

How Green Policy and Investment Drive Sustainable Transport Infrastructure Development in Iraq

Areej M. Abdulwahab^{1*} , Gofran J. Qasim¹ , Sharinatol Akmanida Jamaludin² , Lubna Sami Amireh² ,
Muhammad Amir³ 

¹Highway and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

²School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14600 Nibong Tebal, Pulau Pinang, Malaysia

³School of Management, Universiti Sains Malaysia, 11800 Penang, Malaysia

*Email: eng.areej.m@uomustansiriyah.edu.iq

Article Info	Abstract
<p>Received 19/04/2026</p> <p>Revised 16/10/2026</p> <p>Accepted 25/10/2026</p>	<p>Developing sustainable transport infrastructure is a critical challenge in emerging economies. This study examines how green transport policy effectiveness and investment in green transport infrastructure contribute to sustainable transport infrastructure development in Iraq through environmentally sustainable practices and technological advancements in transport. Data were collected from 272 transport managers, engineers, and sector experts and analyzed using partial least squares structural equation modeling (PLS-SEM). Statistical tests of reliability, convergent validity, discriminant validity, model fit, predictive relevance, and hypothesis testing were applied. Findings indicate that green transport policy effectiveness and investment significantly enhance environmentally sustainable practices, which subsequently promote technological advancement in transport. Both environmentally sustainable practices and technological advancements were found to positively influence sustainable transport infrastructure development. The results further support significant sequential mediation effects, demonstrating that environmentally sustainable practices and technological advancements jointly transmit the effects of policy effectiveness and investment on sustainable infrastructure outcomes. In addition, digital infrastructure readiness strengthens the relationship between technological advancement and sustainable transportation infrastructure development. This study contributes to the sustainable transportation literature by validating a comprehensive mediated-moderated framework in an emerging economy and providing practical guidance for aligning policy initiatives, investment decisions, and technological innovation to achieve sustainable transport development.</p>

Keywords: Digital Infrastructure Readiness, Environmentally Sustainable Practices, Green Transport Investment, Green Transport Policy Effectiveness, Sustainable Transport Infrastructure Development, Technological Advancement in Transport.

1. Introduction

The transportation sector is one of the most significant contributors to pollution and environmental degradation through its core activities. Din et al. [1] emphasized that the transportation sector worldwide needs to consider developing sustainability through modern strategies and technologies. The current situation of environmental destruction and climate change across the globe requires a significant shift to sustainable transportation, making it essential to develop and adopt green transport systems, as conventional forms of transportation derived from fossil energy are significant contributors to environmental destruction, resource depletion, and climate change [2]. The term green transport encompasses

various concepts and technologies designed to diminish the environmental impacts of transport and enhance the economic, social, environmental, and personal welfare associated with the system [2], [3]. Hence, Bhattacharya et al. [4] emphasized that the contemporary world strongly demands the sustainable development of transportation infrastructure.

The transport sector in Iraq faces significant operational and sustainability challenges owing to inefficiencies in the existing transport systems and infrastructure. Given the conventional transportation plans and modes, this sector is considered a major source of environmental destruction in the country and region [5], [6]. Abdulwahab et al. [7] suggested that appropriate governance and decision-making are crucial to the

sustainable development of the transportation sector of Iraq; therefore, there is an intense need to come up with effective policies for the transport sector of Iraq to promote green transportation and sustainable practices to improve overall sustainable development of the transport infrastructure. Given the growing need to develop sustainable transport infrastructure, transportation companies and policymakers worldwide are seeking ways to control the sector's environmental impact and mitigate the climate change it causes.

According to the United Nations [8], the sector and economic development are directly linked to overall infrastructure development; therefore, appropriate approaches and governance should be identified to guide sustainable transport infrastructure development (STID). However, the existing literature provides a very limited understanding of the factors determining STID, especially in an emerging economy like Iraq. Kottala et al. [2] emphasize that STID requires a comprehensive approach, including social, economic, and environmental goals. For instance, environmental goals include diminishing emissions, improving climate, and preserving natural resources through sustainable transport infrastructure, whereas social goals include enhancing social equity and access in transportation [9]. Despite growing interest in sustainable transportation, a clear gap remains in the literature regarding the integration of these goals, as most prior studies focus on a single goal (e.g., environmental or social) while ignoring their interactions. Rehman et al. [10] and Kottala et al. [2] emphasized that a more synchronized approach is needed to understand the intricacy of these interactions.

Although the topic of sustainable transport has increased in focus, there are still gaps in the literature. Previous research has focused on the determinants of STID one by one, and little has been done to consider how the effectiveness of green transport policy (GTPE) and investment in green transport infrastructure (IGTI) lead to sustainable outcomes. The sequential contribution of environmentally sustainable practices (PESP) and technological developments in transport (TAT) is not well explored, particularly in emerging economies. Furthermore, there is limited research on the conditional role of digital infrastructure readiness (DIR) in enhancing the impact of technological progress on STID. Therefore, the purpose of this study is to investigate the mediating effect of PESP and TAT between GTPE and IGTI on STID. This study also examines if DIR enhances the relationship between TAT and STID.

The novelty of this study lies in the integration of policy effectiveness, green investment, sustainability practices, technological advancement, and digital readiness into a single mediated-moderated framework. Unlike prior studies that have primarily examined isolated relationships among policy, investment, sustainability practices, technological advancement, and sustainable infrastructure outcomes, this study adopts a process-based perspective by examining the sequential mechanisms through which policy effectiveness and green investment contribute to sustainable transport infrastructure development.

This study contributes to the literature in three main ways. First, it extends the understanding of sustainable transport infrastructure development by explaining the sequential

pathways linking policy effectiveness and green investment to sustainable results. Second, it enriches stakeholder theory and the diffusion of innovation theory by explaining how policy effectiveness, investment, sustainability practices, and technological advancement jointly contribute to sustainable transport infrastructure development in an emerging economy context. Third, it offers practical insights for policymakers and transport sector stakeholders seeking to align policy initiatives, investment strategies, sustainability practices, and technological innovations to accelerate sustainable transport infrastructure development.

The remainder of the manuscript is organized as follows. The next section reviews the relevant literature and develops the hypotheses. Subsequently, the methodology, results, discussion, and conclusion sections are presented.

2. Literature Review

Stakeholder theory suggests that companies must address the concerns of all stakeholders to create value [11], [12]. Transport companies should avoid unsustainable effects, such as air pollution and climate change, by monitoring and improving their sustainable development and creating value for all stakeholders [11]. According to Din et al. [1], the transportation industry is a key contributor to global warming and greenhouse gas emissions. Therefore, scholars such as Stiebe [13] and Kottala et al. [2] have emphasized that transportation should be made more sustainable to lessen the social costs and environmental impacts of the existing transportation system. According to Stiebe [13], this can be achieved with the assistance of policies and technologies such as autonomous vehicles, integrated urban policy, ITS solutions, and other technological advancements that can significantly enhance STID.

2.1. GTPE and PESP

Stiebe [13] suggested that policies are a great way to promote sustainable transport practices. The literature provides grounds to argue that well-designed green transport policies such as emission regulations, low-carbon initiatives, and other green transport schemes can considerably promote sustainable transport behaviors and practices. For example, Sun [14] suggested that green transport policies significantly reduce carbon emissions, indicating their role in promoting environmental sustainability. A review by Shah et al [15] suggests that effective green transport policy can lead stakeholders to adopt different sustainable practices, such as using optimized logistics systems, shifting transport modes, using unconventional transportation methods, and using substitute fuels in order to comply with green transport policy. Shokoohyar et al. [16] also emphasized through their review of case studies that regulatory frameworks such as green transport policy tend to improve responsible transport consumption. However, the policy should not only be well-designed but also well-enforced in order to be fully effective and to achieve sustainability outcomes [17]. This means that GTPE can play a crucial role in promoting sustainable transport practices. For instance, rewarding people for adopting eco-friendly modes of transport can promote the use of sustainable practices in the sector [18], [19]. However, the literature provides no further

empirical explanation of the role played by GTPE in determining PESP, thus raising the need to assess this possible nexus.

