

Can electric buses encourage greater public transport use? The role of the green halo effect[☆]

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ABSTRACT

The electrification of urban bus fleets is widely promoted as a strategy to reduce emissions and enhance the sustainability of public transport systems. Beyond environmental benefits, electric buses may also influence user perceptions and travel behavior. This study investigates how the introduction of electric buses in Thessaloniki affects both actual public transport usage and intentions to increase future use, adopting a holistic approach that considers both users and non-users. Building on existing electric bus adoption models, we extend the Theory of Planned Behavior (TPB) by introducing the green halo effect, capturing the positive spillover of electric bus deployment on the overall image of public transport. The framework also incorporates green self-identity, attitudes, social norms, and satisfaction-related perceptions. Data were collected through an online survey of Thessaloniki residents (N = 474), including both electric bus users (N = 323) and non-users (N = 151). For users, the model examines changes in usage frequency, while for non-users it analyzes intentions to adopt public transport. Structural Equation Modeling (SEM) is applied to test relationships among psychological constructs and behavioral outcomes, complemented by Necessary Condition Analysis (NCA) to identify critical limiting factors for intended modal shift. Results indicate that for current users, physical ride quality is a necessary condition for satisfaction, while the green halo effect independently increases usage frequency. For non-users, exploratory findings suggest that the green halo effect emerges as the strongest model-based predictor and primary limiting factor for future adoption within this sample, overriding general attitudes toward public transport. These findings highlight the potential of fleet electrification to act as a facilitator for behavioral change regarding increasing public transport use.

1. Introduction

Urban mobility is fundamental to societal well-being, yet the transportation sector remains a persistent contributor to global greenhouse gas (GHG) emissions and environmental degradation (Lamb et al., 2021). Rapid urbanization and continued reliance on private vehicles have intensified travel demand, making transport a central driver of climate change and underscoring the urgent need to decouple mobility from carbon emissions (Lanzini & Khan, 2017). While public transport is widely promoted as a sustainable alternative to private car use, conventional diesel bus fleets remain a major source of localized air pollution. Operating in dense urban areas, these heavy-duty vehicles emit substantial nitrogen oxides (NOx) and fine particulate matter (PM_{2.5}), contributing to public health risks and environmental

inequalities. Transitioning urban bus fleets to zero-emission technologies is therefore not only a climate imperative but also a public health priority (Correa et al., 2019).

In response, governments worldwide have adopted ambitious transport decarbonization strategies. China has led the global transition through strong national subsidies and coordinated industrial policy (IEA, 2024), while European cities are rapidly integrating zero-emission buses to modernize public transport infrastructure (Li et al., 2019; Iliopoulou & Kepaptsoglou, 2019). At the policy level, the European Green Deal and the Clean Vehicles Directive mandate substantial zero-emission procurement targets by 2030. Despite this momentum, internal combustion buses still dominate European fleets, highlighting the scale of renewal required (ACEA, 2025). Technological maturity and declining battery costs have further accelerated the global diffusion of

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battery electric buses (BEBs). By late 2023, the global electric bus stock had reached approximately 635,000 units (IEA, 2024). Electrically chargeable buses accounted for nearly 16% of new registrations in the European Union in 2023, with countries such as the Netherlands and Denmark leading the shift toward zero-emission fleets (ACEA, 2025). European metropolitan authorities increasingly monitor electrification progress as part of broader sustainability transitions (EMTA, 2025). Yet deployment remains geographically uneven, with China accounting for over 90% of the world's electric buses, while other regions are still in earlier phases of scaling (Li et al., 2019).

Although the technological and environmental case for electrification is well established, a crucial question remains insufficiently explored: does the introduction of electric buses influence public transport use itself? Electrification may enhance service quality perceptions through reduced noise, smoother rides, and improved environmental image, potentially strengthening public transport's attractiveness. However, whether such improvements translate into measurable behavioral change, rather than merely positive perceptions, remains unclear.

Within the emerging field of behavioral transit research, most empirical studies focus on adoption intentions, examining how environmental attitudes and psychological constructs shape willingness to use electric transit (Nguyen & Pojani, 2023; Herrenkind et al., 2019; Flaris et al., 2023). Extensions of the TPB have incorporated constructs such as environmental concern and green self-identity to explain sustainable mobility choices (Flaris et al., 2023; Chen & Chao, 2011). However, electrification is typically treated as a service attribute rather than as a potential catalyst for broader behavioral transformation. Furthermore, the literature remains fragmented. Some studies focus exclusively on current public transport users, examining satisfaction and retention (Thilakshan et al., 2024), while others target potential adopters, such as private car users, to assess modal shift intentions (Sunitiyoso et al., 2022; Flaris et al., 2023). Previous literature has largely treated users and non-users in isolation, primarily due to the lack of simultaneous, large-scale deployments that allow for direct, localized comparisons of retention versus initial adoption. This separation limits understanding of how electrification may reshape public transport behavior at a system-wide level.

Existing research on bus electrification has also concentrated predominantly on technological performance (Skarlis et al., 2025; Tian et al., 2025; Pan et al., 2026; Lou et al., 2026) and environmental impacts (Dulce et al., 2024; Sunitiyoso et al., 2022; Lee et al., 2023; Ji et al., 2026), with comparatively less attention to behavioral mechanisms. Critically, limited evidence exists on whether electric bus deployment leads to self-reported, sustained changes in public transport usage frequency, as opposed to merely objective ridership logs. Moreover, while psychological drivers have been explored, reputational spillover mechanisms remain largely unexamined. While temporary novelty effects frequently accompany new transit deployments, sustained behavioral shifts require deeper cognitive alignment. In particular, the concept of the green halo effect, whereby environmentally friendly innovations enhance the broader image of a service, has not been systematically investigated in the context of public transport electrification (Sörqvist et al., 2013; Lee et al., 2013). Understanding whether electric buses improve the overall perception of public transport, and whether such reputational gains influence behavior, constitutes a significant research gap.

Against this backdrop, the present study examines how the introduction of electric buses in Thessaloniki influences both actual public transport usage frequency and intentions to increase future use. Building on an extended TPB framework, the study incorporates green self-identity, attitudes, social norms, satisfaction-related perceptions, and the green halo effect. Using SEM and survey data from both electric bus users and non-users, the analysis disentangles the psychological mechanisms linking fleet electrification to behavioral outcomes. This study makes three principal contributions. First, it advances sustainable

transport research by moving beyond intention-based models and explicitly examining self-reported behavioral change in usage frequency. Second, it introduces and operationalizes the green halo effect within public transport electrification, extending behavioral theory through the incorporation of a reputational spillover mechanism. Third, by jointly analyzing users and non-users within a unified theoretical framework, the study provides a holistic assessment of how electric bus deployment may function not only as a technological innovation but also as a facilitator for behavioral change supporting broader urban mobility transitions.

2. Literature review and theoretical background

2.1. Public transport electrification and users' perceptions

Research has consistently highlighted the environmental benefits of BEBs, specifically their ability to eliminate tailpipe emissions and significantly reduce life-cycle greenhouse gas emissions compared to diesel and compressed natural gas alternatives (Dulce et al., 2024; J. Lee et al., 2023; Ji et al., 2026). Recent life-cycle assessments have further quantified these gains, emphasizing that the decarbonization potential of BEBs is maximized when integrated with renewable energy sources (Zhang et al., 2024; Zhou et al., 2016). Beyond these macro-level benefits, electrification fundamentally alters the micro-level passenger experience. Early investigations into user perceptions indicate that passengers perceive BEBs as superior to conventional buses due to reduced noise levels and the absence of engine vibrations, which directly enhances on-board comfort and convenience (Sunitiyoso et al., 2022).

