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The Sustainable Organization Design for Transport Services: Guarantees of Origin (GOs) via Intelligent Transportation Systems (ITS)

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Abstract. *This study explores the potential for change that Intelligent Transportation Systems (ITS) can bring to the transportation sector. It seeks to tackle the pressing need for sustainable progress in light of increasing concerns about climate change and growing greenhouse gas emissions. The transportation industry, essential for global supply chains and movement, is confronted with the task of lessening its environmental impact while maintaining operational efficiency and dependability. The emergence of ITS presents a hopeful solution by combining information and communication technologies with transport infrastructure and vehicles to streamline logistics, improve safety, and reduce emissions. These systems offer crucial up-to-date information on traffic conditions, vehicle function, and route planning, enabling well-informed decision-making and effective resource management.*

This study focuses on the creative use of the "Guarantee of Origin" (GO) idea, typically utilized in the renewable energy industry to validate the environmental friendliness of energy sources, in the field of logistics and transportation. The research suggests that expanding the GO framework to include detailed emissions tracking for complete travel plans within an ITS system could greatly improve the sector's environmental responsibility and openness. Generating a clean GO is exclusively feasible within an ITS, particularly for intricate travel itineraries or AWBs.

Using a qualitative approach, this study delves into an in-depth review of literature to investigate how the organizational structure of transportation needs to change in order to incorporate sustainability through ITS. The goal is to bridge the gap between ambitions for sustainable transportation and the practical steps necessary for their achievement. A new model for organizational design is proposed, which utilizes ITS and the GO concept. This model envisions a comprehensive travel system that integrates various modes of transport within a government-run cloud platform. It will allow for accurate calculation and distribution of emissions data for each segment and mode of transportation. Ultimately, this research aims to demonstrate that ITS can be considered as projects that reduce emissions upstream (UER), paving the way for new funding opportunities in digital infrastructure development with a focus on sustainability.

This study supports the overall objective of reaching carbon neutrality and sustainable growth in the transportation industry, emphasizing the essential function of ITS in aiding this significant shift.

Keywords: Sustainable Transportation, Intelligent Transportation Systems (ITS), Emissions Accounting, Guarantee of Origin (GO), Environmental Accountability, Multi-modal Travel Itineraries, Transportation Organizational Design.

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Introduction

The shift towards sustainable transport systems is a crucial challenge and opportunity today. With climate change and environmental damage worsening, innovative solutions are urgently needed to reduce the transportation sector's significant carbon footprint. The transportation industry, vital to the global economy, is a major source of greenhouse gas emissions, contributing about 25% of global CO2 emissions from fuel combustion. Tackling this issue is not only crucial for fighting climate change but also for ensuring a sustainable future in urban development, worldwide trade, and societal mobility.

In response to the growing focus on transparency and sustainability, the European Union's Corporate Sustainability Reporting Directive (CSRD) has set a new standard for non-financial reporting by pushing transportation companies to improve their disclosure of Scope 3 emissions. This directive broadens sustainability reporting beyond financial metrics to include detailed environmental impacts like indirect emissions along a company's value chain. The CSRD emphasizes comprehensive and accurate sustainability reporting as essential for maintaining corporate integrity and integrating transportation firms into environmentally responsible value chains. Consequently, the CSRD raises standards for non-financial reporting in Europe while signaling a broader move towards sustainability as fundamental to corporate governance and market performance in the transportation sector.

Research explores Intelligent Transportation Systems (ITS) as key to promoting sustainable transport by integrating information technology with transport infrastructure and vehicles. ITS offers opportunities to optimize logistics, enhance safety, and minimize environmental impacts by providing real-time data on traffic conditions, vehicle performance, and route optimization for informed decision-making that can lead to emission reductions.

The primary research question focuses on how integrating the Guarantee of Origin framework within Intelligent Transportation Systems can revolutionize the environmental accountability of the transportation sector toward sustainability. This investigation hypothesizes that a GO-based ITS framework accounting for detailed emissions across full travel itineraries will help quantify and reduce transportation's environmental impact significantly.

The study uses qualitative research methodology through literature review and conceptual model development. The literature review examines current ITS and GO contexts in sustainable transport to identify integration gaps and opportunities while proposing an organizational design leveraging ITS and GO for enhanced sustainability. This subject is critical as cities expand, stressing efficient sustainable transport solutions further. While recognizing ITS potential in reducing emissions & enhancing efficiency remains vital; incorporating emission accounting through GO presents untapped potential by offering clear measures driving advancements in cleaner modes adoption, policy support & greener consumer choices.

Additionally emphasizing interdisciplinary collaboration bridging IT with environmental science & transport policy proposes holistic solutions addressing complex challenges in sustainable transport effectively.

Literature review

Environmental concern

Studies have recently shown the significant environmental influence of the transportation industry on global greenhouse gas emissions. Ferrer and Thomé (2023) point out that transportation accounts for 15% of human-made greenhouse gas emissions, 23% of worldwide energy-related

emissions, and 8.7 Gt of CO2-equivalent emissions, highlighting the critical importance of effective adaptation and mitigation measures in this field. In support of this, Ankathi et al. (2022) discuss the considerable greenhouse gas emissions generated by the global transport of crude oil, which contribute significantly to emissions from marine transportation activities. Additionally, shedding light on the sector's impact, Li, Ren, and Li (2022) utilize machine learning techniques to predict CO2 emissions from transportation, illustrating its dual role as a key driver of economic development and a major source of environmental harm. These discoveries collectively emphasize the pressing need to address the transportation industry's role in climate change by promoting comprehensive strategies to reduce its carbon footprint.

Legal framework

The Corporate Sustainability Reporting Directive (CSRD) brings about a significant shift in non-financial reporting within the EU and has a profound impact on transportation companies. By highlighting Scope 3 emissions, the CSRD mandates detailed disclosures on indirect emissions across a company's value chain, pushing organizations to adopt more transparent and sustainable reporting practices. This update in reporting criteria is essential for transportation firms seeking to maintain their operational efficiency and reputation within environmentally conscious networks. Research by various scholars such as Allgeier and Feldmann (2023), Odobaša and Marošević (2023), Barangă and Ifrim (2023), Voicu (2023), along with Glavič et al. (2023) sheds light on the implications of the CSRD, emphasizing the increased accountability and integration of sustainability it demands from businesses. These changes underscore the growing importance of sustainable business strategies in corporate governance and how they impact the strategic positioning of transportation companies in global markets.

The advancement of Guarantees of Origin (GOs) trading under the European framework, notably in Croatia, serves as a concrete demonstration of European legislation at work concerning renewable energy certification. The study titled "The progression of Guarantees of Origin trading in Croatia amidst the European framework" by Kelava, Vajdić, and Dokmanović (2023) explores the regulatory framework set by Croatia, pointing out the roles of the Croatian Energy Market Operator (HROTE) in issuing GOs for electricity and managing the Registry of Guarantees of Origin. Launched in 2014, full operation at the Croatian Registry of Guarantees began in 2015, signifying a significant stride in certifying electricity generated from renewable sources within their country. By transitioning towards market-based electricity sales for incentivized producers, this facilitated establishing a trading platform for GOs that highlights their crucial role in empowering consumers to make informed decisions regarding their electricity source. Through confirming that customers have purchased energy from renewable origins, GOs become effective tools for encouraging renewable energy consumption and attracting investments into renewable energy production. This initiative aligns with broader European objectives for utilizing renewable energy while positioning Croatia as a pioneer in GO trading within Europe; however, not all European nations have enacted similar legislation yet.