H1: GTPE significantly positively influences PESP.

2.2. IGTI and PESP

IGTI plays a crucial role in promoting sustainable practices in the transport sector by supporting low-carbon transportation and diminishing environmental impacts. Literature suggests that investment in green transport systems such as electric vehicles or zero-emission transport infrastructure can considerably promote shifts from conventional transportation towards sustainable mobility behavior [20], [21]. Insights from IEA [22] suggest that investment in green transport systems can facilitate the adoption of sustainable practices and clean technologies. Rogaczewski and Ejdays [23] suggest that such investments not only generate environmental benefits but also produce various socio-economic outcomes such as better public health, improved air quality, and reduced traffic congestion. Song et al. [24] reveal that green investments in the transport system can considerably accelerate sustainable practices and lessen environmental impacts. However, very few past studies have attempted to evaluate the direct impact of IGTI on PESP empirically. Kottala et al. [2] found an interconnection between IGTI and PESP in their structural equation modeling, but the explanation of this nexus still remained limited, thus raising the need to analyze the impact of IGTI on PESP particularly. The current study therefore hypothesizes that:

H2: IGTI significantly positively influences PESP.

2.3. PESP and TAT

Sustainable practices considerably accelerate technological advancements in transportation (TAT) so that sustainable outcomes targeted by those practices could be realized. Wang et al. [25] suggested that sustainable practices and initiatives create substantial pressure for innovation through which those sustainable practices could be better practiced. It encourages the development of modern transport technologies. Fatorachian et al. [26] suggest that sustainable transportation requires the application of advanced digital as well as smart technologies such as big data analytics and artificial intelligence (AI) because such technologies can allow organizations to promote operational efficiency and control emissions. Liu et al. [27] emphasize that sustainable practices motivate a shift towards substitute fuels, energy-efficient transportation, and intelligent transport infrastructure, thereby encouraging TAT. This means that PESP can considerably lead towards TAT, as sustainable initiatives tend to cause continuous innovation and advancement of technologies, allowing better realization of sustainable goals.

A number of researchers emphasized that Industry 4.0 technologies and sustainable transportation have a close linkage with each other, as advancement of technologies is crucially needed for successful application of sustainable transportation projects [28]-[31]. Kottala et al. [2] also found an interconnection between PESP and TAT in their structural equation modeling. However, they did not explain how PESP can lead to TAT. Hence, the literature provides enough grounds

to claim that PESP can foster TAT by matching sustainable objectives with digital transformation and innovation in the system. However, most of the prior research focused on the crucial role of technological advancement in promoting sustainable transportation, while the particular effect of PESP on TAT has been rarely explained, particularly in the context of an emerging economy like Iraq, where there is already limited TAT. The current study, therefore, seeks to evaluate this nexus by hypothesizing that:

H3: PESP significantly positively influences TAT.

2.4. PESP and STID

Besides promoting technological advancement, PESP also drives the development of sustainable transport infrastructure because scholars suggest that integration of social, economic, and environmental sustainability concerns into transport planning and practices allows for improving the sustainable development of transport infrastructure [32]-[35]. Promoting sustainable practices, such as using resource-efficient materials or adopting emission-control methods, can support transport infrastructure development in ways that better mitigate environmental impacts and optimize social benefits [36]. Researchers such as Alanazi and Alenezi [37] suggest that sustainable practices encourage transport organizations to incorporate innovative design and smart technologies for enhancing the transport infrastructure. These practices help develop the transport infrastructure in such a way that it can better address sustainability concerns through resilient and environmentally friendly networks. Liu et al. [27] also advocate the crucial role of sustainable planning and practice in improving governance, performance, and stakeholder collaboration in the transport system, thereby escalating STID. Despite the literature providing grounds to argue the positive contribution of sustainable practices towards STID, particular empirical studies explaining the impact of PESP on STID are still rare, as the literature does not provide any further empirical evidence on this nexus. The current study seeks to shorten this gap in the literature by hypothesizing that:

H4: PESP significantly positively influences STID.

2.5. TAT and STID

TAT helps strengthen the sustainable development of transport infrastructure by improving flexibility, efficiency, and diffusion of innovations into the system [38], [39]. It is evident from the literature that incorporating digital and smart technologies such as AI or big data analytics facilitates better infrastructure planning, management, and maintenance that contribute to the realization of better sustainable outcomes [40]-[42]. According to Abbasnejad et al. [31], advanced technologies integrated into transportation systems enable intelligent management and monitoring of transport infrastructure while optimizing energy and resource utilization and diminishing environmental impacts. Furthermore, Hasheminezhad et al. [43] indicate that technological advancements related to materials and engineering allow reducing carbon emissions, preserving energy and resources, and enhancing infrastructure strength. Similarly, Li et al. [44] also support the view that TAT, including digital transformation, can boost the resilience and

sustainability of the transport system through reduction of congestion and improvement of transport efficiency. Hence, the literature suggests that TAT acts as the predictor of STID.

H5: TAT significantly positively influences STID.

2.6. Mediating Roles of PESP and TAT

The review of literature in section 2.1 indicates that GTPE can result in PESP in transportation as a number of researchers posited that sustainable practices could be promoted through effective public policies and governance, e.g., Stiebe [13], Sun [14], Shah et al. [15], Shokoohyar et al. [16], Mateu and Sanz [19], and Hsu and Chen [18]. Like GTPE, IGTI also leads towards PESP in transportation (see section 2.2) because multiple researchers support the viewpoint that investment in green transport systems enhances the adoption of sustainable practices, e.g., [2], [20], [21], [24]. Being the outcome of each of GTPE and IGTI, PESP in turn tends to enhance TAT as well as STID. The discussion of literature in section 2.3 indicates that sustainable practices facilitate the application and advancement of digital as well as smart technologies in transportation, such as big data analytics and artificial intelligence (AI), in order to effectively realize their sustainable goals [25], [27]-[31]. Similarly, the review of literature in section 2.4 indicated that sustainable practices result in the development of sustainable transport infrastructure, as several supportive arguments are found in the literature that advocate the positive contribution of PESP towards STID [27], [32]-[37]. This means that PESP can mediate the paths between GTPE and TAT and between IGTI and TAT. However, past studies never attempted to explain how PESP can play a possible intervening role between GTPE or IGTI and TAT.

TAT resulting from PESP, in turn, improves STID, as the discussion of the literature in section 2.5 indicates that multiple researchers supported the positive contribution of technological advancements and digitalization towards the sustainable transport system, e.g., [31], [40]-[43]. This means that GTPE leads to PESP, which promotes TAT, while the resulting TAT determines STID, thus indicating the possible sequential mediating roles played by PESP and TAT in the path from GTPE to STID. Similarly, IGTI also leads towards PESP, which promotes TAT, while TAT in turn determines STID, thus revealing the possible serial mediating roles played by PESP and TAT in the path from IGTI to STID. Nonetheless, these possible mediating chains have never been explained by prior studies, thereby creating a void in the existing literature. The present research seeks to examine these chains of mediation in order to shorten the existing void in the literature through the assessment of the following hypotheses:

H6: PESP and TAT significantly sequentially mediate the relationship between GTPE and STID.

H7: PESP and TAT significantly sequentially mediate the relationship between IGTI and STID.