However, a balanced assessment must also acknowledge the potential disadvantages and implementation challenges associated with electrification. Operationally, public transport networks face significant hurdles regarding charging infrastructure requirements, depot capacity upgrades, and route scheduling adaptations due to battery range limitations (Li et al., 2019)(Thorne et al., 2021). Furthermore, from a passenger perspective, the physical integration of large battery systems can sometimes compromise vehicle interior layouts and accessibility (Gao et al., 2017). Additionally, while the electric powertrain generally offers a quieter ride, the high instant torque of electric motors can lead to abrupt acceleration and deceleration patterns. If not carefully managed by operators, this dynamic behavior can reduce ride comfort and present safety challenges, particularly for standing or mobility-impaired passengers (Miles & Potter, 2014).

Despite these physical advantages, the widespread adoption of electric public transport is influenced by a complex array of psychological and service-related factors. Previous studies utilizing behavioral frameworks have shown that while environmental concern acts as a significant motivator, adoption intentions are often moderated by perceived service quality, reliability and the availability of infrastructure (Thorne et al., 2021; Nguyen & Pojani, 2023). However, much of this research has treated electrification as a secondary service attribute rather than a core driver of behavioral change. While technical studies focus on energy efficiency, charging logistics and state-of-charge prediction (Skarlis et al., 2025; Tian et al., 2025; Lou et al., 2026), there remains a critical need to understand how these technological shifts translate into long-term changes in passenger loyalty and actual usage frequency.

2.2. Theory of Planned Behavior in public transport research

TPB remains the most widely applied framework for understanding pro-environmental travel choices (Ajzen, 1991). According to this model, an individual's intention to perform a specific behavior, such as choosing public transport over a private car, is determined by three core constructs: attitudes toward the behavior, subjective norms and perceived behavioral control. In the context of sustainable transport, attitudes often reflect the balance between personal convenience and

environmental values, while subjective norms capture the perceived social pressure to adopt green travel modes (Lanzini & Khan, 2017; Donald et al., 2014).

Building on this foundational model, extensive research has applied extended versions of the TPB specifically to evaluate conventional public transport ridership. For instance, integrated models combining the TPB with customer satisfaction and personal norm theories have been utilized to explain transit users' word-of-mouth behaviors (Yuda Bakti et al., 2020). Similarly, researchers have expanded the TPB to include perceived value and corporate image to better explain passengers' intentions to reuse public transport (Sumaedi et al., 2016). Other exploratory studies have demonstrated the model's flexibility by incorporating spatiotemporal variables and lifestyle factors (Hartieni et al., 2024), as well as applying TPB extensions to assess localized behavioral intentions, such as the willingness to use public transport in specific geographic contexts like Kanazawa, Japan (Ali et al., 2023).

Transitioning from conventional transit to electrified fleets, recent studies have sought to increase the explanatory power of the TPB by incorporating additional constructs strictly tailored to the nuances of electric buses. For instance, green self-identity, the extent to which an individual sees themselves as an environmentally friendly person, has been found to significantly strengthen the link between attitudes and intentions specifically regarding the use of electric buses (Chen & Chao, 2011; Humagain et al., 2024). Furthermore, environmental concern and personal moral norms have been integrated to understand the altruistic motives driving public acceptance of both standard and autonomous electric buses, including insights drawn from medium-sized cities in emerging economies (Herrenkind et al., 2019; Ganga et al., 2025). Crucially, recent literature extending the TPB framework to evaluate transit bus electrification, specifically by incorporating green self-identity, normative needs, and electric bus comfort attributes, has provided vital insights into how these psychological factors interact to predict behavioral intentions (Humagain et al., 2024). This specific framework heavily assisted in defining the theoretical hypotheses of the present research. However, while these extended models have successfully predicted general electric vehicle adoption intentions over time (Moras et al., 2024), they have rarely been applied to measure actual post-implementation behavioral changes. Specifically, the literature still lacks a unified framework that simultaneously analyzes both current electric bus users and potential adopters to evaluate self-reported increases in overall public transport usage frequency.

To clearly position the contribution of the present study within the wider literature, Table 1 provides a summary of recent key studies examining user and non-user perceptions of electric buses, highlighting their methodological focus and target groups.

2.3. The green halo effect

The green halo effect refers to a cognitive bias where the eco-friendly nature of a product or service leads consumers to perceive its other, unrelated attributes more favorably (Sörqvist et al., 2013). Originating from broader marketing and environmental psychology research, the effect suggests that green labels can create a positive spillover, improving the perceived quality, performance and even the comfort of a service (Lee et al., 2013).

Recently, the role of cognitive biases has gained significant traction in transportation research, demonstrating that subjective perceptions often override objective service metrics. For instance, recent surveys have established how various cognitive biases fundamentally shape mobility choices and dictate public responses to urban transport policies (Adam, 2026). Furthermore, the specific manifestation of the halo effect has been empirically observed in complex transport infrastructure environments; for example, in airport terminals, positive initial experiences such as efficient wayfinding can create a halo effect that significantly enhances passengers' perceived reliability and even their emergency preparedness (Zhang et al., 2025). While extensively

Table 1
Summary of recent studies examining perceptions of electric buses.

Study	Context	Target Group	Key Theoretical Constructs	Primary Behavioral Outcome
Herrenkind et al. (2019)	Autonomous electric buses (Germany)	General Public / Potential Adopters	TPB, Norm Activation Model, Environmental Concern	Intention to adopt
Sunitiyoso et al. (2022)	E-bus deployment (Indonesia)	General Public	Perceived Quality, Environmental Perceptions	Acceptance & Willingness to Use
Flaris et al. (2023)	E-bus deployment (Utah, USA)	Transit Riders	Environmental Concern, Green Self-Identity	Willingness to Pay / Use
Humagain et al. (2024)	General transit usage (USA)	General Public	TPB, Green Identity, Comfort Attributes	General Transit Usage Intentions
Current Study	E-bus deployment (Thessaloniki, Greece)	Current Users & Non-Users	TPB, Green Halo Effect, Physical Comfort	Intended usage changes (Users) & Adoption intentions (Non-Users)

documented in marketing and physical infrastructure, the operationalization of the Green Halo Effect within dynamic transit environments, where mobility choices are habitual, represents a novel application of this cognitive bias.

In the public transport sector, this implies that the introduction of electric buses may do more than just reduce emissions; it may improve the overall brand image of the municipal transport authority and the perceived quality of the entire network. This reputational spillover is particularly relevant in cities where public transport is often perceived as a mode of last resort. The deployment of BEBs acts as a visible symbol of modernization and environmental stewardship, potentially triggering a halo effect that makes passengers more tolerant of service delays or more appreciative of the interior environment. Psychological mechanisms of this bias suggest that the positive ecological profile of the vehicle acts as a heuristic for overall service excellence (Ninikala K., 2024).

Despite its potential to act as a behavioral catalyst, the green halo effect has not been systematically operationalized within a TPB framework to examine its influence on transport mode choice. Recognizing these gaps, it is necessary to construct a theoretical model that bridges traditional TPB constructs with emerging psychological biases related to green technologies.

