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Evaluating Sustainable Development Practices in a Zero-carbon University Campus: A Pre and Post-COVID-19 Pandemic Recovery Study

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Abstract

This paper aims to understand the critical areas for sustainable behavioural change on a university campus in order to achieve the net zero-carbon ambition pre- and post-COVID-19 pandemic recovery. For this purpose, the current empirical study is the first attempt to statistically examine the whole campus as a system, considering staff and student views (campus users), by developing an index measuring propensity for sustainable behavioural change to achieve a net zero-carbon campus. The novelty of this study is based on the following: (i) The impact of environmental sustainability measures due to COVID-19 is examined on three themes: physical activity routines on a daily basis, research, and teaching and learning, and (ii) the index that is compatible with quantifying the behavioural change. A multi-indicator questionnaire is used to collect empirical data for each of the three themes. Based on 630 responses, descriptive statistical analysis, normality tests, significance tests, and t-tests are performed using statistical and graphical software, and conducting uncertainty and sensitivity analyses on this quantitative data. The study found that 95% of campus users agreed to use reusable materials on campus, and 74% were willing to pay more for sustainable products. In addition, 88% agreed to seek alternative and sustainable transportation for

short research trips, while 71% prioritised online conferences and project meetings for sustainable hybrid working. Moreover, the COVID-19 pandemic had a negative impact on the frequency of reusable material usage among campus users, as indicated by the index analysis, which showed a significant decrease from 0.8536 to 0.3921. The statistical findings show that campus users are more likely to initiate and endorse environmental sustainability measures in research and daily life than in teaching and learning, and there is no difference in their propensity for change. This research provides net zero-carbon sustainability researchers and leaders with a crucial baseline for scientific advances in the sustainability field. It also offers practical guidelines for implementing a net zero-carbon campus, engaging users from various disciplines, which has important implications and contributions.

Keywords: Zero-carbon; Sustainable university campus; Sustainable waste management; Renewable energy; Energy behaviour; Performance index.

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1 Introduction

In the last several decades, the commitment of researchers and governments to adopt sustainable development on university campuses in order to achieve almost zero-energy buildings (NZEBs) has been rapidly increasing. However, the United Nations Environment Program (UNEP) has issued a Global Status Report in 2020 (REN21, 2020),

indicating that in 2019, buildings worldwide consumed 35% of the total primary energy and emitted 38% of the carbon dioxide.

For this reason, higher education institutions are implementing considerable measures to achieve environmental sustainability, both within the campus and beyond the campuses in the community (Leal Filho et al., 2021; and Ramakreshnan et al., 2020).

To advance understanding in this area, several critical features of a sustainable system are identified. These include the provision of education aimed at equipping university students with

environmental knowledge, student assessments of campus sustainability components, the integration of sustainability into curriculum and research, efficient campus operations, as well as outreach and community relations which involve active participation from all stakeholders.

(Visser & Brundtland, 1987). According to Cole & Wright (2003), a sustainable campus is a community that "acts upon its local and global responsibilities to protect and enhance the health and well-being of humans and ecosystems", addressing our present and future ecological and social challenges.

However, the relationship between campus users' occupant behaviour and energy consumption remain unclear, and this is attracting considerable attention from academia and industry. In addition, the COVID-19 outbreak substantially affected the number of operational activities performed by a college/university student population during and after the lockdowns compared to the pre-pandemic period. Stakeholder behaviour has been identified as a critical factor influencing the energy performance of buildings and can be classified into three categories affecting energy consumption (Chen et al., 2021). To fully utilise this, a list of variables has been produced to identify the social impacts of the campus user's behaviour and find those determining influences for future studies towards achieving a net zero-carbon university campus before and after the lockdown. Nevertheless, there are very few studies that have investigated the impact of the COVID-19 on environmental sustainability and the degree to which campus users are committed to sustainability at the university campus.

To fill this gap, data analyses and statistical tests based on quantitative methods were conducted to investigate survey data and insights based on three main themes of sustainable development activities: daily life, research, and teaching and learning. In addition, creating an index that is compatible with the responses to the Likert scale questionnaire form is another important and novel contribution from this research.

To the authors' knowledge, no study has yet attempted to simultaneously evaluate the impact of CCOVID-19 on these three themes.

Drawing on these sustainable development measures, this paper examines:

i. Various levels of knowledge and importance of sustainability by university staff and students.

ii. Perceived understanding of net zero-carbon campuses and their importance are linked to different representations of sustainability.

Section 1 discusses the elements that influence sustainable systems and some of the benefits and characteristics that implementing sustainable universities can provide. Additionally, a review of published studies on campus energy reduction strategies, especially in pre- and post-COVID 19 contexts, and their integration into campuses is conducted to identify the research gaps that the current study intends to address. The research's primary aims and research questions are described in Section 2. Section 3 presents and justifies the research methodologies of this study. Section 4 discusses the results and findings. Finally, Section 5 shows the conclusions, implications, and future research.

1.1. The impact of the pandemic on universities

This paper sets out to examine the nexus between sustainable development strategies and the whole university campus as a system across the three themes by developing an index measuring the propensity for sustainable behavioural change to achieve net zero-carbon campuses, linking the literature about zero-carbon campus activities, campus sustainability assessment, and the impact of the COVID-19 outbreak. The results show a high likelihood that campus users will demonstrate initiative and support for new environmental sustainability measures. This research aims to examine campus users' views from diverse departments and faculties regarding sustainable behaviour measures to achieve carbon neutrality. The results can be utilised to assist policymakers, university management, and other key stakeholders in

developing a strategy to engage and promote sustainable practices. The purpose of this work is also to outline the post-pandemic social impact and engagement with the efforts made toward a zero-carbon campus and provide recommendations towards improving the sustainable university campus strategy.

Globally, the COVID outbreak has significantly impacted higher education institution's operations. In particular, it has impacted the sustainable development of physical, research, and teaching activities. Therefore, some research has been undertaken worldwide on the impact of the pandemic on sustainable development. Tleuken et al. (2022) used a rigorous online survey during the COVID-19 outbreak in two countries with different climate conditions to examine the impact of the residential built environment on student academic achievement. To this end, a structural equation model based on three variables, which are safety, health, and comfort of student services, was implemented, and they found that the architectural environment influences distant learning satisfaction and performance. Leal Filho et al. (2021) studied a survey to outline future measures that help better utilise existing technologies that promote the sustainable development of research. The main limitation of this work is that it only undertakes sustainability research. Whilst Leal Filho et al. (2021) examined how Covid-19, and the lockdown it prompted, affected teaching on sustainable development and the suspension of presence-based education in universities worldwide using a large-scale survey of 238 academics from 147 institutions. Furthermore, the influence of the epidemic on various routines of physical activity amongst university students has been evaluated in three studies by (Hudgins et al., 2021), (Bertocchi et al., 2021) and (Grigsby-Toussaint & Shin, 2022). However, to the best of the authors' knowledge, there have not yet been any studies regarding the impact of COVID-19 on these three aspects simultaneously: on-campus life, research, and teaching and learning. Table 1 outlines the latest research works in the field to highlight the novelty of the present work.

Table 1: A summary of quantitative studies recently conducted on the sustainable development strategies.

Author (s)	Study objective	Sustainable development activity's themes	Methodology used	Key findings
Leal Filho et al. (2021)	Outline future measures to promote sustainable research	Research	Questionnaire via on-line survey	• There is a need to better utilize existing technologies to promote the sustainable development of research. • The limitation is focused on sustainability research only.
Leal Filho et al. (2021)	Explore the impact of the Covid-19 on sustainable development education.	Teaching and learning	Survey based on descriptive approach	• The limitation is focused on Covid-19 impacts on sustainable development teaching. • Covid-19 pandemic has resulted in the increased utilisation of online communication tools as a substitute for regular lessons.
Hudgins et al. (2021)	Evaluate the influence of Covid-19 on physical activity	Daily life	Online survey and focus groups	• Covid-19 pandemic has resulted in reduced physical activity among university students. • The limitation is focused on Covid-19 impacts on daily life routines.
Bertocchi et al. (2021)	Examine the impact of Covid-19 on physical activity routines	Daily life	Online survey and statistical analysis	• Covid-19 pandemic has resulted in a decrease in physical activity among university students.

				• The limitation is focused on Covid-19 impacts on daily life routines.
Grigsby-Toussaint & Shin (2022)	Investigate the socio-environ impact of Covid-19 on physical activity	Daily life	Online survey and statistical analysis using secondary data sources	• Covid-19 pandemic has resulted in decreased physical activity among university students. • The limitation is focused on Covid-19 impacts on daily life routines.
Tleuken et al. (2022)	Examine the impact of residential built environment	Teaching and learning	Online survey and structural equation model	• The architectural environment influences distant learning satisfaction and performance. • The limitation is focused on Covid-19 impacts on teaching.
Present study	Achieve net zero-carbon ambition pre and post Covid-19 pandemic recovery	Three themes: daily life, research, and teaching.	Multi-indicator questionnaire and mathematical equations based on statistical testing hypothesis.	• This study gives a foundation for future campus sustainability leaders to advance net zero-carbon campuses scientifically and practically.

1.2. Campus sustainability assessment on behavioural change, transport and waste reduction

Numerous studies have been conducted to better understand how occupant's impact building energy consumption. Previous research has shown that the number of occupants inside a building is insufficient to accurately assess the occupant's impact on energy usage. Other factors to consider include arrival and departure times, stay duration, presence or absence, etc. Menezes et al. (2012) have pointed out that acquiring comprehensive details on realistic occupancy information could increase the accuracy of the energy prediction.