2.7. Moderating Role of DIR between TAT and STID

DIR refers to the extent to which the organization, sector, or country possesses the essential digital systems, capabilities, and technologies needed to appropriately adopt and use advanced

technologies [45]. DIR entails great importance in the process of STID, as the existing literature provides insights that the successful integration of technological advancements into transport infrastructure to enhance its sustainable development relies on the degree of digital readiness [40], [46], [47]. This means that technological advancements such as AI, big data analytics, and IoT can produce better STID outcomes if the system has a higher level of DIR, such as ICT capability, network capability, and other institutional capabilities. Alanazi and Alenezi [41] suggest that high digital readiness facilitates effective incorporation of new technologies into infrastructure, thereby enhancing real-time supervision, management, and resource optimization. Philipp [48] revealed that digital readiness promotes sustainability outcomes such as smart port development. Furthermore, Liu et al. [49] also supported the crucial role of digital infrastructure readiness in producing sustainability outcomes, as they suggest that weak DIR and limited technical capacity can act as barriers to developing sustainable transport infrastructure. Hence, the crucial role of DIR in the way of STID is though evident from the literature, but the particular moderating effect of DIR on the relationship between TAT and STID has not been explained efficiently in the literature. Thus, the study hypothesizes that:

H8: DIR significantly amplifies the impact of TAT on STID.

Fig. 1 depicts the conceptual framework of the study.

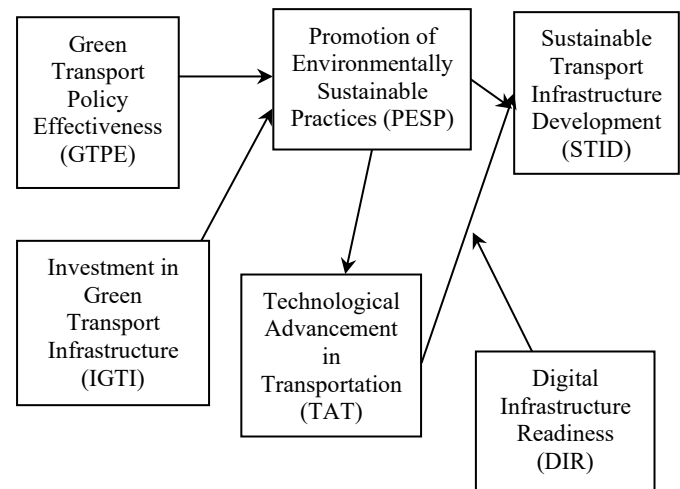


Figure 1. Conceptual framework of the study.

3. Material and Methods

3.1. Research Design

This study adopted a quantitative research approach to examine the hypothesized relationships among the study variables. To explain the sequential mediation mechanisms linking GTPE and IGTI to STID within the Iraqi transport sector, an explanatory research design was employed. Data were collected in two waves to reduce the potential risk of common method bias. At the first stage, the data were collected at Time 1 (T1), and then the data were collected at Time 2 (T2), with a time lag of six weeks between the two waves. The hypothesized relationships were tested using partial least squares structural equation modeling (PLS-SEM), which is appropriate for examining complex relationships involving direct, mediating,

and moderating effects while simultaneously assessing the explanatory power of the proposed research model.

3.2. Population and Sample

The transportation sector of Iraq was the key target of the study to evaluate the process of attaining STID from GTPE and IGTI. Given the ongoing challenges of climate change and environmental destruction caused by the transport sector in Iraq and its developing transport infrastructure, there exists a need to find key ways through which STID in Iraq could be enhanced [5], [7]. Therefore, the transport sector of Iraq is selected as the unit of analysis. Given the purpose of the study to evaluate the role of GTPE and IGTI in determining PESP and the ultimate process of developing STID through them, the current study targets the transport sector of Iraq to collect data about them. The population of the research consisted of managers, experts, administrators, and infrastructure engineers in the transport sector of Iraq, depending on the type of data needed from them. As the variables studied relate to different fields of transport, a purposive sampling technique was used to select the sample participants for the study. For instance, the information related to GTPE and IGTI could better be provided by senior transport managers, municipal planners, and infrastructure administrators, so they were selected as sample participants for collecting the data about GTPE and IGTI. The information related to PESP, TAT, DIR, and STID can better come from technical transport officers, ITS managers, and infrastructure engineers, so they were selected as sample participants for collecting the data about PESP, TAT, DIR, and STID. The required sample size was determined using both the 10-times rule and a priori power analysis conducted in G*Power 3.1. Following recommendations for PLS-SEM, the maximum number of predictors directed at a single endogenous construct in the proposed model was three. Using a medium effect size ($f^2 = 0.15$), a significance level of 0.05, statistical power of 0.95, and three predictors, the G*Power analysis indicated a minimum required sample size of 119 respondents. Therefore, the final sample of 272 valid responses substantially exceeded the recommended threshold, indicating adequate statistical power and supporting the robustness of the study findings.

3.3. Research Instrument

The present study employed a survey-based research design within the transport sector of Iraq. This questionnaire was designed by drawing and adapting validated measurement scales for each variable that were previously used by researchers. To measure GTPE, four items were adapted from the study of Kottala et al. [2]. IGTI was measured using four items, PESP was measured using five items, and TAT was measured using four items, each adapted from Kottala et al. [2]. To evaluate the construct of STID, seven items were adopted from Bhattacharya et al. [4], while four items used to measure DIR were adapted from Aldhi et al. [50]. All the latent variables were measured using a five-point Likert scale. The adopted measurement scales were reviewed and contextually adapted to ensure their relevance and applicability to the Iraqi transport sector. Minor wording modifications were made where necessary to improve clarity and contextual appropriateness while preserving the original meaning of the items. Table 1

presents the operational definitions of the constructs used in this study and their respective roles in the proposed research model.

Table 1. Operational Definitions of the Constructs.

Construct	Operational Definition	Position
Green transport policy effectiveness (GTPE)	The extent to which transportation policies, regulations, and enforcement mechanisms effectively enhance an environmentally sustainable transport system, diminish emissions, and facilitate green transport objectives [14], [16].	Independent Variable
Investment in green transport infrastructure (IGTI)	The provision of physical, monetary, and institutional resources towards a low-carbon and environmentally sustainable transport system [20], [21].	Independent Variable
Promotion of environmentally sustainable practices (PESP)	Promoting the implementation of operational practices in the sector that curtail environmental impacts and enhance sustainable transport implementation [18], [19].	1 st Mediator
Technological advancement in transport (TAT)	The extent to which innovative and modern transport technologies are implemented to encourage a sustainable transport system [26], [28], [31].	2 nd Mediator
Digital infrastructure readiness (DIR)	The degree to which the digital infrastructure of the transport system is ready and sufficiently capable of supporting innovative transport technologies and practices [45].	Moderator
Sustainable transport infrastructure development (STID)	The long-run development of transport infrastructure that concurrently boosts economic efficiency, environmental performance, and social inclusion [2], [9], [10].	Dependent Variable

3.4. Data Collection Procedure

To collect data from participants, questionnaires were sent to targeted senior transport managers, municipal planners, infrastructure administrators, technical transport officers, ITS managers, and infrastructure engineers through online channels such as e-mail or LinkedIn business links. Once the data was selected at T1, the data was collected six weeks later (i.e., T2) to complete two rounds of data collection. See Appendix A for the full details of respondents' profiles.

3.5. Ethical Considerations

Major ethical standards of research were taken under close consideration while performing this study. Researchers obtained informed consent from participants to ensure that they voluntarily participated in the research and were fully aware of the purpose of the research. The data collected from respondents was kept fully confidential, and it was not disclosed to any third party. Researchers used their data in the form of unidentifiable responses to produce quantifiable results and presented them without revealing the identity of respondents.

3.6. Data Analysis

Researchers performed PLS-SEM to evaluate the studied paths through SmartPLS. The significance of the structural model relationships was assessed using a bootstrapping procedure with 10,000 subsamples in SmartPLS 4. A one-tailed test was applied at a 5% significance level. The percentile bootstrap method was used to generate confidence intervals for evaluating the significance of direct, indirect, and moderating effects. To CMB, the marker variable technique recommended by Lindell and Whitney [51] was employed (see Appendix B). The results show that the relationships between the marker variable and the endogenous constructs were statistically non-significant ($p > 0.05$), indicating that the marker variable did not systematically influence the study variables. These findings suggest that the marker variable did not share substantial variance with the substantive constructs, further indicating that CMB is unlikely to have materially affected the study results. In addition, the full collinearity assessment revealed that all variance inflation factor (VIF) values ranged from 1.000 to 1.216, i.e., far below the recommended threshold of 3.3

proposed by Kock [52]. Collectively, these findings indicate that common method bias is unlikely to threaten the validity of the study's results.