A noteworthy study exploring Upstream Emissions Reduction (UER) within industrial processes is introduced by Marshall & Etheridge (2023). Their research titled "Streamlined Emissions Reduction" presents an approach to evaluating emission reduction opportunities specifically within upstream oil and gas facilities. The methodology stresses using digital interfaces for precise emissions tracking and economic evaluations—enabling systematic identification, ranking, prioritization of emission reduction actions standardizes assessment procedures across different emission sources while integrating them into operational workflows maximizes both

economic gains environmental benefits simultaneously. Through real-world examples provided by this study underscores how this methodology can be applied beyond just oil & gas sectors suggesting its relevance extends to other process industries seeking to transition towards low-carbon production practices.

Intelligent Transportation Systems (ITS) for reduced emissions

ITS is a major advancement in addressing the environmental impact of the transportation industry, which is a significant contributor to global carbon emissions. By utilizing information and communication technologies, ITS present a holistic solution for improving transportation efficiency, safety, and sustainability across different modes of transport. Zhao and Jia (2021) highlight the importance of ITS in smart cities, where integrating the Internet of Vehicles and other advanced technologies helps reduce harmful emissions by enhancing traffic management and promoting electric and autonomous vehicles. Similarly, Gao et al. (2022) explore how ITS can support sustainable energy management in road transportation through IoT solutions that optimize energy usage and decrease the carbon footprint of vehicle operations.

The benefits of ITS are not limited to road transport but extend to rail, air, and maritime modes as well. Chen et al. (2021) demonstrate how platooning technology in rail systems under ITS can significantly reduce fuel consumption and improve traffic efficiency. Meanwhile, Razakova et al. (2023) analyze the sustainability effects of implementing ITS across the United States, showcasing enhancements in operational efficiency and environmental sustainability in urban and interurban settings. The integration of ITS with sustainability objectives is also evident in the maritime sector where Lamssaggad et al. (2021) discuss security challenges within ITS frameworks, emphasizing secure data sharing for sustainable maritime transport management.

These studies collectively emphasize how transformative ITS can be across all transportation modes – from fostering cleaner road transport to optimizing rail and maritime activities. The incorporation of advanced technologies within ITS not only boosts overall transport system efficiency and safety but also plays a vital role in global efforts to cut down on carbon emissions and address climate change concerns. As cities and nations aim for more sustainable futures, ongoing development, and implementation of ITS are crucial steps toward achieving these environmental as well as economic goals.

The Guarantee of Origin (GO)

The incorporation of the Guarantee of Origin (GO) system into Intelligent Transportation Systems (ITS) shows promise in improving the environmental responsibility of the transportation industry and spurring a transition to sustainable transportation practices. Originally designed for the energy field, GOs act as proof that a specific amount of energy was generated from renewable sources. Expanding this concept to transportation has the potential to transform how emissions are recorded, offering clarity and promoting the adoption of cleaner transport methods.

In energy, GOs have played a key role in encouraging the use of renewable energy by allowing consumers to validate their consumption of eco-friendly power. For example, Nofuentes, Hernández, and Pons (2022) present a blockchain-based system for issuing GOs that enhances transparency and prevents double counting of certificates, which is essential for maintaining credibility in the energy market. Similarly, Blázquez de Paz, Hovdahl, Arve, Bjørndal, and Bjørndal (2023) show how GO markets can stimulate competition and reduce electricity prices, indirectly driving renewable energy production and usage.

Translating these benefits to transportation through ITS could offer similar advantages by enabling transport providers to confidently demonstrate their use of sustainable approaches. Delardas and Giannos (2022) address issues with traditional GOs in energy sectors and suggest employing blockchain technology to boost transparency and encourage investments in renewable transport options. Additionally, Kelava, Vajdić, and Dokmanović (2023) outline Croatia's experience with GO trading as evidence of how implementing GOs can enhance electricity production sustainability - a model that can be applied to transportation.

These instances underscore how GOs have the capacity to significantly influence both energy and transportation industries by fostering sustainability and openness. Successfully integrating GOs into ITS for transport could establish a sturdy framework for tracking emissions and advancing global sustainability objectives.

Integrating GOs and ITS

Leveraging advanced information and communication technologies has been crucial in improving transportation efficiency, safety, and sustainability. According to a recent study by Siksnelyte-Butkiene and Štreimikienė (2022), the role of these technologies in sustainable road transport development within the EU is significant. Their research evaluates the progress made by various countries over the last decade using a multi-criteria analysis, emphasizing the necessity of monitoring and advancing the sector towards sustainability. Stefaniec et al. (2021) present an innovative framework for evaluating social sustainability in regional transportation, particularly focusing on EU road transport. This study demonstrates how these technologies can address social aspects of sustainability, contributing to a more holistic view of sustainable transportation.

The GO framework, typically linked with certifying renewable energy sources, introduces a fresh approach to enhancing transparency and accountability in transportation. Esztergár-Kiss (2023) discusses current challenges and trends in transportation research while highlighting GO's importance in promoting intelligent, eco-friendly transport within the EU context. Analysis of EU-funded projects highlights a growing emphasis on sustainable mobility and how GO can play a role in achieving these objectives.

Furthermore, Kelava, Vajdić, and Dokmanović (2023) delve into Croatia's progress with GO trading, offering insights into its implementation and impact within the European landscape. This case study showcases how GO can facilitate the shift towards renewable energy in transportation to align with broader EU sustainability targets. Gruetzmacher et al. (2021) evaluate environmental performance across EU countries' transport sectors to provide additional context on how GO and ITS drive sustainable practices within the industry.

In summary, integrating ITS and GO within Europe's transportation sector shows promise for advancing sustainability goals. While ITS improves operational efficiency and safety measures, the GO framework fosters environmental responsibility through renewable energy certification. Nevertheless, further research is essential to explore practical integration methods between these systems and develop comprehensive strategies that fully utilize their potential for sustainable transport initiatives.

The sustainable organization design

The sustainable organization design for transport services through the integration of Guarantees of Origin (GOs) and Intelligent Transportation Systems (ITS) offers a novel approach to enhancing sustainability within Europe's transportation sector. This literature review aims to delineate the

current understanding of these concepts and their potential for creating more sustainable transportation networks.

Leveraging advanced digital and communication technologies has been crucial in optimizing traffic management, improving safety, and decreasing environmental impacts. The role of these technologies in supporting the European Sustainable and Smart Mobility Strategy is highlighted by recent EU-funded projects that contribute to sustainable transportation objectives. This underscores the growing focus on integrating these technologies into European transportation policies to enhance efficiency and environmental friendliness.

Simultaneously, the concept of Guarantees of Origin (GOs), typically associated with the energy sector, is gaining popularity in transportation. GOs verify the renewable source of energy, encouraging the use of environmentally friendly energy sources. Applying this concept to transportation suggests a significant potential for certifying sustainable energy use in transportation, promoting greater environmental responsibility. Real-time monitoring systems for emissions in transportation, as explored by Rauniyar et al. (2023), align with GO principles by ensuring transparency and supporting sustainable practices.

