Review

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Valuing Sustainability: An Empirical Analysis of ESG Risk and Financial Performance in the Global Transportation Sector

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Review

Valuing Sustainability: An Empirical Analysis of ESG Risk and Financial Performance in the Global Transportation Sector

Running Title: ESG Risk and Financial Performance in Transportation

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Abstract: The global transportation sector faces pressing sustainability challenges, driving interest in Environmental, Social, and Governance (ESG) factors, yet empirical evidence on ESG's financial impact in this capital-intensive sector is limited. This study examines the relationship between corporate ESG risk scores (Sustainalytics) and excess stock returns for global transportation firms, controlling for Fama-French 6 factors via panel regression (2015–2024, ESG analysis post-Nov 2019). Findings are contextualized within a Global Sustainable Transportation System (GSTS) framework. Empirical results show that while financial factors explain returns, no statistically significant relationship was found between overall or pillar ESG risk scores and excess stock returns for Low or medium-ESG-risk firms during the analyzed period. High-risk firm analysis was inconclusive due to data limitations. Although the GSTS vision stresses sustainability, these findings suggest current broad ESG scores did not significantly impact short-term, risk-adjusted returns beyond traditional factors, highlighting potential gaps between long-term sustainability value and immediate market pricing.

Keywords: ESG (Environmental; Social; Governance); Financial Performance; Stock Returns; Transportation Sector; Logistics; Panel Regression; Asset Pricing; Sustainability; Sustainable Transportation Systems.

Introduction

Contemporary global transportation systems face profound challenges demanding fundamental transformation. Expanding urban areas and population growth intensify demands on existing infrastructure, leading to substantial congestion and reduced efficiency, particularly in metropolitan regions [1]. Concurrently, the transport sector is a major source of greenhouse gas emissions, necessitating widespread decarbonization efforts across all modes to mitigate climate change [1,10,12,17].

Furthermore, ageing infrastructure requires significant investment in maintenance and resilience to ensure reliable service [1,8]. Persistent inequalities in access to transport services also continue to limit opportunities for individuals in rural and marginalized areas [1]. Successfully addressing these interconnected challenges necessitates the integration of rapidly advancing technologies, including artificial intelligence (AI), autonomous vehicles (AVs), blockchain, and digital twins, which offer potential solutions while simultaneously introducing new complexities in system design and management [1,3,5,6,8,11,13–15,19–21]. This requires a fundamental shift towards more integrated, robust, efficient, equitable, and environmentally sustainable transportation paradigms [1].

Considering the need for such a systemic shift, this project explores the conceptual framework of an advanced global transportation initiative, referred to as the Global Sustainable Transportation

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System (GSTS). This concept proposes integrating principles of profound sustainability, cutting-edge technology, and a strong commitment to societal value to create smart and inclusive multimodal networks [1]. The central aims driving the GSTS vision include achieving significant decarbonization by 2040 through accelerated adoption of clean energy, enhancing systemic resilience against environmental and geopolitical shocks, reducing accessibility gaps to promote equitable mobility, and strategically employing AI and other advanced technologies for improved efficiency, safety, and predictive capabilities [1]. These objectives resonate with global calls for sustainable development and draw inspiration from contemporary research into the potential of new technologies and policy frameworks for reshaping transport [9,11,16,20,22].

While the technical design and operational aspects of realizing a comprehensive initiative like GSTS are complex and require extensive research, its financial viability and appeal to a broad range of investors are equally crucial for widespread implementation. The growing focus on Environmental, Social, and Governance (ESG) criteria in global investment trends, especially in sectors like transportation and infrastructure, indicates a potential connection between sustainable business practices and financial outcomes [1]. However, the empirical evidence specifically quantifying how corporate ESG performance influences financial returns, such as stock returns, within the diverse and capital-intensive transportation and logistics sector is not yet definitively established, especially when considering the potential influence of a firm's inherent ESG risk profile. The need for empirical validation of such relationships within this domain has been highlighted in relevant literature [1].

This study seeks to contribute to addressing this empirical knowledge gap by combining insights drawn from a systematic literature review with a quantitative empirical analysis. The empirical component specifically investigates the relationship between corporate ESG performance and the excess stock returns of transportation and logistics firms. The research questions guiding this analysis are:

RQ1: Does overall corporate ESG performance have a statistically significant impact on the excess stock returns of publicly traded firms in the transportation and logistics sector, after controlling for established market risk factors from asset pricing models?

Do the individual dimensions of corporate ESG performance (Environmental, Social, and Governance scores) exhibit statistically significant impacts on the excess stock returns of these firms, and do these impacts differ from the influence of the overall ESG score or differ from each other?

RQ2: Does the statistical significance and magnitude of the relationship between corporate ESG performance and excess stock returns vary among groups of transportation and logistics firms categorized based on their inherent overall ESG risk levels (specifically, Low, Medium, and High-risk profiles)?

The motivation for this research stems from the pressing global demand for sustainable and resilient transportation systems, as envisioned by the GSTS concept, and the necessity to understand all factors influencing their successful development, including their financial attractiveness to stakeholders [1]. As investor focus on ESG factors increases, financial markets may increasingly incentivize more sustainable corporate behaviors [1]. However, empirically demonstrating this link within the transportation sector is complex and may depend on firm-specific characteristics. This project aims to provide empirical evidence to connect the vision of intelligent, sustainable transport with the financial market dynamics that will shape its practical realization.

This report is structured to first provide context on the challenges and innovative approaches in the transportation sector through a synthesis of relevant literature. Section 2 details the materials and methodologies used for both the literature review and the empirical analysis. Section 3 presents findings from the literature synthesis and outlines the GSTS concept. Section 4 then presents the empirical results from the panel regression analysis. Section 5 interprets these empirical findings in the context of the literature and discusses their implications for financial considerations relevant to sustainable transportation. Section 6 offers concluding remarks, summarizing key findings, acknowledging limitations, and suggesting future research directions.

2. Materials and Methods

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This study employed a mixed-methods approach, integrating a systematic literature review with a quantitative empirical analysis using panel regression.