4. Results

Before applying PLS-SEM, normality of the data was assessed by computing descriptive statistics (see Table 2). Six latent constructs made up the studied model, i.e., GTPE, IGTI, PESP, TAT, STID, and DIR. Table 2 indicates that the mean value of each measurement item of all variables remained within 1-5 (i.e., normal range), thereby showing that there were no outliers in the data. Loadings against each factor (except DIR2 and GTPE2) of the measurement model were >0.5 , indicating that each studied construct had an adequate connection with the respective factor. Both DIR2 and GTPE2 were removed during the measurement model analysis to enhance the convergent validity and overall quality of the measurement model, as they both exhibited factor loadings below the recommended threshold. Hence, there was no issue of multicollinearity left in the data [53].

Table 2. Loadings, Reliability, and Convergent Validity.

Construct	Item	Loading	Cronbach's α	rho_A	Composite Reliability	AVE
DIR	DIR1	0.759	0.729	0.840	0.832	0.623
	DIR3	0.741				
	DIR4	0.863				
GTPE	GTPE1	0.901	0.872	0.874	0.921	0.796
	GTPE3	0.903				
	GTPE4	0.872				
IGTI	IGTI1	0.759	0.857	0.864	0.904	0.702
	IGTI2	0.860				
	IGTI3	0.875				
	IGTI4	0.852				
PESP	PESP1	0.758	0.853	0.854	0.894	0.629
	PESP2	0.780				
	PESP3	0.830				
	PESP4	0.798				
	PESP5	0.798				
STID	STID1	0.849	0.930	0.932	0.943	0.704
	STID2	0.829				
	STID3	0.803				
	STID4	0.867				
	STID5	0.876				
	STID6	0.865				
	STID7	0.781				
TAT	TAT1	0.856	0.874	0.886	0.914	0.726
	TAT2	0.893				
	TAT3	0.874				
	TAT4	0.780				

*Source: Developed by the authors

4.1. Reliability of Results

Reliability of current results was ensured by assessing indices of internal consistency, convergent and discriminant validity, model robustness, and predictive relevance. To evaluate the reliability of constructs, indices of internal consistency including Cronbach's Alpha, Composite Reliability (CR), and rho_A were computed. The decision about the reliability of each construct was made based on CR, which is an unbiased and more accurate indicator of reliability as compared to

Cronbach's alpha. CR against each construct was >0.7 (see Table 2), which suggested that each of the six studied constructs has good reliability, as it was accurately measured by its respective items [51]. This means that the items used to measure each construct efficiently measured the respective variable.

Besides reliability assessment, researchers also evaluated the convergent validity of variables by computing AVE, as reported in Table 2. Hair et al. [53] suggested that AVE should exceed 0.5 to affirm the convergent validity of the variable; therefore,

it was found that all constructs in the study showed adequate convergent validity. This is because AVE against each of the six variables exceeded 0.5 (e.g., 0.7 for STID), thereby affirming that the measurement items of each construct were strongly linked to the respective construct. To assess the discriminant validity of constructs, researchers applied the “heterotrait-monotrait ratio of correlations” (HTMT) criteria, the results of which are presented in Table 3. HTMT of each variable against all other five variables stayed within the threshold, i.e., <0.85. This means that no correlation of a particular variable with any other variable exceeded its correlation with itself, thus affirming the discriminant validity of each of the six variables [51]. Additionally, cross-loading analysis was conducted to further confirm discriminant validity. As presented in Appendix C, all measurement indicators exhibited higher loadings on their respective constructs compared with other constructs, confirming adequate discriminant validity.

Table 3. Discriminant Validity (HTMT).

	DIR	GTPE	IGTI	PESP	STID	TAT
DIR	-					
GTPE	0.367	-				
IGTI	0.141	0.354	-			
PESP	0.256	0.466	0.525	-		
STID	0.171	0.412	0.463	0.613	-	
TAT	0.301	0.276	0.345	0.441	0.375	-

*Source: Developed by the authors

To further assess the structural model, the authors examined model fit, explanatory power, and predictive performance, as reported in Table 4.

Table 4. Model Fit, Predictive Assessment, and Explained Variance.

Construct	Q ² predict	RMSE	MAE	R ²	Adjusted R ²	SRMR	NFI
PESP	0.265	0.863	0.694	0.284	0.279	0.067	0.785
TAT	0.091	0.958	0.817	0.146	0.143		
STID	0.181	0.909	0.754	0.343	0.333		

*Source: Developed by authors

The R² values for PESP, TAT, and STID were 0.284, 0.146, and 0.343, respectively, while their adjusted R² values were 0.279, 0.143, and 0.333. These results indicate that the model explains 28.4%, 14.6%, and 34.3% of the variance in the respective endogenous constructs. The standardized root mean square residual (SRMR = 0.067) was below the recommended threshold of 0.08, indicating satisfactory approximate model fit. However, the normed fit index (NFI = 0.785) remained below the commonly referenced threshold of 0.90, suggesting that the fit evidence should be interpreted cautiously. The Q²predict values for PESP (0.265), TAT (0.091), and STID (0.181) were all positive, indicating predictive relevance for the endogenous constructs [54].

4.2. Hypotheses Testing

After establishing the reliability and validity of the measurement model, the structural model was assessed using PLS-SEM. As presented in Table 5, GTPE exerted a significant positive effect on PESP ($\beta = 0.298$, $p < 0.001$), supporting H1. Similarly, IGTI positively influenced PESP ($\beta = 0.361$, $p < 0.001$), providing support for H2. The results further indicated that PESP had a significant positive effect on TAT ($\beta = 0.383$, $p < 0.001$), thereby supporting H3. In addition, PESP was found to positively influence STID ($\beta = 0.491$, $p < 0.001$), supporting H4. The relationship between TAT and STID was also positive and significant ($\beta = 0.161$, $p = 0.003$), confirming H5.

Table 5. Structural Model and Hypothesis Testing Results.

Hypothesis	Relationship	β	t-value	p-value	95% CI	f ²	Result
H1	GTPE → PESP	0.298	5.054	0.000	0.194–0.389	0.112	Supported
H2	IGTI → PESP	0.361	5.747	0.000	0.257–0.462	0.165	Supported
H3	PESP → TAT	0.383	6.375	0.000	0.269–0.470	0.172	Supported
H4	PESP → STID	0.491	9.205	0.000	0.400–0.575	0.305	Supported
H5	TAT → STID	0.161	2.760	0.003	0.066–0.259	0.032	Supported
H6	GTPE → PESP → TAT → STID	0.018	2.058	0.020	0.007–0.037	—	Supported
H7	IGTI → PESP → TAT → STID	0.022	2.004	0.023	0.008–0.045	—	Supported
H8	DIR × TAT → STID	0.108	1.974	0.024	0.024–0.198	0.022	Supported

*Source: Developed by the authors

Regarding the indirect effects, the results revealed significant sequential mediation through PESP and TAT. Specifically, the indirect effect of GTPE on STID through the sequential pathway of PESP and TAT was significant ($\beta = 0.018$, $p = 0.020$), supporting H6. Likewise, the sequential indirect effect of IGTI on STID through PESP and TAT was significant ($\beta = 0.022$, $p = 0.023$), providing support for H7. These findings

suggest that both policy effectiveness and green investment contribute to sustainable transport infrastructure development through a process involving sustainable practices and technological advancement. Furthermore, DIR significantly moderated the relationship between TAT and STID ($\beta = 0.108$, $p = 0.024$), indicating that higher levels of digital infrastructure readiness strengthen the positive influence of technological

advancement on sustainable transport infrastructure development. Lastly, the effect size assessment (f^2) indicated that the relationships in the structural model ranged from small to moderate effects. According to Cohen's criteria, the effect sizes for the hypothesized relationships were mostly moderate, with the strongest contribution observed for PESP in explaining

STID ($f^2 = 0.305$). Other relationships demonstrated small to moderate practical effects, while the moderation effect of DIR showed a small effect size ($f^2 = 0.022$). Accordingly, H8 was supported. Fig. 2 illustrates the structural model and the estimated relationships among the study constructs.

