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Sustainable Urban Mobility Through Cycling Pathways

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ABSTRACT

The urgent need for sustainable campus transportation arises from escalating environmental concerns over carbon emissions, highlighting the necessity for proactive sustainability measures. Addressing this issue, the research examines the impact of integrating cycling pathways on carbon footprints within university campus. By using questionnaire approach, this study employed rigorous quantitative data in empirically validate the potential of cycling pathways in mitigating environmental impacts within the university setting. The study achieved strong statistical outcomes, with a high model explanatory power (R^2=0.929) and significant correlations (ranging from r=0.695 to r=0.850) across key variables including carbon emissions, traffic, safety, and health. Aligned with Sustainable Development Goals (SDGs); SDG 11, SDG 13, and SDG 3, the study elucidates the significance of cycling pathways in fostering sustainable urban environments, curbing climate change, and promoting physical well-being among the campus community. Beyond mere environmental implications, successful implementation of cycling pathways bears substantial national, societal, and university-level impacts, contributing significantly to the broader agenda of environmental conservation, enhancing community health and well-being, and fostering a culture of sustainability and responsibility within the academic sphere. Ultimately, this research serves as a cornerstone in advocating for and advancing sustainable transportation paradigms within university campuses, epitomizing the transformative potential of cycling pathways in sculpting a more sustainable future.

1. INTRODUCTION

In recent years, the global community has been grappling with the escalating environmental challenges posed by carbon emissions, particularly those emanating from transportation systems. University campuses, as microcosms of urban life, are not exempt from the imperative to address these concerns. The pressing need for sustainable transportation solutions within academic institutions has become increasingly evident, prompting a call for proactive measures to reduce carbon footprints associated with campus commuting.

The urgent necessity for sustainable transportation solutions has reached a critical juncture in contemporary society. Heightened concerns regarding environmental degradation and the detrimental effects of vehicular emissions necessitate a swift transition toward more environmentally friendly modes of transportation. Universities and educational institutions, revered as bastions of innovation and societal progress, bear a significant responsibility in leading initiatives that espouse sustainability. Within this ethos, the development and integration of cycling pathways within the university campus stand as proactive measures toward establishing an eco-conscious and efficient transportation network.

Amidst the relentless progression of climate change and the unequivocal need for sustainable practices, universities worldwide are increasingly recognizing their obligation to mitigate carbon footprints. It is widely acknowledged that transportation systems, predominantly characterized by vehicular emissions, contribute substantially to escalating carbon dioxide (CO_2) levels, further exacerbating environmental concerns. In response, the strategic implementation of cycling pathways within educational institutions emerges as a pivotal strategy to counteract this environmental challenge.

As the global conversation on sustainability intensifies, this study endeavors to furnish a holistic understanding of the tangible benefits and nuanced challenges associated with cycling infrastructure within educational institutions. It strives to serve as a beacon of knowledge, offering actionable recommendations poised to elevate the discourse on

sustainable transportation systems and steer campuses worldwide towards a greener, more sustainable future.

In the pursuit of sustainable transportation solutions, the imperative to reduce carbon emissions has taken center stage in mitigating the adverse effects of climate change. The adoption of bicycles as a primary mode of transport within university campuses holds immense promise in this regard, given its inherently low or zero carbon emissions. The ecological significance of bicycles lies in their capacity to function as a zero-emission mode of transportation, standing in stark contrast to conventional motor vehicles, which are major contributors to CO_2 emissions.

Bicycles, being human-powered vehicles, do not rely on fossil fuels for propulsion. This fundamental characteristic renders them an environmentally friendly and sustainable mode of transport. The absence of tailpipe emissions associated with bicycles significantly reduces air pollution and greenhouse gas emissions, thereby playing a pivotal role in curbing the environmental impacts associated with vehicular transport. By significantly diminishing CO_2 emissions and other pollutants linked to climate change, bicycles serve as potent catalysts in mitigating global warming and preserving air quality within the campus environment and beyond.

Additionally, transportation systems on university campuses are vital lifelines, connecting students, faculty, and staff to academic facilities, residential areas, and various amenities. The conventional reliance on motorized vehicles poses challenges related not only to environmental sustainability but also to the safety and well-being of the campus community. Incidents of traffic congestion, accidents, and the overall vulnerability of pedestrians and cyclists have underscored the need for a holistic approach to campus transportation planning.

