. Due to climate change, the weather is changing dynamically. Energy consumption on artificial cooling and heating increases when extreme cold or hot weather hits during unexpected times of the year. In this case, green roofs help in heat insulation of buildings thereby ultimately reducing greenhouse gas emissions.

Table 1. Schematic list of management strategies affecting GHG emissions from forest ecosystems.

afforestation/reforestation	
from pasture to forest	$\downarrow N_2O$, $\uparrow CO_2$
From crop to forest	$\downarrow N_2O$, $\downarrow CO_2$
From wetland to plantation	$\downarrow CH_4$, $\uparrow CO_2$
Silvicultural practices	
Conversion of degraded coniferous plantations	$\downarrow\uparrow N_2O$, $\downarrow CO_2$
Thinning intervention	$\downarrow CO_2$, $\downarrow\uparrow N_2O$
Reduced soil compaction	$\downarrow N_2O$, $\downarrow CO_2$
Permanent soil cover	$\downarrow N_2O$, $\downarrow\uparrow CO_2$
Prevention of acidification	$\downarrow CH_4$, $\downarrow N_2O$
Hydrological regime	$\downarrow CH_4$, $\downarrow N_2O$
Management of plantations	
Appropriate fertilization	$\downarrow N_2O$, $\downarrow CO_2$
Appropriate irrigation	$\downarrow CH_4$
Minimum ploughing	$\downarrow CO_2$

Fig 9: Reduction & Increment of Concentration of Greenhouse gas emissions with mitigation measures (Iagomarsino, Mazza and Elio Agnelli, 2015)

However, on the flip side, the paper (Iagomarsino, Mazza and Elio Agnelli, 2015) also discussed the complications that can occur during the implementation of the mitigation measures. Hence this should be kept in mind when the measures are implemented in the study area to ensure efficient mitigation.

Conclusion

Through statistical analysis and data interpretation, it is evident that the concentration of greenhouse gases in the study area surpasses the global average. Therefore, it is imperative to implement mitigation measures to bridge the gap between current levels and standard benchmarks. While it may be contended that the study area is rich in greenery and lacks visible pollution, the invisible nature of greenhouse emissions poses a significant threat to public health and environmental conditions over time. Thus, the implementation of mitigation measures is crucial to bring the study area closer to achieving environmental sustainability.

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APPENDIX-A :

1) Gas Chromatography

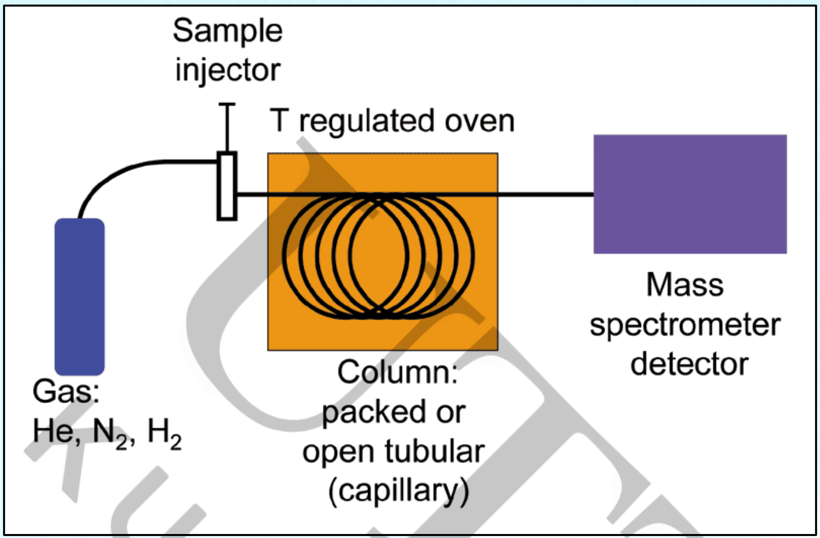

Fig: Schematic Diagram of Gas Chromatography (File:Gcms schematic.gif - Wikipedia, 2006)

Section 1: Introduction to Gas Chromatography

- Gas Chromatography is a technique for separating greenhouse gases in air mixtures.
- The stationary phase in the system in which the chromatography is performed is a column that is coated with a high boiling point liquid or filled with solid particles.
- Apart from this, the mobile phase, also known as the carrier gas, is a continuously flowing stream through the system.
- Furthermore, the mobile phase is nitrogen gas, which is obtained from a cylinder in a gas cage.

Section 2: Sample Injection and Separation:

- The main sample is extracted using an airtight syringe and placed into vials.
- The sample is then injected into the system through the inlet port.
- The carrier gas transports the components over the stationary phase, causing separation based on molecular properties.
- The molecular masses of carbon dioxide and methane, which are both non-polar, cause them to exhibit different retention times.

Section 3: Detection:

- Each component in the mixture is identified and measured by a detector at the end of the column.
- In this chromatography, two detectors are used: an electron capture detector (ECD) for nitrous oxide and a flame ionization detector (FID) for methane and carbon dioxide.

Section 4: Control System and Monitoring:

- The computer-based control system computes peak areas proportionate to component levels in the mixture.
- It also regulates oven temperature, gas flow rate, pressure, and retention durations that are critical for component identification.

Section 5: Quantification and Calibration:

- In terms of quantification, three standards are used in the calibration process to build a calibration curve.
- The computer then compares with the given samples to determine the amounts of each component in the combination.

2) Coordinates of Sites:

Site Number	Latitude	Longitude	Area Type
1	473087	172012	Car park
2	473160	171779	Bus stop
3	473408	171761	library
4	473170	171928	Grassland
5	473736	171884	Whiteknights Lake
6	473690	171343	Harris Garden

3) One Sample T Test

AREA_TYPE	Global CH4	Global CO2	Global N2O	CH4	CO2	N2O
1	1.95	418.00	.34	2.21	639.64	.98
2	1.95	418.00	.34	2.49	1078.70	1.00
2	1.95	418.00	.34	2.59	720.37	1.06
2	1.95	418.00	.34	2.40	508.10	.99
2	1.95	418.00	.34	2.34	508.32	.98
2	1.95	418.00	.34	2.71	590.85	.99

Note: In Area Type: 1 = Indoor, 2 = Outdoor.

a) CH4

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Area Type	6	1.8333	.40825	.16667
CH4	6	2.4562	.17854	.07289

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Area Type	11.000	5	.000	1.83333	1.4049	2.2618
CH4	33.697	5	.000	2.45620	2.2688	2.6436

b) CO2

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Area Type	6	1.8333	.40825	.16667
CO2	6	674.3300	214.00879	87.36872

One-Sample Test

	Test Value = 0

	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Area Type	11.000	5	.000	1.83333	1.4049	2.2618
CO2	7.718	5	.001	674.33000	449.7415	898.9185

c) N2O

One-Sample Statistics				
	N	Mean	Std. Deviation	Std. Error Mean
Area Type	6	1.8333	.40825	.16667
N2O	6	.9999	.02908	.01187

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Area Type	11.000	5	.000	1.83333	1.4049	2.2618
N2O	84.223	5	.000	.99991	.9694	1.0304

APPENDIX -B :

Chat GPT was used in the essay for the following:

- improving the English and structure of the content.
- Getting guiding points for creating the explanation of Gas Chromatography.