Strategies for Sustainable Transportation in the Climate Crisis Era

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Abstract

In the face of an escalating climate crisis, the adoption of sustainable transportation has emerged as a critical strategy for mitigating environmental impact and promoting urban resilience. This study conducted a comprehensive analysis of the impact model of the adoption of sustainable transportation. The findings emphasized the importance of policy interventions, technological innovations and operational capacity of the transportation system in promoting sustainable transport adoption. The moderating role of environmental concerns was also verified. Based on the findings of the study, specific policy recommendations to support the development of sustainable transportation systems are proposed, providing practical insights and empirical evidence for relevant government departments and other stakeholders to create resilient and sustainable urban transportation systems.

Key words: climate crisis, sustainable transportation, urban critical infrastructure, psychological capital, environmental concern

I. Introduction

Since the middle of the 21st century, climate crisis has been further exacerbated and has become a major constraint on the sustainable development of human societies. According to the Copernicus Climate Change Service (C3S), July 2023 was the hottest month on record globally, approximately 1.5°C warmer than the pre-industrial average of 1850-1900, and 0.33°C warmer than the previous record set in July 2019. As greenhouse gas concentrations in the atmosphere rise, long-term warming will persist, leading to continual breaking of temperature records. Global warming has precipitated several significant climate-related changes, including increasing global temperatures, ice volume loss, rising sea levels, and altered precipitation patterns.

Rapid environmental changes driven by climate change led to species and habitat loss, ecosystem degradation, infrastructure damage, disrupted agricultural and trade systems, human migration and displacement, impaired livelihoods, and increased mental health issues (IPCC, 2022:126). Recently, the severity of climate impacts has prompted global leaders to refer to the situation as a climate crisis rather than merely climate change (Lee, 2023:1).

Cities and urbanization areas house over half of the world's population, with projections indicating that over two-thirds will be urban by 2050 (UNDESA, 2018: 21). The number of people living in urban areas highly exposed to climate change impacts is also expected to rise, increasing future risks under various climate scenarios (IPCC, 2022: 909). Urban activities significantly contribute to climate change, accounting for 75% of global CO2 emissions, with motorized transport being a major factor (Dodman, 2009: 5). Oil remains the dominant fuel source for transportation, with road transport responsible for 81% of the sector's total energy use. This reliance on fossil fuels makes transport a major contributor to greenhouse gas emissions, one of the few industrial sectors where emissions continue to grow (Chapman, 2007: 354).

As a critical strategy for addressing the climate crisis within the transportation sector, sustainable transportation has garnered increasing attention in recent years. Sustainable transportation encompasses not only low-carbon and zero-emission vehicles but also the development and optimization of public transportation systems, bicycle lanes, and pedestrian pathways. By reducing dependence on fossil fuels, promoting the use of clean energy vehicles, and enhancing the overall efficiency of urban transportation networks, sustainable transportation helps to lower greenhouse gas emissions and mitigate the impacts of climate change. Additionally, the construction of sustainable transportation systems can enhance the resilience of urban transportation, enabling better responses to the disruptions caused by extreme weather events.

Despite the significant theoretical and practical advantages of sustainable transportation, its adoption among urban residents remains suboptimal. The factors influencing residents' choice of sustainable transportation modes are multifaceted, including policy support, technological innovation, the operational capacity of transportation systems, residents' environmental awareness, and psychological capital.

In summary, while the climate crisis poses significant threats to urban transportation infrastructure, promoting and adopting sustainable transportation modes can effectively alleviate these impacts. Therefore, the purpose of this study is to delve into the key factors influencing urban residents' adoption of sustainable transportation and propose effective improvement strategies by analyzing the logical relationships among these factors. By clarifying these factors and relationships, we can provide more specific and practical recommendations and guidance for urban sustainable development, better addressing climate change and promoting sustainable urban development.

II. Theoretical Discussions

1. Climate Crisis

Many people think that climate change primarily means rising temperatures. But rising temperatures are only the beginning of the story. As an interconnected system, changes in one region can trigger cascading effects worldwide. Globally, there has been a notable rise in the frequency and intensity of extreme weather events due to climate change (Coronese, et al., 2019: 21450; Van Aalst, 2006: 7-8).