Moreover, the occupants' interactions with buildings, specifically HVAC, indoor environmental quality lighting (Wei et al., 2023), electrical appliances, hot water supply, and window opening behaviour, have been extensively studied. Interestingly, operating building service systems based on realistic occupancy information can reduce energy demand. Yun et al. (2012) found that dimming the lighting system could reduce the amount of light used by 43% in an office building. In addition, behavioural efficiency has been demonstrated to be effective in reducing energy consumption by increasing occupant awareness. Therefore, a strategy to encourage energy-saving behaviour is essential (Park & Chung, 2023) and thus supports the design of potential management measures and electricity savings for higher-educated buildings (H. Yang et al., 2023). Energy usage feedback to building occupants has been identified as the most sustainable and efficient educational approach (Chen et al., 2021). Due to its ability to detect inefficient energy behaviour and make recommendations to occupants on how to proceed, a study conducted by (Pollock et al., 2009) at the University of Vermont showed that the level of importance and the focus on sustainability varied across the different subgroups of stakeholders. Using this study as a starting point, Conner et al. (2018) analysed the stakeholders' perspectives on the importance and performance of university sustainability initiatives and the effectiveness of sustainability in the education

delivered. They concluded that the community lacks a common direction to pursue common sustainability goals.

Udas et al. (2018) further confirmed the importance of mainstreaming sustainable actions through teaching and research in developing a successful sustainability strategy. Pereira Ribeiro et al. (2021) conducted a study of 1,013 participants using multivariate statistical techniques at four Brazilian universities to establish a link between knowledge and action on sustainable development. Similarly, (Sonetti et al., 2021; and Sánchez-Carracedo et al., 2021) have presented sustainable education and knowledge in a university environment. A successful approach may reorient resource management, teaching, learning, and the relationships between universities and society, according to Minguet et al. (2011) of the University of Valencia. All of these factors were considered when developing the study's methodology. Moreover, Howell (2021) has demonstrated student perspectives on effective education for sustainable development courses that included a 'flipped classroom' design, and subsequently provided recommendations for adopting this strategy.

Sustainable transport incorporates numerous strategies for mitigating social and economic impacts. Universities have implemented different techniques and policies to transition from traditional single-occupant automobiles into more efficient modes of campus transportation. Unlimited access to transit, pedestrian and bicycle capital improvements, carpooling programmes with preferential space assignment, park-and-ride facilities, and traffic calming systems are some of the policies mentioned by Litman (2003). Daggett & Gutkowski (2003) conducted a university transportation survey at 48 universities across the USA to maximise transit performance. In order to provide cost-effective, efficient, and effective student transportation, this study outlines some factors that impact transit performance.

Furthermore, increasing the service frequency and offering direct routes from the accommodation to campus and reducing the wait time for a bus could substantially enhance transport sustainability (Bond

& Steiner, 2006). Versteijlen et al. (2021) investigated the travel behaviour of Dutch students and highlighted that many university students commute to their institution every day, contributing to GHG emissions and air pollution. Some authors have claimed that online learning might decrease these travel movements, especially in countries with high car dependence, such as Canada, the USA, and Australia. Nevertheless, in the light of COVID-19 and the post pandemic, the authors have only examined the travel behaviour of students and have not investigated other sustainable behaviours across university stakeholders.

Due to depleting natural resources and growing concerns about climate change, solid waste has become a significant environmental issue. These factors have laid the groundwork for sustainable waste management. Solid waste management integrates a variety of waste reduction, recycling, composting, and disposal practices to satisfy a community's waste management needs and local conditions. Higher education institutions play a vital role in promoting the development of a sustainable society. Emanuel & Adams (2011) have investigated the effect of sustainable programmes on students at the Alabama and Hawaii campuses. According to the survey results, students expressed concern about environmental problems, including pollution and resource conservation. Additionally, Tiew et al. (2010) studied waste composition at the Universiti Kebangsaan, Malaysia's main campus, to determine recycling potential. Source segregation could alleviate waste containing significant amounts of plastics and organics. Islam et al. (2021) have evaluated the e-waste consumer behaviour among the educated urban youth. They reported a significant lack of awareness of pickup locations and current recycling schemes.

Solo-Gabriele et al. (2023) assessed the efficacy of environmental monitoring in predicting COVID-19 cases by collecting air, surface swabs, and wastewater samples from a dorm housing 500 students from March to May 2021, at the University of Miami. Moreover, Dihan et al. (2023) offered a comprehensive review of medical waste formation, management practices in Bangladesh, the impact of

COVID-19 from treatment to testing and vaccination, and the idea of a circular economy for sustainable waste management. However, to the best of the authors' knowledge, a multi-sustainable campus evaluation by creating an index that measures the propensity for change to link behavioural change with the three themes using empirical data has not yet been an objective of a study.

Furthermore, Mahyari et al. (2022) pointed out the importance of adaptability in waste management systems during and after the COVID-19 era. In addition, they have emphasised the need to support and implement a circular economy as a basic strategy for waste management. Ranjbari et al. (2021) presented research directions for post-COVID-19 sustainable development that are in line with the Sustainable Development Goals (SDGs) of the United Nations.

1.3 Aim and research questions

In the wake of COVID-19, the UK has a great opportunity to shape its activities and develop new solutions to long-term sustainability challenges. The UK should seize this opportunity for a green recovery and entirely use recent changes in behaviour and practices. This study is designed to examine net zero-carbon campus activities, with a focus on campus users' behaviour, including energy efficiency and building occupancy. The boundaries of this study are set within a sustainable university aiming for zero-carbon emissions**.**

The University of Net Zero (UNZ) aims to achieve net zero-carbon neutrality on its campus by 2030. Previous research indicates that community support, engagement in sustainable behaviour, and empowerment are essential factors in achieving carbon neutrality. This study focuses on the impact of environmental sustainability measures on two categories of university campus users: students and staff members, across three themes: day-to-day life, research, and teaching and learning.

Building on the literature, this work is driven by the following overarching research questions:

i. What are the primary views and perceptions regarding the adoption of sustainability at the university from the campus users' perspective?

ii. What is the level of commitment of the campus users towards sustainability across the three different themes: day-to-day life, research, and teaching and learning?

iii. What are the main similarities and differences across campus user groups?

iv. What is the current level of commitment of the campus users towards sustainability compared to their willingness to commit to additional measures in the future?

Regarding these questions, the purpose of this work is to outline the post-pandemic social impact and engagement with the efforts made towards a zero-carbon campus, and provide recommendations for improving the sustainable university campus strategy. Thus, this empirical study has carried out a multiple-indicator online questionnaire survey based on the Likert scale with 630 campus users. The UNZ campus serves as a case example in this zero-carbon campus research. Appropriate quantitative data analyses and tests were conducted to investigate the survey data. Herein, the questionnaire is divided into three main groups of themes of zero-carbon activity based on daily life, research, and teaching and learning.

The unit of analysis for this study is set at the organisational level for campus users (staff and students), and not at specific types of staff (e.g., professors, lecturers, etc.) and specific types of students (e.g., postgraduates, undergraduates, etc.). It is anticipated that all campus users are aware of the sustainability strategy of UNZ. Awareness of the strategy does not bias the answers because there is a distinction between awareness and adoption of net zero-carbon activities. This study assesses the propensity for change amongst campus users across faculties, measuring whether or not campus users are inclined to sustainable behaviour.

2 Methods

The methodology applied in this research work includes the following steps: selecting the university, collecting data through an online questionnaire, performing detailed data analysis using statistical and graphical software, conducting uncertainty and sensitivity analyses, assessing university building performance alongside NZEB goals, and suggesting sustainable energy developments. This methodology is independent of any case study aiming to achieve the net zero-carbon campus ambition. The stepwise methods for implementation of this research work are shown in Figure 1.

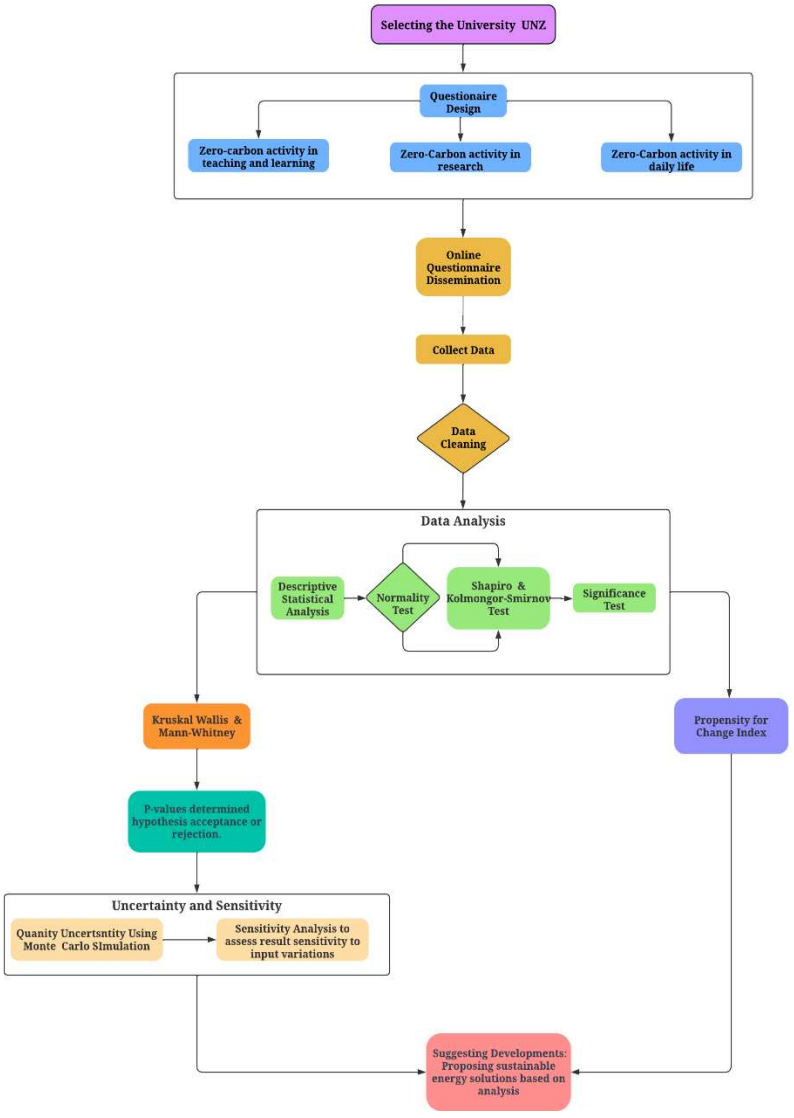

Figure 1. Flow chart of the study methods.