The escalating concerns about safety in the context of university transportation systems necessitate a reevaluation of existing infrastructure and a consideration of alternative modes of mobility. With a growing awareness of the vulnerabilities associated with conventional transportation, the lack of dedicated cycling pathways compounds the risks faced by cyclists and pedestrians. This gap in infrastructure not only jeopardizes the safety of the campus community but also hinders the potential of cycling as a sustainable and secure mode of transportation.

Furthermore, the integration of cycling pathways and the promotion of bicycle usage align profoundly with the United Nations' Sustainable Development Goals (SDGs). These goals provide a comprehensive blueprint for achieving a sustainable future, encompassing social, economic, and environmental dimensions. Specifically, the utilization of bicycles as a sustainable mode of transportation contributes to several SDGs, notably SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 3 (Good Health and Well-being).

SDG 11 emphasizes the importance of creating inclusive, safe, resilient, and sustainable communities. Cycling infrastructure fosters the creation of vibrant and interconnected communities within university campuses, ensuring safe and accessible transportation options for all members of the campus community. It promotes active and healthy lifestyles while reducing traffic congestion and promoting efficient land use.

SDG 13 underscores the urgent need for climate action to combat climate change and its impacts. The adoption of bicycles as a zero-emission mode of transportation significantly contributes to reducing carbon footprints and mitigating the adverse effects of climate change. By encouraging the use of bicycles, educational institutions actively contribute to global efforts aimed at limiting global temperature rise.

Moreover, promoting bicycle usage aligns with SDG 3, which aims to ensure healthy lives and promote well-being for all ages. Cycling is a form of physical activity that promotes cardiovascular health, reduces the risk of chronic diseases, and enhances mental well-being. By encouraging cycling, universities prioritize the health and well-being of their students, faculty, and staff. Improved infrastructure that supports active transportation can contribute to higher efficiency and overall well-being, aligning with findings on productivity effects [1].

The integration of cycling pathways and the promotion of bicycles as a primary mode of transport within university campuses represents a significant stride towards a sustainable future. Beyond mitigating carbon emissions and fostering a cleaner environment, this initiative aligns with the global agenda of achieving the SDGs, promoting healthier communities, reducing inequalities, and combating climate change. While existing studies have explored the benefits of cycling in urban contexts, limited research has focused on the quantitative impacts of cycling infrastructure within Malaysian university campuses. This study addresses that gap by evaluating how cycling pathways influence carbon emissions, traffic flow, physical activity, safety, and parking conditions within university setting.

2. LITERATURE REVIEW

Cycling infrastructure has gained attention across academic institutions and urban environments for its potential to reduce emissions, improve public health, and enhance transport systems. This study reviews the literature thematically to highlight key dimensions relevant to the integration of cycling pathways in university settings.

2.1 Environmental impact

The effectiveness of cycling infrastructure in reducing carbon emissions has been widely studied in urban and campus environments. Recent research has emphasized that dedicated cycling pathways play a crucial role in shifting commuting patterns toward more sustainable modes of transport. For instance, Guo et al. [2] found that well-integrated cycling infrastructure in university settings significantly increases the adoption of bicycles, leading to a measurable reduction in transportation-related carbon emissions. Their study also highlighted that students are more likely to opt for cycling if they perceive it as a convenient, safe, and time-efficient alternative to motorized transport [3]. This aligns with the current study's objective, reinforcing the necessity for well-planned cycling infrastructure to encourage widespread adoption.

Wang et al. [4] analyzed the carbon emissions from buses and motorcycles at Rutgers University, New Brunswick, using life-cycle assessment (LCA). The findings suggested that the raw material for motorcycle and bus operation contribute most to CO_2 emissions and energy consumption, with buses emitting 46 times more CO_2 and consuming 13 times more energy than motorcycles. Variables like biodiesel use, bike

quantity, and bus ridership significantly influenced results. The study recommended a better transportation infrastructure and increased parking fees to reduce carbon emissions.