2.1. Literature Review Search Strategy and Synthesis Approach

A systematic literature review synthesized research on state-of-the-art sustainable and technologically advanced transportation systems and the role of ESG. Searches in Scopus and Dimensions databases used keyword combinations related to transportation, technology, sustainability, ESG, and societal value. Relevant theoretical frameworks on technological diffusion and socio-technical transitions were also explored [22–39]. Search results were filtered by publication year (2020–2025), document type (articles, reviews), and subject areas [3–21]. A sample of 20 publications from Dimensions was specifically included for analysis [3–21]. The synthesis involved thematic analysis of retrieved abstracts and full texts.

2.2. Empirical Analysis Methodology (Panel Regression)

Quantitative empirical analysis using panel data regression was performed to investigate the financial impact of ESG performance on transportation and logistics firms.

2.2.1. Data Sources and Description

Financial data for publicly listed global transportation companies, including monthly total stock returns, market capitalization (MCap), and book-to-market (B/M) ratios, were obtained from the Refinitiv Eikon database. Corresponding ESG data, specifically Sustainalytics ESG Risk Ratings (overall score and E, S, G pillar scores), were sourced via the yesg library access point, supplemented by MSCI ESG Ratings where available for context. Control variables based on the Fama-French six-factor model (Mkt_RF, SMB, HML, RMW, CMA, WML) were used to account for established sources of financial risk.

2.2.2. Data Period, Sample Selection, ESG Risk Grouping

The analysis period spanned January 2015 to December 2024 for factor models, with ESG analysis constrained to the post-November 2019 period due to a change in Sustainalytics' rating methodology. The initial target sample comprised leading global companies involved in logistics, freight, shipping, and rail, including United Parcel Service (UPS), FedEx Corporation (FDX), Deutsche Post DHL Group (DPSGY), A.P. Møller - Mærsk (AMKBY), Kuehne + Nagel International (KHNGY), DSV A/S (DSDVY), Union Pacific Corp. (UNP), Canadian National Railway (CNI), Canadian Pacific Kansas City (CP), CSX Corporation (CSX), XPO, Inc. (XPO), Old Dominion Freight Line (ODFL), J.B. Hunt Transport Services (JBHT), ZIM Integrated Shipping Services (ZIM), and Jayud Global Logistics (JYD). The final sample for regression analysis was determined by data availability within the Refinitiv and Sustainalytics (yesg) sources, excluding firms with insufficient data (e.g., data retrieval failed for DPSGY via yesg). Based on available Sustainalytics/MSCI ratings and qualitative assessments, firms were grouped for analysis:

Low ESG Risk: A.P. Møller - Mærsk (AMKBY), Kuehne + Nagel (KHNGY), DSV A/S (DSDVY), Canadian National Railway (CNI), Canadian Pacific Kansas City (CP). (Note: DHL data was unavailable via yesg).

Medium ESG Risk: United Parcel Service (UPS), FedEx (FDX), Union Pacific (UNP), CSX Corporation (CSX), XPO, Inc. (XPO), Old Dominion Freight Line (ODFL), J.B. Hunt Transport (JBHT), ZIM Integrated Shipping (ZIM).

High ESG Risk: Jayud Global Logistics (JYD). (Note: JYD lacked specific Sustainalytics/yesg ratings; categorized based on industry/regional factors and limited transparency). Data limitations, particularly the lack of historical ESG data for some firms (especially ZIM, XPO, ODFL in earlier periods and JYD entirely via yesg), necessitated careful interpretation and restricted ESG model application for the High-Risk group.

2.2.3. Data Preprocessing (Excess Returns, Imputation)

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Monthly excess returns were calculated by subtracting the US 1-month Treasury bill rate (risk-free rate proxy) from total stock returns. Logarithmic transformation was applied to market capitalization to mitigate skewness. Minor gaps in ESG data within the post-2019 period were addressed using Multiple Imputation by Chained Equations (MICE), acknowledging that imputation for firms with sparse original data. Companies with substantial gaps in core financial data were excluded.

2.2.4. Econometric Model (Panel Regression with Fixed Effects)

A panel regression model incorporating firm and time fixed effects was employed to analyze the relationship between ESG risk and excess returns, controlling for the Fama-French six factors. The model specification is:

ExcessReturn_it = α_i + λ_t + β * ESG_Risk_it + γ * Controls_it + ε_it

Here, ExcessReturn_it is the excess return for firm i at time t, α_i represents firm-specific fixed effects, λ_t captures time (year-month) fixed effects, ESG_Risk_it is the Sustainalytics ESG risk score (or E/S/G pillar score), Controls_it is the vector of the six Fama-French factors, β is the coefficient of interest for ESG risk, γ is the vector of coefficients for the control factors, and ε_it is the error term. Fixed effects control for time-invariant firm characteristics and common time trends.

2.2.5. Statistical Techniques

Statistical studies were carried out using Python 3.11 and Python modules (statsmodels, linearmodels). Variance Inflation Factor (VIF) tests were conducted to assess multicollinearity among predictors within each model specification; VIF values generally remained below common thresholds (e.g., 5 or 10) for most factors, though HML occasionally exceeded 5, suggesting moderate collinearity. The Hausman test typically supported the use of fixed effects over random effects. Robust standard errors, clustered by both firm and time, were used to address potential heteroskedasticity and autocorrelation. For the High ESG Risk group containing only one firm (JYD), panel regression was not feasible, and Ordinary Least Squares (OLS) with robust standard errors was used as a descriptive alternative for the factor model only. Statistical significance was evaluated at the $p < 0.10$, $p < 0.05$, and $p < 0.01$ levels.

3. Results: Literature Synthesis and Empirical Findings

This section presents the findings from the literature synthesis and outlines the conceptualization of the Global Sustainable Transportation System (GSTS).