3. Theoretical framework

Building upon the theoretical foundations established in the previous sections, this chapter outlines the structural model developed to test the behavioral impacts of electric bus deployment. To address the existing limitations in the literature, specifically the fragmentation between user retention and non-user adoption, this study adopts a holistic approach that considers both current users and potential non-users.

The analytical logic of this research is grounded in the “Identity-Halo-Behavior” nexus, representing a significant extension of the classic TPB. Rather than viewing the transition to electric buses merely as a functional upgrade, this framework explores how tangible engineering improvements interact with psychological triggers. The theoretical framework bridges the established TPB constructs with both physical ride evaluations (Comfort Attributes) and the Green Halo Effect (GHE), a cognitive bias where the eco-friendly label of the vehicle creates a halo of overall quality. To account for the different stages of technological

adoption and accurately map these relationships, two distinct theoretical models are proposed (Fig. 1 and Fig. 2).

Within the extended TPB framework, an individual's self-perception plays a fundamental role in shaping their subsequent evaluation of green technologies. GSI represents the subject, an internal characteristic that exists prior to the interaction with the electric bus. While we acknowledge the potential for bidirectionality, where frequent use of green transit might retroactively inflate self-reported environmentalism, we operationalize GSI as a baseline psychological trait that precedes the immediate evaluation of a newly introduced technology. Previous applications of self-identity in sustainable mobility have established that high levels of environmental consciousness act as a baseline that strengthens pro-environmental attitudes and heightens the perceived social pressure to adopt green behaviors (Chen & Chao, 2011). Furthermore, recent literature has demonstrated that green identity serves as a powerful predictor in behavioral models, directly influencing how users formulate their attitudes toward zero-emission transit and their subjective norms (Flaris et al., 2023; Humagain et al., 2024). In our framework, we suggest that GSI also fundamentally shapes the Green Halo Effect, as individuals with stronger environmental identities are more likely to project positive cognitive biases onto eco-friendly services, aligning with the altruistic motives seen in public acceptance of sustainable transit (Ganga et al., 2025). Crucially, we hypothesize that this environmental identity also creates a sensory priming effect, where eco-conscious riders physically perceive the BEB Comfort Attributes (BCA), such as noise and vibration, more favorably. Because GSI acts as a foundational psychological trait, the relationships originating from it remain structurally identical across both the user and non-user pathways. Building on these theoretical perspectives, we propose the following hypotheses:

- H1a: Green Self-Identity positively influences the Green Halo Effect.
- H1b: Green Self-Identity positively influences Attitude.
- H1c: Green Self-Identity positively influences BEB Comfort Attributes.
- H1d: Green Self-Identity positively influences Social Norms.

The core of the classic TPB asserts that behavioral choices are driven by personal evaluations (Attitudes) and perceived social pressures (Subjective Norms) (Ajzen, 1991). However, current literature increasingly acknowledges that the TPB operates as an open framework, requiring the addition of supplementary factors to fully capture complex human decision-making (Ajzen, 2020; Zulkapeli et al., 2024). Driven by this theoretical consensus, we augment the classic TPB pathways with the GHE. In this extended framework, we operationalize how the physical and psychological dimensions of the electric bus shape user evaluation. Rather than relying on the ecological label to influence satisfaction, we propose that the actual engineering improvements, specifically the BCA, act as the primary determinant of a passenger's experiential evaluation. It is crucial to distinguish between BCA, which capture the objective sensory improvements of an electric vehicle (e.g.,

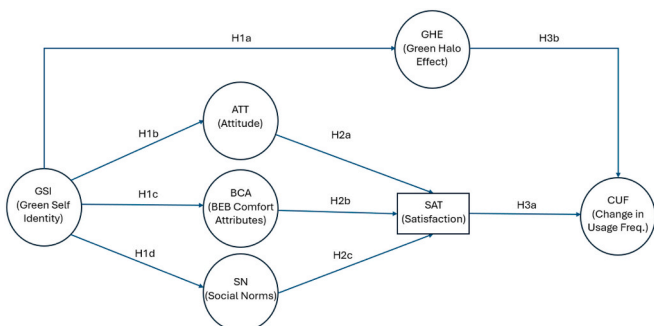


Fig. 1. Theoretical framework for the electric buses users group.

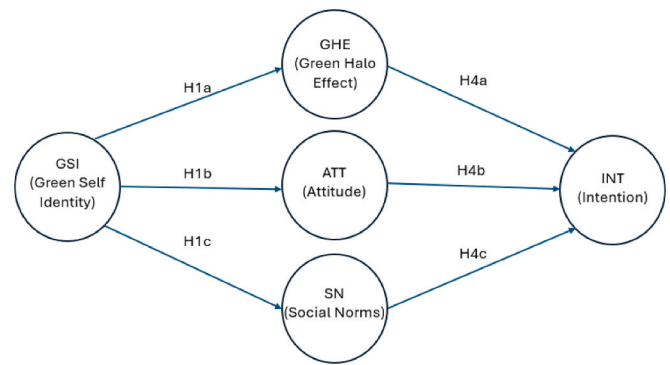


Fig. 2. Theoretical framework for the electric buses non-users group.

lower decibels), and the GHE, which captures the subjective spillover of quality onto unrelated service aspects. Extensive transport literature confirms that tangible ride quality factors, such as reduced noise, lower vibration, and smooth acceleration, are dominant predictors of overall transit satisfaction (Lai & Chen, 2011). Furthermore, prior behavioral studies indicate that preexisting positive attitudes and strong social validation can significantly elevate the perceived quality of a transit service (Donald et al., 2014). When integrated with personal evaluations (Attitudes) and perceived social pressures (Social Norms), these constructs form the core of the transit experience. In light of these behavioral mechanisms, we propose the following hypotheses for the users' group:

- H2a: Attitude positively influences overall Satisfaction.
- H2b: BEB Comfort Attributes positively influence overall Satisfaction.
- H2c: Social Norms positively influence overall Satisfaction.

Conversely, for non-users who lack direct physical experience with the electric fleet, these constructs project a favorable expectation onto the technology. Extensive research highlights that perceived value, corporate image and subjective norms strongly dictate passengers' intentions to use public transport (Sumaedi et al., 2016; Ali et al., 2023). Furthermore, subjective perceptions and cognitive biases frequently override objective service metrics when individuals form their mobility choices (Adam, 2026). This projected image, combined with general attitudes and social influences, serves as a recruitment mechanism that directly encourages a broader intended modal shift, shaping their overall public transport usage (Herrenkind et al., 2019; Moras et al., 2024). Guided by these findings, we propose the following hypotheses for the non-users group:

- H4a. The Green Halo Effect positively influences Intended Public Transport Usage.
- H4b. Attitude positively influences Intended Public Transport Usage.
- H4c. Subjective Norms positively influence Intended Public Transport Usage.

For the user pathway, understanding the final behavioral outcome requires moving beyond theoretical intentions and evaluating self-reported changes in actual transit habits. Exploratory studies incorporating lifestyle and spatiotemporal factors emphasize the need to measure actual, sustained public transport use (Hartieni et al., 2024). In public transport research, satisfaction is widely recognized as the primary mediator for passenger retention and loyalty (de Oña, 2021). However, we propose that the introduction of zero-emission fleets creates a parallel psychological pathway. We hypothesize that the Green Halo Effect (GHE) acts as an independent facilitator for behavioral change; the modern, eco-friendly image of the bus strongly encourages users to ride public transport more frequently, regardless of their

physical satisfaction. Consequently, we propose the following hypotheses:

- H3a: Overall Satisfaction positively influences the Change in Usage Frequency.
- H3b: The Green Halo Effect positively influences the Change in Usage Frequency.