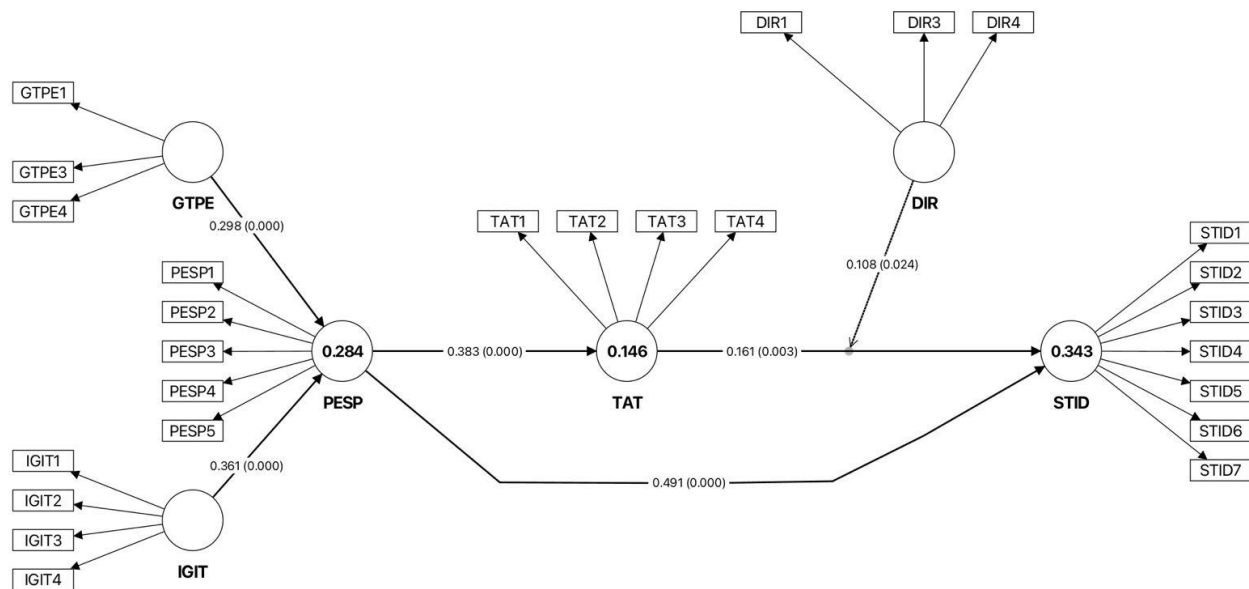


Figure 2. Structural Model Assessment.

Assessment of the moderating influence of DIR on the association between TAT and STID revealed that the presence of DIR significantly amplified the positive effect of TAT on STID (p -value < 0.05). It posited that DIR acts as a significant moderator in the association between TAT and STID. We also evaluated each variable in terms of the extent to which it was linked to STID and how transport organizations in Iraq are currently performing in the area of that construct. Fig. 3 shows importance-performance map analysis (IPMA), which indicated that PESP entails the highest importance for attaining STID, but its performance has not been fully realized in the transport sector of Iraq. Furthermore, GTPE, though having moderate importance in attaining STID, has been better realized, showing higher performance in the sector. IPMA indicates that the transport sector in Iraq needs to improve its performance in terms of PESP, as it can serve as the best way of boosting STID.

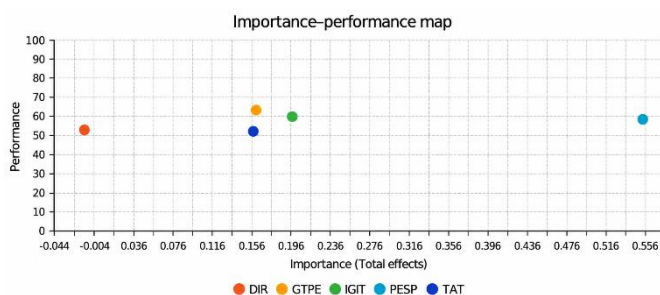


Figure 3. Importance-Performance Map.

5. Discussion of Results

The current study found that GTPE in Iraq serves as a significant antecedent of PESP. H1 of the study was confirmed, which indicated that the transport sector of Iraq should focus on GTPE in order to promote sustainable practices in the sector. These findings are consistent with viewpoints of various prior studies such as Stiebe [13], Sun [14], Shahet al. [15], Shokoohyar et al. [16], Mateu and Sanz [19], and Hsu and Chen [18] because these researchers also somehow advocated the positive contribution of policy and governance towards sustainable practices. Results of the study further posited that IGIT acts as a significant determinant of PESP, thereby confirming H2. Based on these findings, it was concluded that improving IGIT in Iraq can result in better PESP. It is also aligned with past studies supporting the positive role of investment in green transport towards PESP, e.g., [2], [20], [21], [24]. In a developing transport system, regulatory support alone may be insufficient without adequate investment, while investment initiatives may be less effective in the absence of supportive policies. Therefore, the combined presence of effective policies and targeted green investment appears essential for encouraging sustainable transport practices.

PESP was found to positively affect TAT in Iraq, thereby confirming H3. It posited that PESP facilitates the integration of technological and digital advancements in transportation, such as big data analytics and AI, that help achieve sustainable goals. These viewpoints are consistent with those of multiple prior researchers, thus showing alignment with the previous literature, e.g., [25], [27]-[31]. Besides promoting TAT, PESP also significantly improves STID. Results confirmed H4 and

suggested that promotion and adoption of sustainable practices in transport act as the antecedent of STID. These viewpoints drawn from the current findings are in line with revelations made by various past researchers who advocate the positive contribution of PESP towards STID, e.g., [27], [32]-[37]. Moreover, findings of the study deduce that TAT allows enhancing performance and development of sustainable transport infrastructure, thereby confirming H5. These revelations also showed consistency with the previous literature because a number of past researchers had supported the positive role of technological advancements and digitalization towards STID, e.g., [31], [40]-[43]. These findings indicate that PESP functions as a mechanism through which transport organizations align sustainability objectives with technological modernization. As organizations adopt environmentally responsible practices, they are increasingly required to invest in digital and technological solutions that improve operational efficiency, resource utilization, and environmental performance. Consequently, sustainability initiatives become an important driver of technological advancement within the transport sector.

Results on the mediating paths showed that the path from GTPE to STID was mediated by PESP and TAT in turn in Iraq, which supports H6. In addition, the sequential mediating role of PESP and TAT between IGTI and STID in Iraq was also significantly supported, which led to acceptance of H7. The results indicate that each of GTPE and IGTI facilitates PESP and consequently increases TAT, and that technological advancement is the ultimate factor that enables the development of transport infrastructure in Iraq, thereby solving the sustainability issue. While previous research has validated the individual relationships in these mediation chains, the current study contributes to the literature by showing how these relationships work together in a sequential manner to produce STID. These sequential mediation pathways also suggest that the relationship between GTPE and IGTI is not a direct one, as there are certain intervening variables. Instead, their impact is more subtle, as sustainable practices stimulate technological progress, which then leads to STID. This discovery offers a more process-oriented explanation for the development of sustainable transport infrastructure than has been found in previous studies.