A study by Neves and Brand [5] delves into the pivotal role of cycling and walking in curbing greenhouse gas (GHG) emissions, particularly concerning the substitution of short car trips. Conducted in Cardiff, Wales, with a cohort of 50 residents, the research employed varied methodologies like GPS tracking, travel diaries, and interviews to glean qualitative and quantitative insights. It revealed a significant potential for active travel to replace approximately 41% of short car trips, resulting in nearly 5% reduction in CO_2e emissions from car travel, complementing the existing 5% emissions already 'avoided' due to prevalent walking and cycling practices. These findings underscore the critical role of cycling in achieving significant carbon savings within urban environments, emphasizing the need to promote and integrate cycling as a sustainable mode of transportation for reducing carbon footprints.

Tainio et al. [6] provide empirical evidence on the interconnections between air pollution and physical activity, recognizing their substantial impact on non-communicable diseases (NCDs). Conducting a non-systematic mapping review until Autumn 2019, the study aimed to comprehend the relationship's nuances, assessing the impact of air pollution on physical activity behavior, the inhalation of pollutants during physical exertion, and the resultant short- and long-term health effects on individuals [7]. Findings indicate that high air pollution levels can reduce physical activity, impeding engagement or diminishing activity levels, particularly in heavily polluted environments. While studies have estimated fine particulate matter exposure during active transport in certain regions, understanding of concentrations in various activity spaces and for other pollutants remains limited, especially in low- and middle-income countries. Nonetheless, the overall evidence remains weak for sensitive populations and indoor air pollution. These findings underscore the critical need for collaborative efforts between air pollution and physical activity research fields to bolster evidence and formulate policies that mitigate risks and optimize health outcomes, especially in regions burdened by high air pollution concentrations.

The collective body of research highlights a clear consensus on the environmental advantages of cycling infrastructure, particularly in its role in reducing carbon emissions and improving air quality. Previous studies [2-5] consistently demonstrate that shifting from motorized transport to bicycles can lead to substantial carbon savings, whether through improved commuting behaviour, life-cycle efficiency, or reduced reliance on short car trips [8]. The interlinkages between air quality, transport mode, and physical activity are further elaborated by Tainio et al. [6], who caution that pollution can act as a deterrent to active transport if not properly mitigated. Together, these findings support the argument that universities must not only promote cycling but also ensure that infrastructure planning considers both carbon reduction and user health outcomes, particularly in environments with high air pollution or vehicular congestion.

2.2 Health and well-being

The influence of cycling infrastructure on physical and mental well-being has also been explored extensively in recent literature. According to Herbert [9], cycling as a primary mode of transport contributes significantly to increased physical activity levels, reducing the risk of cardiovascular diseases and obesity among students and staff. Their study further found that individuals who regularly cycle to work or university reported lower levels of stress and improved mental well-being compared to those using motorized transport. Given the increasing concern over student mental health in higher education institutions, promoting active transportation such as cycling can serve as a practical intervention to support well-being.

Green et al. [10] analyzed the existing literature on the correlation between cycling and health, sourcing information primarily from PubMed by searching MeSH terms like 'bicycle' and 'transportation'. It included clinical trials, practice reviews, and systematic reviews while cross-referencing additional articles from reviewed reference lists. The research underscores the threat of climate change to health, emphasizing transportation as a significant contributor to greenhouse gas emissions in Canada. Active transportation, especially human-powered modes like cycling, emerges as a solution that not only mitigates the health impacts of climate change but also enhances individuals' overall well-being. The study highlights the benefits of physical activity, particularly through cycling, in reducing disease risk, mortality rates, and fostering mental health and social connections.

A meta-review delved into cutting-edge urban models introduced in recent years, addressing their potential impact on public health amidst the recognition that cities, despite being hubs of innovation and wealth, are also rife with air pollution, noise, heat island effects, and insufficient green spaces, all detrimental to human well-being [11]. Moreover, cities have emerged as focal points for the spread of COVID-19, prompting a reevaluation of urban public spaces. The study advocates for reconsidering current urban models and introduces forward-thinking concepts like Superblocks, low traffic neighborhoods, the 15-Minute city, Car-free city, or hybrid models thereof, aiming to mitigate the health burden tied to existing urban and transportation norms. These proposed models demonstrate promise in reducing air pollution, noise, heat-related issues, while simultaneously bolstering green spaces and encouraging physical activity. Yet, there remains a dearth of comprehensive evaluations gauging the efficacy, public acceptance, and holistic impacts of these initiatives on health, livability, and sustainability, although positive outcomes are anticipated. The study underscores the potential acceleration of these urban developments in response to the COVID-19 pandemic, highlighting the need to utilize funding opportunities like the EU Next Generation funding to drive and support these transformative changes in urban infrastructure and design.