3.1. Key Pressures: Urbanization, Climate Change, Infrastructure, Equity, Technology

Publications consistently highlight critical pressures on contemporary transportation systems. Accelerating urbanization and population growth intensify demand, leading to congestion and strain on existing infrastructure [1]. The substantial contribution of transportation to greenhouse gas emissions underscores the urgency of climate action and decarbonization efforts across road, maritime, and air transport [1,10,12,16,17,21]. Infrastructure degradation poses ongoing challenges for efficiency, safety, and resilience [1,8]. Furthermore, issues of equitable access persist, limiting opportunities for individuals in rural and marginalized communities [1]. The disruptive force of emergent technologies, such as AI, autonomous systems, IoT, blockchain, and digital twins, is radically changing these enduring difficulties. These technologies introduce both novel challenges and opportunities for solutions [1,3,5,6,8,11,13–15,17,19–21].

3.1.1. Emerging Solutions & Innovations: Electrification, Fuels, Autonomy, Smart Infra, MaaS, Resilience

The literature describes a wide array of innovations and solutions aimed at addressing these pressures. Electrification of vehicles, particularly passenger cars and aspects of freight, is a key pathway to reducing emissions, although challenges related to charging infrastructure and grid integration remain critical [4,16,19,20]. The development and deployment of alternative fuels, such as green hydrogen and advanced biofuels, are highlighted as crucial for harder-to-abate sectors such

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as aviation and long-haul freight, where electrification is less feasible [9,11,16,17,21]. Autonomous vehicle technologies and urban air mobility (UAM) are presented as potential solutions for enhancing safety and efficiency, and facilitating new logistics models like drone delivery, although their widespread integration faces significant technical, safety, and regulatory hurdles [3,5,6,8,11,13,15,19,20]. The concept of smart infrastructure is pervasive, encompassing AI-driven traffic management and optimization systems [6,14], integrated charging grids [4,19], and the use of technologies like IoT and blockchain for enhanced system transparency and security in logistics and supply chains [3,4,5,9,15]. The application of digital twins is explored for creating dynamic, virtual replicas of systems to aid in planning, monitoring, and optimizing complex urban mobility and airspace management for autonomous drones [11,13,14]. Mobility-as-a-Service (MaaS) is discussed as a means to integrate diverse transport options and potentially improve accessibility, particularly in urban areas [1]. Discussions of resilient infrastructure, such as the use of durable materials or designs resistant to environmental impacts, also feature in addressing climate vulnerabilities [1].

3.1.2. Understanding Mobility Cultures and Behavior

Beyond the technological and infrastructural aspects, the literature acknowledges the crucial role of human factors, including mobility cultures and individual behavior, in shaping transportation outcomes and influencing the successful adoption of new systems and services [1,7,21,34]. Research suggests that the adoption and diffusion rates of innovations are significantly influenced by user perceptions, the level of trust in new technologies (especially concerning safety, security, and data privacy) [3–6,15,19], and the dynamics of changing established habits and preferences [21,26,28]. Designing transportation systems that are not only technologically advanced but also generally accepted, used, and equitable depends on an awareness of these socio-cultural aspects [1,33,34,39].

3.1.3. State of Play: ESG Investing in Transportation and Related Sectors

While the primary focus of the sampled literature was on technological and operational aspects, a broader review indicates a growing trend of incorporating ESG factors into investment decisions across many sectors, including transportation and infrastructure [1]. The trend reflects investors' growing understanding of the long-term risks and opportunities linked with a company's environmental impact, social responsibility practices, and governance frameworks. The emergence of dedicated sustainable finance mechanisms, green bonds, and increased corporate ESG reporting underscores this shift. However, the direct empirical link between overall corporate ESG performance (as measured by widely available composite or pillar-specific scores) and short-to-medium term financial market performance, such as stock returns, appears less consistently established or specifically studied within the core transportation and logistics sector compared to some other industries. This suggests a potential gap in the literature regarding the explicit financial market valuation of ESG within this diverse and capital-intensive domain, particularly when considering different levels of inherent risk.

3.1.4. Synthesis of the Evolving Transportation Landscape (Literature Review Findings)

The systematic literature review revealed a transportation sector in a state of significant evolution, shaped by pronounced pressures and driven by rapid innovation and underlying theoretical dynamics.

3.1.5. Theoretical Frameworks from Literature

Several theoretical frameworks identified in the literature provide valuable perspectives for understanding the complex transformations occurring in transportation. Theories of Technological Change and Diffusion frameworks, such as Everett Rogers' Diffusion of Innovations, provide insights into how new technologies, services, or ideas spread through a population or system, concepts discussed in [22–25,27–32]. These frameworks analyze the characteristics of the innovation itself (e.g., relative advantage, compatibility, complexity), the communication channels used, the time over which diffusion occurs, and the characteristics of the social system [22,32]. Applying this perspective helps explain the varying rates of adoption for technologies like EVs [21], biofuels [26], or information

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and communication technologies in logistics [15,16,28], highlighting factors like infrastructure readiness, cost, regulatory support, and user acceptance as critical determinants [21,25].

Meanwhile, the Socio-Technical Transition Theory, e.g., the Multi-Level Perspective (MLP), offers a framework for analyzing large-scale, long-term systemic transformations, concepts discussed in [22,24,29,33,37,38]. It describes the dynamics between the established "regime" (the dominant system of practices, institutions, and infrastructure, often centered around fossil fuels in transport), emerging "niches" (radical innovations such as electric mobility, autonomous systems, or MaaS), and broader "landscape" developments (macro-level pressures like climate change, global economic shifts, or changing demographics) [24,33,37]. Transitions occur when innovations in niches develop sufficiently, are supported by landscape pressures, and destabilize the existing regime [24,33,37]. Applying the MLP helps frame the vision of a system like GSTS as a collection of interconnected niches seeking to form a new, sustainable socio-technical regime for mobility, acknowledging the inherent inertia and potential resistance from the incumbent system [24,37]. Studies on transport transitions frequently employ this lens to understand shifts towards sustainability and the roles of various actors and technologies [24,33,35,37,38,39].

These theoretical frameworks provide crucial context for understanding the drivers and inhibitors of change within the transportation sector, illustrating that transitions are not solely technological but involve complex interactions across social, institutional, economic, and environmental dimensions [22,33,39].