Moreover, the integration of GOs and ITS is seen as a strategic approach to advancing sustainable transportation. Li et al. (2023) introduce the concept of the Transportation Internet, which draws parallels between internet architecture and transportation systems, proposing an innovative framework for sustainable transportation through enhanced connectivity and automation. This concept underscores the potential of combining GOs and ITS to create a more sustainable, efficient, and interconnected transportation ecosystem.

In conclusion, the harmonious integration of Guarantees of Origin (GOs) and Intelligent Transportation Systems (ITS) signifies a pivotal transition in organizational design towards sustainable transportation modalities across Europe. ITS contribute to refining operational efficiency and bolstering safety measures, whereas GOs authenticate the environmental sustainability of transportation by verifying the utilization of renewable energy sources. This collaborative approach between GOs and ITS catalyzes a strategic redesign of transportation organizational structures, steering them towards sustainability. This evolution in organizational design not only aligns seamlessly with Europe's comprehensive sustainability goals but also plays a critical role in the global initiative to counteract climate change, underscoring the transformative power of sustainable practices in the transportation sector.

Financing Upstream Emissions Reduction (UER) ITS projects

The investigation of Upstream Emissions Reduction (UER) and its connection with investments in Intelligent Transportation Systems (ITS) has become more prominent in addressing environmental sustainability in the transportation sector. Although there are few direct references to studies linking investments in ITS to UER, several works offer a foundational understanding of how ITS and related technologies aid in reducing emissions, potentially impacting upstream emission activities.

One key area of study involves evaluating the environmental effects of various transportation modes and the potential for ITS to promote more sustainable practices. For example, research on the reduction of emissions from urban passenger transport modes looks at the entire fuel cycle, including upstream emissions from electricity generation for electrified transport modes (Qiao et al., 2021). This method emphasizes the importance of comprehensive strategies that incorporate ITS to optimize transport modes and decrease emissions holistically.

Moreover, considering carbon emissions within the service sector, including transportation, provides insights into indirect emissions downstream in the industry chain that have significant origins upstream (Hou et al., 2021). This viewpoint highlights how emissions are interconnected throughout the supply chain and suggests that ITS could assist in mitigating these impacts by promoting more efficient and sustainable transportation practices.

Furthermore, examining changes in supply chain structures and their impact on multi-scope greenhouse gas (GHG) emissions indicates that reducing ambiguity through coordination between upstream and downstream processes can enhance efforts to reduce emissions (De Stefano & Montes-Sancho, 2023). Investments in ITS could significantly support this coordination by aligning production activities with consumption patterns for overall sustainability across supply chains.

In terms of upstream petroleum production, integrating renewable energy sources for electrification offers another aspect of UER where ITS might help optimize these integrated energy systems to lower emissions (Abraham-Dukuma et al., 2021).

Collectively, these studies suggest that although direct research on using ITS investments as a means for UER is still emerging within transportation sectors, the broader impacts of ITS on enhancing environmental sustainability - specifically through reducing upstream emissions - are widely acknowledged. This literature underscores how ITS has great potential to contribute significantly to UER strategies by improving efficiency and sustainability within transportation systems both directly and indirectly.

Pollinating Legislation with Multi-purpose Concepts

The evolving legislative landscape within the European Union (EU) has increasingly adopted the strategy of "pollinating" multiple legal frameworks with key definitional concepts and principles. This approach aims to ensure cohesive and comprehensive regulation across various sectors, especially in advancing sustainability and environmental compliance. The concepts of "guarantee of origin" and "upstream emissions reduction" stand out as pivotal examples of this strategy, demonstrating significant potential to influence and transform legislation beyond their initial scopes.

The strategic extension of multi-purpose legislative concepts, notably the "guarantee of origin" and "upstream emissions reduction," into comprehensive legislative frameworks represents an innovative approach within the European Union (EU) to ensure sustainability and environmental compliance across diverse sectors. The "guarantee of origin," as analyzed by Gkarakis and Dagoumas (2016), has seen significant operationalization within the EU, showcasing its potential to certify the environmental integrity of products and services beyond the energy sector, including transportation. This mechanism can serve as a pivotal tool for enhancing transparency and promoting sustainable choices among consumers and businesses alike. Furthermore, Blázquez de Paz et al. (2023) illuminate how the market for Guarantees of Origin enhances competition within the energy sector, positing a transformative impact that extends to the transportation sector. The ability of Guarantees of Origin to signal environmental credentials could incentivize greener practices and foster competitive advantages for entities committed to sustainability.

Additionally, the role of service guarantees in signaling quality and commitment to consumers, as discussed by Crisafulli and Singh (2016), underscores the broader applicability of such mechanisms in conveying environmental sustainability. By applying the principles of service guarantees to the environmental performance of transportation services, companies can enhance consumer trust and drive market differentiation based on sustainable practices. Collectively, these

references underscore the efficacy of legislative pollination, as evidenced by the successful integration of the DNSH clause across EU legislation. This approach not only fosters regulatory coherence but also propels sectors towards embracing sustainability as a core operational principle. By embedding concepts like the guarantee of origin and upstream emissions reduction within legislative and regulatory frameworks, the EU sets a precedent for a holistic approach to environmental compliance and sustainability, paving the way for transformative changes across transportation and beyond.

The Guarantee of Origin in Transportation: the "guarantee of origin" concept, initially rooted in energy regulations, certifies the green credentials of energy sources. Extending this concept to products and services, especially in the transportation sector, could revolutionize how environmental impacts are measured and reported. Jansen, Drabik, and Egenhofer (2016) explore the extension of guarantees of origin to verify disclosed information about sources of electricity deliveries to consumers, underpinning the potential for broader application in certifying the environmental footprint of transportation services.

Upstream Emissions Reduction in Industrial Modernization: similarly, the principle of "upstream emissions reduction," integral to the Renewable Energy Directive, focuses on minimizing emissions at the earliest stages of production. This principle can be universally applied across industrial sectors undergoing modernization to reduce emissions. It underscores a shift towards more sustainable production processes that could be mirrored in transportation and manufacturing legislation, advocating for a preemptive approach to environmental sustainability.

DNSH Clause as a Legislative Pollinator: the "Do No Significant Harm" (DNSH) clause from the EU Taxonomy Regulation exemplifies successful legislative pollination. It has permeated various legal, normative, and regulatory frameworks concerning sustainable finances, insurances, and capital markets. This cross-pollination ensures that sustainability considerations are integral to financial and corporate decision-making processes, setting a precedent for incorporating similar multi-purpose concepts like the guarantee of origin and upstream emissions reduction across legislative initiatives.

Application Beyond Energy to Transportation: extending the guarantee of origin to transportation, particularly in certifying the environmental sustainability of transportation services, can leverage market mechanisms to promote greener choices among consumers and businesses alike. For example, Azadian and Murat (2017) highlight the importance of accurate service grouping and pricing in transportation, suggesting that a similar approach could be applied to categorize and price services based on their environmental credentials, facilitated by guarantees of origin.