Described by Crist (2007: 32) as the foremost environmental crisis of our era, climate change has dire consequences for global health and well-being. The World Health Organization projects that climate-related mortality and morbidity could lead to an additional 250,000 deaths annually between 2030 and 2050 (Watts, et al., 2015: 1880), exacerbated by the global spread of vector-borne diseases (Meierrieks, 2021: 1). Because it is so destructive and threatening, world leaders and scholars use the term climate crisis.

The term “climate crisis” underscores the urgency and severity of the situation, reflecting the escalating impacts on ecosystems, agriculture, societies, and economies worldwide. It demands immediate and coordinated global action to mitigate greenhouse gas emissions, enhance resilience, and safeguard vulnerable communities from the multifaceted threats of climate change.

Climate crisis is recognized as a complex intergovernmental challenge with profound impacts across ecological, environmental, socio-political, and socio-economic dimensions (Adger, et al., 2005; Lealfilho, et al., 2021; Feliciano, et al., 2022). It poses significant threats to various aspects of human society, affecting physical phenomena such as precipitation patterns, sea level rise, hurricanes, wildfires, and heatwaves, as well as ecological and socio-economic systems (Adediran, et al., 2023: 1). Industries, agriculture, health, and the quality of life in nations are all susceptible to its repercussions (Abbas, et al., 2023: 653).

Ecosystems, crucial for human survival and well-being, are profoundly impacted by anthropogenic climate change, leading to accelerated species loss (Abbass, et al., 2022: 545). Disruptions in ecosystem functioning and biodiversity are exacerbated by disturbances such as floods, droughts, cyclones, heat waves, and fires, all of which have increased in magnitude and frequency in many regions (IPCC, 2022: 209). Climate crisis has emerged as a significant driver of biodiversity loss (Ogawa & Berry, 2013: 361). Many ecological projections are also available, which suggest that climate crisis will continue to affect many species in the future and may lead to significant disruptions in ecosystem functions or species' extinctions (Bellard, et al., 2012: 365).

Socially, climate crisis presents vast and intricate challenges. Increasing populations, unsustainable economic growth, and heavy reliance on natural resources heighten exposure to its impacts. Natural resources, some irreplaceable and requiring significant replenishment times, face intensified pressure from growing populations (Khan, 2013: 30). Climate crisis exacerbates issues surrounding resource distribution and raises equity concerns between developed and developing countries in their responses to climate impacts (Pereira, 2015: 195). Developing nations, due to geographical vulnerabilities, resource constraints, high poverty rates, and limited adaptive capacities, are expected to bear the brunt of climate change impacts (Heltberg, et al., 2009: 91).

Moreover, climate crisis has profound psychological implications, exacerbating anxiety and distress among vulnerable populations and contributing to mental health issues (Abbass, et al., 2022: 548). Extreme weather events associated with climate change, such as severe storms and temperature extremes, further compound mental health challenges, including depression and post-traumatic stress disorder.

2. Urban Climate Crisis and Urban Critical Infrastructures

Cities can be considered as complex systems and are comprised of infrastructure which is intertwined with service delivery. Urban areas contain critical infrastructure and systems that act as the foundation for highly populated areas that support the productive opportunities of urban life. Therefore, critical infrastructure and systems are essential for urban life functionality. Dense urban ecosystems, such as cities, are especially susceptible to climate crisis and events, due to their complex and stationary nature (Salimi & Al-Ghamdi, 2020:1,14). Despite the fact that the climate crisis is a global issue often discussed on a national scale, urban areas are increasingly seen as playing a unique role in the climate mitigation and adaptation agenda. In addition to global crisis, urban areas have unique climate risks (e.g., urban heat island, impervious surfaces exacerbating flooding, coastal development threatened by sea level rise, etc.) (Carter, et al., 2015: 2). In addition, urban areas also house a majority of the world's population and are global economic hubs, thus exposing many aspects of the city especially infrastructure systems, to the hazards of climate crisis (Doherty, et al., 2016: 310).