3.1.6. Identified Knowledge Gaps from Literature

Based on the synthesis, several key knowledge gaps were identified. There is a need for more integrated perspectives on emerging technologies, moving beyond analyses of single innovations to understand their combined effects within complex systems [6]. Further empirical validation of the effectiveness and scalability of advanced technologies and policy interventions in real-world settings is also required [1]. A deeper understanding of the socio-technical dimensions, including user acceptance and institutional inertia, is crucial for the successful implementation of transformative transport systems [8,21,24,34,39]. Critically, the literature review highlighted a need for more robust empirical evidence on how financial markets explicitly value corporate ESG performance, specifically within the transportation and logistics sector, accounting for sector-specific risks and using granular ESG data. The empirical analysis presented in Section 4 directly addresses this specific gap regarding the financial market valuation.

3.2. Result Area 2: The Global Sustainable Transportation System (GSTS)

Drawing from the synthesis of challenges, emerging solutions, and theoretical understandings derived from the literature review, the Global Sustainable Transportation System (GSTS) is conceptualized as a potential blueprint for future global transportation [1].

3.2.1. Core Principles: Sustainability, Technology, Equity, Resilience

The GSTS concept is built upon four foundational principles: achieving deep sustainability encompassing environmental and social dimensions, leveraging advanced technology as an enabler, ensuring equitable access to mobility for all populations, and building systemic resilience against disruptions [1]. These interconnected principles are intended to guide the development and operation of the entire system.

3.2.2. Key Innovations and Components

The envisioned system integrates several key innovations aligned with trends identified in the literature [1]. Smart infrastructure is a central component, involving the deployment of modular EV charging networks, potentially powered by renewable sources and incorporating battery swap capabilities, inspired by initiatives in leading markets [1,4,20]. Dedicated autonomous freight corridors are proposed to leverage IoT-enabled platooning, aiming to improve efficiency and reduce emissions [1]. Urban drone delivery networks, operating from last-mile hubs with necessary infrastructure like vertiports, are envisioned to alleviate road congestion for goods movement

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[1,2,11,14]. The system incorporates AI-driven predictive systems for real-time traffic microsimulation to optimize flow and congestion-based dynamic pricing models, with revenue potentially channeled towards public transit improvements [1,6,14]. A crucial element is the transition to sustainable fuels, including the establishment of green hydrogen hubs, particularly important for decarbonizing maritime and heavy-duty transport, and biofuel blending stations utilizing agricultural waste to support energy transitions in rural areas [1,9,10,16,19,21]. Equity is addressed through solutions like unified Mobility-as-a-Service (MaaS) platforms integrating diverse transport options, aimed at increasing convenience and affordability in low-income cities [1], and implementing resilient infrastructure upgrades (e.g., flood-resistant roads) using sustainable materials in regions vulnerable to climate impacts [1].

3.2.3. Integration Strategy

A key differentiator of the GSTS concept is the strategic integration of these diverse components into a cohesive network [1]. This integration relies heavily on digital technologies such as AI, IoT, and potentially digital twins and blockchain, acting as the backbone for data exchange, real-time monitoring, system-wide optimization, enhanced security, and transparency across different modes and geographical areas [1,3,4,5,9,11,14,15]. The aim is to create a synergistic ecosystem where different transport modes and infrastructure elements work together efficiently and intelligently.

3.2.4. Societal Value Proposition

The GSTS is designed with an explicit focus on delivering significant societal value [1]. Environmentally, it aims for substantial annual reductions in CO_2 emissions through widespread adoption of clean energy and shifts towards more sustainable modes [1]. Economically, it is projected to stimulate job creation in emerging green technology and infrastructure sectors [1]. Health benefits are anticipated from reduced air pollution, particularly in urban areas [1]. Socially, the system seeks to improve mobility access and equity, reducing disparities in transportation availability and affordability [1].

3.2.5. Alignment with Global Trends and SDGs

In concordance with prevailing global movements focused on digitalization and enhanced sustainability [1], the proposed GSTS offers a pathway to support several United Nations Sustainable Development Goals (SDGs). The system's emphasis on clean energy technologies [1,5,10,19,33,35], intelligent infrastructure [3,6,9–11,17,21,22,32,34], and efficient operations directly addresses targets within SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) [3,6,11,14,17,25,26,34], and SDG 13 (Climate Action) [1,19,33]. Furthermore, anticipated improvements in air quality and safety contribute to SDG 3 (Good Health and Well-being) [5,14,19,34], while enhanced logistics and connectivity can foster economic growth (SDG 8) [9,20].

3.2.6. Potential Implementation Pathways and Challenges

Realizing the GSTS vision would likely involve a phased, modular implementation strategy, potentially starting with pilot projects for specific innovations in collaborating regions [1]. Successful deployment would necessitate strong public-private partnerships, significant capital investment, and international cooperation. Key challenges include navigating complex regulatory environments, ensuring interoperability between diverse technological systems and transport modes, addressing critical cybersecurity and data privacy concerns inherent in connected networks [3,9,17,31], managing public acceptance and behavioral shifts related to new mobility options [1,8,21,39], and overcoming potential institutional inertia or resistance from established transport structures [24,37].

3.3. Empirical Analysis of ESG Valuation (Panel Regression Findings)

This section presents the quantitative results from the empirical panel regression analysis examining the relationship between corporate ESG performance and the excess stock returns of transportation and logistics firms, segmented by ESG risk level.

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3.3.1. VIF Analysis Results

Before interpreting the regression coefficients, Variance Inflation Factors (VIFs) were computed for the independent variables in each estimated model to assess the degree of multicollinearity.

Table 1. Variance Inflation Factor Calculation.

feature VIF	**FF6 Model Only VIF**	**Low ESG Risk Total-Score VIF**	**Medium ESG Risk Total-Score**	**High ESG Risk**
Const	1.15	20.99	13.2	1.75
Mkt_RF	1.41	1.42	1.44	1.66
SMB	1.23	1.36	1.37	3.5
HML	5.22	5.41	5.49	2.96
RMW	1.82	1.87	1.89	1.89
CMA	3.76	4.04	4.14	2.68
WML	1.60	1.55	1.54	2.82
Total-Score Low ESG Risk		1.04		
Total-Score Medium ESG			1.1	
Thresholds: Typically VIF > 5 or 10 indicates high multicollinearity.				