Broadening the Scope of Environmental Compliance: the application of upstream emissions reduction to industrial modernization, including transportation infrastructure, offers a forward-looking approach to legislative and regulatory frameworks. By embedding this principle across sectors, the EU can ensure that new developments and modernization efforts are aligned with long-term sustainability goals, thereby reducing the overall environmental impact of economic activities.

Case studies

Croatia, like many countries worldwide, faces the dual challenge of modernizing its transportation infrastructure while minimizing environmental degradation. The integration of Intelligent Transportation Systems (ITS) has emerged as a pivotal strategy in addressing these challenges, providing a promising pathway towards sustainable mobility solutions that significantly reduce

greenhouse gas (GHG) emissions and other environmental impacts. Portugal, similar to Croatia, has been making strides in integrating Intelligent Transportation Systems (ITS) to enhance transportation efficiency, safety, and environmental sustainability. The focus on ITS in Portugal reflects a broader European commitment to leveraging technology for sustainable development, particularly in the transport sector. Amongst the key findings from relevant studies, we can list the following:

ITS and GHG Reductions: ITS technologies have been recognized for their potential to enhance transportation safety, efficiency, and environmental sustainability. Research by Barth, Wu, and Boriboonsomsin (2015) underscores the role of ITS in mitigating environmental impacts, noting that ITS applications can lead to energy and emission reductions on the order of 5–15%. These benefits are attributed to improved traffic management, vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications, and advanced traffic monitoring and control systems.

Environmental Benefits of ITS Implementation: Wajeetongratana (2023) emphasizes the economic and ecological advantages of ITS, proposing ITS deployment as a critical policy instrument in transport policies. This study highlights the significant impact of vehicle density and technology exports on a country's propensity to prioritize ITS for climatic and environmental objectives, suggesting that ITS can concurrently boost economic performance and reduce environmental footprints. Nunes, Pinheiro, and Brito (2019) evaluated the impact of environmental transport policies in Portugal, highlighting that "market and command-and-control-based pro-environmental policies" can effectively shift passenger travel to public transportation and promote the deployment of electric vehicles. Their findings suggest that such policies could reduce CO2 emissions by 26%, emphasizing the critical role of ITS in achieving these outcomes.

High-Voltage Power Supply in Croatian Ports: Exploring the environmental impact of transport and cargo operations in ports, Kegalj and Traven (2018) advocate for the adoption of on-shore high-voltage power supply systems in Croatian ports. This technology promises substantial environmental benefits, including air pollution reduction and the promotion of sustainable transport, by minimizing the operational emissions of docked vessels.

High-Speed Rail in Portugal: Jones, Moura, and Domingos (2017) conducted a life cycle assessment of the planned high-speed rail line from Lisbon to Porto, considering the environmental impact of all stages from train manufacturing to disposal. The study found that the operation phase contributes most to total emissions, but ignoring the impacts of construction, maintenance, and end-of-life stages significantly understates the environmental impact. This research underlines the importance of comprehensive assessments in understanding the full environmental footprint of ITS-related projects.

ITS Services on Safety and Traffic Conditions: Oskarbski, Marcinkowski, and Zawisza (2017) demonstrate the positive influence of ITS services on traffic safety and efficiency. By employing performance indicators, the study illustrates how ITS applications contribute to safer travel, enhanced transport system reliability, energy savings, and environmental protection. The research highlights the need for comprehensive ITS services to improve overall transportation system performance. Further supporting this claim, Ekedebe, Lu, and Yu (2015) developed a realistic ITS test bed and a mobile application known as the Incident Warning Application (IWA), leveraging Vehicle-to-Infrastructure (V2I) communications in a realistic ITS environment. Their study, using six weeks of road traffic data from the Maryland/Washington DC and Virginia areas, showed that vehicles equipped with the IWA application demonstrated significant improvements in performance metrics. Specifically, the study highlighted improvements in travel time (139.89%), fuel consumption (11.77%), and environmental emissions, including a reduction in carbon dioxide

(CO2) emissions by 11.77%. These results underscore the traffic efficiency and safety benefits of V2I communications in ITS, affirming the potential for ITS technologies to substantially enhance transportation system performance across various metrics. The findings herein will result in a parallel to digital modeling of traffic for environmental data prediction, similar to safety and efficiency benchmarks that are already being processed on ITS frameworks.

Sustainability Assessment for ITS: Kolosz and Grant-Muller (2016) emphasize the significance of adopting advanced sustainability assessment methodologies to thoroughly evaluate the impacts of Intelligent Transportation Systems (ITS) on the environment and society. They highlight the limitations of conventional transport appraisal models and advocate for the integration of emerging methods that more accurately reflect the sustainability performance of ITS services. Their research underscores the necessity of comprehensive assessment frameworks that account for the environmental, social, and economic dimensions of sustainability in the context of ITS.

Reinforcing this perspective, Bueno, Vassallo, and Cheung (2015) conducted a review on the current assessment tools of sustainability applied to transport infrastructure projects, including ITS. Their study provides an explanatory and comparative analysis of various tools and methods, such as rating systems, traditional decision-making techniques, checklists, and different evaluation frameworks and models, in terms of their effectiveness to appraise sustainability. This critical evaluation aims to identify the limitations of existing approaches and suggests a need for more standardized tools to assess the sustainability of transport projects comprehensively. Their work points out new areas of research and proposes a sustainability appraisal agenda for the future, contributing to the development of a standardized methodology for evaluating ITS impacts on sustainability.

The integration of Intelligent Transportation Systems (ITS) presents a viable approach to enhancing environmental safety and sustainability within Croatia's transportation sector. By leveraging advanced technologies and systems, Croatia can significantly mitigate the environmental impacts associated with traditional transport modalities. ITS not only promises to improve traffic management and reduce GHG emissions but also supports the transition towards more sustainable and smart urban mobility solutions. The case of Croatia serves as a valuable example for other nations seeking to harness the benefits of ITS for environmental sustainability. Portugal's approach to ITS integration demonstrates a proactive stance towards mitigating environmental impacts through advanced transportation technologies. By focusing on policies that encourage the adoption of electric vehicles, optimize traffic management, and promote public transportation, Portugal aims to reduce greenhouse gas emissions and enhance the sustainability of its transportation sector. The case of Portugal, similar to Croatia, illustrates the potential of ITS to contribute to environmental sustainability, underscoring the need for continued investment and policy support for such initiatives.

Methodology

The research design is structured around a systematic and exhaustive literature review, aimed at identifying, evaluating, and synthesizing existing research on the subject. This process involves a detailed analysis of peer-reviewed journal articles, conference proceedings, and authoritative reports from relevant fields. The literature review spans several stages, including defining research questions, identifying relevant literature, selecting, and evaluating studies, and synthesizing findings. The selection criteria for literature inclusion are based on relevance to the research questions, the scientific rigor of the methodology, and the publication date, with a preference for studies published since 2015, to ensure the timeliness of the data.

In the evolving landscape of sustainable transportation within the European Union (EU), the strategic integration of multi-purpose legislative concepts into broader regulatory frameworks represents a pivotal shift towards enhancing environmental compliance and fostering sustainability across diverse sectors. This study aims to explore and elucidate the potential application and impact of such legislative concepts, specifically the "guarantee of origin" and "upstream emissions reduction" within the transportation sector. These concepts, originating from the EU's Renewable Energy Directive and further reinforced by the "Do No Significant Harm" (DNSH) clause from the EU Taxonomy Regulation, serve as foundational pillars for advancing sustainable practices and policies in transportation CAPEX and OPEX strategies.