4. Description of the case study

Thessaloniki, Greece's second largest urban agglomeration, is a major economic and commercial hub with a metropolitan population exceeding 1.09 million and a regional GDP of €16 billion (ELSTAT, 2021). The city's morphology is highly constrained, bordered by the Thermaic Gulf to the south and mountainous terrain to the north. This geography has produced a dense, linear urban core, with the central municipality reaching 16,525 residents per square kilometer.

Thessaloniki was selected to participate in the European Commission's "100 Climate-Neutral and Smart Cities by 2030" mission, committing through its Climate City Contract to reduce projected greenhouse gas emissions within municipal boundaries by at least 80% by 2030 (Municipality of Thessaloniki, 2023). Urban transport accounts for approximately 23% of local emissions (Municipality of Thessaloniki, 2023), positioning mobility transformation at the center of the decarbonization agenda. Also, Thessaloniki's Sustainable Urban Mobility Plan (2019) sets an ambitious goal of increasing public transport's modal share from 32% to over 39% by the end of the decade.

A pivotal milestone in this transition was the inauguration of Metro Line 1 on November 30, 2024. The 9.6-kilometer, fully automated underground system, comprising 13 stations, is designed to carry nearly 20,000 passengers per hour in each direction, offering a faster alternative to road transport (European Commission, 2026). However, the metro alone cannot achieve the required modal shift. Its effectiveness depends on seamless integration with the surface network, particularly through multimodal hubs.

Within this integrated framework, the electrification of the surface bus network has emerged as a cornerstone of Thessaloniki's mobility transition. In May 2024, the city deployed an initial fleet of 110 electric buses, marking the most substantial modernization of the bus system in decades. These vehicles were strategically assigned to areas with distinct environmental and operational priorities. In the western part of the city, areas are characterized by industrial activity and elevated concentrations of particulate matter and nitrogen oxides (Karakoltzidis et al., 2025), zero-emission buses directly mitigate pollution at source.

Beyond environmental gains, the new fleet plays a critical operational role. Electric buses function as high-efficiency lateral feeders, connecting peripheral neighborhoods to metro terminals and multimodal hubs, thereby discouraging private car entry into the urban core. Because these electric buses predominantly replaced older diesel units on existing routes rather than establishing entirely new network topologies, changes in user frequency can be more confidently attributed to the technological upgrade rather than spatial alterations. However, it is important to note that this technological upgrade inherently involved the introduction of brand-new vehicles. Consequently, the electrification was accompanied by upgraded, modern interiors and improved climate control systems, which inevitably factor into the overall perceptual shift of both users and non-users. Supported by advanced charging infrastructure, the buses offer an operational autonomy of up to 300 kilometers, comfortably meeting daily service requirements.

Importantly, this rollout represents only the first phase of a comprehensive fleet transformation. As of early 2025, an additional 100 electric buses are undergoing registration and are scheduled to enter suburban service beginning of summer 2026 under a transitional operating contract. A further tender for 50 articulated electric buses is expected to expand capacity within 2026. The city's long-term objective is the full electrification of its 335-vehicle urban bus fleet. Taken together,

the introduction and planned expansion of electric buses positions fleet electrification not merely as a technological upgrade, but as a systemic intervention designed to improve air quality, enhance service attractiveness, and support the broader modal shift required for Thessaloniki's climate-neutral transition.

5. Data collection and analysis approach

To address the research objectives, a comprehensive questionnaire was designed to investigate the psychological drivers of public transport adoption and usage frequency. To effectively capture the perceptions of different passenger segments, the survey utilized two parallel pathways: one for current users and one for non-users of the newly introduced electric buses. The questionnaire was structured into four distinct thematic sections, as detailed below.

5.1. Survey design

The survey instruments were developed based on a comprehensive review of established behavioral scales, specifically adapted for the context of public transport electrification in Thessaloniki.

Part 1 - Socioeconomic Characteristics and Mobility Profiles: This initial section collected fundamental data on the respondents' age group, gender and annual individual income. A critical functional element of this part was the assessment of car ownership status and accessibility. Most importantly, this section contained the primary filtering question. This item served as a conditional branching mechanism that governed the dynamic flow of the questionnaire. This ensured that while all participants answered the shared psychological modules with only minor contextual phrasing adjustments, the final section was fully customized and users were directed to feedback on physical experiences and actual behavioral changes, while non-users were directed to intention-based adoption items.

Part 2 - Psychological Constructs and Social Influences: This section operationalized the core behavioral components of the research through standardized perceptual items. It measured the GSI of the respondents, capturing dimensions of environmental concern, personal energy footprint and the felt moral obligation to protect the environment. Additionally, this part evaluated the Attitude (ATT) toward bus usage, focusing on perceived utility and pleasantness and the Subjective Norms (SN), which assessed the perceived social pressure or approval from family and friends regarding the choice of public transport.

Part 3 - Perception of the GHE: This section introduced the primary innovative element of the research. The GHE was conceptualized as a cognitive bias where the eco-friendly "label" of the electric buses positively spills over onto other, theoretically unrelated attributes. Respondents assessed whether they perceived the zero-emission fleet as offering superior overall quality or symbolizing urban modernity purely due to its green technology. Items in this section specifically measured the "forgiveness factor" or tolerance of the passengers; specifically, whether they were willing to overlook minor service failures, such as delays or crowding, based on the knowledge that the vehicle is non-polluting.

Part 4 - Experience, Satisfaction and Behavioral Intentions: The final section of the questionnaire diverged based on the user profile established in Part 1. For the user group, the module focused on evaluating specific comfort attributes (BCA), such as noise levels and ride smoothness, alongside overall satisfaction (SAT). Users also stated their intention to change their usage frequency (CUF), including potential modal shifts from private vehicles and their likelihood of providing positive word-of-mouth recommendations. Conversely, the non-user group was presented with an alternative module measuring their overall willingness to try the electric bus in the future (INT) and their specific preference for electric vehicles over conventional diesel buses. It is important to note that non-users were not provided with photographs or technical specifications of the new vehicles prior to answering; this

deliberate omission ensured that the survey captured their organic, unprompted perceptions of the fleet based purely on existing public awareness and the general green label.

The measurement items for the latent constructs were adapted from established behavioral scales in transport and environmental psychology (e.g., Sparks & Shepherd, 1992; Hausteine & Hunecke, 2007; de Oña, 2021) to fit the specific context of public transport electrification, as detailed in Table 2.

A consistent 5-point Likert scale (Likert, 1932) was utilized throughout the questionnaire for all modules involving subjective assessment. This 5-point format was selected to minimize respondent cognitive load during the online survey while maintaining sufficient variance and providing a distinct neutral midpoint, consistent with standard practices in transport psychology studies. This approach ensured statistical comparability across the diverse psychological and behavioral constructs. Respondents were asked to indicate their level of agreement with each statement, with the scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

5.2. Data collection

Data collection commenced on February 2026 and continued through March, 2026. The survey was hosted on the EU Survey platform (EU Survey), the official online survey management system of the European Commission. This platform was specifically selected due to its ability to enable a strictly anonymous response mode, ensuring full compliance with the General Data Protection Regulation (GDPR).