Table 1 indicates that, while the constant term shows higher VIF values in some models (which is often expected and not typically a concern for interpreting other coefficients), the VIF values for the Fama-French factors and the ESG scores are generally well below the common thresholds of 5 or 10 that would indicate problematic multicollinearity. The highest VIF among the factor/ESG variables is around 5.49 for HML and CMA in some models, suggesting a moderate level of correlation but likely not severe multicollinearity that would significantly impact the reliability of coefficient estimates for these variables. The ESG scores themselves show very low VIFs (around 1.04-1.10), indicating minimal multicollinearity with the other predictors. These results suggest that multicollinearity among the key independent variables is not a significant concern in this analysis.

3.3.2. Panel Regression Results: Low ESG Risk Group

Table 2 presents the estimation results for firms classified as Low ESG Risk using Fixed Effects Panel-OLS with robust standard errors. The FF6-only model for this group includes 5 entities and 593 observations, covering the period September 2014 to March 2025. The augmented models incorporating ESG scores include the same 5 entities but are limited to 320 observations from December 2019 to March 2025 due to data constraints.

Table 2. Medium ESG Risk - FF6 Only, E-Score, E-Score, E-Score and Total-Score.

Dep. Variable	**Excess_Return**			
Estimator	PanelOLS			
R-squared (Within)	0.31			
No. Observations	939			
Parameter	Parameter	Std. Err.	T-stat	P-value
Mkt_RF	1.30	0.08	16.08	0.00
SMB	-0.04	0.19	-0.22	0.83
HML	0.13	0.25	0.50	0.62
RMW	0.10	0.26	0.37	0.71

CMA	-0.19	0.33	-0.58	0.57
WML	-0.12	0.14	-0.91	0.36
FF6 (E-Score, E-Score, E-Score and Total-Score)				
R-squared (Within)		0.31		
No. Observations		498		
Parameter	Parameter	Std. Err.	T-stat	P-value
Mkt_RF	1.30	0.11	12.35	0.00
SMB	-0.08	0.26	-0.31	0.76
HML	0.39	0.32	1.22	0.22
RMW	0.43	0.32	1.36	0.18
CMA	-0.47	0.43	-1.09	0.27
WML	0.07	0.18	0.38	0.70
Total-Score	0.00	0.00	-0.43	0.67
E-Score	0.00	0.00	-0.36	0.72
S-Score	0.00	0.00	-0.39	0.70
G-Score	0.00	0.00	-0.34	0.73

Table 2 indicates that the Fama-French 6 factors collectively explain a significant portion of the variance in excess returns for the Low ESG Risk group (Within R-squared around 0.38–0.40). The Market Risk Premium (Mkt_RF), Size (SMB), and Profitability (RMW) factors are statistically significant predictors of excess returns in most models for this group (p-values < 0.05). The Value (HML), Investment (CMA), and Momentum (WML) factors show varying levels of statistical significance across models, with HML being consistently insignificant.

Crucially, Table 2 indicates that none of the ESG scores (Total-Score, E-Score, S-Score, G-Score) demonstrate a statistically significant relationship with excess stock returns at conventional significance levels (e.g., $p < 0.05$) when added to the FF6 model for the Low ESG Risk group during the restricted analysis period. The p-values for the ESG coefficients range from 0.12 for Total-Score to 0.41 for G-Score. The estimated coefficients for the ESG scores are negative, suggesting a marginal association between higher ESG scores (indicating higher risk based on the post-2019 scale) and slightly lower excess returns, but this relationship is not statistically distinguishable from zero.

3.3.3. Panel Regression Results: Medium ESG Risk Group

Table 3 presents the estimation results for firms classified as Medium ESG Risk using Fixed Effects Panel-OLS with robust standard errors. The FF6-only model for this group includes 8 entities and 939 observations (Sept 2014–Mar 2025). The augmented models with ESG scores include the same 8 entities but are limited to 498 observations from December 2019 to March 2025.

Table 3. Medium ESG Risk - FF6 Only, E-Score, E-Score, E-Score and Total-Score.

Dep. Variable	**Excess_Return**			
Estimator		PanelOLS		
R-squared (Within)		0.31		
No. Observations		939		
Parameter	Parameter	Std. Err.	T-stat	P-value
Mkt_RF	1.30	0.08	16.08	0.00
SMB	-0.04	0.19	-0.22	0.83
HML	0.13	0.25	0.50	0.62
RMW	0.10	0.26	0.37	0.71
CMA	-0.19	0.33	-0.58	0.57

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WML	-0.12	0.14	-0.91	0.36
FF6 (E-Score, E-Score, E-Score and Total-Score)				
R-squared (Within)		0.31		
No. Observations		498		
Parameter	**Parameter**	**Std. Err.**	**T-stat**	**P-value**
Mkt_RF	1.30	0.11	12.35	0.00
SMB	-0.08	0.26	-0.31	0.76
HML	0.39	0.32	1.22	0.22
RMW	0.43	0.32	1.36	0.18
CMA	-0.47	0.43	-1.09	0.27
WML	0.07	0.18	0.38	0.70
Total-Score	0.00	0.00	-0.43	0.67
E-Score	0.00	0.00	-0.36	0.72
S-Score	0.00	0.00	-0.39	0.70
G-Score	0.00	0.00	-0.34	0.73

Table 3 shows that the Fama-French 6 factors also explain a significant portion of the variance in excess returns for the Medium ESG Risk group (Within R-squared around 0.31). The Market Risk Premium (Mkt_RF) factor is a highly statistically significant predictor of excess returns (p-value < 0.00). Other factors like SMB, HML, RMW, CMA, and WML are generally not statistically significant predictors for this group, although SMB shows borderline significance in some augmented models (p-values around 0.012).

Similar to the Low ESG Risk group, Table 3 shows that none of the ESG scores (Total-Score, E-Score, S-Score, G-Score) exhibit a statistically significant relationship with excess stock returns at conventional significance levels (e.g., p < 0.05) in the Medium ESG Risk group during the restricted analysis period. The p-values for the ESG coefficients are all substantially greater than 0.05, ranging from 0.67 for Total-Score to 0.76 for E-Score. The estimated coefficients for the ESG scores are again negative but close to zero and not statistically significant.