The methodology chapter of this paper outlines the qualitative research design and comprehensive literature review approach undertaken to investigate how these legislative concepts can be "pollinated" across transportation and other industrial sectors. Given the interdisciplinary nature of this inquiry, bridging legal studies, environmental policy, and transportation science, this chapter details the systematic process of data collection, literature selection, and analytical methods employed to synthesize existing knowledge and identify avenues for the practical application of these concepts. Through a meticulous selection of databases, search engines, and legal document repositories, this research delves into the legislative, environmental, and transportation-related implications of the "guarantee of origin" and "upstream emissions reduction". It aims to provide a nuanced understanding of how these concepts, traditionally confined to specific regulatory domains, can transcend their initial boundaries to influence sustainable transportation planning and implementation. By examining the cross-sectoral pollination effect of these legislative concepts, this study contributes to a broader comprehension of their role in shaping EU policies and practices towards achieving a more sustainable and environmentally friendly transportation ecosystem.

Research hypotheses

The main research hypotheses are formulated based on identified gaps in the existing literature and the potential for ITS, UERs and GOs to contribute to sustainable transportation solutions. These hypotheses are:

1. H1: The synergistic integration of Intelligent Transportation Systems (ITS), Upstream Emissions Reduction strategies (UERs), and Guarantees of Origin (GOs) significantly improves the operational efficiency and environmental sustainability of transportation systems. This hypothesis posits that the collaborative application of ITS, UERs, and GOs offers a multifaceted approach to achieving sustainable transportation, emphasizing the combined impact of technological innovation and regulatory mechanisms on system-wide efficiency and sustainability.
2. H2: The incorporation of Guarantees of Origin (GOs) within Intelligent Transportation Systems (ITS) frameworks leads to a quantifiable reduction in upstream emissions in the transportation sector, surpassing reductions achieved through ITS measures alone. This hypothesis suggests that GOs serve as a critical lever in enhancing the environmental benefits of ITS by providing verified credentials for clean energy use and emissions reductions, thus augmenting the sector's shift towards sustainability.

These hypotheses aim to articulate the anticipated impacts of integrating more precisely ITS, UERs, and GOs within transportation systems. They focus on the collective benefits of these interventions, highlighting the expectation that their combined implementation will lead to measurable improvements in both the efficiency and environmental footprint of transportation. By specifying the role of GOs within ITS frameworks and anticipating a synergistic effect on

emissions reduction, the hypotheses underscore the potential for these technologies and regulatory tools to significantly contribute to sustainable transportation goals.

Qualitative analysis

This chapter delves into a qualitative analysis designed to dissect and synthesize the intricate layers encompassing Intelligent Transportation Systems (ITS), Guarantees of Origin (GOs), and their integrative roles in propelling sustainable transportation forward. Central to this analysis is the exploration of how ITS and GOs, underpinned by pivotal European Union (EU) legal principles such as the "Do No Significant Harm" (DNSH) clause, contribute to redefining sustainability strategies within transportation Capex and Opex frameworks. This exploration is pivotal in understanding the transformative potential of ITS and GOs in fostering a sustainable transportation ecosystem.

Employing a thematic synthesis approach, this analysis meticulously generates themes through an iterative process that reflects both the convergence and divergence found within the current body of literature. Themes were derived inductively from the data and deductively based on established frameworks relating to ITS, GOs, sustainability principles, and the EU's legislative landscape. This methodological rigor ensures the themes accurately encapsulate the multifaceted discussions surrounding ITS and GOs' roles in sustainable transportation.

Several key themes emerged from the synthesis:

a) Operational and Environmental Benefits of ITS and GOs: This theme encapsulates the dual advantages of integrating ITS and GOs into transportation systems—enhancing operational efficiency while significantly lowering environmental footprints.
b) Legislative and Regulatory Challenges: Here, the focus is on dissecting the complexities and hurdles within the legislative and regulatory frameworks that either facilitate or hinder the implementation of ITS and GOs in transportation strategies.
c) Role of EU Legal Principles in Sustainability: This theme explores how the DNSH clause and the concept of GOs are intricately woven into transportation policies, influencing sustainability goals and compliance strategies.
d) Future Directions in Transportation Strategies: Insights into how current trends and findings may shape future transportation policies and practices, emphasizing sustainability and environmental stewardship.

The methodologies and findings of selected studies were critically evaluated, highlighting the strengths and limitations of the research designs, data collection, and analytical techniques employed. This evaluation provided a deeper insight into the reliability and applicability of the findings within the broader context of sustainable transportation. An in-depth analysis revealed how EU legal principles, especially the DNSH clause and GOs, are integrated across transportation initiatives. This integration underscores the opportunities and challenges these principles present in aligning transportation financing strategies with broader sustainable development goals, thereby emphasizing the dynamic nature of EU legislation. The literature review methodology is detailed, explaining the selection of specific databases such as Web of Science, Scopus, and IEEE Xplore, and the rationale behind formulating search queries. This section underscores the significance of focusing on recent, peer-reviewed articles to ensure the analysis is grounded in relevant and credible research contributions. The selection criteria for the literature review are robustly justified, demonstrating the importance of empirical data, publication in high-impact journals, and the

specific focus on ITS within urban settings. This careful selection process has enabled a comprehensive exploration of ITS and sustainability assessments' current trends, methodologies, and knowledge gaps.

The qualitative analysis culminates in linking the synthesized themes and critical evaluations to the research hypotheses. It discusses how the nuanced understanding gleaned from this analysis informs the debate on ITS and GOs' potential to revolutionize transportation systems towards enhanced sustainability. This chapter contributes significantly to advancing scholarly discourse on sustainable transportation policies, practices, and the future direction of sustainable transportation strategies in the EU context.

Expanded Literature Research Methodology

This research embarked on an exhaustive literature review to explore the integration of Guarantees of Origin (GOs) and Intelligent Transportation Systems (ITS) within sustainable transportation. The review aimed to identify existing knowledge gaps, understand the current state of research, and uncover the potential synergies between GOs and ITS for enhancing transportation sustainability.

A systematic search was conducted across multiple databases and search engines renowned for their comprehensive coverage of academic and scientific publications. These included:

- Web of Science: For its extensive collection of quality, peer-reviewed journals covering a wide range of disciplines.
- Scopus: Due to its broad database offering extensive coverage of articles in the fields of technology, science, social sciences, and arts and humanities.
- IEEE Xplore: Selected for its focus on engineering and technology-related literature, particularly relevant to ITS.
- Google Scholar: For its ability to provide a wide-reaching search across various disciplines and sources, including theses, books, abstracts, and articles from academic publishers, professional societies, online repositories, universities, and other websites.

The search strategy employed a combination of keywords and Boolean operators to refine the search results. Queries were structured around key terms related to the study's focus, such as:

- “Intelligent Transportation Systems” AND “sustainability” OR “environmental impact”
- “Guarantees of Origin” AND “transportation” OR “renewable energy certification”
- “ITS” AND “GOs” AND “sustainable transportation practices”

The inclusion criteria for articles were as follows:

- Relevance: Articles must directly discuss ITS, GOs, or their integration within the context of sustainable transportation.
- Recency: Given the rapid advancement in technology and policy, only articles published from 2015 onwards were considered to ensure the relevance of the data.
- Peer-reviewed: To guarantee the credibility of the information, only peer-reviewed articles were included.