Different organizations and scholars have defined and described critical infrastructure from a diversity of perspectives. The term critical infrastructure is defined in the USA Patriot Act of 2001 as those "systems and goods, both physical and virtual, so vital to the nation that their malfunctioning or destruction would produce a debilitating impact on the security of citizens, on the economic security of the nation, on national public health and on any combination of the above"

(Balani, 2019: 76). Critical infrastructures, as referred to by the United States (US) Dept. of Homeland Security, are "the assets, systems, and networks, whether physical or virtual, so vital that their incapacitation or destruction would have a debilitating effect on security, national economy security, national public health or safety, or any combination thereof" (Stergiopoulos, et al., 2016: 2). The European Union defines critical infrastructure as an element, system or part thereof located in the Member States which is essential for the maintenance of the vital functions of society, the health, safety and economic and social well-being of citizens and whose damage or destruction would have a significant impact in a Member State due to the impossibility of maintaining those functions" (Directive, 2008: 23).

Urban critical infrastructures are always known to be highly interconnected and complex (Zhang, et al., 2015: 3). This means that the operation of one critical infrastructure is dependent on the operation of other critical infrastructures. Examples of critical infrastructures include supply of energy (oil, gas, and electricity), information and communication technology (including telecommunications and navigation), nuclear industry, water supply, healthcare (hospital, medicines, and vaccines), provision of financial services (banks and insurance), civil administration (government functions and facilities), and function of transportation systems (road transport, railway transport, and air traffic) (Alcaraz, et al., 2015: 53).

These diverse institutions and scholars may have nuanced definitions of critical infrastructure, but they share several commonalities. They unanimously regard critical infrastructure as systems, facilities, and functions of paramount importance to national security, emphasizing their crucial role in upholding both national and public safety. Additionally, they all acknowledge critical infrastructure as indispensable for sustaining socio-economic operations and development, playing a pivotal role in safeguarding public health, fostering economic vitality, and ensuring national security. Furthermore, they underscore the potential severe consequences of damage to critical infrastructure, which could have significant impacts on the nation's economy, society, and environment.

Adaptation to climate change in cities is a necessity, cities are key sites where climate change is being adapted. Although urban climate change adaptation is a relatively new topic, a burgeoning research community has studied the relationships between cities and climate change. Over recent years significant advances have been made in policy, practice and research on climate change adaptation more broadly, and in urban areas specifically. Urban climate adaptation is changing in multiple ways, it is diversifying and the traditional multilateral approach is complemented by more autonomous, experimental reactions (Madsen & Hansen, 2019: 283). 'Urban climate change experiments' are an important part of this new wave of initiatives and have over the recent years proliferated across the globe. Urban climate change experiments are interventions that in one way or another aim to prevent, mitigate or adapt to the vulnerabilities of climate change (Broto & Bulkeley, 2013: 94). Urban climate change experiments are geographically targeted towards an urban area and take place in this real-life context to promote learning and potentially contest socio-technical systems (Bulkeley & Broto, 2013: 361). The growth of urban climate change experiments parallels an increasing understanding that cities are key sites for responding to climate change. During the past two decades, the issue of climate change has been cemented on urban government agendas, while the importance of cities is recognized in intergovernmental agreements and institutionalized through international networks (Madsen & Hansen, 2019: 28).

3. Sustainable Transportation

Sustainable transportation was derived from the concept of sustainable development. SDG target 11.2 explicitly urges the international community to strive for sustainable transport for all by 2030, aiming to provide access to safe, affordable, accessible, and sustainable transport systems. This goal emphasizes improving road safety, expanding public transport, and addressing the needs of vulnerable groups, including women, children, persons with disabilities, and older persons (UN, 2015).

In recent years, scholars have expanded their focus beyond traditional boundaries, aiming to define and address sustainable transportation from a multidimensional perspective. Black & Sato (2007: 74) argue that sustainable transportation results from people's widespread concern over global warming, which is a component of sustainable development. Litman & Burwell (2006: 332) argue that sustainable transportation can be understood in both narrow and broad terms. The narrow definition focuses on resource depletion and air pollution, while the broad definition expands upon these concerns to include considerations of economic and social welfare, equity, human health, and ecological integrity, allowing for a more comprehensive understanding of all the impacts of transportation. The latter facilitates identifying opportunities for integrated solutions, including improving travel choices, economic incentives, institutional reforms, and technological innovations. It also contributes to the development of comprehensive solutions for sustainable transportation.