The current study also examined the moderating effect of DIR on the nexus between TAT and STID and found that DIR serves as a positive catalyst in the association between TAT and STID. The confirmation of H8 suggested that the existence of DIR boosts the translation of TAT into STID in Iraq. These results complemented the existing literature, which advocated the positive contribution of digital readiness towards sustainable development, e.g., [37], [40], [41], [46]-[49]. However, those studies did not explain DIR's moderating role in the association between TAT and STID, as the current study does. This finding implies that investments in advanced transport technologies alone may not be sufficient to achieve sustainable infrastructure outcomes. The effectiveness of such technologies depends on the availability of supporting digital infrastructure and organizational readiness. Consequently, policymakers should prioritize the parallel development of digital infrastructure and transport technologies, as the sustainability benefits of

technological advancement are more likely to be realized when adequate digital readiness exists.

6. Conclusion

The current study explored the process of achieving STID in Iraq using a mediated-moderated conceptual model. It evaluated the role of GTPE and IGTI in the facilitation of PESP and serial mediation of PESP and TAT between GTPE and STID, and IGTI and STID. The results revealed that GTPE and IGTI are important predictors of PESP in Iraq. Furthermore, PESP encourages TAT, which in turn, facilitates STID. The significant serial mediation paths were found between GTPE and STID via PESP and between IGTI and STID via TAT. Besides, DIR greatly enhances the linkage between TAT and STID. Therefore, the implementation of effective green transport policies and investments in green transport infrastructure can encourage sustainable practices and technological progress, which can help achieve STID.

The study's development and evaluation of an integrated mediated-moderated framework that connects GTPE and IGTI with STID via PESP and TAT is a contribution to sustainable transportation research. Previous studies focused on these constructs individually or in direct relationships, but the current study examined these constructs in a sequential manner to provide a more complete picture of the outcomes of STID in an emerging economy such as Iraq. Moreover, the identification of DIR as a facilitating condition that enhances the relationship between TAT and STID is another contribution. The study contributes to the understanding of the mechanisms of sustainable transport infrastructure development by exploring previously unexplored relationships [31], [38], [41] and extends stakeholder theory and diffusion of innovation theory by providing empirical evidence of these relationships [27], [40].

The findings provide practical guidance for transport organizations and policymakers in Iraq. Transport organizations can promote STID by strengthening GTPE and mobilizing IGTI to facilitate sustainable practices. Understanding the role of TAT can also help organizations make informed decisions regarding the adoption of smart and digital technologies in transport planning and operations. Likewise, the adoption of effective green transport policies and investment in green transport systems can help to incentivize sustainable transport. They can also create policies that promote the incorporation of technological innovations and enhance DIR to help translate technological innovation into sustainable infrastructure outcomes. The measures can help to mitigate environmental impacts and enhance the sustainability of Iraq's transport sector.

Despite its contributions, the study has several limitations. First, the findings are limited to the transport sector in Iraq, which is different from transport systems in developed countries, especially in terms of technological development and innovation. Thus, the linkages between GTPE, IGTI, PESP, TAT, DIR and STID can differ from country to country. Future researchers are advised to make comparisons between the findings in different national and sectoral contexts. Second, while the study takes into account several intervening variables,

there are other factors that can have an impact on the process of achieving STID. Institutional capacity can influence the translation of TAT to STID, for example. To improve knowledge on sustainable transport infrastructure development, future research should take into account such factors.

Acknowledgements

The authors also acknowledge the valuable guidance and constructive feedback provided by colleagues and reviewers, which significantly improved the quality of this research.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Areej M. Abdulwahab and Gofran J. Qasim conceptualized the research problem and designed the study. Muhammad Amir performed the data analysis and developed the methodology. Sharinatol Akmanida Jamaludin and Lubna Sami Amireh contributed to data collection, validation, and technical review. Muhammad Amir contributed to manuscript structuring, editing, and critical revision. All authors discussed the results and contributed to the final version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Use of LLM and AI

ChatGPT (OpenAI) was used solely to improve the language, grammar, and readability of the manuscript. The authors reviewed and approved the final content.

Research Funding

The authors received no external financial funding for the research, authorship, or publication of this article.

References

- [1] A. U. Din *et al.*, "How sustainable transportation can utilize climate change technologies to mitigate climate change," *Sustainability*, vol. 15, no. 12, Art. no. 9710, 2023. doi: <https://doi.org/10.3390/su15129710>.
- [2] S. Y. Kottala, C. Shankar, and A. K. Sahu, "Navigating green transport sustainability model (GTSM) under socio-economic and environmental goals for road-mapping sustainability and mitigating carbon footprints," *Journal of International Logistics and Trade*, vol. 23, no. 1, pp. 7–37, 2025. doi: <https://doi.org/10.1108/JILT-06-2024-0035>.
- [3] M. A. Jamil *et al.*, "A structural equation modeling framework for exploring the Industry 5.0 and sustainable supply chain determinants," *Supply Chain Analytics*, vol. 6, Art. no. 100060, 2024. doi: <https://doi.org/10.1016/j.sca.2024.100060>.
- [4] K. Bhattacharya, D. Sarkar, and S. Chaturvedi, "Application of factor analysis and structure equation modelling for evaluation of key performance indicators for development of sustainable transportation infrastructure," *Journal of The Institution of Engineers (India): Series A*, vol. 104, no. 4, pp. 791–806, 2023. doi: <https://doi.org/10.1007/s40030-023-00761-6>.
- [5] J. Szpytko, "Concept of the sustainable intelligent transport system, Iraq case study," *Archives of Transport System Telematics*, vol. 11, no. 4, pp. 48–52, 2018. [Online]. Available: <https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-a3819985-4221-4c94-8522-1fcfb87f5eae>.
- [6] R. M. Abd-Alstaar Ahmed and H. S. Moslem, "Economic importance of FAW's Large Port and its role in promoting sustainable development in Iraq," *Journal of Economics and Administrative Sciences*, vol. 31, no. 146, pp. 81–90, 2025. doi: <https://doi.org/10.33095/dfv7wp95>.
- [7] A. M. Abdulwahab, N. T. Ismael, and S. F. Al-Nuaimi, "Institutional framework for sustainable transportation in Iraq," in *Proc. 2018 International Conference on Advanced Science and Engineering (ICOASE)*, 2018, pp. 485–490. doi: <https://doi.org/10.1109/ICOASE.2018.8548874>.
- [8] United Nations Department of Economic and Social Affairs, Population Division, *2018 Revision of World Urbanization Prospects*. New York, NY, USA: United Nations, 2018. [Online]. Available: <https://www.un.org/en/desa/2018-revision-world-urbanization-prospects>.
- [9] I. Heidari, A. T. Eshlaghy, and S. M. S. Hoseini, "Sustainable transportation: Definitions, dimensions, and indicators—Case study of importance-performance analysis for the city of Tehran," *Heliyon*, vol. 9, no. 10, Art. no. e20457, 2023. doi: <https://doi.org/10.1016/j.heliyon.2023.e20457>.
- [10] F. U. Rehman, M. M. Islam, and Q. Miao, "Environmental sustainability via green transportation: A case of the top 10 energy transition nations," *Transport Policy*, vol. 137, pp. 32–44, 2023. doi: <https://doi.org/10.1016/j.tranpol.2023.04.013>.
- [11] E. Ceulemans *et al.*, "Synchromodal transport vs. conventional hinterland transport: A stakeholder theory analysis," *Transport Reviews*, vol. 45, no. 1, pp. 1–25, 2025. doi: <https://doi.org/10.1080/01441647.2024.2403471>.
- [12] R. Davtyan, "Urban sustainability and public transport: Stakeholder dynamics in Finnish cities," *Transport Policy*, vol. 175, Art. no. 103870, 2026. doi: <https://doi.org/10.1016/j.tranpol.2025.103870>.
- [13] M. Stiebe, "Social big data mining for the sustainable mobility and transport transition: Findings from a large-scale cross-platform analysis," *European Transport Research Review*, vol. 16, Art. no. 28, 2024. doi: <https://doi.org/10.1186/s12544-024-00651-3>.
- [14] J. Sun, "Can green transport policy drive urban carbon emission reduction? Evidence from pilot cities of China's low-carbon transportation system," *Frontiers in Environmental Science*, vol. 13, Art. no. 1660200, 2025. doi: <https://doi.org/10.3389/fenvs.2025.1660200>.
- [15] K. J. Shah *et al.*, "Green transportation for sustainability: Review of current barriers, strategies, and innovative technologies," *Journal of Cleaner Production*, vol. 326, Art. no. 129392, 2021. doi: <https://doi.org/10.1016/j.jclepro.2021.129392>.
- [16] S. Shokoohyar *et al.*, "Sustainable transportation in practice: A systematic quantitative review of case studies," *Sustainability*, vol. 14, no. 5, Art. no. 2617, 2022. doi: <https://doi.org/10.3390/su14052617>.
- [17] J. Eliasson and S. Proost, "Is sustainable transport policy sustainable?," *Transport Policy*, vol. 37, pp. 92–100, 2015. doi: <https://doi.org/10.1016/j.tranpol.2014.09.010>.
- [18] C.-L. Hsu and M.-C. Chen, "Advocating recycling and encouraging environmentally friendly habits through gamification: An empirical investigation," *Technology in Society*, vol. 66, Art. no. 101621, 2021. doi: <https://doi.org/10.1016/j.techsoc.2021.101621>.
- [19] G. Mateu and A. Sanz, "Public policies to promote sustainable transports: Lessons from Valencia," *Sustainability*, vol. 13, no. 3, Art. no. 1141, 2021. doi: <https://doi.org/10.3390/su13031141>.
- [20] G. Ang and V. Marchal, *Mobilising Private Investment in Sustainable Transport: The Case of Land-Based Passenger Transport Infrastructure*, OECD Environment Working Papers, no. 56. Paris, France: OECD Publishing, 2013. doi: <https://doi.org/10.1787/5k46hjm8jpmv-en>.
- [21] J. Tan and Y. A. Solangi, "Assessing impact investing for green infrastructure development in low-carbon transition and sustainable