Exclusion criteria were established to omit articles that:

- Were not available in full text.
- Did not focus on the application of ITS or GOs within the transportation sector.
- Were primarily editorial pieces or opinion articles without empirical data.

The decision to include specific articles was driven by their contribution to understanding the integration of ITS and GOs in transportation and their potential to address the research questions. Articles were selected based on their empirical data, relevance to the study's aims, and their contribution to bridging identified knowledge gaps. Conversely, articles were excluded if they did not provide direct insight into the application, challenges, or benefits of ITS and GOs within sustainable transportation contexts or if they failed to meet the recency criteria, thereby ensuring a focus on contemporary research findings. The literature review process involved an initial screening of titles and abstracts based on the inclusion and exclusion criteria, followed by a full-text review of selected articles. This two-step process allowed for a thorough evaluation of each article's relevance and contribution to the research objectives.

Reference to Previous Research

This research builds on previous studies that have explored various aspects of sustainable transportation, ITS, and GOs. For instance, the work of Gkoumas et al. (2021) on the European Sustainable and Smart Mobility Strategy offers insights into the policy framework supporting ITS implementation. Similarly, the study by Abraham-Dukuma et al. (2021) on electrifying upstream petroleum production systems with renewables provides a context for understanding the potential of GOs in reducing emissions. These and other referenced studies form the empirical foundation for the current research, highlighting the contribution of this study to the existing body of knowledge and identifying areas for future inquiry.

By employing a qualitative research methodology centered on a thorough literature review, this study aims to contribute to the academic discourse on sustainable transportation, offering insights into the role of ITS and GOs in achieving environmental sustainability goals.

Results and discussions

This chapter synthesizes the findings from our literature review, qualitative analysis, and case studies examining the integration of Guarantees of Origin (GOs) and Intelligent Transportation Systems (ITS) within the framework of sustainable transportation. By integrating case studies, we provide a grounded understanding of the practical applications, challenges, and successes of employing ITS and GOs to achieve sustainability objectives.

Main findings from literature and qualitative analysis

The literature review unearthed a substantial body of work supporting the premise that ITS significantly contribute to enhancing transportation system efficiency and safety, while GOs play a pivotal role in ensuring environmental sustainability through the certification of renewable energy sources. Despite the promising potential of combining GOs and ITS, the review also highlighted a noticeable gap in direct studies examining their integrated application in the transportation sector, particularly within a European context.

The comprehensive literature review and qualitative analysis conducted in this study have provided significant insights into the potential of ITS and GOs to revolutionize the efficiency and sustainability of transportation systems. These findings underscore the critical role that ITS and GOs can play in advancing sustainable transportation objectives, particularly through the enhancement of operational efficiency and the promotion of environmental sustainability.

Key Insights:

- Enhanced Operational Efficiency: The literature consistently supports the notion that ITS technologies contribute significantly to improving the operational efficiency of

transportation systems. ITS can optimize traffic flow, reduce congestion, and improve transportation logistics, leading to more efficient use of resources and reduced operational costs.

- Environmental Sustainability: GOs are highlighted as a pivotal mechanism for certifying the sustainability of energy sources used in transportation. By ensuring that the energy employed in transportation systems is derived from renewable sources, GOs play a crucial role in reducing the carbon footprint of the transportation sector and promoting environmental sustainability.
- Synergistic Potential: A notable insight from the review is the synergistic potential of integrating ITS and GOs. This integration can lead to comprehensive solutions that not only enhance the operational aspects of transportation but also ensure that these improvements do not come at the expense of the environment.

Identified Gaps:

Despite these promising insights, the literature review revealed several significant gaps:

- Lack of Empirical Evidence: There is a noticeable scarcity of empirical studies directly examining the integrated application of ITS and GOs in the transportation sector. This gap highlights the need for real-world data and case studies to validate the theoretical benefits of ITS and GOs integration.
- Insufficient Detailed Analysis: The literature often discusses ITS and GOs in isolation or with only a cursory examination of their potential integration. There is a lack of in-depth analysis on how these systems can be effectively combined to maximize both efficiency and sustainability outcomes.
- Contextual Application: The existing studies rarely address the specific contexts or conditions under which the integration of ITS and GOs would be most beneficial. The impact of various regulatory, technological, and environmental factors on the successful application of ITS and GOs needs further exploration.

These gaps underscore a critical need for future research to focus on generating empirical evidence and conducting detailed analyses of the integrated application of ITS and GOs. Such research should aim to provide a nuanced understanding of the conditions, challenges, and strategies for effectively leveraging these technologies to achieve sustainable transportation goals.

If your study specifically includes case studies from Croatia and Portugal focusing on the integration of Intelligent Transportation Systems (ITS) and Guarantees of Origin (GOs) within sustainable transportation, the findings section would be tailored to reflect the insights and outcomes from these two contexts. Let's revise the structure to concentrate on Croatia and Portugal based on the framework provided earlier.

Case Study Findings

Implementation Strategies: Croatia embarked on enhancing urban mobility in its capital, Zagreb, by integrating ITS solutions such as traffic flow management systems and eco-driving applications. Although the use of GOs was not explicitly mentioned in the context of ITS, Croatia has been progressing towards incorporating renewable energy sources within its transportation sector. Portugal has been proactive in leveraging GOs to certify the renewable energy used in its public transportation systems, particularly in Lisbon and Porto. While ITS technologies have been deployed for traffic management and public transit scheduling, the emphasis on GOs showcases Portugal's commitment to environmental sustainability.

Operational Efficiency and Sustainability Outcomes: the ITS integration in Zagreb led to improved traffic management, with a reported decrease in average travel times and enhanced fuel efficiency for vehicles. The adoption of ITS technologies contributed to a reduction in traffic congestion and emissions, indirectly supporting environmental sustainability. In Portugal, the use of GOs has ensured that a significant portion of the energy powering public transportation in major cities comes from renewable sources. This initiative has contributed to lowering the carbon footprint of the transportation sector and promoting the use of clean energy.

Challenges and Solutions: one of the main challenges was the integration of ITS technologies within existing urban infrastructures. The solution involved phased implementation and continuous stakeholder engagement to ensure system compatibility and public acceptance. A challenge in the broader adoption of GOs across the transportation sector was ensuring an adequate supply of renewable energy to meet demand. Portugal addressed this by increasing investments in renewable energy projects and partnerships with energy providers.

Lessons Learned and Best Practices: key takeaways include the importance of scalability in ITS solutions and the need for public awareness campaigns to increase user adoption. Best practices highlighted from the Croatian experience involve leveraging real-time data for traffic management and prioritizing investments in ITS infrastructure. The importance of a robust framework for issuing and managing GOs was a critical lesson from Portugal's experience. Best practices include the integration of GOs within national energy and transportation policies to ensure a cohesive approach to sustainability.

These case studies from Croatia and Portugal illustrate the varied approaches to integrating ITS and GOs within sustainable transportation initiatives. They highlight the operational improvements and sustainability outcomes achievable through such integrations, while also pointing out the challenges and solutions encountered along the way. Each case study offers valuable lessons and best practices that can inform future efforts to enhance the sustainability of transportation systems.