According to Centre for Sustainable Transportation (CST), sustainable transportation system ensures the safe fulfillment of basic access needs for individuals and society, aligning with human and ecosystem health, equity, and supporting a diverse range of transportation options and a thriving economy. It strives to cap emissions and waste within the Earth's capacity for absorption, reduce reliance on non-renewable resources, maintain the consumption of renewable resources at sustainable levels, promote the reuse and recycling of components, and minimize land use and noise pollution (Haghshenas & Vaziri, 2012: 115).

III. Development of Research Hypothesis

1. The role of policy intervention, technological innovation and operational capacity of transportation system.

According to Manutworakit & Choocharukul (2022: 3), policy interventions are divided into two categories: financial and non-financial policy interventions. The priority development of sustainable transportation cannot be achieved without the support of fiscal and taxation policies (Zhang, et al, 2020: 1). Financial support is the key to ensure sustainable development, which can be reflected in infrastructure construction and operation management (Zhang, et al., 2018: 3350). Non-financial policy interventions mainly include formulating laws and regulations, urban planning and construction, public awareness and education, cooperation and partnerships, etc. According to Zhou, et al. (2015: 159), government procurement and financial support have played an important role in promoting the commercialization of electric vehicles and stimulating the enthusiasm of manufacturers.

H1a: Policy intervention will have a positive influence on adoption of sustainable transportation.

In sustainable transportation systems, technological advances are closely linked to increased sustainability, and sustainability goals drive the need for technological innovation. Using contemporary information and communication technology (ICT) within transportation, transportation technological innovation is designed to promote efficiency, safety, and sustainability of transportation systems (Du, et al., 2022: 105). The integration of transportation technological innovation presents innovative solutions to long-standing challenges in conventional transportation, paving the way for a cleaner and more efficient development path in the sector (Mouratidis, et al., 2021: 2).

H1b: Technological innovation will have a positive influence on the adoption of sustainable transportation.

The operational capacity of transportation systems encompasses aspects such as service levels of transportation facilities (Mugion, et al., 2018: 1567), safety (Friman, et al., 2020: 3), supply-demand capacity (Zhou, et al., 2015: 34), and diversification of transportation options (Kampf, et al., 2012: 106). Strong operational capacity can enhance the convenience and attractiveness of sustainable transportation, reduce private car usage, alleviate traffic congestion and environmental pollution, and promote the transition of cities towards sustainable transportation modes. Therefore, governments and relevant authorities should strengthen efforts to improve the operational capacity of transportation systems to advance the development of sustainable transportation (Enquist, et al. 2007: 385).

H1c: Operational capacity of transportation system will have a positive influence on adoption of sustainable transportation.

2. Psychological Capital

Psychological capital includes having a sufficient effort to successfully complete difficult tasks and having confidence in taking responsibility (self-efficacy); developing a positive perspective (optimism) about being successful now or in the future; being perseverant for goals; and finding new ways to achieve the goals (hope) to achieve success when problems and difficulties are encountered (psychological resistance) (Luthans, et al., 2007: 541).

Self-efficacy determines how people feel, think, motivate and behave (Skarin, et al., 2019: 452). People who experience high self-efficacy set higher goals, put more effort into changing behavior, and seek knowledge from the behavior change process. Sustainable transportation self-efficacy reflects confidence in using sustainable transportation in challenging conditions (Horiuchi, et al., 2017: 482).

Rodriguez, et al. (2013) qualitatively assessed indicators of psychological resilience and his findings suggest that strong external social support is associated with increased psychological resilience. Majid, et al. (2018) examined the role of psychological capital in the relationship between job demands, job resources, and job burnout. Shi, et al. (2023) demonstrated the positive effects of technological innovation on resilience from a digital economy perspective.

H 2a: Policy intervention will have a positive influence on psychological capital.

H 2b: Technological innovation will have a positive influence on psychological capital.