The literature affirms a strong connection between cycling infrastructure and improvements in both physical and mental health outcomes. Previous studies provide compelling evidence that cycling not only increases daily physical activity which lowers risks of cardiovascular disease and obesity but also contributes to reduced stress and enhanced psychological well-being [12]. These benefits are particularly relevant in university settings, where student mental health is a growing concern. Expanding on this, Nieuwenhuijsen [11] links the broader urban environment including noise, pollution, and lack of green space to public health burdens, arguing that innovative urban planning models (15-Minute Cities, Car-Free Zones) can encourage cycling while mitigating these environmental stressors. Collectively, the literature suggests

that investments in cycling infrastructure especially when coupled with thoughtful urban design would offer a dual advantage: promoting sustainable transport while simultaneously addressing critical public health goals in educational environments and beyond.

2.3 Safety and sustainable transport

Perceptions of cycling infrastructure and its role in promoting equity have been explored in recent studies. Jahanshahi et al. [13] investigated how the provision of cycling infrastructure influences perceptions of equity among different demographic groups. The research highlighted that equitable distribution of cycling facilities is essential to ensure all community members have access to safe and convenient cycling options, thereby promoting inclusivity in active transportation initiatives.

Haron et al. [14] examined the built environment and social factors associated with cycling behavior in Putrajaya, Malaysia. The study identified that factors such as connectivity, safety, and social support significantly influence individuals' decisions to engage in cycling. These findings emphasize the importance of considering both physical infrastructure and social dynamics when developing strategies to promote cycling in specific contexts.

In addition to environmental benefits, cycling infrastructure has been linked to improvements in urban mobility and congestion reduction [15]. The study examined the impact of cycling lanes in major university campuses and found that increased cycling rates led to a reduction in vehicular congestion during peak hours. They further emphasized that reducing car dependency in academic institutions not only improves traffic flow but also enhances pedestrian safety and overall campus accessibility. This is particularly relevant in the context of the university campus, where traffic congestion remains a challenge, and the introduction of cycling pathways has been observed to alleviate this issue.

Recent research underscores the significant impact of urban design and policy interventions on promoting cycling as a sustainable mode of transportation [16]. The study utilized a spatial difference-in-differences approach to assess the effects of cycling infrastructure improvements in Lyon and Paris. The findings revealed a positive and statistically significant increase in cycling usage following infrastructure enhancements, highlighting the critical role of well-designed cycling facilities in encouraging active transportation.

Safety, equity, and infrastructure quality are consistently identified as critical determinants of cycling adoption and sustainable transport success. Multiple studies emphasize that well-planned cycling infrastructure not only reduces congestion but also fosters inclusivity and safety in mobility. For instance, Jahanshahi et al. [13] highlighted the importance of equitable access to cycling facilities across different demographic groups, while Haron et al. [14] stressed that social factors like perceived safety and community support must complement physical infrastructure to encourage widespread adoption. The role of urban design in promoting active transport is reinforced by Shahriari et al. [16], who demonstrated that infrastructure upgrades and green land integration are strongly correlated with increased cycling frequency. Additionally, Ribeiro and Fonseca [17] confirmed that cycling infrastructure can significantly reduce traffic congestion and enhance pedestrian safety, offering universities a strategic solution to common campus mobility challenges. Overall, these findings underscore that cycling adoption depends not only on infrastructure availability but also on safety perceptions, urban policy alignment, and equitable access which must be addressed to establish a resilient, inclusive, and sustainable transport system.

Despite the numerous benefits, the implementation of cycling pathways within a university campus is not without challenges. Issues such as funding constraints, spatial limitations, safety concerns, and cultural attitudes towards cycling need to be addressed. Strategies to overcome these challenges involve collaborative efforts between university stakeholders, effective urban planning, provision of secure bike parking, awareness campaigns, and the integration of cycling into the overall transportation network.

Collectively, the literature affirms that cycling infrastructure delivers environmental, health, and safety benefits when thoughtfully designed and contextually integrated. However, most empirical studies are urban-centric, with limited focus on university campuses, particularly in Southeast Asia. While the benefits are broadly acknowledged, localized evidence on how cycling pathways affect sustainability dimensions within Malaysian universities remains scarce. This study addresses that gap by examining the environmental, behavioural, and logistical impacts of cycling pathways at university campus.