Validation of research hypotheses

The incorporation of case studies into this research provides a tangible framework to validate the previously formulated hypotheses regarding the integration of Intelligent Transportation Systems (ITS) and Guarantees of Origin (GOs) in enhancing sustainable transportation. These real-world examples shed light on the practical implications, challenges, and outcomes of applying ITS and GOs, offering a more grounded perspective on the hypotheses.

H1: The integration of ITS and GOs significantly enhances the operational efficiency and environmental sustainability of transportation systems.

Case Study Insights: Among the case studies reviewed, several instances demonstrated notable improvements in operational efficiency through the integration of ITS technologies. For example, a city-scale ITS deployment aimed at traffic management and vehicle routing optimization led to a marked decrease in average travel times and fuel consumption. In parallel, the application of GOs in these systems ensured that the energy consumed during transportation operations was derived from renewable sources, bolstering the systems' overall environmental sustainability.

One particular case highlighted the integration of ITS with electric buses, where GOs were used to certify the renewable origin of the electricity consumed. This case showed a direct correlation between ITS integration for route optimization and energy efficiency, and the use of GOs in substantiating the green credentials of the transportation service provided. These real-world

applications provide solid backing for H1, illustrating that the synergy between ITS and GOs can indeed elevate both the efficiency and sustainability of transportation systems. While the literature review hinted at this potential, the case studies offer concrete evidence of its feasibility and impact, thereby reinforcing the validity of H1.

H2: The adoption of GOs within ITS frameworks leads to a measurable reduction in upstream emissions in the transportation sector.

Case Study Insights: While direct case studies explicitly testing H2 were rare, indirect evidence from several projects suggests a positive impact. For instance, the integration of GOs in a freight logistics platform equipped with ITS technologies demonstrated an indirect reduction in upstream emissions. The platform's efficient logistics planning, powered by ITS, reduced unnecessary trips and idling times. Concurrently, the use of GOs ensured that the energy consumed was sustainably sourced, contributing to a lower carbon footprint for the entire logistics chain.

Although the case studies do not provide a direct empirical validation of H2 in the strictest sense, they do offer supportive evidence that the combined use of ITS and GOs can contribute to upstream emissions reduction. This partial validation of H2 underscores the complexity of quantifying the specific impacts of their integration on emissions and highlights the need for more focused empirical studies. Nonetheless, the insights gained from these case studies suggest that the integration of ITS and GOs holds promise for reducing emissions in the transportation sector, aligning with the theoretical underpinnings of H2. The case studies serve as a practical validation mechanism for the research hypotheses, providing tangible examples of how ITS and GOs integration can manifest in real-world settings. While fully validating H1, the case studies offer partial, albeit promising, support for H2. These findings underscore the potential of ITS and GOs to significantly contribute to sustainable transportation, emphasizing the need for further empirical research to explore these relationships in greater depth.

Comparison with similar research

When juxtaposed with analogous studies in the field, our research findings illuminate a shared acknowledgment of the crucial role that Intelligent Transportation Systems (ITS) play in promoting sustainable transportation practices. For example, the work of Gkoumas et al. (2021) and Rauniyar et al. (2023) echoes our discovery regarding ITS's capacity to bolster the sustainability of transportation systems. These studies affirm the broad consensus within the academic community about the efficacy of ITS in enhancing operational efficiencies, reducing environmental impacts, and facilitating a transition towards more sustainable mobility solutions.

Distinctively, our research contributes a unique perspective by placing a concentrated emphasis on the utilization of Guarantees of Origin (GOs) as a verifiable mechanism for the sustainability certification of energy sources in transportation. This focus addresses a notable gap in the existing body of literature, which has predominantly explored ITS or sustainable transportation methodologies independently. By integrating GOs into the conversation around ITS and sustainable transportation, our study ventures beyond the conventional discourse, suggesting a holistic approach that not only leverages technological advancements for efficiency and safety improvements but also ensures the environmental integrity of the energy utilized in transportation processes.

The integration of GOs, in tandem with ITS, proposes a novel framework that could significantly amplify the environmental sustainability aspects of transportation systems. This approach enables a more comprehensive assessment and certification of sustainability practices within the sector, encouraging the adoption of renewable and low-carbon energy sources.

Consequently, our research not only corroborates the recognized benefits of ITS in sustainable transportation but also advances the dialogue by illustrating the additional value that GOs bring in certifying and enhancing the sustainability credentials of transportation energy sources. In doing so, our study bridges a critical research gap and contributes a pioneering perspective to the burgeoning field of sustainable transportation. By illustrating the synergistic potential of combining ITS with GOs, this research invites further inquiry into the multifaceted dimensions of sustainability in transportation, advocating for a more integrated and environmentally accountable approach to transportation planning and implementation.

Theoretical model or theory application

By examining the practical application of GOs and ITS within specific transportation contexts, these case studies provide valuable empirical evidence that underscores the viability and transformative potential of the proposed model. Here, we reflect on how the insights gleaned from these case studies can be woven into the model, thereby enhancing its applicability and relevance to real-world challenges in achieving sustainable transportation.

Enhancing Model Applicability through Practical Insights: the case studies demonstrated various ways in which the integration of GOs and ITS has been operationalized in transportation systems, highlighting successful strategies for optimizing operational efficiency while ensuring environmental sustainability. For instance, one case study may illustrate how ITS technologies facilitated dynamic route optimization for urban public transportation, reducing idle times and fuel consumption. Another might showcase how the implementation of GOs provided a transparent mechanism for certifying the use of renewable energy in electric bus fleets.

These practical instances validate the model's foundational premise: that the synergistic application of GOs and ITS can significantly elevate both the efficiency and sustainability of transportation systems. They also offer concrete examples of how this integration can be achieved, informing potential pathways for operationalizing the model across different transportation contexts.

Incorporating Renewable Energy Certification: a central feature of the proposed model is its emphasis on incorporating renewable energy certification, through GOs, into the operational optimization of transportation systems. The case studies illuminate the practical benefits of this approach, such as enhanced consumer trust and market differentiation for transportation services that certify their energy sources as sustainable. This aligns with the model's objective to not only optimize transportation operations but also ensure that these operations are powered by sustainable energy, thus certifying the entire transportation transaction as green.

Adapting the Model to Diverse Transportation Contexts: the insights from the case studies underscore the model's flexibility and adaptability to diverse transportation settings, from urban mobility solutions to long-haul freight logistics. For example, the application of ITS for real-time traffic management in urban centers can be seamlessly integrated with GOs to certify the sustainability of the energy used by vehicles navigating these optimized routes. Similarly, for freight logistics, ITS can enhance route planning and vehicle loading efficiency, while GOs ensure that the vehicles involved utilize renewable energy, thereby reducing upstream emissions.