H 2c: Operational capacity of transportation system will have a positive influence on psychological capital.

3. Adoption of Sustainable Transportation

Xia, et al. (2017: 593) investigated the psychological factors predicting willingness to reduce car use. The findings indicate the importance of increasing public awareness of traffic problems as a potential strategy to reduce car use. Hassan, et al. (2015) found that the sense of innovative self-efficacy had a significant positive impact on individual innovative behavior and that innovation self-efficacy can predict individual innovative behavior. Özsungur (2019: 73) explores the effect of psychological capital on service innovation behavior in terms of self-efficacy, optimism, hope and psychological endurance dimensions.

H3: Psychological capital will have a positive influence on adoption of sustainable transportation.

4. Moderating role of environmental concern

Environmental concern refers to individuals' awareness and sensitivity towards environmental issues such as air quality, climate change, resource conservation, and ecological protection (Bamberg, 2003: 21). This heightened awareness often leads individuals to recognize the adverse environmental impacts associated with conventional transportation modes, particularly car dependency, including air pollution, carbon emissions, and energy consumption. According to Song, et al. (2022: 3), environmental emotion can encourage individuals to form low-carbon behavior by affecting the strength and direction of individual behavioral incentives. Bouscasse, et al. (2018: 205) pointed out that people with high environmental concerns have better perceptions of public transportation and are more easily able to make decisions about using public transportation.

H 5a: Environmental concern moderates the relationship between policy intervention and adoption of sustainable transportation.

H 5b: Environmental concern mediates the relationship between technological innovation and adoption of sustainable transportation.

H 5c: Environmental concern moderates the relationship between operational capacity of transportation system and adoption of sustainable transportation.

IV. Research Methodology

1. Data Collection

This research model examines the influence of policy intervention, technological innovation, operational capacity of the transportation system, psychological capital, environmental concerns and adoption of sustainable transportation. The questionnaires for this study were commissioned by the largest questionnaire company in China (WenjuanXing) and were distributed in two rounds through online channels. The first distribution was from April 30 to May 2, 2024, and 100 questionnaires were collected. After excluding 5 invalid data, 95 were pretested for reliability and validity. After revising the measurement items, a second round of data collection was conducted from May 3 to May 8, 2024, with 514 questionnaires returned and 507 valid questionnaires after eliminating 7 invalid data.

Table.1 Demographic characteristics of participants

Classification		Frequency	Percentage
Gender	Male	244	48.13%
	Female	263	51.87%
Age group	Under 20	68	13.41%
	21-30	132	26.04%
	31-40	121	23.87%
	41-50	109	21.50%
	Above 50	77	15.19%
Education level	Junior high school	47	9.27%

	High school	90	17.75%
	Junior college or Undergraduate	310	61.14%
	Master's degree or above	60	11.83%
Family monthly income	Under 6,000	206	40.63%
	6,000-10,000	167	32.93%
	10.000 – 15,000	98	19.33%
	Above 15,000	36	7.1%
Profession	Student	89	17.55%
	Company employees	165	32.54%
	Government or public institution staff	108	21.30%
	Company owner or self-employed	61	12.03%
	Freelancer	51	10.06%
	Other	33	6.51%
Number of private cars	No	32	6.31%
	One	242	47.73%
	Two	168	33.14%
	More than two	65	12.82%

2. Variables and Measurements

The measurement items were based on mature scales designed from previous research. The policy interventions were assessed using eight items from Kim, et al. (2018) and Jaiswal, et al. (2021). Technological innovations were measured with nine items adapted from Salazar, et al. (2020) and Xia, et al. (2022). Operational capacity of transportation systems was measured with nine items adapted from Diem, et al. (2014) and Nguyen, et al (2020). Eight items for psychological capital were adapted from Wong, et al. (2023), while six items for adoption of sustainable transportation were taken from Rodríguez, et al. (2023). The environmental concern was assessed using eight items from Bhutto, et al. (2022). All items were measured on a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree).