2.1 Methodological approach and empirical context

To establish an empirical context for a university campus aiming to become net zero-carbon by 2030, this research focuses on ways that staff and students can support this effort. This chosen university (referred to as UNZ) was selected based on convenience sampling (Hu & Qin, 2018), and empirical data is collected from a university in the UK.

A Likert-type scale survey was administered to garner quantitative data from campus users, efficiently measuring respondents' attitudes towards zero-carbon activities (Alan Bryman, 2016). The online questionnaire was randomly distributed to campus users, including both students and staff.

2.2 Data collection method and design

The most appropriate research method for this study involved gathering empirical quantitative data for every group of items, with the aim of gleaning more information on campus users' attitudes and behaviours towards carbon emissions through an online questionnaire survey. Similar methods have been employed by (Emanuel & Adams (2011); and Conner et al. (2018)).

The questionnaire was structured into three main themes or groups of items, namely: (i) Zero-carbon activity in your daily life, (ii) Zero-carbon activity in research, and (iii) Zero-carbon activity in teaching and learning. The questionnaire format consisted of a series of statements that focused on certain questions with each respondent asked to indicate their level of agreement with the statement. A five-point scale, ranging from one being 'strongly agree' to five 'strongly disagree' was adopted. The middle position of three represented 'neither agree nor disagree' for neutrality. These statements were drawn from the University's Sustainability Strategy. As the study is primarily concerned with campus users' attitudes, and hence the online questionnaire was randomly distributed to the campus users, which included both students and staff.

Moreover, the opinions and attitudes of individuals across different faculties and professional services have been recorded regardless of their gender, age, and ethnicity. In total, 22 statements, three open-ended questions, one multiple-choice question, five demographic questions and several questions regarding stakeholder's faculty. Focusing on university campus users can be beneficial for two reasons, firstly, universities are leading the way in developing innovative sustainable practices since they produce cutting edge research, and secondly, they offer a diverse sample (i.e. staff and students) from various disciplines and faculties within the university community. Too & Bajracharya (2015) have claimed that engagement in sustainability requires a paradigm shift towards nurturing a sustainability culture among diverse groups of people within university campuses, therefore every stakeholders' efforts is required from all departments (Anwar et al., 2020). The questionnaire was sent out online to 5000 campus users (staff and students) randomly at the UNZ.

Due to the online questionnaire survey being administered during the COVID-19 pandemic, it took approximately a month to collect 630 valid responses and completed questionnaires. Thus, a high and acceptable response rate of 12.6% (Great Brook Consulting, 2022) was achieved enabling inferences to be drawn.

Accordingly, the survey statements have been formulated based on the following:

- Efficiency of the buildings and ensuring effective monitoring and reporting of energy use in buildings.
- Low-carbon heating options.
- Efficient electricity and energy heating.
- Reducing the sale of high-impact food and reducing single-use packaging and waste.
- Discouragement of flying and encouragement of remote working, when possible, to reduce carbon emissions when travelling to work or conferences.

- Reducing food waste.

2.3 Data analysis method

After the data collection, data purging was performed, variable columns were organised and re-coded, and the missing values were addressed. The collected data was processed and analysed using appropriate statistical analysis and performing appropriate statistical tests: such as descriptive statistical analysis, normality tests and significance tests. A new index, called the Propensity for Change Index (*P*), was developed to measure the overall propensity for adopting sustainable behavioural change, leveraging the Likert scale themes datasets from campus users on zero-carbon activities in daily life, research, and teaching and learning.

Appropriate non-parametric tests, such as the Mann-Whitney test and the Kruskal-Wallis test were used due to the non-normal distribution of the data (Andy Field et al. 2012). The Mann-Whitney test was used to test for a difference in scoring tendencies between staff and students, while the Kruskal-Wallis test was conducted to statistically test the difference in scoring tendencies between each faculty for every Likert item and identify any significant difference.

Uncertainty and sensitivity analyses were undertaken to understand the impact of potential variations in the data and identify the key factors driving the results. The uncertainty analysis aimed to quantify the degree of uncertainty associated with the data, while the sensitivity analysis helped determine how sensitive the results were to changes in the input variables (Kleijnen, 1994).

Herein, the mathematical equations of the statistical testing hypothesis are presented. Typically, these numerical equations include measures of the quantitative data, namely, the Shapiro-Test (W), Kolmogorov-Smirnov-test (D), Mann-Whitney test (U), and Kruskal-Wallis test (H) as expressed in equations (1)-(4).

Equation 1 presents the formula for the (W) value, as given from the Shapiro-Test, based on the work of (Bai & Chen, 2003):

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (1)$$

Where:

x_i is the ordered random sample values and a_i are constants generated from the covariances, variances and means of the sample (size n) from a normally distributed sample.

The value of the test statistic (D) is calculated as indicated in Equation 2 (F. Wang & Wang, 2010):

$$D = Maximum|F_o(X) - F_r(X)| \quad (2)$$

Where:

$F_o(X)$ is the observed cumulative frequency distribution of a random sample of n observations and $F_r(X)$ is the theoretical frequency distribution.

The Mann-Whitney formula (U) can be written in Equation 3 (Martínez-Murcia et al., 2012):

$$U_a = n_a n_b + \frac{n_b(n_b + 1)}{2} - \sum_{i=n_a+1}^{n_b} R_i \quad (3)$$

Where:

U is the Mann-Whitney U test, n_a is the sample size one, n_b is the sample size two, and R_i is the rank of the sample size.

The Kruskal-Wallis test (H) is expressed in Equation 4 as follows (Ostertagová et al., 2014):

$$H = \frac{12}{n(n+1)} \sum \frac{{R_i}^2}{n_i} - 3(n+1) \quad (4)$$

Where:

329 n is the total number of values, R is the sum of the ranks for each sample, and n_i is the number in each
330 sample.

331 The P per theme is computed by taking the mean over all the responses for all the questions and
332 then normalising it using the min-max normalisation to obtain a value between 0 and 1, as obtained in
333 equations (5) & (6) (Austin, 2011; and Rosenbaum & Rubin, 2006):

334 $$P = \frac{\frac{\sum r}{n} - 1}{4} \quad (5)$$

335 $$P =' \frac{P - min(P)}{max(P) - min(P)} \quad (6)$$

336 where:

337 P is the index of the propensity for change, r is the response for one question, and n is the overall number
338 of responses for all questions.

339 Within UNZ, we assumed that all staff and students are involved in research, teaching and learning,
340 and daily life activities, which can contribute to the net zero-carbon campus ambition; therefore, there are
341 no biased results in this study. This is a realistic assumption due to the nature of UNZ. Moreover, the
342 Likert scale's neutral option allows campus users to express their indifferent views. Therefore, the P
343 provides a robust mechanism to measure the tendency for change towards sustainability actions, and such
344 sustainable behaviours are assessed across the faculties and the three themes. In addition, the index has
345 been validated theoretically and statistically.

346 **3. Results and discussion**

347 The perceptions and attitudes of campus users towards a zero-carbon campus across daily
348 activities, research, and teaching and learning are presented and discussed in this section, with a view to
349 explaining how they contribute to the sustainability strategy of UNZ and in comparison with literature or
350 cases elsewhere.

3.1. *Overall descriptive statistics visualisation*

Figures 2-4 show the highest and lowest response scores for each Likert item, and the horizontal axis indicates the average of the responses. The colours represent the level of agreement, light turquoise for Agree and shadow turquoise for Strongly Agree, light grey for Neutral, while shadow yellow is Strongly Disagree and yellow is Disagree. On each graph, the Agree/Strongly and Agree scores are grouped together on the right-hand side, starting with the statement items that received the highest positive scores and then going down to the items with the lowest positive scores. The left-hand side of the graph indicates the statement items with the Disagree and Strongly Disagree scores grouped together, starting with the item with the lowest Disagree and Strongly Disagree scores and going down to the statement items with the highest Disagree and Strongly Disagree scores. In the middle, the neutral responses scores represent the Neutral scores that emerged from the 'Neither Agree nor Disagree' option in the questionnaire.