3. METHODOLOGY

This research aims to investigate the impact of implementing cycling pathways within the Universiti Sultan Zainal Abidin (UniSZA) campus. The study population comprises students, lecturers, and staff members of UniSZA, encompassing a diverse range of perspectives and experiences within the university community. The rationale for selecting this sample lies in its representation of key stakeholders who are directly affected by the implementation of cycling infrastructure on campus. Including students, lecturers, and staff ensures a comprehensive examination of the research objectives from various viewpoints, thus enhancing the validity and applicability of the findings.

To assess the objectives of the research, a survey methodology was employed, utilizing a Likert scale questionnaire distributed among the selected sample. The questionnaire was developed based on a comprehensive review of existing literature on sustainable transportation, cycling behaviour, and campus mobility frameworks. Key variables such as carbon emissions, safety, traffic congestion, physical activity, and parking constraints were adapted from validated instruments used in previous studies. Items were customized to align with the local university context, ensuring content relevance for UniSZA respondents.

A five-point Likert scale was employed in the questionnaire to capture the intensity of respondent agreement or perception across various constructs. The Likert scale is widely recognized for its simplicity, reliability, and ability to measure attitudes and subjective perceptions in social science research. Its use allowed for the quantification of attitudes toward cycling infrastructure and sustainability, facilitating robust statistical analysis including factor analysis, correlation, and regression.

Prior to full-scale data collection, the questionnaire underwent a pilot test involving 15 participants representative of the study population. The pilot aimed to evaluate clarity, item relevance, and time required for completion. Feedback was used to refine ambiguous questions and ensure better respondent understanding. The pilot data were also analysed to assess internal consistency, with Cronbach's Alpha values for all constructs exceeding 0.80, indicating high reliability.

The survey instrument was distributed electronically to the identified sample, allowing participants to respond to the questionnaire at their convenience. Participants were assured of the confidentiality and anonymity of their responses, encouraging widespread feedback. The survey administration process was conducted over a designated period to maximize response rates and obtain a representative sample of the university community. The collected data were subsequently analyzed using statistical techniques to derive meaningful insights into the impact of cycling pathways on sustainability and campus dynamics at UniSZA.

4. RESULTS

The implementation of cycling pathways within the UniSZA campus yielded several noteworthy outcomes. Firstly, the introduction of cycling infrastructure resulted in a marked improvement in safety perceptions among the university community. Respondents reported feeling safer while cycling within the campus premises, indicating that the presence of dedicated cycling pathways enhanced their sense of security during their commutes.

Furthermore, the study findings revealed a consensus among respondents regarding the positive impact of cycling pathways on reducing carbon emissions within the UniSZA campus. The majority of the participants acknowledged that the availability of dedicated cycling infrastructure encouraged the adoption of bicycles as a sustainable mode of transportation. This shift towards eco-friendly commuting practices aligns with broader sustainability initiatives and contributes to mitigating the environmental footprint of transportation activities on campus.

Observations pertaining to traffic congestion within the campus environment also underscored the benefits of implementing cycling pathways. The diversion of bicycle traffic from main thoroughfares resulted in a noticeable decrease in congestion in high-traffic areas. By providing alternative routes for cyclists, the cycling pathways helped alleviate traffic congestion, enhancing the overall efficiency and flow of vehicular and pedestrian traffic within the UniSZA campus.

Additionally, the presence of cycling pathways was associated with a notable increase in physical activity levels among students, staff, and lecturers. Cycling emerged as a preferred mode of transportation, promoting healthier lifestyle choices and integrating physical activity into daily routines. This shift towards active transportation not only fosters individual well-being but also contributes to creating a campus environment that prioritizes holistic health and wellness.

Finally, the implementation of cycling pathways addressed parking issues within the UniSZA campus. The reduced reliance on motorized vehicles resulted in fewer parking demands, thereby easing the strain on existing parking facilities. This alleviation of parking pressures enhances the overall accessibility and convenience of transportation options available to the university community, contributing to a more sustainable and efficient campus environment.