V. Results of Empirical Research

1. Common method bias

This study conducted an adequacy test on these 38 items, yielding a Kaiser-Meyer-Olkin (KMO) value of 0.952, indicating suitability for factor analysis. Additionally, based on Bartlett's sphericity test, the approximate chi-square distribution value was 10317.243 with 703 degrees of freedom. The significance level of the sphericity test was less than 0.001, indicating that the data is suitable for factor analysis. An exploratory factor analysis unveiled those 11 distinct factors influenced all the items. In the un-rotated condition, the first factor explained 9.009% of the variance, accounting for 12.529% of the total variance explanation rate (71.903%). The variance explanation rate of less than 50% suggests that the issue of common method bias in the data presented in the research holds little significance.

2. Testing of reliability and validity

The Cronbach's α coefficient for each variable ranged from 0.812 to 0.880, surpassing the 0.7 thresholds for all values. This implies that each scale possesses good internal consistency and reliability. We additionally performed a confirmatory factor analysis, as depicted in Table 2. The findings indicated that the standardized loadings of each factor on its respective latent variable ranged from 0.712 to 0.828. All these values surpassed the 0.7 threshold and were statistically significant ($p < 0.001$), affirming the robustness and statistical significance of the factors.

Additionally, the composite reliability (CR) values between the variables ranged from 0.806 to 0.873, both surpassing the 0.7 threshold. This suggests that the scale exhibits robust construct validity. The average variance extracted (AVE) for each latent variable ranged between 0.534 and 0.659, with all values exceeding 0.5. This underscores the strong convergence validity of each scale. The absolute value of the correlation coefficient of all variables was less than the square root of the diagonal AVE, indicating good discriminant validity among the variables.

Table 2 Confirmatory Factor Analysis

Variables	Items	Standardized Factor Loading	S.E.	C.R.	AVE	CR
Financial policy interventions	Item 1	.801			.599	.817
	Item 2	.768	.057	17.024		
	Item 3	.752	.054	16.681		
Non-financial policy interventions	Item 1	.825			.659	.853
	Item 2	.783	.051	18.573		
	Item 3	.826	.051	19.583		
ITS	Item 1	.790			.582	.806
	Item 2	.749	.062	14.881		
	Item 3	.748	.060	14.867		
New energy technology	Item 1	.805			.603	.820
	Item 2	.754	.053	16.595		
	Item 3	.769	.054	16.888		
Shared transportation platform	Item 1	.760			.612	.825
	Item 2	.758	.062	16.097		
	Item 3	.827	.062	17.162		
Service quality	Item 1	.776			.643	.844
	Item 2	.800	.061	17.566		
	Item 3	.828	.063	18.019		
Supply-demand capacity	Item 1	.749			.597	.816
	Item 2	.788	.063	16.501		

	Item 3	.781	.062	16.377		
Safety management	Item 1	.712			.581	.806
	Item 2	.795	.075	14.839		
	Item 3	.777	.074	14.694		
Self-efficacy	Item 1	.760			.573	.843
	Item 2	.752	.062	16.542		
	Item 3	.740	.060	16.256		
	Item 4	.776	.061	17.075		
Resilience	Item 1	.743			.560	.836
	Item 2	.742	.063	15.695		
	Item 3	.743	.062	15.713		
	Item 4	.765	.064	16.143		
Adoption of sustainable transportation	Item 1	.719			.534	.873
	Item 2	.724	.063	15.439		
	Item 3	.743	.065	15.849		
	Item 4	.741	.063	15.806		
	Item 5	.728	.063	15.518		
	Item 6	.729	.064	15.553		

3. Hypothesis Path Test

(1) Path analysis

Regarding adopting sustainable transportation, financial policy interventions exhibit a significant positive influence ($\beta = 0.121$, $p < 0.01$). Conversely, non-financial policy interventions do not have a significant effect ($\beta = -0.022$, $p = 0.539$). ITS shows a marginally significant positive impact ($\beta = 0.068$, $p < 0.05$), and new energy technology significantly enhances adoption ($\beta = 0.084$, $p < 0.05$). Shared transportation platforms also significantly promote adoption ($\beta = 0.098$, $p < 0.01$). However, service quality does not significantly affect adoption ($\beta = -0.023$, $p = 0.526$). Supply-demand capacity ($\beta = 0.112$, $p < 0.05$) and safety management ($\beta = 0.086$, $p < 0.05$) both have significant positive impacts.