- development in China,” *Environment, Development and Sustainability*, vol. 26, no. 10, pp. 25257–25280, 2024. doi: <https://doi.org/10.1007/s10668-023-03678-z>.
- [22] International Energy Agency, *Global EV Outlook 2022*. Paris, France: IEA, 2022. [Online]. Available: <https://www.iea.org/reports/global-ev-outlook-2022>.
- [23] R. Rogaczewski and S. Ejdyś, “The impact of investment in transport infrastructure on sustainable development in Central and Eastern European countries,” *Rocznik Ochrona Środowiska*, vol. 27, pp. 469–479, 2025. doi: <https://doi.org/10.54740/ros.2025.039>.
- [24] M. Song *et al.*, “Technology transfer for green investments: Exploring how technology transfer through foreign direct investments can contribute to sustainable practices and reduced environmental impact in OIC economies,” *Environmental Science and Pollution Research*, vol. 31, no. 6, pp. 8812–8827, Feb. 2024. doi: <https://doi.org/10.1007/s11356-023-31553-x>.
- [25] C. Wang *et al.*, “Exploring the synergy of logistics, finance, and technology on innovation,” *Scientific Reports*, vol. 14, Art. no. 21918, 2024. doi: <https://doi.org/10.1038/s41598-024-72409-9>.
- [26] H. Fatorachian, H. Kazemi, and K. Pawar, “Digital transformation for sustainable transportation: Leveraging Industry 4.0 technologies to optimize efficiency and reduce emissions,” *Future Transportation*, vol. 5, no. 2, Art. no. 34, 2025. doi: <https://doi.org/10.3390/futuretransp5020034>.
- [27] Y. Liu, D. Zhou, and C. Wu, “Strategies for sustainable road transport: Technological innovation and organizational management through AI,” *Transportation Research Part D: Transport and Environment*, vol. 141, Art. no. 104651, 2025. doi: <https://doi.org/10.1016/j.trd.2025.104651>.
- [28] A. Kwilinski, O. Lyulyov, and T. Pimonenko, “Environmental sustainability within attaining sustainable development goals: The role of digitalization and the transport sector,” *Sustainability*, vol. 15, no. 14, Art. no. 11282, 2023. doi: <https://doi.org/10.3390/su151411282>.
- [29] I. A. Olaleye *et al.*, “Innovative frameworks for sustainable transportation coordination to reduce carbon footprints in logistics,” *International Journal of Science and Technology Research Archive*, vol. 7, no. 2, pp. 68–75, 2024. doi: <https://doi.org/10.53771/ijstra.2024.7.2.0068>.
- [30] M. A. Kashem, M. Shamsuddoha, and T. Nasir, “Sustainable transportation solutions for intelligent mobility: A focus on renewable energy and technological advancements for electric vehicles (EVs) and flying cars,” *Future Transportation*, vol. 4, no. 3, pp. 874–890, 2024. doi: <https://doi.org/10.3390/futuretransp4030042>.
- [31] B. Abbasnejad *et al.*, “Industry 4.0 technologies for sustainable transportation projects: Applications, trends, and future research directions in construction,” *Infrastructures*, vol. 10, no. 5, Art. no. 104, 2025. doi: <https://doi.org/10.3390/infrastructures10050104>.
- [32] T. Kharlamova, L. Desfontaines, S. Barykin, and R. Gavrilova, “Prospects for the development of transport infrastructure to ensure sustainable development,” *Transportation Research Procedia*, vol. 63, pp. 789–797, 2022. doi: <https://doi.org/10.1016/j.trpro.2022.06.075>.
- [33] W. Bénichou, “Sustainable development of transport infrastructure in the system of national economy,” *Journal of Economics, Innovative Management and Entrepreneurship*, vol. 1, no. 1, 2024. doi: <https://doi.org/10.59652/jeime.v1i1.116>.
- [34] R. Kapur, S. Das, and R. D. Nandineni, “Sustainable transportation infrastructure’s role in attaining sustainable development goals,” in *Industry, Innovation and Infrastructure*, W. Leal Filho, A. M. Azul, L. Brandli, A. Lange Salvia, and T. Wall, Eds. Cham, Switzerland: Springer, 2021, pp. 1135–1147. doi: https://doi.org/10.1007/978-3-319-95873-6_52.
- [35] B. B. Badassa, B. Sun, and L. Qiao, “Sustainable transport infrastructure and economic returns: A bibliometric and visualization analysis,” *Sustainability*, vol. 12, no. 5, Art. no. 2033, 2020. doi: <https://doi.org/10.3390/su12052033>.
- [36] G. B. Suprayoga, M. Bakker, P. Witte, and T. Spit, “A systematic review of indicators to assess the sustainability of road infrastructure projects,” *European Transport Research Review*, vol. 12, Art. no. 19, 2020. doi: <https://doi.org/10.1186/s12544-020-0400-6>.
- [37] F. Alanazi and M. Alenezi, “Sustainable transportation and intelligent infrastructure development in Saudi Arabia: A study on the impact of Saudi Vision 2030 and renewable energy integration,” in *Emerging Cutting-Edge Applied Research and Development in Intelligent Traffic and Transportation Systems*. Amsterdam, The Netherlands: IOS Press, 2024, pp. 90–101. doi: <https://doi.org/10.3233/ATDE241184>.
- [38] H. Ahn and E. Park, “For sustainable development in the transportation sector: Determinants of acceptance of sustainable transportation using the innovation diffusion theory and technology acceptance model,” *Sustainable Development*, vol. 30, no. 5, pp. 1169–1183, Oct. 2022. doi: <https://doi.org/10.1002/sd.2309>.
- [39] A. J. Bokolo, “Examining the adoption of sustainable eMobility-sharing in smart communities: Diffusion of innovation theory perspective,” *Smart Cities*, vol. 6, no. 4, pp. 2057–2080, 2023. doi: <https://doi.org/10.3390/smartcities6040095>.
- [40] M. A. Kashem, M. Shamsuddoha, and T. Nasir, “Digitalization in sustainable transportation operations: A systematic review of AI, IoT, and blockchain applications for future mobility,” *Future Transportation*, vol. 5, no. 4, Art. no. 157, 2025. doi: <https://doi.org/10.3390/futuretransp5040157>.
- [41] F. Alanazi and M. Alenezi, “Driving the future: Leveraging digital transformation for sustainable transportation,” *Journal of Infrastructure, Policy and Development*, vol. 8, no. 3, Art. no. 3085, 2024. doi: <https://doi.org/10.24294/jipd.v8i3.3085>.
- [42] F. Jelti, A. Allouhi, and K. A. Tabet Aoul, “Transition paths towards a sustainable transportation system: A literature review,” *Sustainability*, vol. 15, no. 21, Art. no. 15457, 2023. doi: <https://doi.org/10.3390/su152115457>.
- [43] A. Hasheminezhad, H. Ceylan, and S. Kim, “Advances in innovative sustainable transportation geotechnics,” *Transportation Geotechnics*, vol. 49, Art. no. 101397, 2024. doi: <https://doi.org/10.1016/j.trgeo.2024.101397>.
- [44] M. Li, D. Gong, and Y. Song, “Research on multiple paths of transportation system resilience building in digital contexts,” *Scientific Reports*, vol. 15, Art. no. 28644, 2025. doi: <https://doi.org/10.1038/s41598-025-14245-z>.
- [45] B. Cucor *et al.*, “Physical and digital infrastructure readiness index for connected and automated vehicles,” *Sensors*, vol. 22, no. 19, Art. no. 7315, 2022. doi: <https://doi.org/10.3390/s22197315>.
- [46] I. G. Sahebi *et al.*, “AI-enabled green hydrogen adoption for sustainable transportation: The moderating role of network capability,” *International Journal of Hydrogen Energy*, vol. 219, Art. no. 154078, 2026. doi: <https://doi.org/10.1016/j.ijhydene.2026.154078>.
- [47] R. Kaewsang-on, “Organizational readiness, digital technology, and sustainable performance: The moderating role of knowledge acquisition,” *Journal of Digitization and Information System*, vol. 4, no. 1, pp. 98–111, 2024. doi: <https://doi.org/10.54433/JDIIS.2024100040>.
- [48] R. Philipp, “Digital readiness index assessment towards smart port development,” *NachhaltigkeitsManagementForum / Sustainability Management Forum*, vol. 28, pp. 49–60, 2020. doi: <https://doi.org/10.1007/s00550-020-00501-5>.
- [49] R. Liu *et al.*, “Digital transport infrastructure and environmental sustainability: STIRPAT perspective based on China’s evidence,” *Research in Transportation Business & Management*, vol. 59, Art. no. 101314, 2025. doi: <https://doi.org/10.1016/j.rtbm.2025.101314>.
- [50] I. F. Aldhi *et al.*, “Bridging digital gaps in smart city governance: The mediating role of managerial digital readiness and the moderating role