The first theme or group of items, as shown in Figure 2**,** was related to the zero-carbon daily activities that campus users were willing to undertake within the campus on a daily basis. Overall, the results show a positive attitude towards zero-carbon actions; for instance, 95% of the participants agreed to use reusable materials on campus, and 88% of the participants responded positively to having fewer product choices on campus to eliminate waste. Moreover, 74% of the respondents were willing to pay more if there were sustainable products around the campus. These findings demonstrate that the COVID-19 recovery has not affected all behaviours towards adopting zero-carbon daily activities.

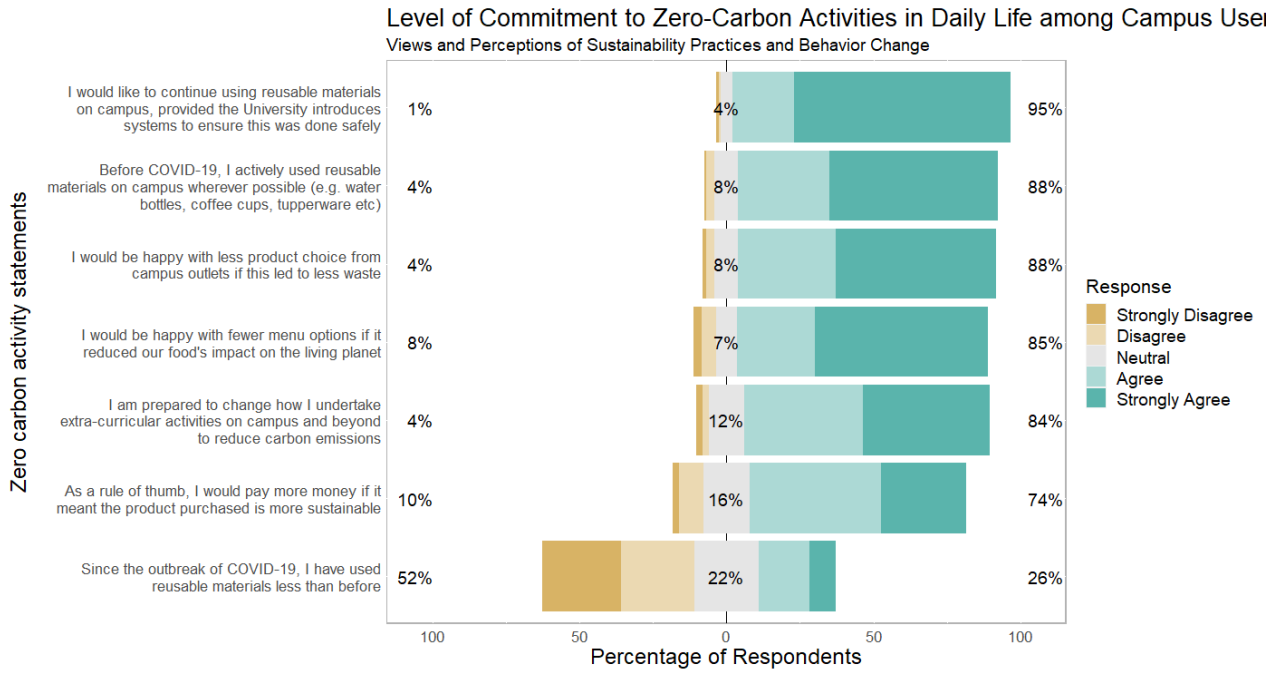

Figure 2. Zero-carbon daily activities, overall results.

Results indicate that campus users are willing to adopt sustainable measures to minimise their carbon footprint and emissions, despite COVID-19. Overall, the results revealed that the standard deviation is below the mean, indicating that this data is not dispersed out and has a low variance. Campus users continue to use reusable materials and are putting efforts into living a sustainable life, as indicated by 52% and 76% of the responses respectively.

To illustrate, the relevant research carried out by Hynes et al. (2021) revealed that the widespread COVID-19 has caused an upsurge in environmental awareness and concern, thereby, encouraging more individuals to adopt sustainable practices. Similarly, an investigation executed by Li et al. (2022) indicated that people severely affected by the COVID-19 outbreak were more likely to adopt sustainable strategies. Furthermore, several researchers in literature have proven the new ways of partnership and collaboration in the academic and research communities. For example, Liu et al. (2020) have demonstrated that the COVID-19 has notably facilitated online communication and collaboration among researchers.

382 Additionally, a study by Wang and Huang (2021) found that the spread of Covid-19 has prompted the
383 emergence of further research collaborations in multidisciplinary groups.

384 Figure 3 reveals that campus users are willing to encourage and implement zero-carbon behaviours
385 and attitudes within research. Supplementary Table 2 presents a summary of the statistics for each Likert
386 statement, including the low, high, and neutral values, as well as the mean values and the standard
387 deviation for zero-carbon activities in research. Some interesting patterns and attitudes towards travelling
388 and online conferencing emerge which warrant further discussion and analysis. Specifically, 94% of the
389 respondents agreed that the university should work in partnership with its supply chain to become carbon
390 neutral, which appears to be a sustainable policy for the university to manage its footprint emissions, while
391 61% agreed that carbon reduction would justify reducing the time that research/lab equipment is kept on.
392 In addition, 88% agreed with the statement that one should seek an alternative and sustainable mode of
393 transportation for short research trips, whilst 71% agreed with the statement that university staff and
394 students should prioritise online conferences and project meetings, indicating that campus users wish to
395 adopt a sustainable mode of hybrid working.

396 The findings related to the sustainable supply chain to achieve a net zero-carbon campus for
397 research extend the work by Koh et al. (2012). This leads to a low-carbon supply chain, while the findings
398 related to the energy efficiency of the research equipment are consistent with the x's campus study
399 recommendation by Leal Filho et al., (2019). Interestingly, the high percentage of sustainable travel and
400 increased online and hybrid working methods confirm the evidential impact of the COVID-19 recovery
401 towards such a new emerging pattern, which aligns with the findings from Yang et al., (2021).

402 There have been research efforts that endorse the outcomes of the present study in the areas of
403 sustainable supply chain and energy efficiency of research equipment. For instance, a research
404 investigation analysed by Mardani et al. (2020) indicated that using sustainable supply chain techniques

could mitigate the detrimental consequences on the environment and economic performance. Liu et al. (2022) revealed in a subsequent study that energy use and greenhouse gas emissions can be significantly diminished by utilising energy-efficient solutions in research facilities. Moreover, the overall number of overseas student flights and conferences has fallen considerably as a result of the coronavirus disease. Milford et al. (2021) discovered that the unprecedented situations due to the pandemic has declined travel-related emissions while increasing online conferences and meetings, which can have a positive impact on sustainability.

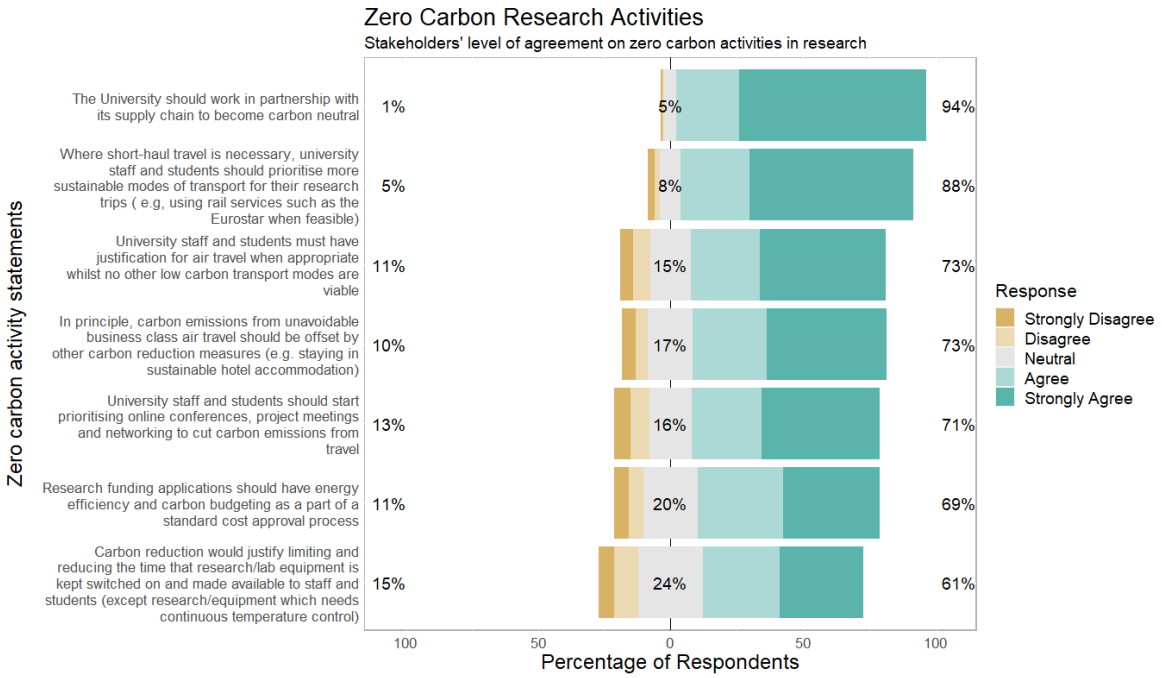

Figure 3. Zero-carbon activities in research overall results.