Dissemination was carried out digitally through a multi-channel approach, including targeted social media campaigns and advertisements on local digital news portals. Participation was completely voluntary, and no financial incentives were offered to respondents to minimize self-selection bias. The study protocol and data processing procedures were reviewed and approved by the institutional Data Protection Officer (DPO), conducted within the framework of the UPPER project. The survey strictly adhered to the General Data Protection Regulation (GDPR - 2016/679/EU) and national legislation (Law 4624/2019), with the EU Survey platform ensuring full anonymity and data security. Through this process, a total of 474 valid responses were collected.

5.3. Structural equation modeling approach

To investigate the underlying predictors of public transport usage frequency and adoption intentions, SEM was adopted as the primary analytical technique. SEM is a powerful multivariate approach increasingly preferred in transport research, as it moves beyond traditional regression analysis to explore the complex interplay between unobserved latent constructs and observed variables. This methodology is particularly advantageous for behavioral research because it allows for the simultaneous analysis of multiple direct, indirect, and mediated effects while specifically accounting for measurement error, thereby providing highly robust estimations of theoretical frameworks (Golob, 2003; Hair et al., 2010). All SEM analyses were conducted using the lavaan package (Rosseel, 2012) in the R statistical environment (R Core Team, 2025).

The modeling process followed the rigorous two-step approach recommended by Anderson and Gerbing (Anderson & Gerbing, 1988). First, Confirmatory Factor Analysis (CFA) was conducted to evaluate the measurement model, ensuring strict construct validity, reliability, and the appropriate loading of individual survey items onto their respective latent factors. Second, the structural model was fitted to map the structural pathways and test the formal hypotheses. Given the behavioral nature of the 5-point Likert scale data, which frequently deviates from strict multivariate normality, models were estimated using the Robust Maximum Likelihood (MLR) estimator (Finney & DiStefano, 2013). MLR provides robust standard errors and a scaled test statistic,

Table 2
Measurement items and variables.

Construct	Source	Question	Target Group	Code
Green Self-Identity (GSI)	(Sparks & Shepherd, 1992)	I am deeply concerned about the environmental impact of travel.	Both	GS11
		I consider it important to reduce my personal energy footprint.	Both	GS12
	(Flaris et al., 2023)	I feel a personal moral responsibility to protect the environment.	Both	GS13
		I consider myself a person who chooses “green” mobility solutions.	Both	GS14
Attitude (ATT)	(Chen & Chao, 2011)	Generally, I consider commuting by bus to be the right choice for me.	Both	ATT1
	(Flaris et al., 2023)	I find using the bus as a means of transport pleasant.	Both	ATT2
		Using the bus is beneficial for my daily commutes.	Both	ATT3
Subjective Norms (SN)	(Flaris et al., 2023)	People who are important to me think I should use the bus.	Both	SN1
		My social environment generally encourages the use of Public Transport.	Both	SN2
		Most of my friends or colleagues would agree with my choice to use the bus.	Both	SN3
Green Halo Effect (GHE)	(Sörqvist et al., 2013)	I believe electric buses offer a better experience due to eco-friendliness.	Both	GHE1
		The use of electric buses makes the city appear more modern.	Both	GHE2
	(Lee et al., 2013)	I am willing to overlook minor delays, knowing the vehicle does not pollute.	Both	GHE3
		I have a more positive image of the electric bus compared to conventional buses.	Both	GHE4
BEB Comfort Attributes (BCA)	(Flaris et al., 2023)	The noise level and comfort are excellent.	Users	BCA1
		The movement of the vehicle is smooth and reliable.	Users	BCA2
		The interior is comfortable and I feel safe during the commute.	Users	BCA3
Satisfaction (SAT)	(Flaris et al., 2023)	Overall, I am very satisfied with the experience of the electric bus.	Users	SAT1
Usage Change (CUF)	(Flaris et al., 2023)	I intend to use Public Transport more often now.	Users	CUF1
	(de Oña, 2021)	I would prefer the electric bus instead of a private car or taxi.	Users	CUF2
		I would unreservedly recommend the use of the electric bus to others.	Users	CUF3
Intention (INT)	(Flaris et al., 2023)	I am willing to try the electric bus in the immediate future.	Non-Users	INT1

(continued on next page)

Table 2 (continued)

Construct	Source	Question	Target Group	Code
	(Haustein & Hunecke, 2007)	If I had the choice, I would prefer an electric bus over a conventional one.	Non-Users	INT2
		It is very likely that I will use an electric bus in the coming months.	Non-Users	INT3

ensuring that the significance levels of the structural paths remain highly reliable.

Model fit was evaluated using a combination of absolute and incremental goodness-of-fit indices. The primary metrics included the normed Chi-square ratio (χ^2/df), the Robust Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). Traditional thresholds dictate that a χ^2/df ratio <3.0 , CFI and TLI values ≥ 0.90 , and RMSEA and SRMR values <0.08 indicate an acceptable model fit.

Finally, to complement the SEM framework, which identifies factors that are sufficient to encourage behavior or increase probabilities, an NCA was deployed (Dul, 2016). While SEM operates on a compensatory logic, meaning a low score in one predictive variable can be statistically offset or “compensated” by a high score in another to still produce a positive outcome, NCA operates on a strict bottleneck logic (Dul, 2016). It mathematically evaluates whether a specific behavioral outcome is practically impossible to achieve without a minimum required level of a precursor variable. NCA was executed using latent factor scores extracted from the finalized SEM frameworks, using the regression scoring method within the lavaan package, calculating effect sizes (d) via the Ceiling Envelopment with Free Disposal Hull (CE-FDH) technique. According to standard NCA guidelines, an effect size $d \geq 0.10$ denotes a practically significant necessary condition, while an effect size $d \geq 0.30$ represents a substantial limiting factor, providing critical operational insights into foundational requirements for intended behavioral change.

6. Results

6.1. Descriptive statistics

The survey yielded a total of 474 valid responses from residents across the Thessaloniki metropolitan area. The dataset reflects a diverse cross-section of the city's commuting population. In terms of gender, the sample consisted of 57.6% male and 41.8% female respondents (with 0.6% identifying as other or preferring not to answer). The age distribution successfully captured a wide range of active commuters: the largest segment consisted of adults aged 26–35 (32.3%), followed by the 36–45 demographic (17.9%) and the 18–25 demographic (17.1%). Adults aged 46–55 accounted for 16.9%, while residents over 55 made up the remaining 15.8%.

When compared to the broader demographic profile of the Thessaloniki metropolitan area based on the 2021 national census (ELSTAT, 2021), certain divergences are observed. Specifically, males are over-represented in the survey sample (57.6% versus approximately 48% in the general regional population). Furthermore, the sample skews heavily toward younger and middle-aged cohorts, with the 26–35 age group being particularly prominent. Conversely, older residents, notably those over 65 years old (6.1% of the sample), are significantly under-represented, given that this demographic constitutes over 22% of the national and regional population. This underrepresentation of older adults is a well-documented limitation of digitally disseminated surveys and indicates that the current findings predominantly reflect the perceptions and behavioral intentions of the active, technologically

engaged commuting population.

It is important to note that while sociodemographic and mobility characteristics (such as age, gender, income, and private vehicle access) were initially considered during the preliminary modeling phase to account for potential background effects, their integration did not significantly improve the overall model fit. Furthermore, their inclusion did not alter the fundamental significance or direction of the primary theoretical pathways. Therefore, to maintain model parsimony and ensure the analytical focus remained strictly on the core psychological and perceptual mechanisms driving behavioral change, these socio-demographic variables were ultimately excluded from the final structural equation models.