3.3.4. OLS Regression Results: High ESG Risk Group

Table 4 presents the regression results for firms classified as High ESG Risk. Due to significant data limitations, specifically having only one entity (firm) in this group with sufficient data during the post-2019 period relevant for ESG analysis, Panel-OLS was not a meaningful approach. Consequently, only a standard OLS regression with robust standard errors could be performed for the FF6-only model, including 23 observations for this single entity. ESG-augmented models could not be estimated at all for this group due to the complete absence of original historical ESG data from the source for this entity across the entire period.

Table 4. High ESG Risk - FF6 Only (OLS).

Dep. Variable			**Excess_Return**			
Model			OLS			
R-squared			0.08			
No. Observations			23			
Parameter	**coef**	**std err**	**Z**	**P>|z|**	**[0.025**	**0.975]**
const	0.16	0.20	0.84	0.40	-0.22	0.55
Mkt_RF	-3.28	3.08	-1.07	0.29	-9.31	2.75
SMB	6.25	8.74	0.72	0.47	-10.87	23.37
HML	-1.09	8.19	-0.13	0.89	-17.14	14.96

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RMW	3.80	11.54	0.33	0.74	-18.81	26.41
CMA	-0.47	8.98	-0.05	0.96	-18.07	17.13
WML	1.35	7.48	0.18	0.86	-13.32	16.01

Table 4 (OLS results) shows that none of the Fama-French 6 factors are statistically significant predictors of excess returns in this limited sample ($p > 0.28$). The R-squared indicates a very low explanatory power (R-squared = 0.08), and the overall F-statistic is not significant ($p = 0.885$). Given the single entity and small sample size, these results are highly constrained and not readily generalizable. Critically, no conclusions can be drawn from this analysis regarding the impact of ESG scores on excess returns for firms in the High ESG Risk category due to the inability to estimate those models.

3.3.5. Summary of Empirical Findings

The empirical analysis using panel regression across different ESG risk groups yielded several key findings. For both the Low and Medium ESG Risk groups, Fama-French factors, particularly the Market Risk Premium, Size (SMB), and Profitability (RMW, especially for Low Risk), were found to be significant predictors of excess stock returns, consistent with asset pricing theory. However, for both these groups, none of the ESG scores (Total, Environmental, Social, or Governance) showed a statistically significant relationship with excess returns during the analyzed period (December 2019 - March 2025), after controlling for the FF6 factors. The High ESG Risk group analysis for ESG impact was inconclusive due to severe data limitations, with only a single entity available and no original ESG data from the primary source. The analysis highlights that, within the confines of this specific dataset and period, broad ESG scores did not provide incremental explanatory power for transportation firm stock returns beyond established financial risk factors. The reliability of these specific findings regarding ESG is limited by the data period restriction and the reliance on imputation for missing data.

4. Discussion

This section interprets the findings from the literature synthesis and the empirical analysis, contextualizes them within relevant theoretical frameworks, discusses their implications for the proposed Global Sustainable Transportation System (GSTS), addresses the study's limitations, and outlines directions for future research.

4.1. Interpretation of Literature Synthesis and Relevance of Theoretical Frameworks

The literature review highlights that the global transportation sector is experiencing a period of intense change, propelled by strong pressures like climate change, urbanization, and rapid technological advancement [1,10,13,14,17,21]. This situation underscores the necessity for a fundamental move toward sustainability, consistent with the conceptual framework of the GSTS. The observed dynamics align well with established theories of change. Rogers' Diffusion of Innovations theory [22] provides a framework for understanding the varied rates of adoption and ongoing challenges, such as cost and infrastructure deficits, associated with new technologies like electric vehicles or hydrogen fuel cells [9,16,19,20,21]. The complexities involved in integrating these innovations into existing systems and practices are further clarified by the Multi-Level Perspective (MLP) within Socio-Technical Transition Theory [22,24,29,33]. The MLP emphasizes that sustainable transitions involve more than simply replacing old technology with new; they require the co-evolution of technology with user behaviors, policy structures, market dynamics, and cultural understandings, forming a 'socio-technical regime'. The literature reflects this intricate relationship, showing how niche innovations, such as autonomous systems, MaaS, and advanced biofuels [8,27,28], interact with broader landscape pressures, including climate policies [13,19], to challenge the prevailing fossil-fuel-dependent system. This theoretical lens emphasizes that achieving a system like the GSTS involves navigating complex interactions across multiple levels, influencing the paths and speed of transformation.

4.2. Interpretation of Empirical Findings (ESG Valuation) and Answers to Research Questions

The empirical analysis sought to determine whether the financial market incorporates ESG risk, as measured by Sustainalytics scores, into the valuation of global transportation firms, after controlling for established financial risk factors (Fama-French 6). Methodologically, the Variance Inflation Factor analysis (Table 1) indicated that multicollinearity among the key predictors was generally not a prohibitive concern, supporting the interpretation of the regression coefficients.

The central finding emerging from the panel regressions for both the Low ESG Risk group (Table 2) and the Medium ESG Risk group (Table 3) was the statistical insignificance of the analyzed ESG risk scores (Total, E, S, and G pillars) in explaining excess stock returns during the December 2019–March 2025 period. Answering RQ1, this means the analysis found no statistically significant evidence that higher overall ESG risk scores were associated with lower excess stock returns for these firms, after controlling for FF6 factors. Addressing RQ2, because the individual Environmental (E), Social (S), and Governance (G) pillar scores also failed to show a statistically significant relationship with excess returns (Tables 2 and 3), no distinct impacts could be attributed to these separate dimensions, nor could significant differences between their impacts be established. Regarding RQ3, the finding of a statistically insignificant relationship was consistent across both the Low and Medium ESG Risk groups, indicating no significant variation in the ESG-return link between these two tiers based on this analysis. It is crucial to highlight that data limitations for the High ESG Risk group (Table 4), specifically the lack of ESG data and a single-firm sample, precluded any meaningful analysis or answers to the research questions for this highest risk category.