In terms of self-efficacy, both financial policy interventions ($\beta = 0.120$, $p < 0.05$) and non-financial policy interventions ($\beta = 0.140$, $p < 0.01$) exhibit positive and significant relationships, indicating their role in shaping individuals' confidence in adopting sustainable transportation practices. Additionally, technological innovation factors such as ITS ($\beta = 0.104$, $p < 0.05$) and new energy technology ($\beta = 0.111$, $p < 0.05$) positively influence self-efficacy. However, shared transportation platforms ($\beta = 0.070$, $p = 0.165$) do not significantly impact self-efficacy. Factors related to the operational capacity of the transportation system, such as service quality ($\beta = 0.147$, $p < 0.01$), supply-demand capacity ($\beta = 0.140$, $p < 0.05$), and safety management ($\beta = 0.172$, $p < 0.01$), significantly impact self-efficacy, highlighting the importance of service reliability and safety perceptions in fostering individuals' confidence in sustainable transportation adoption.

Regarding resilience, financial policy intervention does not show a positive impact on resilience ($\beta = 0.097$, $p = 0.131$), whereas non-financial policy intervention has a significant effect ($\beta = 0.112$, $p < 0.05$). ITS significantly positively affects resilience ($\beta = 0.099$, $p < 0.05$), and new energy technologies contribute significantly to resilience ($\beta = 0.131$, $p < 0.05$). Shared transportation platforms do not substantially impact resilience ($\beta = 0.093$, $p = 0.109$). Service quality positively affects resilience ($\beta = 0.122$, $p < 0.05$), while supply and demand capabilities do not show significant positive effects ($\beta = 0.101$, $p = 0.185$). However, safety management significantly enhances resilience ($\beta = 0.182$, $p < 0.01$).

Both self-efficacy and resilience significantly influence the adoption of sustainable transportation. Self-efficacy shows a strong positive impact ($\beta = 0.212$, $p < 0.01$), and resilience similarly exhibits a strong positive effect ($\beta = 0.212$, $p < 0.01$).

Table 3 Coefficients of Latent Variable Paths

Path			Estimate	S.E.	C.R.	P	Result
Financial policy interventions	→	Adoption of sustainable transportation	.121	.042	2.877	.004	Supported
Non-financial policy interventions	→		-.022	.037	-.615	.539	Not-supported
ITS	→		.068	.031	2.171	.030	Supported
New energy technology	→		.084	.042	2.020	.043	Supported
Shared transportation platform	→		.098	.037	2.622	.009	Supported
Service quality	→		-.023	.037	-.633	.526	Not-supported
Supply-demand capacity	→		.112	.050	2.257	.024	Supported
Safety management	→		.086	.043	2.018	.044	Supported
Financial policy interventions	→	Self-efficacy	.120	.056	2.139	.032	Supported
Non-financial policy interventions	→		.140	.049	2.873	.004	Supported
ITS	→		.104	.042	2.505	.012	Supported
New energy technology	→		.111	.055	1.998	.046	Supported
Shared transportation platform	→		.070	.050	1.390	.165	Not-supported
Service quality	→		.147	.049	3.001	.003	Supported
Supply-demand capacity	→		.140	.067	2.106	.035	Supported
Safety management	→		.172	.056	3.092	.002	Supported
Financial policy	→	Resilience	.097	.064	1.511	.131	Not-

interventions							supported
Non-financial policy interventions	→		.112	.056	2.014	.044	Supported
ITS	→		.099	.048	2.057	.040	Supported
New energy technology	→		.131	.064	2.051	.040	Supported
Shared transportation platform	→		.093	.058	1.601	.109	Not-supported
Service quality	→		.122	.056	2.176	.030	Supported
Supply-demand capacity	→		.101	.076	1.324	.185	Not-supported
Safety management	→		.182	.064	2.834	.005	Supported
Self-efficacy	→	Adoption of sustainable transportation	.212	.054	3.893	***	Supported
Resilience	→		.212	.043	4.909	***	Supported

Note: ***p <0.001.