Financially, the sample represented a broad economic spectrum. Approximately 21.5% of respondents reported an annual individual income below €10,000, while 34.2% reported earning between €10,001 and €20,000. A notable portion of the sample reported higher incomes, with 19.0% earning between €20,001 and €30,000, and 15.2% exceeding €30,000 (10.1% preferred not to disclose their income). Interestingly, despite this diverse income distribution, private vehicle access was notably high; a strong majority (73.0%) of the total sample reported having direct access to a private car or motorcycle. This high rate of vehicle access is highly relevant to the study, as it indicates that the majority of respondents are “choice riders” who actively weigh the decision between driving and shifting to public transport.

Crucially for the holistic analytical framework of this study, the primary filtering question, “Have you used the new electric buses in the last six months?”, was used to partition the dataset into two highly robust behavioral segments. It is important to note that this filtering question assessed any physical exposure to the new fleet rather than strict habituation. As detailed in Table 3, the Users' group represents a spectrum of riding frequencies, ranging from daily commuters (14.6%) to those who rarely ride (37.8% combined). Therefore, this group captures anyone who has formed a physical, experiential evaluation of the

Table 3

Sociodemographic profile of the sample (N = 474).

Characteristics	Frequency (N)	Percentage (%)
Gender		
Male	273	57.6 %
Female	198	41.8 %
Other	2	0.4 %
Prefer not to say	1	0.2 %
Age group		
18–25	81	17.1 %
26–35	153	32.3 %
36–45	85	17.9 %
46–55	80	16.9 %
56–65	46	9.7 %
>65	29	6.1 %
Annual individual income		
0—5,000€	68	14.3 %
5,001—10,000€	34	7.2 %
10,001—15,000€	87	18.4 %
15,001—20,000€	75	15.8 %
20,001—30,000€	90	19.0 %
>30,000€	72	15.2 %
Prefer not to say	48	10.1 %
Private vehicle access		
Yes	346	73.0 %
No	128	27.0 %
E-bus usage in last 6 months		
Yes	323	68.1 %
No	151	31.9 %
Frequency of E-Bus Usage (Users Only)		
Sometimes	92	28.5 %
Rarely	75	23.2 %
Often	62	19.2 %
Daily	47	14.6 %
Very rarely	47	14.6 %

electric buses. The majority of the sample (N=323, 68.1%) identified as current users of the electric buses, forming the basis for the Retention Mechanism model. The remaining respondents (N=151, 31.9%) were classified as non-users, providing a robust, statistically viable group for testing the Expectation Paradigm. The complete sociodemographic profile of the sample is shown in Table 3.

To evaluate the distributional properties of the collected data prior to structural modeling, descriptive statistics were calculated for all measurement items across both groups (Table 4). As shown, mean scores indicate a strong baseline of environmental consciousness (GSI) across both groups. More importantly, the skewness and kurtosis values for all variables fall strictly within the recommended thresholds for multivariate analysis (absolute skewness <2.0 and absolute kurtosis <7.0). This confirms that the data does not severely deviate from normal distribution, fully justifying the deployment of the Robust Maximum Likelihood (MLR) estimator in the subsequent analytical phases.

A preliminary review of the 5-point Likert scale items revealed strong foundational dispositions toward sustainable transit across both groups. Notably, indicators for GSI scored highly across the total sample, suggesting an environmentally conscious baseline among Thessaloniki residents. For the current user group, initial evaluations of the actual BCA, such as ride smoothness and noise reduction, skewed overwhelmingly positive, foreshadowing the profound impact of physical engineering upgrades on passenger satisfaction. Conversely, among non-users, behavioral intentions skewed cautiously optimistic, indicating that while the population is receptive, the transition from passive observation to active ridership remains highly dependent on external perceptions.

(Note: Items marked with a dash (-) were not evaluated by that specific group due to the study's logical framework. Items GHE3 and INT3 were permanently excluded during the CFA refinement process to maximize construct validity. Item SN2 was permanently excluded from both models to ensure strict structural symmetry. Their descriptive statistics are retained here solely for preliminary observation prior to structural modeling.)

6.2. Measurement model validity and structural evaluation

Prior to evaluating the structural paths, the measurement models for both groups were assessed for internal consistency, construct reliability and convergent validity (Table 5). The majority of the latent constructs,

Table 5

Construct validity and reliability metrics (Users and Non-Users).

Latent Construct	Group	Cronbach's Alpha (α)	Composite Reliability (CR)	Average Variance Extracted (AVE)
Green Self-Identity (GSI)	Users	0.823	0.825	0.543
	Non-Users	0.818	0.836	0.571
Attitude (ATT)	Users	0.752	0.755	0.507
	Non-Users	0.821	0.816	0.599
Social Norms (SN)	Users	0.634	0.660	0.503
	Non-Users	0.688	0.681	0.517
Green Halo (GHE)	Users	0.815	0.813	0.591
	Non-Users	0.879	0.882	0.714
BEB Comfort Attributes (BCA)	Users	0.816	0.753	0.555
Intention to Use (INT)	Non-Users	0.672	0.677	0.515
Change in Usage (CUF)	Users	0.817	0.813	0.593

including Green Self-Identity, Attitude, the Green Halo Effect, Physical Comfort, and Change in Usage, demonstrated robust performance, meeting or exceeding the recommended thresholds for Cronbach's Alpha (> 0.70), Composite Reliability (CR > 0.70), and Average Variance Extracted (AVE > 0.50).

The SN and INT constructs initially presented marginal convergent validity. To ensure strict structural symmetry and maximize statistical rigor, underperforming items (specifically SN2 and INT3) were permanently trimmed from both groups. Following this specification, the Average Variance Extracted (AVE) for all constructs across both models successfully surpassed the strict 0.50 threshold, completely resolving the initial convergent validity threats. While the reduction to two-item constructs caused the Cronbach's Alpha and Composite Reliability (CR) for SN to marginally dip below 0.70 (Alpha = 0.634, CR = 0.660), values above 0.60 are widely accepted as adequate in behavioral research for two-item scales, given that alpha is highly sensitive to the number of items (Hair et al., 2010). Furthermore, because these two-

Table 4

Descriptive statistics and normality assessment of measurement items.

Latent Construct	Item	Users (N = 323)				Non-Users (N = 151)			
		Mean	SD	Skew	Kurtosis	Mean	SD	Skew	Kurtosis
Green Self-Identity	GSI1	3.508	0.979	-0.477	0.053	3.391	1.052	-0.618	-0.083
	GSI2	3.780	0.967	-0.782	0.490	3.675	1.068	-1.029	0.662
	GSI3	3.879	0.930	-0.823	0.628	3.808	0.950	-0.771	0.494
	GSI4	3.533	0.998	-0.295	-0.428	3.020	1.128	0.017	-0.653
Attitude	ATT1	3.548	1.022	-0.582	-0.071	3.603	1.020	-0.464	-0.250
	ATT2	2.604	1.152	0.227	-0.755	3.172	1.258	-0.244	-1.071
	ATT3	3.189	1.133	-0.386	-0.737	2.596	1.287	0.404	-0.981
Social Norms	SN1	2.768	1.042	0.160	-0.333	2.735	1.024	0.024	-0.491
	SN2*	2.718	1.005	0.144	-0.431	2.821	1.155	0.014	-0.900
	SN3	2.864	0.965	0.005	-0.271	3.053	1.031	-0.214	-0.280
Expected Green Halo	GHE1	3.830	0.961	-0.827	0.469	4.093	0.897	-1.006	0.932
	GHE2	4.062	0.924	-1.112	1.200	4.212	0.884	-1.227	1.518
	GHE3*	2.740	1.156	0.215	-0.808	4.007	0.913	-0.849	0.734
	GHE4	4.015	0.951	-0.939	0.621	4.040	0.958	-0.936	0.584
Physical Comfort	BCA1	4.068	0.861	-0.771	0.322	-	-	-	-
	BCA2	3.740	1.003	-0.642	-0.155	-	-	-	-
	BCA3	3.604	1.002	-0.442	-0.267	-	-	-	-
Satisfaction	SAT	3.675	1.017	-0.558	-0.073	-	-	-	-
Change in Usage	CUF1	3.146	1.013	-0.096	-0.274	-	-	-	-
	CUF2	3.690	1.135	-0.645	-0.416	-	-	-	-
	CUF3	3.628	1.008	-0.515	-0.098	-	-	-	-
Intention to Use	INT1	-	-	-	-	3.874	1.015	-0.888	0.439
	INT2	-	-	-	-	4.325	0.813	-1.315	2.237
	INT3*	-	-	-	-	3.152	1.237	-0.120	-0.946