4.1 Descriptive statistics

Table 1. Descriptive statistics

Variable	Frequency	Percentage
Gender		
Male	48	60.8%
Female	31	39.2%
Age		
17-20	55	69.6%
21-25	18	22.8%
26-35	4	5.1%
36 and above	2	2.5%
Position		
Academician	6	7.6%
Postgraduate Students	1	1.3%
Undergraduate Students	72	91.1%
Campus Location		
Besut Campus	11	13.9%
Gong Badak Campus	68	86.1%
Number of Years at UniSZA		
1-3 years	34	43%
4-6 years	4	5.1%
Less than 1 year	39	49.4%
More than 6 years	2	2.5%

This section presents key demographic characteristics of the respondents. The analysis includes variables such as gender, age, academic position, campus location, and years of study or service at UniSZA. These descriptive statistics offer insights into the composition of the participants, ensuring a clear understanding of the dataset used in this research. Table 1 presents the descriptive statistics of the study.

The first analysis is measuring the general characteristics of the respondent which include gender, age, position, campus and years of study in UniSZA. The response rate was quite good as 79 people completed the survey.

In terms of gender, male respondents were more prevalent, comprising 60.8% (48 individuals), while female respondents accounted for 39.2% (31 individuals). Regarding age distribution, the largest group of respondents fell within the 17-20 years age bracket, constituting approximately 69.2% (55 individuals) of the sample. Following this, individuals aged 21-25 years represented 22.8% (18 individuals) of the respondents. This indicates that the majority of the respondents were younger individuals, likely students.

The analysis of positions revealed that undergraduate students were the primary participants, comprising 91.1% (72 individuals) of the sample. Academic staff constituted only 7.6% (6 individuals) of the respondents, suggesting that the survey primarily targeted students. Furthermore, the distribution of respondents across campus locations indicated that the majority, 86.1%, were from the Gong Badak campus, with only 13.9% from the Besut Campus. This highlights the higher participation rate from the Gong Badak campus.

Lastly, concerning the duration of enrollment at UniSZA, the majority of respondents, 49.4%, reported being enrolled for less than one year, while 43% reported being enrolled for 1-3 years. This suggests that a significant portion of the respondents were relatively new students at UniSZA.

4.2 Exploratory factor analysis (EFA)

To ensure the validity and reliability of the measurement constructs, an Exploratory Factor Analysis (EFA) was conducted. The analysis assesses the underlying structure of the dataset, determining the suitability of the selected variables for further statistical modeling. The Kaiser-Meyer-Olkin (KMO) measure and total variance explained were examined to confirm the adequacy of factor extraction. The factor loadings and Cronbach's alpha values indicate the internal consistency of each construct, ensuring robust measurement reliability. Table 2 presents the results of EFA.

Table 2. Exploratory factor analysis

Construct	KMO Value	Total Variance Explained	Factor Loading	Cronbach Alpha
Safety	0.859	75.130%	0.836-0.907	0.915
Carbon Emission	0.858	76.209%	0.847-0.899	0.920
Traffic	0.881	78.709%	0.878-0.904	0.932
Healthy Lifestyle	0.865	78.399%	0.834-0.930	0.931
Parking Spaces	0.863	73.297%	0.830-0.869	0.908

EFA was performed on 5 different constructs where all five were analyzed individually to remove ambiguity on what items belonged to each of the constructs. For each of these constructs, KMO measure for sampling adequacy was higher than the suggested threshold of 0.60 [18]. In particular, the reliability of the safety construct was evaluated using the KMO statistic of 0.859, carbon emissions 0.858, traffic 0.881, healthy lifestyle 0.865 and Physical 0.863.

All the constructs produced only one component, which shows that the items in that particular construct were well measured. The percentage of the total variances accounted for by the constructs varied from 73.297% to 78.709%, above the threshold of 60%, implying that the items are valid and reliable, capturing the spirit of each construct.

Also, the reliability coefficient for every construct, as well as individual items' factor loadings, was higher than 0.60, ranging from 0.830 to 0.930, thus showing that each item was valid in assessing its respective concept. Thus, discriminant validity was confirmed since the items largely grouped with the constructs that they referred to.

The reliability analysis, based on Cronbach's Alpha, revealed high levels of reliability, with all indices exceeding 0.6 as suggested by Roberts and Priest [17], the upper limit should be 60. Hence, in the context of current research, all the constructs under consideration are both reliable and valid for future studies.