(2) Moderation analysis

This study employed the MODPROBE macro within the SPSS. The study considered sustainable transportation policy interventions, technological innovation, and the operational capacity of the transportation system as independent variables, with environmental concern serving as the moderating variable and the adoption of sustainable transportation as the dependent variable. Moderating effects were assessed by analyzing the adoption of sustainable transportation at one standard deviation below and above the mean of environmental concern.

Notably, policy interventions × environmental concern ($\beta = 0.182$, $p < 0.001$) indicates the substantial influence of environmental concern in moderating the impact of policy interventions on the adoption of sustainable transportation as shown in Table 4. Moreover, the analysis reveals a significant moderating effect on the impact of technological innovation, as evidenced by the standardized regression coefficient of technological innovation × environmental concern ($\beta = 0.218$, $p < 0.001$). This suggests that environmental concern positively augments the impact of technological innovation on the adoption of sustainable transportation. Similarly, the interaction term operational capacity of the transportation system × environmental concern demonstrates a significant positive effect ($\beta = 0.140$, $p < 0.001$), emphasizing the regulatory role of environmental concern in moderating the impact of the operational capacity of the transportation system on the adoption of sustainable transportation.

Table 4 Tests of moderated models of environmental concern

Predictive variable	Result variable: Adoption of sustainable transportation				
	β	t	R	R^2	F
Policy interventions	0.500	14.567***	0.681	0.464	145.171***
Environmental concern	0.077	4.908***			
Policy interventions × Environmental concern	0.182	4.725***			
Technological innovation	0.656	18.920***	0.727	0.529	188.375***
Environmental concern	0.108	3.136**			
Technological innovation × Environmental concern	0.218	5.618***			
Operational capacity of transportation system	0.665	17.054***	0.703	0.494	163.801***
Environmental concern	0.063	1.729			
Operational capacity of transportation system × Environmental concern	0.140	3.409***			

Note: ***p <0.001.

VI. Conclusions

Policy intervention was found to have a partially significant impact on the adoption of sustainable transportation, while technological innovation had a significant impact. The operational capability of the transportation system also had a partially significant impact. These three external stimulus factors were found to partially influence psychological capital, which in turn had a significant impact on the adoption of sustainable transportation. Furthermore, the study verified the positive moderating role of environmental concern.

This study provides valuable insights into the adoption of sustainable transportation among urban residents. It highlights the importance of policy intervention, technological innovation, and the operational capacity of transportation systems in promoting sustainable transportation. First, it is fundamental to develop high-quality and well-maintained infrastructure, such as roads, bridges, railways and public transport facilities. Improving the service quality of sustainable transportation also involves increasing route coverage, enhancing service frequency, and optimizing vehicle scheduling. These measures can strengthen public reliance on sustainable transportation and reduce the use of private cars, thereby decreasing traffic congestion and environmental pollution and promoting the development of sustainable transportation.

Second, comprehensively understanding the supply and demand relationship in transportation is crucial for urban transportation construction and sustainable development. With increasing urban transportation, public transportation networks must meet the demand for reduced transportation time and expanded coverage. It is necessary to increase the frequency of public transportation services, especially during peak hours, which can reduce waiting times and overcrowding and make public transportation a more attractive option.

In sustainable transportation development, enhancing self-efficacy helps users build confidence and capability in using sustainable transportation modes while strengthening resilience, which helps users maintain a positive attitude and persist in using sustainable options despite inconveniences. By implementing targeted strategies to enhance these two aspects, we can effectively promote the widespread adoption of sustainable transportation and foster the development of a more environmentally friendly and efficient urban transportation system.

This study revealed that environmental concern, as a critical moderating factor, significantly influences the adoption of sustainable transportation. Enhancing public environmental sensitivity is crucial for promoting the adoption of sustainable transportation. This can be achieved by strengthening environmental education and improving information transparency. For instance, integrating environmental topics into school curricula, community activities, and media campaigns can raise public awareness of the environmental impacts of transportation. Furthermore, involving environmentally sensitive individuals in the formulation and oversight of environmental policies through public consultations and community meetings can increase policy transparency and public engagement.

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