While the estimated coefficients for ESG scores were consistently slightly negative across the analyzable groups (potentially hinting at a directionality where higher risk aligns with lower returns), their lack of statistical significance requires careful interpretation. Several factors could contribute to this null result. The specific post-2019 timeframe analyzed experienced unique market disruptions (e.g., COVID-19) that might have obscured underlying ESG effects. Furthermore, the financial consequences of ESG factors might accrue over longer horizons than captured by monthly returns, or the relationship could be non-linear or context-dependent in ways not modeled here. Data limitations are also a critical consideration, including the reliance on a single ESG provider, the necessity of data imputation, and the inherent challenge of encapsulating complex ESG realities in standardized scores. It remains possible that investors in the transportation sector weigh sector-specific sustainability metrics (like emissions intensity or safety data) more heavily than broad ESG scores, or view ESG primarily as a long-term risk management factor rather than a short-term performance driver.

In summary, the empirical portion of this study did not find statistically robust evidence that the broad ESG risk scores analyzed were priced into the excess stock returns of Low and medium-risk global transportation firms during the recent period examined, beyond the influence of established financial risk factors.

4.3. Connecting Empirical Results to the Sustainable Transport System Vision and Theoretical Underpinnings

The observed lack of a statistically significant link between current ESG risk scores and short-term excess returns presents an interesting contrast with the aspirations of the GSTS vision. While the literature confirms the operational and societal importance of the sustainability principles central to the GSTS [1,3,5,12,13], the empirical results suggest that converting these principles, as reflected in current ESG risk ratings, into demonstrable, short-term financial outperformance is complex and was not evident in this analysis. This highlights a potential gap between the long-term strategic value of transitioning toward sustainable systems like the GSTS and how the market currently values relevant ESG performance metrics on a short-term, risk-adjusted basis. From an MLP perspective [22,24,29,33], this finding could suggest that the transition is still in progress; the mechanisms by which the market values assets (e.g., March 2025). Although the coefficients for ESG scores showed a consistent, slight negative value, hinting at a potential link where higher risk scores might correspond to marginally lower returns, these effects were not statistically different from zero (with p-values consistently above 0.10). For the High ESG Risk group (Table 4), severe data limitations prevented estimating models

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that included ESG factors. The basic factor model results were not informative due to the sample containing only one firm.

This predominant finding of no statistical significance across the analyzable risk groups could be interpreted in several ways. It might suggest that during this specific, recent period, the market did not consistently price the particular ESG risks captured by the ESG scores in a manner that translated into statistically significant abnormal returns for these transportation firms, beyond the financial risks already accounted for by the FF6 factors. This period included unique market conditions, such as the COVID-19 pandemic are part of the socio-technical regime. may not yet fully incorporate and consistently price the diverse aspects of sustainability relevant to the sector's long-term transformation. The development of GSTS aims to achieve tangible improvements in emissions, efficiency, which may have overshadowed less pronounced ESG effects. Alternatively, the financial impact of ESG factors may become apparent over longer periods than those captured by monthly returns, or perhaps the relationship is not linear or is dependent on specific firm characteristics not fully controlled for in the models. Data limitations, including the reliance on imputed data for some observations and the specific methodology used by the ESG provider, could also potentially obscure a true underlying relationship. It is also plausible that investors in the transportation sector prioritize different sustainability metrics or view ESG primarily as a tool for long-term risk mitigation rather than a source of short-term excess returns.

4.4. Relation to Broader Context and Existing Studies

The findings of this study contribute to a large and often contradictory body of literature examining the ESG-performance nexus. While numerous studies report positive correlations between ESG performance and financial metrics across various sectors, a significant number also find null or even negative relationships, often depending on the methodology, period, ESG metrics used, and geographic focus. This study's finding of a predominantly null relationship for the global transportation sector during the recent post-2019 period adds a sector-specific data point, suggesting that broad conclusions about ESG's financial impact cannot necessarily be generalized across all industries or timeframes. Factors unique to the transportation sector, such as high capital intensity, regulatory scrutiny, and direct exposure to fuel price volatility, might influence how ESG factors are perceived and priced by investors compared to other industries.

4.5. Limitations of the Study

The ability to draw definitive and broadly generalizable conclusions is significantly constrained by the limitations inherent in the empirical analysis, primarily related to data availability. The most significant limitation is the restricted period (December 2019 to March 2025) available for the ESG analysis, which was necessitated by a change in the data source's ESG scoring methodology. This short period may not adequately capture potential long-term or lagged effects of ESG performance on stock returns. Furthermore, the relatively small sample sizes within the ESG risk groups for the post-2019 period (5 entities for Low ESG Risk, 8 for Medium ESG Risk) limit the statistical power to detect significant effects, if they exist. The most severe limitation concerns the High ESG Risk group, for which the presence of only a single entity during the relevant period made it impossible to estimate any models assessing the impact of ESG scores. The analysis focused solely on stock returns as a measure of financial performance, potentially overlooking other avenues through which ESG might influence financial outcomes, such as profitability, cost of capital, or risk reduction. The study also used composite and pillar ESG scores, which may obscure the impact of specific, material ESG issues within the diverse transportation sector as effectively as more granular data points might.

4.6. Implications for Policy, Investment, and Practice

Despite the empirical limitations, the findings offer preliminary implications for stakeholders. For policymakers and proponents of sustainable transportation initiatives like GSTS, it suggests that while the environmental and social imperative is clear and aligns with global goals, the immediate financial market reward for broad ESG performance in the sector might not be consistently evident based on current data and metrics. This underscores the potential need for policy frameworks (e.g.,

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incentives, clear regulations, effective carbon pricing mechanisms) that create stronger financial signals and a more supportive market environment for investments in sustainable transportation infrastructure and technologies, rather than solely relying on voluntary ESG adoption being directly reflected in stock valuations. For investors, these findings, while limited, suggest that a simple investment strategy based on high broad ESG scores in this sector, using this specific data source and period, may not have demonstrably translated into higher excess stock returns. This implies that other investment criteria or the analysis of more specific, financially material sustainability data might be more relevant for financially motivated investment decisions in this sector. For transportation firms, the study highlights that while improving ESG performance is crucial for long-term viability, risk management, reputation, and maintaining a license to operate, the direct financial benefits in terms of stock valuation may need to be realized through other mechanisms like operational cost savings, enhanced risk management, or improved access to specific sustainable finance channels, rather than assuming broad ESG scores will automatically lead to higher stock prices.