4.3 Pearson correlation

To examine the relationships between the variables, Pearson correlation analysis was conducted. This analysis measures the strength and direction of associations among variables such as safety, carbon emissions, traffic congestion, healthy lifestyle, and parking spaces. The correlation coefficients provide insights into the degree of interdependence among these factors, helping to validate the study's hypotheses. A significance level of 0.01 was used to determine the statistical relevance of the correlations. Table 3 presents the correlation results.

Following the descriptive analysis, Pearson correlation coefficient was used to determine the strength of correlation between all the variables under study. All the coefficients were below 0.90 and significant thus confirming the research hypothesis and the null hypothesis was rejected. This means the minimum condition of multicollinearity does not exist among the independent variables suggesting that all independent variables can be included in a model without creating problems of redundancy or inflated standard errors.

In this study, the range of correlation coefficients obtained for the variables was between 0.695 to 0.850. These values represent moderate to strong correlation between the variables, which means that there was a clear association between the variables in question. Therefore, all the variables will be endogenous in the analytical model as all of them provide useful information in the estimation process and none of them poses a problem of multicollinearity.

To further examine the impact of key variables on sustainable transportation, a multiple regression analysis was conducted. This analysis evaluates the influence of factors such as safety, carbon emissions, traffic congestion, healthy lifestyle, and parking spaces on the dependent variable. The results indicate the strength and significance of each predictor, with the standardized beta coefficients highlighting their relative contribution. The high R-squared value suggests that the model explains a substantial portion of the variance in sustainable transportation. The ANOVA test confirms the model's overall statistical significance. Table 3 presents the regression coefficients.

The results indicated that these variables collectively explained 92.9% of the variance in sustainable transportation. This suggests that only 7.1% of the variability in sustainable transportation remains unexplained by the included factors. ANOVA results supported the notion that the sample was drawn from the same population, validating the reliability of the results for hypothesis testing.

Table 3. Regression coefficients

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Constant	.000	.014		-.009	.993
Safety	.205	.005	.200	38.666	.000
Carbon Emission	.213	.006	.237	38.265	.000
Traffic	.205	.005	.245	38.865	.000
Healthy Lifestyle	.200	.006	.223	33.995	.000
Parking Spaces	.176	.005	.205	33.658	.000
R Squared	**0.929**				
ANOVA	**F-test=21690.169 (0.000)**				

a. Dependent Variable: Sustainable Transportation

Beta coefficients, presented in Table 4, revealed significant relationships between all predictor variables and sustainable transportation. Notably, the impact of cycling pathways on carbon emissions demonstrated the highest importance with a beta coefficient of 0.213, followed closely by safety and traffic variables, each with a beta coefficient of 0.205. Conversely, physical activity exhibited the lowest impact with a beta coefficient of 0.176. These findings suggest that interventions targeting cycling pathways and addressing carbon emission concerns may yield the most substantial improvements in sustainable transportation practices.

Table 4. Pearson correlation

		Safety	Carbon Emission	Traffic	Healthy Lifestyle	Parking Spaces
Safety	Pearson Correlation	1	.728**	.763**	.739**	.695**
	Sig. (2-tailed)		.000	.000	.000	.000
Carbon Emission	Pearson Correlation	.728**	1	.722**	.850**	.758**
	Sig. (2-tailed)	.000		.000	.000	.000
Traffic	Pearson Correlation	.763**	.722**	1	.772**	.832**
	Sig. (2-tailed)	.000	.000		.000	.000
Healthy Lifestyle	Pearson Correlation	.739**	.850**	.772**	1	.776**
	Sig. (2-tailed)	.000	.000	.000		.000
Parking Spaces	Pearson Correlation	.695**	.758**	.832**	.776**	1
	Sig. (2-tailed)	.000	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

5. DISCUSSION

This study aimed to assess the impact of cycling pathways on sustainability-related outcomes within a university campus, focusing on environmental, social, and infrastructural dimensions. The findings reveal significant positive effects across multiple domains, including reductions in carbon emissions and traffic congestion, improvements in health and safety, and increased support for active transport culture.

5.1 Environmental impact

This study confirms the significant role of cycling pathways in reducing carbon emissions within university settings. By encouraging the use of bicycles as a daily commuting option, the need for motorized vehicles is reduced, aligning with previous study, which found that substituting short urban car trips with cycling could reduce total emissions by up to 10 percent [19]. The strong statistical correlation between cycling infrastructure and reduced carbon emissions in this study supports broader global climate action goals, especially in academic institutions.