Covid-19 enforced new ways of partnership and collaboration between academics, researchers and professionals, as identified by Filimonau et al. (2021). The new hybrid working mode, with which most campus users are aligned, appears to be consistent with the trend set globally. This new normal explains the active encouragement of online conferencing and the re-appraisal of air travel for research purposes, despite the fact that this might affect the way collaboration within the research spectrum is being achieved, as suggested by Paul et al. (2012).

418 Figure 4 highlights the overall results of the zero-carbon activities in the teaching and learning
419 scores. The results indicate some interesting and significant patterns, but it can also be observed that the
420 neutral scores in this theme tend to be quite high. Campus users were asked to indicate their level of
421 agreement on possible sustainable measures in teaching and learning. Specifically, campus users were
422 asked how willing they are to wear extra layers of clothing indoors to help reduce carbon emissions by
423 saving on heating, and 67% agreed with this statement, 16% disagreed, and 16% neither agreed nor
424 disagreed. While the majority of the responses agreed with the statement, it is observed that there is a
425 variety and a mix of feelings regarding the particular statement as well as the rest of the statements. For
426 instance, the statement regarding the reduced hours of library buildings openings and the 24-hour service
427 received a higher score on neutrality, ranging from 30%-32%. In this regard, the same study topic
428 implemented by Marans and Edelstein (2010) discovered that people could endure lower interior
429 temperatures when dressed in warmer clothes, leading to additional energy savings.

430 Furthermore, 39% disagreed with the statement ‘carbon reduction would justify increased online
431 activity and reduced physical interaction on the campus, while 26% of the respondents had a neutral
432 attitude towards the statement, and 34% agreed. The statement concerning 24-hour opening of library
433 buildings’ received a significant score of neutrality and disagreement. Therefore, care must be exercised
434 when considering the library opening hours and heating provision in buildings. The interesting findings
435 signify the importance of heating in buildings and accessibility to the library by campus users despite the
436 COVID-19 recovery. As such, it can be deduced that energy efficiency and key infrastructure and facilities
437 on campus are highly likely to be the main dynamic factors influencing behavioural change towards net
438 zero-carbon teaching and learning. Roy et al. (2008) support the argument about energy efficiency and
439 heating on campuses, but no research has explored the innovation in process and service provision for
440 significant assets, such as campus libraries.

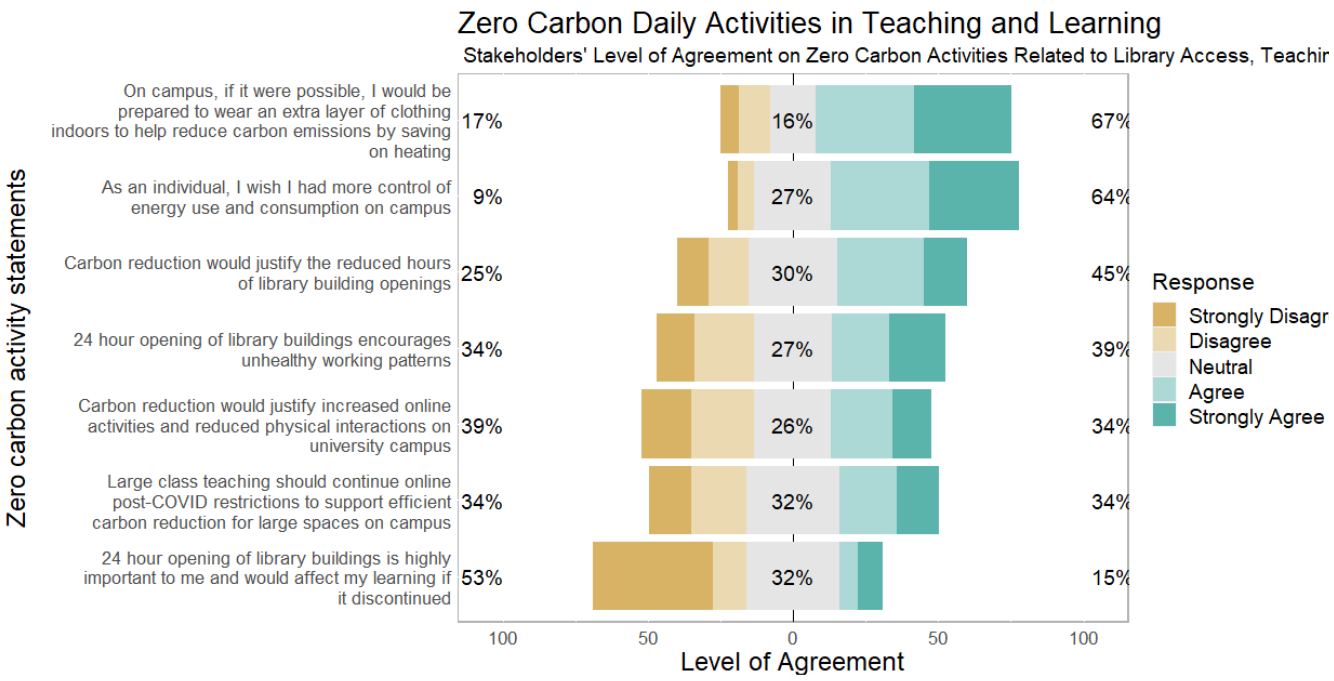

Figure 4. Zero-carbon activities in teaching and learning overall results.

Regarding the statement about shortened library building opening hours, a research paper published by Noranai et al. (2014) discovered that reducing building operations can result in considerable reductions in energy use and carbon emissions. Furthermore, a study conducted in 2018 by Abdou et al. (2018) showed that putting into practice energy-saving strategies, such as limiting building operating hours, can also result in cost savings. Additionally, the study by Ayeleru et al. (2017) identified a correlation between carbon reduction and social engagement, which may help explain how carbon reduction impacts physical interaction on campus. This could be because individuals with similar environmental values and beliefs are motivated to engage in sustainable behaviours and social interactions.

Supplementary Table 3 shows the mean values of each Likert statement from the zero-carbon activities in the teaching and learning theme. The low values represent the disagreement scores, which tend to be higher than the ones that are encountered in Supplementary Tables 1 and 2. The same mean value representation is being indicated about the neutral scores; however, the high score for each

454 statement, which represents the level of agreement, tends to be high, but it must be considered that the
455 majority of the respondents are likely to be staff, and this can explain the level of neutrality in some of the
456 statements. The means and the levels of the standard deviation spread are highlighted.

457 The unit of analysis for this study is set at the organisational level (faculties) for campus users for
458 both staff and students in general. Therefore, it does not examine granular differences, such as the specific
459 categories of staff (e.g., research, academic, full time, and part-time) or students (e.g., postgraduate,
460 undergraduate, overseas, and home). A valid assumption made is that all staff and students are aware of
461 the sustainability strategy and have prior knowledge and experience of net zero-carbon activities related
462 to the three themes. The 22 Likert scale statements in the questionnaire are informed by the sustainability
463 strategy of the UNZ.

464 3.2. *Normality, significance and uncertainty tests*

465 3.2.1. *Normality and significance tests*

466 Table 2 shows the results of the Mann-Whitney test, Kruskal-Wallies test and their corresponding
467 p-values. The p-values < 0.05 are highlighted with an asterisk (*).

Table 2. Results of the Mann-Whitney test and Kruskal-Wallis test.

	Item	p-value of Mann-Whitney test	p-value of Kruskal-Wallis test	Median	95% Range
Qst1	I try to actively live a sustainable life	0.6742	0.0226*	4	[4, 4]
Qst2	I am prepared to change how I undertake extra-curricular activities on campus and beyond to reduce carbon emissions, e.g. Avoiding travel for sports fixtures or single-use giveaways from societies.	0.9603	0.03804*	4	[4 - 4]

Qst3	I would be happy with less product choice from campus outlets if this led to less waste.	0.2741	0.09748	5	[5 - 5]
Qst4	I would be happy with fewer menu options if it reduced our food's impact on the living planet - for example fewer red meat-based options and more plant and poultry options.	0.568	0.1856	5	[5 - 5]
Qst5	As a rule of thumb, I would pay more money if it meant the product purchased is more sustainable.	0.02193*	0.0344*	4	[4 - 4]
Qst6	Before Covid-19, I actively used reusable materials on campus wherever possible e.g. water bottles, coffee cups, Tupperware etc.	0.03449*	0.7959	5	[5 - 5]
Qst7	Since the outbreak of Covid-19, I have used reusable materials less than before.	0.2457	0.3832	2	[2 - 3]
Qst8	I would like to continue using reusable materials on campus, provided the university introduces systems to ensure this was done safely.	0.7682	0.747	5	[5 - 5]
Qst9	University staff and students must have justification for air travel when appropriate whilst no other low carbon transport modes are viable.	1.606×10^{-06} *	0.00599*	4	[4 – 5]
Qst10	In principle, carbon emissions from unavoidable business class air travel should be offset by other carbon reduction measures, e.g. staying in sustainable hotel accommodation.	0.2301	0.09358	4	[4 - 4]
Qst11	Where short-haul travel is necessary, university staff and students should prioritise more sustainable modes of transport for their	0.1379	0.5883	5	[5 – 5]

	research trips, e.g. using rail services such as the Eurostar when feasible.				
Qst12	University staff and students should start prioritising online conferences, project meetings and networking to cut carbon emissions from travel.	8.72×10^{-05} *	5.48×10^{-05} *	4	[4 - 4]
Qst13	Carbon reduction would justify limiting and reducing the time that research/lab equipment is kept switched on and made available to staff and students (except research/equipment, which needs continuous temperature control).	0.009802*	6.19×10^{-05} *	4	[4 - 4]
Qst14	Research funding applications should have energy efficiency and carbon budgeting as a part of a standard cost approval process.	0.3081	0.001075*	4	[4 - 4]
Qst15	The university should work in partnership with its supply chain to become carbon neutral.	0.786	0.6404	5	[5 - 5]
Qst16	The 24-hour opening of library buildings encourages unhealthy working patterns.	0.001883*	0.1357	3	[3 - 3]
Qst17	The 24-hour opening of library buildings is highly important to me and would affect my learning if it is discontinued.	1.062×10^{-06} *	0.403	2	[2 - 3]
Qst18	Carbon reduction would justify the reduced hours of library building openings.	0.1538	0.4867	3	[3 - 3]
Qst19	Large class teaching should continue online post-Covid restrictions to support efficient carbon reduction for large spaces on campus.	0.0689*	0.001483*	3	[3 - 3]
Qst20	Carbon reduction would justify increased online activities and reduced physical interactions on the university campus.	0.0003432*	2.06×10^{-05} *	3	[3 - 3]