item constructs are embedded within a larger structural model with ample degrees of freedom, they are empirically identified (Bollen, 1989). Therefore, the refined measurement models provide a highly robust foundation for structural estimation. Additionally, it should be noted that overall Satisfaction (SAT) was operationalized as a single-item global indicator. Because specific ride attributes were already comprehensively captured via the BCA construct, a single global item was utilized to minimize respondent burden. Consequently, standard internal consistency metrics (Alpha, CR, AVE) are not mathematically applicable to SAT, and its measurement error variance was constrained during estimation.

Building upon the analytical framework established in Section 5.3, the structural models were iteratively developed to capture the complex behavioral dynamics of transit electrification. For both groups, a comprehensive a priori model, incorporating all hypothesized theoretical links, was initially tested. Subsequently, specific measurement items and structural pathways were evaluated and respecified based on their standardized factor loadings, modification indices, and statistical significance.

To prevent overfitting and ensure the generalizability of the findings to unseen data, the final model selection process prioritized the optimization of the established Goodness-of-Fit indices alongside the minimization of the Akaike Information Criterion (AIC) (Burnham & Anderson, 2002). Crucially, because psychological heuristics, such as the Green Halo Effect, function fundamentally differently depending on whether an individual has directly experienced the physical service, the analysis was operationalized through two distinct structural models. The first model evaluates the “Retention Mechanism” for current electric bus users, while the second evaluates the “Expectation Paradigm” (or Recruitment Mechanism) for non-users.

6.2.1. Modeling behavior change of e-buses users

The modeling process for the current electric bus users ($N=323$) was designed to test the “Retention Mechanism”. First, a baseline CFA was conducted encompassing all theoretical items. During this baseline evaluation, item GHE3 (“willingness to overlook delays due to zero emissions”) exhibited a weak standardized factor loading. This is likely because GHE3 measured behavioral tolerance (“willingness to overlook delays”) rather than a direct perceptual judgment of quality like the other GHE items, fracturing the construct’s internal consistency. To ensure strict construct validity, this item was also permanently removed. Following these trims, all remaining items exhibited strong, highly significant standardized factor loadings ranging from 0.578 to 0.889 ($p<0.001$).

Next, the a priori structural model (H1a–H3b) was fitted to the data. While the baseline framework fit reasonably well, a formal diagnostic review of the Modification Indices (MI) guided two critical data-driven refinements. First, theoretically justified covariances were added to account for shared variance. Specifically, a structural covariance between GHE and BCA was introduced to account for the simultaneous physical and psychological evaluation of the new technology, while an ATT $\leftrightarrow$ SN covariance captured the known interplay between personal and social evaluations. Measurement error covariances (BCA1 $\leftrightarrow$ BCA2 and ATT2 $\leftrightarrow$ BCA3) were added to resolve residual overlap from similarly worded survey items evaluating sensory comfort. Second, Modification Indices suggested a direct path from general Attitude to overall usage. Aligning with classic TPB theory, which posits that strong attitudes can directly predict behavior without requiring satisfaction as a strict mediator, this partial mediation path was integrated. Crucially, a comparative review confirmed the stability of the model: before applying these modifications, all primary hypothesized pathways were already statistically significant ($p < 0.05$), and their standardized path coefficients fluctuated marginally ($\Delta\beta < 0.05$) after respecification. This explicitly demonstrates that the core findings are robust and not merely artifacts of post-hoc tuning. The final respecified framework, mapping all adjusted pathways and structural relationships, is visually presented in

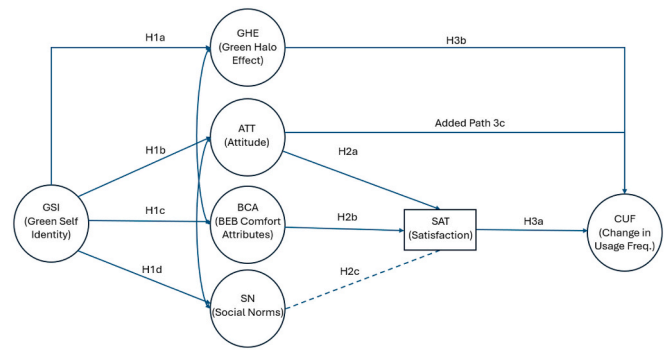


Fig. 3. Final respecified structural model for the electric buses users group.

Fig. 3. Within the diagram, continuous solid lines represent statistically significant structural paths, while the dashed line represents a hypothesized path that was rejected by the data.

Following these adjustments, the final model yielded excellent goodness-of-fit indices. The goodness-of-fit indices are detailed in Table 6, while a comprehensive summary of all standardized path coefficients is provided in Table 7.

The standardized path coefficients provide a profound narrative of user behavior. The results confirm that Green Self-Identity is a foundational predictor of the Green Halo bias ($\beta=0.392$, H1a), attitudes ($\beta=0.382$, H1b), and social norms ($\beta=0.327$, H1d). Furthermore, the hypothesized sensory priming effect was validated ($\beta=0.265$, H1c), proving that eco-conscious riders physically perceive the electric bus as smoother and quieter.

Interestingly, the model reveals that subjective social pressures have absolutely no significant influence on onboard evaluation ($\beta=-0.123$, $p=0.101$), leading to a non-statistically significant impact of H2c. This confirms that satisfaction is isolated from external social validation and is overwhelmingly dictated by actual engineering upgrades, such as the BEB Comfort Attributes ($\beta=0.895$, H2b), with a minor contribution from preexisting personal attitudes ($\beta=0.220$, H2a).

Finally, the behavioral outcomes highlight a triad of associated factors for increasing ridership. While physical satisfaction is strongly associated with broader public transport ridership ($\beta=0.214$, H3a), the partial mediation adjustment confirmed that general attitude acts as an even stronger direct behavioral facilitator ($\beta=0.482$, $p<0.001$, Added Path 3c). Crucially, the parallel psychological pathway was heavily supported: the Green Halo Effect acts as an independent, highly significant magnet for increased overall public transport usage ($\beta=0.411$, $p<0.001$, H3b). This confirms that electrification positively influences transit behavior through distinct channels: it provides functional comfort that satisfies users, while simultaneously projecting a green, modern image that attracts them to ride more frequently. A comprehensive summary of all tested structural paths, including their standardized estimates and significance levels, is detailed in Table 7.