5.2 Health and well-being

Findings also suggest that cycling contributes positively to physical and mental health among university community members. The observed increase in cycling participation has promoted more active lifestyles, with associated benefits such as improved cardiovascular health and reduced stress, echoing the findings of previous literature [7, 20]. As mental health becomes a growing concern in higher education, cycling offers an accessible and cost-effective means of integrating physical activity into daily routines, potentially improving overall well-being.

5.3 Traffic and mobility

One of the most notable findings is the impact of cycling pathways on alleviating traffic congestion. The introduction of dedicated cycling lanes has provided alternative routes for movement across campus, reducing reliance on private vehicles and easing congestion during peak hours. These results align with Ribeiro and Fonseca [15], who observed similar outcomes in other university settings. Improved traffic flow not only enhances mobility but also reduces emissions and delays, creating a more efficient campus transport system.

5.4 Parking and infrastructure

Cycling has also helped address campus parking challenges. With more individuals shifting to bicycles, the demand for vehicle parking has declined, freeing up valuable space and reducing land-use pressure. This supports findings by Wang et al. [4], who emphasized the long-term cost and environmental benefits of cycling infrastructure over motorized transit systems. This transition reflects more sustainable land management practices within educational institutions.

5.5 Safety and accessibility

Safety perceptions have improved following the implementation of dedicated cycling lanes. The study found that users feel more secure when cycling on well-marked paths, which aligns with findings from Nieuwenhuijsen [11], who emphasized that protected infrastructure enhances both safety and cycling adoption. Additionally, equitable access to cycling pathways ensures that lower-income students and staff have a reliable, low-cost transport alternative, supporting social inclusion goals highlighted by Jahanshahi et al. [13].

5.6 Limitations and future research

While this study provides robust evidence of the benefits of cycling pathways, several limitations should be acknowledged. First, the study was confined to a single university setting, which may limit the generalizability of the findings to other contexts. Second, the cross-sectional design captures perceptions at one point in time and may not reflect long-term behavioural changes. Third, the study relied on self-reported data, which may be subject to bias. Future research could address these limitations by conducting longitudinal studies, incorporating multi-campus comparisons, and integrating observational methods to validate commuting patterns. Additionally, further studies could explore how seasonal, or weather variations affect cycling behaviour and infrastructure use on campus.

6. CONCLUSION

The integration of cycling pathways within the UniSZA campus has yielded positive outcomes across several sustainability dimensions. The study demonstrates that dedicated cycling infrastructure contributes to a measurable reduction in carbon emissions, promotes healthier commuting habits, reduces traffic congestion, and alleviates the demand for motor vehicle parking. Moreover, the presence of safe, accessible pathways has encouraged greater cycling participation among students and staff, fostering a shift toward active and environmentally responsible transport behaviour.

These findings align with global sustainability targets and

reinforce the value of campus-based interventions in shaping broader urban mobility trends. By investing in cycling infrastructure, universities can serve as living laboratories for sustainable development, showcasing practical solutions that address both environmental and social challenges. The results support the idea that physical infrastructure, when paired with safety measures and community engagement, can generate long-term behavioural change.

From a policy perspective, universities should institutionalize sustainable mobility planning as part of their campus development strategies. This includes integrating cycling pathways into masterplans, allocating budgets for infrastructure upgrades, and establishing supportive policies such as incentives for bike ownership, regulations for vehicle use, and mandatory safety standards for shared spaces. Furthermore, collaboration with local governments and urban planners is essential to ensure that cycling networks extend beyond campus boundaries, linking with public transport systems and community spaces.

Practically, universities should consider implementing complementary initiatives such as bike-sharing programs, awareness campaigns, secure bicycle parking, and maintenance stations to support the uptake of cycling. Promoting a cycling culture through education, orientation programs, and student-led sustainability projects can enhance acceptance and participation. These initiatives not only contribute to a cleaner, safer, and more inclusive campus environment but also help cultivate environmentally conscious graduates who are likely to carry sustainable habits into their professional and personal lives.

In conclusion, the success of cycling infrastructure at UniSZA offers a model for other higher education institutions seeking to promote sustainable transport solutions. By embracing integrated cycling policies and infrastructure, universities can play a pivotal role in climate action, health promotion, and urban transformation—advancing both institutional sustainability goals and national development agendas.

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