Qst21	On campus, if it were possible, I would be prepared to wear an extra layer of clothing indoors to help reduce carbon emissions by saving on heating.	0.7032	0.3569	4	[4 – 4]
Qst22	As an individual, I wish I had more control over energy use and consumption on campus.	0.0004456*	0.2656	4	[4 – 4]

Key: * p-value < 0.05 (statistical significance)

Table 2 includes the p-value results from the Mann-Whitney test for every Likert item, which tested whether students and staff have the same scoring tendencies or responded differently. The Likert items: 1, 2, 3, 4, 7, 8, 10, 11, 14, 15, 18, 19, and 21 each produced a non-statistically significant p-value, meaning that there is >0.05% probability that the H0 hypothesis (*Null Hypothesis*) is correct. Therefore, it can be officially stated that students and staff had similar scoring tendencies towards the aforementioned Likert items. Further, the Likert items: 5, 6, 9, 12, 16, 17, 20, and 22 each indicated a statistically significant p-value, meaning that there is <0.05% probability that the H0 hypothesis is correct. Therefore, it would reject the H0 hypothesis and conclude that the H1(*Alternative Hypothesis*) is correct, i.e., students and staff do not have the same score tendencies for the mentioned Likert statements.

These findings can be explained and rationalised as follows: For instance, statement 12: *"University staff and students should start prioritising online conferences, project meetings and networking to cut carbon emissions from travel"*, produced a statistically significant p-value, where it would be rejected that students and staff have the same scoring tendencies H0, and the reason for that can be due to potential different goals and needs between students and staff. For instance, postgraduate research students might benefit from travelling and attending conferences for networking in person, whereas established staff might see less value in such activity in comparison. *Statement* 5: *"As a rule of thumb, I would pay more money if it meant the product purchased is more sustainable"* produced a

statistically significant p-value, meaning that H0 is not correct, and students and staff indicated different scoring tendencies for statement 5.

Students tend to be the ones who are financially reliable on their parents and student loans, and with part-time employment, they would not favour paying more for sustainable products. Statement "*17: 24-hour opening of library buildings is highly important to me and would affect my learning if it discontinued"* indicated a p-value < 0.05, which is a statistically significant result, so it will reject the H0 and conclude that there is a difference in scoring tendencies between students and staff. The differential in goals and needs between students and staff can be a factor here; libraries are predominantly used by students. For students, library facilities are essential, and they need full access to them at all times, while the majority of staff might not frequent the libraries, unless they work in those facilities. From the perspective of COVID-19 recovery on sustainable actions, these findings suggest increased relevance of online and hybrid working, reduced opening hours of key facilities, and increased willingness to pay for sustainable products, all with the aim of improving the net zero-carbon campus. Such views demonstrate the transformational paradigm shifts in the behaviours of campus users towards sustainability, despite the differences between staff and students. This is in alignment with the initial conceptualization by Hansmann et al. (2020) .

The p-value results for the Kruskal-Wallis test reveal whether scoring tendencies differ by faculty. The results show that Likert items 3, 4, 6, 7, 8, 10, 11, 15, 16, 17, 18, 21, and 22 each indicated a non-statistically significant p-value, implying that it can accept the H0: *There is no difference in scoring tendencies between faculties.* However, Likert items: 1, 2, 5, 9, 12, 13, 14, 19, and 20 each showed a statistically significant p-value scoring difference from faculties, meaning that it can reject H0 and accept H1. These findings are consistent with previous research that has shown differences in environmental

attitudes and behaviours among different groups, including academic disciplines as reported by Thompson and Barton (1994) and university departments as found by (Shafiei & Maleksaeidi, 2020).

Statement 12 *"University staff and students should start prioritising online conferences, project meetings and networking to cut carbon emissions from travel"* produced a p-value < 0.05, which indicates that there is a significant difference in scoring tendencies among faculties. This can be explained by the fact that the UNZ is a research-led university; thus, conferences and research travel are essential for establishing collaboration and networking. Some faculties can benefit from moving to online conferences and projects, while others might not. The significant scoring difference for statement 12 is supported by the growing body of literature on the effectiveness of virtual meetings and their potential to reduce carbon emissions from travel (Tao et al., 2021). Therefore, implementing this recommendation can not only benefit the environment but also potentially enhance collaboration and communication among university staff and students.

Statement 13 *"Carbon reduction would justify limiting and reducing the time that research/lab equipment is kept switched on and made available to staff and students (except research/equipment which needs continuous temperature control)"*, also produced a statistically significant difference ($p<0.05$). Not all faculties use research equipment. Campus users from different faculties need different facilities to perform their research. Additionally, campus users from different faculties might not share the same views or knowledge with research staff from, for instance, the delta and alpha faculties regarding research equipment. Comparatively, these findings partially support the recommendations by Roy et al. (2008), but further research, including Life Cycle Assessment (LCA), is required to examine the environmental implications of online and hybrid working and the management of research/lab equipment on carbon emissions.

3.2.2. *Uncertainty test*

The Monte Carlo simulation is a computational method that involves running the model or system multiple times with randomly selected input values from their respective probability distributions, and then aggregating the results to estimate the uncertainty in the output (Fong et al., 2020). Regarding the uncertainty analysis for ordinal data, the Monte Carlo method can be used for simulation with bootstrapping. However, for ordinal data, it is more appropriate to report percentiles instead of confidence intervals based on means (Qiu et al., 2016). When analysing the uncertainty in the data, it is not necessary to base it on the Mann-Whitney test results. The goal of uncertainty analysis is to comprehend the range and fluctuations in the data. In this scenario, the bootstrap resampling method can be employed to determine the median values and their corresponding percentile ranges for the ordinal data, such as Qst1.

The Mann-Whitney test is utilized to compare the distributions of two groups, while uncertainty analysis focuses on comprehending the variability within the data. These analyses serve distinct purposes and can be conducted separately. Table 2 displays the outcomes of the uncertainty analysis for all 22 Likert scale items. It presents the median estimate alongside the 95% percentile range (or 95% simulation interval) for each item, providing insights into the variability and uncertainty present in the responses.

When interpreting the findings, it is important for readers to consider the median value as the measure of central tendency and the percentile range as an indicator of data dispersion. A smaller percentile range indicates less uncertainty in the responses, while a wider range indicates a higher degree of uncertainty. The uncertainty analysis conducted for Qst1 yielded a median estimate of 4. The 95% percentile range (or 95% simulation interval) was determined to be [4, 4]. This narrow range suggests that the median value for Qst1 remains consistent and stable within the dataset. Since 95% of the simulation runs resulted in a median value of 4, it can be concluded that there is a low level of uncertainty associated with the responses for Qst1.

A narrow percentile range signifies that the values within the 95% range are closely grouped together (in this case, there is no range since both the lower and upper bounds are 4). This indicates a reduced level of variability or uncertainty in the responses, as the resampled medians tend to be similar throughout the simulation runs. Conversely, a wide range suggests greater variability or uncertainty, with resampled medians that could differ significantly across the simulation runs. Furthermore, for Qst7, the median estimate is 2, and the 95% percentile range is [2, 3], indicating some degree of variability, although the range remains relatively narrow. This suggests that the median value for Qst7 is fairly stable and consistent within the dataset.

The present uncertainty analysis of the resampled medians for the 22 Likert-scale items indicated that most of the items exhibited a stable median estimate and a limited 95% percentile range. For example, Item 1 had a median of 4 and a 95% percentile range of [4, 4], and Item 4 had a median of 5 and a 95% percentile range of [5, 5]. These results suggest that, for most items, the median values are quite stable and consistent within the dataset. However, some items demonstrated a broader 95% percentile range, indicating greater variability in the resampled medians. For instance, Item 7 had a median of 2 and a 95% percentile range of [2, 3], and Item 9 had a median of 4 with a 95% percentile range of [4, 5].

In summary, most items in this analysis showed consistent median estimates and narrow 95% percentile ranges, reflecting stability and consistency in the dataset. A few items displayed greater variability, as indicated by the wider percentile ranges. These findings provide insights into the extent of agreement and variability in the respondents' perceptions of zero-waste and sustainable behaviour in the campus context.

3.3. *Overall tendency for sustainable behaviour adoption: Index development and measurement*

In order to better understand the overall tendency for adopting sustainable behaviour, this study will leverage the Likert scale data to compute an index measuring the propensity for change amongst respondents for each of the three themes: daily activities, research, and teaching and learning. This is termed the Index of Propensity for Change (*P*). The value of *P* was calculated considering not only the whole group of respondents but also dividing the respondents based on their faculty. The results are shown in Table 3.