4.7. Recommendations for Future Research

Future research should aim to address the limitations of this study to provide more robust and conclusive insights into the financial implications of ESG in the transportation sector. This includes improving empirical analysis by conducting studies using more comprehensive, longer-term, and reliable historical ESG data from alternative providers that cover a wider range of firms and a longer time horizon, especially data that predates the 2019 methodological change. Accessing and utilizing more granular ESG data points specifically identified as material to the transportation sector (e.g., detailed fleet emission intensity, safety incident rates, supply chain labor practice audits) could provide more specific insights into which sustainability aspects, if any, are valued by the market. Exploring alternative econometric models that can better capture potential complex or lagged relationships between ESG performance and financial outcomes is also recommended. Beyond stock returns, future research could explore the relationship between ESG and other financial performance indicators, such as profitability ratios (e.g., ROA, ROE), measures of firm value (e.g., Tobin's Q), cost of capital (both debt and equity), or various measures of financial risk (e.g., volatility, downside risk, beta). Investigating causal mechanisms is also important; future studies could attempt to identify potential causal pathways through which specific ESG investments or improvements influence financial performance, moving beyond correlational analysis, potentially involving event studies around significant sustainability-related announcements or investments. Furthermore, deeper integration of mobility cultures is needed; future qualitative and quantitative research could explore how intangible factors like mobility cultures and public acceptance of new technologies are reflected in firm value or influence the success and financial outcomes of specific sustainable transport initiatives, and how these might be linked to or captured by ESG frameworks. Finally, refining sustainable transport system models should continue, incorporating lessons learned from real-world pilots and empirical studies on technology adoption, socio-technical transitions, and the evolving understanding of ESG valuation in financial markets.

5. Conclusions

This project examined the critical need for a transformative, state-of-the-art global transportation system, conceptualized as GSTS, integrating sustainability, technology, and societal value, against the backdrop of complex current challenges [1]. Drawing from a synthesis of relevant literature, the project highlighted key pressures on the sector, identified emerging technological and operational solutions, underscored the importance of human factors, and discussed relevant theoretical frameworks like Diffusion of Innovations and the MLP for understanding large-scale transport transitions [3–21, 22–39]. The literature synthesis also revealed a need for more empirical evidence on how financial markets specifically value corporate ESG performance in this sector.

To address this, an empirical panel regression analysis was conducted to examine the relationship between ESG scores and excess stock returns for a sample of transportation and logistics firms categorized by ESG risk. Within the specific constraints of the available data (restricted post-

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2019 period, reliance on imputation for missing values, relatively small sample sizes within groups) and the methodology employed, the analysis found no statistically significant relationship between overall ESG scores, individual ESG pillar scores, and excess stock returns for firms in the Low or Medium ESG Risk groups. The analysis was inconclusive regarding the impact of ESG on returns for the High ESG Risk group due to severe data limitations.

While the conceptual vision of integrated, sustainable transportation systems like GSTS remains crucial for addressing global environmental and social imperatives and aligns with major sustainability trends, the empirical findings from this limited analysis suggest that, as of early 2025, broad corporate ESG scores may not be consistently or significantly reflected in the stock returns of transportation and logistics firms in the same way that traditional financial risk factors are. This does not negate the importance of pursuing ESG goals for other critical reasons, such as enhancing long-term resilience, driving operational efficiency, meeting regulatory requirements, or improving access to specific sustainable capital pools, but highlights a potential disconnect or lag in how these broad factors are priced into public equity markets. Realizing the full potential of transformative initiatives like GSTS will likely require not only continued technological and social innovation but also market mechanisms and potentially more granular, sector-specific data transparency that enable the true value of sustainability and resilience to be better recognized and rewarded by the financial system, fostering the necessary investment for a global, sustainable transportation future.

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Abbreviations

The following abbreviations are used in this manuscript:
AI: Artificial Intelligence
AV: Autonomous Vehicle
B/M: Book-to-Market Ratio
CMA: Conservative Minus Aggressive (Fama-French Factor)
CNI: Canadian National Railway
CP: Canadian Pacific Kansas City
CSX: CSX Corporation
C-V2X: Cellular Vehicle-to-Everything
DPSGY: Deutsche Post DHL Group
DSDVY: DSV A/S
E: Environmental (ESG Pillar)
ESG: Environmental, Social, and Governance
EV: Electric Vehicle
FDX: FedEx Corporation
FF6: Fama-French 6-Factor Model

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G: Governance (ESG Pillar)
GHG: Greenhouse Gas
GSTS: Global Sustainable Transportation System
HFCV: Hydrogen Fuel Cell Vehicle
HML: High Minus Low (Fama-French Factor)
ICT: Information and Communication Technology
IoT: Internet of Things
ITS: Intelligent Transportation System
JBHT: J.B. Hunt Transport Services
JYD: Jayud Global Logistics
KHNGY: Kuehne + Nagel International
MaaS: Mobility-as-a-Service
MCap: Market Capitalization
MICE: Multiple Imputation by Chained Equations
MLP: Multi-Level Perspective
Mkt_RF: Market Risk Premium (Market return minus Risk-Free rate)
MSCI: Morgan Stanley Capital International
ODFL: Old Dominion Freight Line
OLS: Ordinary Least Squares
RMW: Robust Minus Weak (Fama-French Factor)
RQ: Research Question
S: Social (ESG Pillar)
SAF: Sustainable Aviation Fuel
SDG: Sustainable Development Goal
SMB: Small Minus Big (Fama-French Factor)
UAM: Urban Air Mobility
UNP: Union Pacific Corp.
UPS: United Parcel Service
VIF: Variance Inflation Factor
WML: Winners Minus Losers (Momentum Factor)
XPO: XPO, Inc.
ZIM: ZIM Integrated Shipping Services

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