of digital leadership,” *Smart Cities*, vol. 8, no. 4, Art. no. 117, 2025. doi: <https://doi.org/10.3390/smartcities8040117>.

- [51] M. K. Lindell and D. J. Whitney, “Accounting for common method variance in cross-sectional research designs,” *Journal of Applied Psychology*, vol. 86, no. 1, pp. 114–121, 2001. <https://doi.org/10.1037/0021-9010.86.1.114>.
- [52] N. Kock, “Common method bias in PLS-SEM: A full collinearity assessment approach,” *International Journal of e-Collaboration*, vol. 11, no. 4, pp. 1–10, 2015. <https://doi.org/10.4018/IJeC.2015100101>.
- [53] J. F. Hair, G. T. M. Hult, C. M. Ringle, M. Sarstedt, and K. O. Thiele, “An updated and expanded assessment of PLS-SEM in information systems research,” *Industrial Management & Data Systems*, vol. 117, no. 3, pp. 442–458, 2017. doi: <https://doi.org/10.1108/IMDS-04-2016-0130>.
- [54] J. F. Hair, C. M. Ringle, and M. Sarstedt, “PLS-SEM: Indeed a silver bullet,” *Journal of Marketing Theory and Practice*, vol. 19, no. 2, pp. 139–152, 2011. doi: <https://doi.org/10.2753/MTP1069-6679190202>.

Appendix – A

Demographic Characteristics of Respondents

Variable	Category	n	%
Gender	Male	166	61.0
	Female	106	39.0
Age	≤ 30 years	132	48.5
	31–35 years	88	32.4
	> 35 years	52	19.1
Education Level	Bachelor’s degree	54	19.9
	Postgraduate diploma	98	36.0
	Master’s degree	101	37.1
	PhD	19	7.0
Work Experience	≤ 5 years	68	25.0
	6–8 years	116	42.6
	> 8 years	88	32.4
Position	Senior management	52	19.1
	Middle management	96	35.3
	Technical / engineering	84	30.9
	Administrative	40	14.7
Organization Type	Ministry / Government agency	92	33.8
	Municipal authority	74	27.2
	Transport authority	66	24.3
	Private / other organization	40	14.7

Appendix - B

Common Method Bias Assessment Using Marker Variable Approach

Structural Path	β Without Marker (p-value)	β With Marker (p-value)	Δβ	VIF
GTPE → PESP	0.298 (0.000)	0.298 (0.000)	0.000	1.103
IGTI → PESP	0.361 (0.000)	0.361 (0.000)	0.000	1.103
PESP → TAT	0.383 (0.000)	0.378 (0.000)	-0.005	1.000
PESP → STID	0.491 (0.000)	0.491 (0.000)	0.000	1.204
TAT → STID	0.161 (0.003)	0.162 (0.003)	+0.001	1.216
Marker Variable Relationships				
Marker Path	β	p-value	Interpretation	
WSI → PESP	0.003	0.479	The non-significant relationship indicates the marker variable does not influence PESP	
WSI → TAT	-0.117	0.120	Non-significant relationship indicates no method bias effect on TAT	
WSI → STID	0.009	0.450	Non-significant relationship indicates no method bias effect on STID	

Appendix - C

Cross-Loading Assessment

Indicator	DIR	GTPE	IGTI	PESP	STID	TAT
DIR1	0.759	0.137	0.061	0.113	0.094	0.165
DIR3	0.741	0.143	0.075	0.028	0.077	0.159
DIR4	0.863	0.424	0.135	0.313	0.170	0.253
GTPE1	0.287	0.901	0.311	0.385	0.334	0.248
GTPE3	0.325	0.903	0.251	0.347	0.360	0.192
GTPE4	0.324	0.872	0.252	0.356	0.305	0.195
IGTI1	0.101	0.321	0.759	0.333	0.305	0.184
IGTI2	0.166	0.288	0.860	0.415	0.397	0.276
IGTI3	0.072	0.198	0.875	0.369	0.363	0.278
IGTI4	0.075	0.222	0.852	0.389	0.328	0.261
PESP1	0.231	0.401	0.369	0.758	0.488	0.297
PESP2	0.204	0.334	0.359	0.780	0.529	0.286
PESP3	0.178	0.320	0.314	0.830	0.435	0.298
PESP4	0.157	0.269	0.365	0.798	0.368	0.296
PESP5	0.169	0.273	0.381	0.798	0.354	0.342
STID1	0.161	0.312	0.374	0.494	0.849	0.302
STID2	0.077	0.313	0.313	0.420	0.829	0.269
STID3	0.134	0.331	0.313	0.446	0.803	0.292
STID4	0.143	0.287	0.355	0.490	0.867	0.281
STID5	0.107	0.305	0.323	0.435	0.876	0.248
STID6	0.155	0.394	0.416	0.515	0.865	0.350
STID7	0.146	0.236	0.343	0.446	0.781	0.268
TAT1	0.219	0.197	0.242	0.332	0.301	0.856
TAT2	0.247	0.216	0.212	0.342	0.306	0.893
TAT3	0.207	0.173	0.317	0.346	0.337	0.874
TAT4	0.205	0.240	0.255	0.277	0.214	0.780

Note. Bold values represent the highest loading of each indicator on its respective construct.