Table 3. Value of the Index of Propensity for Change (*P*).

	All	**Epsilon**	**Beta**	**Delta**	**Zeta**	**Gamma**	**Alpha**
Daily life	0.7642	0.7917	0.7495	0.7721	0.7538	0.7698	0.7806
Research	0.7749	0.7679	0.7149	0.8011	0.8219	0.7427	0.7651
Teaching & learning	0.5918	0.5833	0.5637	0.6220	0.6023	0.5700	0.6078

The overall results demonstrate a generally lower propensity for change across all faculties regarding the teaching & learning aspects of the campus use (*P*=0.5918), compared to 0.7642 and 0.7749 for daily life and research, respectively. Thus, recognising the higher complexity involved in achieving net zero-carbon teaching and learning activities on campus compared to daily life and research activities. Thus, it is not surprising to find that its propensity for change is lower. The consistency in the values of propensity for change across faculties verifies the validity of a unified sustainability strategy at the organisational/university level.

The authors Too and Bajracharya (2015) argued that changing attitudes and behaviours is a challenging and complex subject, and they claimed in their study about engaging the university campus

589 community in sustainability that it takes more than just information dissemination to influence and close
590 the attitude behaviour gap. The results can indicate a useful foundation for such behavioural
591 measurements across university campuses. In order to build an integrated strategy and more effectively
592 involve the academic community in sustainability projects, knowledge from diverse disciplines and
593 departments needs to be gathered and synthesised (Anwar et al., 2020). Thus, the novel propensity for the
594 change index provides a useful foundation for such behavioural measurement across campuses.

595 In order to ensure the reliability of the presented results, it treats the present data as continuous
596 and performs a statistical significance test, namely the Paired T-Test. This particular test was chosen since
597 the answers for each category came from the same set of respondents. The aim of this test is to confirm
598 whether the calculated indices show a real difference in the propensity to change across the three themes.
599 A p-value was calculated, and it was within a confidence interval of 0.95, and it was shown that the only
600 significant differences ($p<0.05$) are between two pairs: daily life and teaching & learning, and research
601 and teaching & learning, with both p-values $< 2.2\times10^{-16}$.

602 Conversely, the p-value calculated for daily life and research is 0.0897 ($p>0.05$), which proves that
603 there is no significant difference between the indices for these two categories. In terms of the variation
604 depending on the faculty, there are no significant differences in the index values. This means that the
605 views across these different campus user groups are homogeneous, thus indicating that university-level
606 measures towards sustainability could be more appropriate than separate faculty-level measures. A further
607 index analysis was performed regarding two different aspects of the daily life theme:

608 I. The past/current practice of sustainable behaviours vs. the propensity to change.

609 The results from the index analysis showed that the past/current practice of sustainable behaviour
610 is weaker than the propensity to change (P=0.6655), in comparison to 0.8235. This indicates that
611 additional environmental measures within daily life activities would be well received by campus users.

612 However, both values lie above 0.5, meaning that some sustainable habits are already ingrained within the
613 community.

614 II. The effect of the COVID-19 pandemic on the usage of reusable materials.

615 The Index analysis showed that the COVID-19 pandemic has greatly affected the frequency of
616 reusable material usage across campus users, with an index decreasing from 0.8536 to 0.3921. This
617 indicates that further research into the effect of COVID-19 on-campus sustainable behaviour would be
618 highly valuable, together with countermeasures.

619 3.4. *Energy control elements by campus users*

620 An element control assessment was completed over five faculties and professional services at the
621 UNZ to identify the operational energy consumption controllable elements. The analysis has been
622 conducted at various energy breakdowns for the selected schools to determine where the emphasis should
623 be placed on energy conservation measures. Supplementary Figure 5 indicates the distribution of energy
624 elements, which may be controlled by the faculties for staff and students in the 2021 survey. Each pie
625 chart segment represents the proportion of energy control elements preferred by campus users.

626 The results show a third of all participants wish they had more control over the energy elements,
627 with the highest requirement coming from the Zeta Faculty (32.86%), followed by the Beta Faculty
628 (18.41%), while this proportion was smaller for the Epsilon Faculty (6.67%). The bubble graph elaborates
629 on the share of each energy control element by the Zeta Faculty, as depicted in Supplementary Figure 6.
630 These findings are aligned with those of Lefebure et al. (2022), thus further demonstrating the campus
631 users' desire to have bespoke control over energy consumption.

632 However, this study has many limitations that need to be considered in future research, as follows:

633 • The questionnaires were performed only at UNZ, which may not fully represent the views and
634 experiences of other universities. Therefore, expanding the study to include other institutions

would provide a more comprehensive understanding of sustainable behavioural change on campuses.

- This quantitative study has not fully investigated the roles and experiences of specific campus user groups (e.g., research staff, teaching staff, technical staff, undergraduate students, postgraduate students, etc.). Future research could address this limitation by analysing the adoption of sustainable behaviours and the propensity for change within these distinct groups.
- This study is based on a single survey conducted at a particular point in time. Longitudinal studies could provide more insights into the adoption of net zero-carbon campus behaviour, activities, and performance over time, particularly in the post-Covid-19 pandemic recovery phase.
- While the study emphasised the importance of behavioural change in achieving net zero-carbon campuses, other factors such as leadership, culture, policy, and finance also play crucial roles. Future research could explore the interplay between these factors and their impact on campus sustainability.

3.5. Sensitivity Analysis

Sensitivity analysis typically involves assessing the robustness of statistical model results by considering variations in input data or model parameters (Thabane et al., 2013). However, sensitivity analysis is not commonly applied to non-parametric tests like the Mann-Whitney U test. In the context of ordinal data, one approach to conducting sensitivity analysis is to observe how the results change when manipulating group assignments or modifying scoring schemes. Sensitivity analysis allows for the exploration of the impact of varying inputs or assumptions on the outcomes of a model or analysis (Thabane et al., 2013). In our recent case, two groups (staff and students) are compared using the Mann-Whitney test.

During sensitivity analysis, the main focus is not solely on the outcomes of the Mann-Whitney test. Instead, the objective is to investigate how the test results may be affected by changes in the inputs. This can involve actions, such as removing outliers, adjusting the sample size, or considering different subsets of the data. The goal is to assess the robustness of the findings obtained from the Mann-Whitney test and gain a better understanding of how sensitive the results are to variations in the input data.

To sum up, although the sensitivity analysis is not directly built upon the Mann-Whitney test results, researchers utilise these results to examine how changes in input data affect the comparison between the two groups. It is important to mention that the Mann-Whitney U test is suitable for comparing two groups when dealing with ordinal data like Likert scale items. The test compares the medians of the groups rather than the means, and the sensitivity analysis centers around the p-values derived from these comparisons.

The obtained p-valueis 0.6742, which is greater than the common significance level of 0.05. This suggests there is no statistically significant difference between the staff and student groups for item 1. The proportion of significant p-values obtained from the shuffled data is 0.05. This means that only 5% of the iterations resulted in a significant difference between the staff and student groups in the shuffled data. This low proportion suggests that the original Mann-Whitney U test result is robust and not sensitive to potential variations in the group assignments. In other words, the conclusion that there is no statistically significant difference between the groups for item 1 is reliable.

To summarise, it can be reported that there is no statistically significant difference between the staff and student groups for item 1 (Mann-Whitney U test, p-value = 0.6742), and this finding appears to be robust according to the sensitivity analysis (proportion of significant p-values = 0.05). The results are indicated in Table 4.

Table 4. Mann-Whitney U Test and Sensitivity Analysis Results for Likert items (By UNZ campus' Stakeholders)

Item	Mann-Whitney p-value	Sensitivity results
1	0.6742	0.05
2	0.9603	0.07
3	0.2741	0.02
4	0.568	0.07
5	0.02193*	0.02
6	0.03449*	0.05
7	0.2457	0.01
8	0.7682	0.06
9	1.606×10^{-06} *	0.05
10	0.2301	0.04
11	0.1379	0.04
12	8.72×10^{-05} *	0.03
13	0.009802*	0.07

14	0.3081	0.04
15	0.786	0.05
16	0.001883*	0.06
17	1.062×10^{-06} *	0.02
18	0.1538	0.06
19	0.0689*	0.05
20	0.0003432*	0.09
21	0.7032	0.07
22	0.0004456*	0.09

For statistically significant Mann-Whitney U test results, out of 22 items, 10 items (5, 6, 9, 12, 13, 16, 17, 19, 20, and 22) were found to have statistically significant differences between the staff and student groups according to the Mann-Whitney U test ($p < 0.05$). This implies distinct preferences or attitudes in these areas. For these items, it is reasonable to conclude that the two groups differ meaningfully, and further investigation or interpretation is warranted to understand the reasons for these differences.

For non-significant Mann-Whitney U test results, the remaining 12 items (1, 2, 3, 4, 7, 8, 10, 11, 14, 15, 18, and 21), no statistically significant differences were observed between the staff and student groups ($p >= 0.05$). This implies that there could not be a substantial difference between the staff and student groups with regard to these specific preferences or attitudes. The aforementioned information can be used to narrow on the areas where the differences are more noticeable and investigate possible reasons for the similarities in the irrelevant elements.