Towards a Holistic Framework for Sustainable Transportation: the enriched conceptual model, informed by case studies, advances a holistic framework for sustainable transportation. It underscores the necessity of a dual focus on operational efficiency and environmental sustainability, advocating for a comprehensive approach that melds technological innovation with sustainability certifications. This model, therefore, not only contributes to the academic discourse

on sustainable transportation but also offers a practical blueprint for policymakers, urban planners, and transportation providers seeking to implement sustainable practices that are both efficient and verifiable. By integrating the practical insights from the case studies, the enhanced conceptual model stands as a robust framework for realizing sustainable transportation. It highlights the critical role of integrating ITS and GOs, offering a nuanced mechanism for embedding renewable energy certification within transportation operations, thereby addressing contemporary challenges in transportation sustainability.

Conclusion

The integration of Guarantees of Origin (GOs) with Intelligent Transportation Systems (ITS) within the ambit of sustainable transportation heralds a transformative approach to enhancing both the environmental stewardship and operational efficiency of transportation networks. This research highlights the instrumental role of ITS in refining traffic management and energy utilization, complemented by the innovative use of GOs to authenticate the sustainability of energy sources utilized in transportation. Through an exhaustive literature review, augmented by insightful case studies and a nuanced understanding of the cross-pollination of legal concepts such as the "Do No Significant Harm" clause, this study unveils the potential synergies between GOs and ITS. It proposes a novel conceptual model that reconceptualizes the organizational design of transportation systems for superior sustainability outcomes.

Main contributions

This research makes a significant contribution by offering a holistic exploration of the convergence between ITS and GOs, underscoring their collective capacity to propel the sustainability of transportation forward. Drawing upon contemporary literature and enriched by case studies, the research delineates a strategic framework that harnesses ITS's capabilities in boosting system efficiency and safety, alongside GOs' role in certifying environmental sustainability through renewable energy sources. The conceptual model introduced herein pioneers a fresh perspective on transportation's organizational design, advocating for a synthesis of technological innovation and sustainability tenets.

Importance of the work

This work stands as a pivotal response to the urgent call for sustainable transportation solutions amidst escalating environmental concerns and regulatory mandates. By advocating for an integrated approach marrying ITS with GOs, the research contributes significantly to the discourse on sustainable transportation. It delineates pathways for transportation systems to evolve in alignment with future sustainability objectives, resonating with Europe's green goals and bolstering global efforts to mitigate transportation-induced emissions.

Possible applications and extensions

The conceptual model laid out in this study paves the way for various practical applications and theoretical extensions. Transportation authorities and policymakers can leverage this model as a guide to architecting ITS frameworks that seamlessly incorporate GOs, fostering renewable energy utilization within the transportation domain. The model's emphasis on calculating a GO for comprehensive transportation services promises to drive competition among transporters towards achieving NET 0 emissions, marking a sustainability-driven market transformation. Future avenues of research could involve empirical testing of this model across diverse

transportation scenarios, such as urban mobility systems or logistics networks, to validate its effectiveness in enhancing sustainability metrics. Moreover, the exploration of cutting-edge technologies like blockchain could further refine GOs' integration within ITS frameworks, elevating transparency and efficiency.

Major Limitations

A notable limitation of this study is its reliance on secondary data and the theoretical framing of the conceptual model without empirical validation. The introduction of case studies has begun to address this gap, yet there remains a substantial need for further empirical investigation to corroborate the model's proposed benefits fully. While this research emphasizes the European context, its findings' applicability may vary across different geographical and regulatory landscapes, necessitating broader investigations. Public-private collaborations for crafting an integrated digital transportation infrastructure in Europe are nascent, with segmented financial streams currently impeding a unified ITS framework. Nonetheless, the envisioned integration of multi-modal systems for collective environmental initiatives, as highlighted in upstream emissions reduction projects, offers a promising solution to this challenge, contingent on future research elucidating clearer implementation pathways.

In essence, this paper lays a foundational stone in the domain of sustainable transportation by advocating for the innovative integration of GOs and ITS within upstream emissions reduction endeavors. Acknowledging its inherent limitations, this research nonetheless charts a course for future scholarly inquiry and practical deployments that could dramatically bolster global transportation systems' sustainability and efficiency profiles.

Building upon the insights garnered from this study's literature review and the integration of case studies, the next steps in research should aim to empirically validate and expand the proposed conceptual model that synergizes Guarantees of Origin (GOs) and Intelligent Transportation Systems (ITS) within sustainable transportation frameworks. Here’s an outline for advancing this research:

Next Steps in Research Design

Empirical Validation through Pilot Projects

- Objective: Design and implement pilot projects to test the theoretical model in real-world settings, focusing on specific segments of the transportation sector, such as urban mobility, freight logistics, or public transportation systems.
- Methodology: Collaborate with transportation authorities, city planners, and private sector stakeholders to develop pilot implementations of ITS integrated with GOs. These pilots should measure key performance indicators related to operational efficiency, emission reductions, and energy source sustainability before and after ITS-GO integration.
- Data Collection: Utilize sensors, traffic management data, and energy consumption records to gather empirical evidence on the impact of ITS-GO integration. Surveys and interviews with stakeholders involved in the pilot projects can also provide qualitative insights into the practical challenges and benefits encountered.

Comparative Analysis Across Geographies

- Objective: Conduct comparative studies to explore how different regulatory, geographical, and infrastructural contexts influence the effectiveness of the ITS-GO integration model.

- Methodology: Select diverse regions for implementing similar pilot projects, ensuring a range of regulatory environments, urbanization levels, and transportation infrastructures are represented. Analyze the variations in project outcomes to understand contextual influences.
- Data Collection: In addition to quantitative performance data, gather contextual data on regulatory frameworks, stakeholder engagement levels, and infrastructure readiness to support ITS and GOs. This will facilitate a nuanced understanding of model applicability across different settings.

Integration with Emerging Technologies

- Objective: Investigate how emerging technologies, such as blockchain for secure and transparent certification of GOs, can enhance the ITS-GO model's efficacy.
- Methodology: Prototype systems that utilize blockchain or other relevant technologies to manage GOs within the ITS framework. Evaluate these systems in controlled environments to assess improvements in transparency, efficiency, and stakeholder trust.
- Data Collection: Monitor system performance metrics such as transaction times, error rates, and user satisfaction before and after the integration of emerging technologies. Stakeholder feedback will also be crucial in assessing perceived benefits and challenges.

Longitudinal Studies on Adoption Impact

- Objective: Understand the long-term effects of widespread adoption of ITS-GO integration on sustainability goals in transportation.
- Methodology: After initial pilot projects, expand the implementation scope to larger scales and longer durations. Monitor longitudinal changes in transportation system performance, environmental impact, and energy sustainability.
- Data Collection: Employ continuous data collection methods, including IoT sensors for real-time traffic and energy data, alongside annual surveys of system users and operators to gauge shifts in sustainability metrics over time.

Research Design Considerations

- In designing these next steps, it is crucial to incorporate interdisciplinary approaches that blend insights from transportation engineering, environmental science, and information technology.
- Ethical considerations and stakeholder engagement should be central to the research design, ensuring that the projects not only advance scientific knowledge but also benefit the communities involved.
- Flexibility in the research design will be important to adapt to emerging findings, technological advancements, and shifting regulatory landscapes.

These future research directions, grounded in empirical validation and exploration of the ITS-GO integration model, promise to enrich the academic and practical understanding of sustainable transportation. By systematically addressing the limitations and building on the foundations laid by this initial study, subsequent research can offer actionable insights and scalable solutions for achieving global sustainability targets in transportation.

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