690 Based on the findings of the sensitivity analysis, the proportion of significant p-values for each
691 item varies, ranging from 1% (item 7) to 9% (items 20 and 22), with the majority of items having
692 proportions below 7%. These results suggest that the outcomes are not heavily influenced by the particular
693 sample data employed, instilling confidence that the observed disparities or resemblances between the
694 staff and student groups are trustworthy and not likely a result of the specific data used.

695 To conclude, these findings offer valuable information regarding areas where the staff and student
696 groups exhibit significant distinctions, shedding light on their unique preferences or attitudes. The results
697 of the sensitivity analysis further validate the reliability of the Mann-Whitney U test results, bolstering
698 confidence in the interpretation of these disparities and similarities within the study.

699 It is appropriate to use the Kruskal-Wallis test in the context of comparing the distributions of the
700 responses between different faculty groups for each item. This sensitivity analysis helps assess the
701 robustness of the Kruskal-Wallis test findings by shuffling the Faculty group assignments and calculating
702 the proportion of significant p-values after multiple iterations. Using the Kruskal-Wallis test, coupled
703 performing a sensitivity analysis, is suitable when dealing with non-parametric data and when comparing
704 more than two independent groups. In this case, comparing different faculty groups for each item, the
705 Kruskal-Wallis test is a valid choice, and performing a sensitivity analysis will provide further insight into
706 the stability of the results. The results are presented in Table 5.

Table 5. Kruskal Wallis Test and Sensitivity Analysis Results for Likert items (By UNZ campus' Faculties)

Items	Kruskal Wallis p -value	Sensitivity Analysis
1	0.01879	0.05
2	0.05244	0.08

3	0.129	0.01
4	0.2619	0.03
5	0.02405	0.01
6	0.7667	0.07
7	0.3934	0.06
8	0.7129	0.03
9	0.0003641	0.06
10	0.1287	0.07
11	0.6069	0.07
12	0.0001027	0.06
13	8.79e-05	0.04
14	0.0009118	0.07
15	0.777	0.05
16	0.1052	0.04
17	0.3449	0.03
18	0.5184	0.07
19	0.001507	0.02

20	4.012e-05	0.05
21	0.3359	0.04
22	0.2148	0.04

In Table 5, 6 out of 22 items, (1, 5, 9, 12, 13, and 19) were found to have statistically significant differences among the faculty groups according to the Kruskal-Wallis test ($p < 0.05$). For the remaining 16 items (2, 3, 4, 6, 7, 8, 10, 11, 14, 15, 16, 17, 18, 20, 21, and 22), no statistically significant differences were observed among the faculty groups ($p >= 0.05$). The sensitivity analysis results indicate that the Kruskal-Wallis test findings are generally robust. The proportion of significant p-values across all items in the sensitivity analysis ranges from 1% (items 3 and 5) to 8% (item 2), with most items having proportions below 7%.

These results suggest that for 6 out of the 22 items, there are significant differences in the responses among different faculty groups. The sensitivity analysis adds further credence to these findings, indicating they are not likely due to random chance or small variations in the dataset. For the non-significant items, there are no clear differences in responses among the faculty groups, and the sensitivity analysis also supports these results.

3.6. Results Validation

The results obtained from this study have been compared with the findings reported in three other published studies (Mushtaha et al., 2022, Nordhagen et al., 2021, and Emanuel & Adams, 2011) on various parameters. The key parameters and metrics measured in this article and the selected previous published studies, include attitudes towards zero-carbon actions, preferences for remote work/conferencing, willingness to adopt sustainable measures in teaching and learning, and attitudes towards energy efficiency. Table 6 presents a comparison of the present outcomes with the relevant previous study. Based

726 on the analysis, the recent results are consistent with (Nordhagen et al., 2021 and Emanuel & Adams,
727 2011) demonstrating reliability and validity compared to this previous investigation. In addition, this
728 comparison is essential for identifying potential limitations and areas for future research.

Table 6. Comparison of the obtained results with published data.

Comparison 1		
Parameter/Metric	Present study	(Mushtaha et al., 2022)
Online conferences	71%	77.2%
Increased online activity	34%	75%
Propensity for change (Teaching)	0.5918	0.83
Comparison 2		
Parameter/Metric	Present study	(Nordhagen et al., 2021)
Carbon-neutral supply chain	94%	94.3%
Comparison 3		
Parameter/Metric	Present study	(Emanuel & Adams, 2011)
Waste elimination	88%	85%
Zero-carbon actions	95%	90%
Sustainable products	74%	51.4%

729

730 ## 4. Conclusions and implications

731 This research has been statistically carried out to examine the whole campus as a system,
732 considering staff and students' views (campus users), by developing an index measuring the propensity
733 for sustainable behavioural change to achieve a net zero-carbon campus under pre- and post- COVID-19
734 pandemic recovery by 2030. A total of 630 responses from campus users (staff and students) of the UNZ
735 were collected through an online questionnaire survey, and the data was analysed quantitatively and
736 statistically. 22 Likert scale statements across 3 themes, namely zero-carbon daily activities, zero-carbon

737 research activities, and zero-carbon teaching and learning, were investigated. The questionnaire and its 22
738 statements assessed were set within this context, where COVID-19 recovery is occurring. This real case
739 example of the UNZ is a 'living lab' demonstrator, which showcases the current and future behavioural
740 change towards sustainability on campus.

741 The mathematical equations the statistical testing hypothesis, including the descriptive statistical
742 analysis, normality test, significance test, and t-test, have been implemented to calculate the new index
743 measuring propensity for sustainable behavioural change to achieve net zero-carbon campuses.
744 Uncertainty and sensitivity analyses have been performed to assess the impact of potential variations in
745 the data and to identify the key factors driving the results. Overall, the key highlights of the findings due
746 to the campus sustainability assessment and the COVID-19 outbreak results are as follows:

747 ● Campus users demonstrate a very positive attitude towards zero-carbon actions. For instance, 95% of
748 the participants agreed to use reusable materials on campus, and 88% of the participants responded
749 positively to having less product choice on campus to eliminate waste.
750 ● Results from $p<0.05$ show different campus users have diverse professional goals and needs, thus,
751 when planning for policy and promoting sustainable behavioural change, different components of the
752 campus users' needs should be taken into consideration to achieve inclusivity.
753 ● A third of all the participants wish they had more control over the energy elements, with the highest
754 requirement from the Faculty of Zeta (32.86%), followed by the Faculty of Beta (18.41%), and this
755 proportion was smaller for the Faculty of Epsilon (6.67%).
756 ● The Index of Propensity for sustainable behavioural Change (P) across all groups of respondents and
757 averaged over the three themes of zero-carbon activities considered in this study is 0.71. It can be
758 concluded that campus users are highly likely to show initiative and willingness to adopt new
759 environmental sustainability measures.

- The sensitivity analysis results provide confidence in the robustness of the Mann-Whitney U test findings, with most items having a proportion of significant p-values below 7%.
- Most items in this analysis showed consistent median estimates and narrow 95% percentile ranges, reflecting stability and consistency in the dataset.

The four overarching research questions and gaps were answered through: (i) It has been identified that campus users' main views and perceptions on adopting sustainability at the university were influenced by the impact of COVID-19 recovery; (ii) The level of commitment of the campus users towards sustainability is much higher in daily life and research activities, than in teaching and learning activities; (iii) There are various statistical significant differences ($p<0.05$) between staff and students campus users groups in the adoption of measures to achieve a net zero-carbon campus; and (iv) The level of commitment of the campus users towards sustainability currently, compared to their willingness to commit in the future to additional measures (i.e. *P*), is higher for both daily life and research activities, and lower for teaching and learning activities, while there is no major difference amongst faculties. This research aims to provide the next generation of net zero-carbon sustainability leaders with a framing baseline to make further scientific advances and practical guidelines on campus sustainability.

The findings on sustainability measures and the index provide a novel lens to guide future research in sustainability operational change, clean energy, and net zero operations management. They also support key decision-makers in making appropriate zero-carbon campus interventions. This study highlights several research limitations to guide future research directions: (a) The questionnaires were administered only at the UNZ; the study can be extended to other universities; (b) Further empirical studies can be conducted to expand the unit of analysis from the faculties or organisational level to the individual level (e.g., research staff, teaching staff, technical staff, undergraduate students, postgraduate students, etc.); (c) Longitudinal studies can be performed to assess the adoption of net zero-carbon campus behaviour,

activities and performance on the campuses post COVID-19 pandemic recovery; and (d) Behavioural change is one of the requirements to achieve a net zero-carbon campus. Other requirements, such as leadership, culture, policy, and finance, can also be considered.

5. Future work

The current study only performs the mathematical equations based on quantitative methods from statistical testing hypotheses, such as the normality test, significance test, and t-test based on three main themes of sustainable development activities simultaneously: daily life, research, and teaching and learning. As a consequence, a new index evaluating the probability of sustainable behavioural change leading to net-zero-carbon campuses and suggesting sustainable energy developments has been created. The advanced net-zero-carbon campus analysis techniques based on machine learning methods are scarce in the literature. As a future study, it can be adopted to give detailed analysis, thereby improving the output accuracy.

In addition, the use of advanced sustainability assessment tools, such as life cycle assessment and exergy analysis, is crucial for evaluating the sustainability of waste reduction and management efforts on campuses. Current research works, including by Ranjbari et al. (2021) and Mahyari et al. (2022), have highlighted the importance of these tools suggesting directions for future studies. By incorporating such assessments, researchers can provide a more comprehensive analysis of sustainability in campus waste management and identify areas for improvement to promote a more sustainable future.

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