While SEM effectively identifies the factors that drive or are sufficient for behavioral outcomes, it does not evaluate whether those factors are strict prerequisites. To provide a deeper methodological evaluation, an NCA was conducted (Dul, 2016) using the latent factor scores extracted from the finalized structural model. NCA identifies limiting factors in datasets, statistically demonstrating whether an outcome can

Table 6
Model goodness-of-fit indices – Users Group.

Fit Index	Baseline Model	Respecified Model	Threshold
χ^2/df	3.108	2.341	<3.0
CFI	0.869	0.943	>0.90
TLI	0.845	0.929	>0.90
RMSEA	0.087	0.060	<0.08
SRMR	0.135	0.072	<0.08

Table 7
Standardized Structural Paths – Users Group.

Hypothesis	Structural Path	Standardized Estimate (β)	Standard Error	z-value	p-value
H1a	Green Self-Identity (GSI) → Green Halo Effect (GHE)	0.392	0.074	5.277	< 0.001***
H1b	Green Self-Identity (GSI) → Attitude (ATT)	0.382	0.079	4.811	< 0.001***
H1c	Green Self-Identity (GSI) → BEB Comfort Attributes (BCA)	0.265	0.076	3.487	< 0.001***
H1d	Green Self-Identity (GSI) → Social Norms (SN)	0.327	0.088	3.699	< 0.001***
H2a	Attitude (ATT) → Satisfaction (SAT)	0.220	0.081	2.711	0.002**
H2b	BEB Comfort Attributes (BCA) → Satisfaction (SAT)	0.895	0.024	36.604	< 0.001***
H2c	Social Norms (SN) → Satisfaction (SAT)	-0.123	0.075	-1.638	0.101
H3a	Satisfaction (SAT) → Change in Usage (CUF)	0.214	0.081	2.622	0.008**
H3b	Green Halo Effect (GHE) → Change in Usage (CUF)	0.411	0.088	4.666	< 0.001***
Added Path 3c	Attitude (ATT) → Change in Usage (CUF)	0.482	0.056	8.579	< 0.001***

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

be achieved if a specific precursor is absent or scores poorly.

To evaluate the full theoretical sequence of the framework, the NCA was deployed in two distinct stages: first, to evaluate the necessary conditions for passenger Satisfaction, and second, to evaluate the predictors of Change in Usage Frequency.

The first stage of the analysis yielded profound insights into passenger evaluation. The results confirmed that actual physical comfort, specifically, the BCA, is a highly significant necessary condition for achieving high overall Satisfaction ($d=0.462$). Without a quiet, vibration-free, and smooth ride, it is mathematically impossible to maximize a passenger's satisfaction level. Conversely, general Attitude ($d=0.040$) and Social Norms ($d=0.000$) fell completely below the threshold of necessity. This indicates that while preexisting personal attitudes may positively contribute to satisfaction (as seen in the SEM path coefficients), they are not strictly required. A highly engineered, physically comfortable electric bus can still highly satisfy a rider who boarded with a neutral or skeptical attitude.

The second stage evaluated the final behavioral outcome: the self-reported modal shift towards using public transport more frequently (CUF). The Green Halo Effect emerged as the strongest necessary condition for triggering a broader self-reported modal shift toward public

transport ($d=0.238$), while general Attitude ($d=0.220$) emerged as a medium-strength necessary condition. Meanwhile, physical Satisfaction acted as a smaller, yet still significant, prerequisite ($d=0.127$).

The combination of these two stages provides a powerful narrative for public transport authorities. The findings mathematically demonstrate that transit operators cannot rely on one single dimension to boost ridership. A deficiency in a passenger's green perception (GHE), their underlying psychological attitude (ATT), or their physical ride evaluation (SAT) will act as a ceiling, completely restricting their overall public transport usage from reaching its maximum potential, regardless of how high the other variables score. Furthermore, because physical comfort (BCA) is a critical necessary condition for satisfaction, transit operators must ensure that the engineering reality of the bus matches its eco-friendly marketing; a green label cannot compensate for a noisy, uncomfortable ride.

6.2.2. Modeling e-buses non-users willingness to use public transport

The modeling process for the non-users group ($N=151$) was designed to test the “Expectation Paradigm”. Because this group lacks direct physical experience with the electric fleet, variables relating to onboard physical comfort (BCA) and post-ride satisfaction (SAT) were theoretically excluded. As established during the initial validity assessment (Section 6.2), items SN2, INT3, and GHE3 were excluded from the non-users measurement model to ensure strict statistical rigor and structural consistency. Following this specification, a CFA confirmed that all remaining items exhibited highly significant standardized factor loadings, yielding an excellent global model fit.

Next, the a priori structural model (comprising the non-user hypotheses H1a, H1b, H1d, and H4a-H4c) was fitted to the data. A formal diagnostic review of the Modification Indices (MI) guided the addition of theoretically justified covariances. A structural covariance between ATT and SN was retained, capturing the baseline correlation between personal beliefs and social influences; a standard phenomenon in intention-based models. Furthermore, an error covariance was added between items ATT2 and INT1 to resolve shared semantic variance, as both items prompt the respondent for a direct, personal evaluation of transit usage. As with the users' group, the model demonstrated excellent structural stability: prior to the inclusion of these covariances, all primary structural relationships were already statistically significant, with standardized path estimates changing by negligible margins ($\Delta\beta < 0.04$) post-respecification. This ensures the robustness of the theoretical pathways. The final respecified framework, mapping all adjusted pathways and structural relationships, is visually presented in Fig. 4. Consistent with the visual language of the previous model, continuous solid lines denote statistically significant structural relationships, whereas dashed lines indicate rejected hypotheses.

Following these adjustments, the final model yielded satisfactory goodness-of-fit indices. The goodness-of-fit indices are detailed in Table 8, while a comprehensive summary of all standardized path coefficients is provided in Table 9. Mildly elevated RMSEA and SRMR

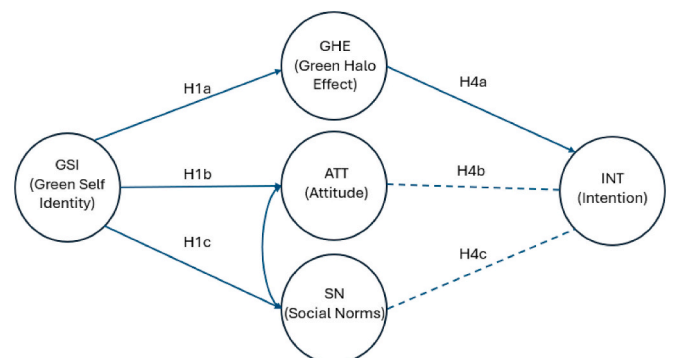


Fig. 4. Final respecified structural model for the electric buses non-users group.

Table 8

Model goodness-of-fit indices – Non-Users Group.

Fit Index	Baseline Model	Respecified Model	Threshold
χ^2/df	2.825	2.289	<3.0
CFI	0.834	0.932	>0.90
TLI	0.797	0.910	>0.90
RMSEA	0.119	0.085	<0.08
SRMR	0.130	0.100	<0.08

Table 9

Standardized Structural Paths – Non-Users Group.

Hypothesis	Structural Path	Standardized Estimate (β)	Standard Error	z-value	p-value
H1a	Green Self-Identity (GSI) → Green Halo Effect (GHE)	0.452	0.113	3.489	< 0.001***
H1b	Green Self-Identity (GSI) → Attitude (ATT)	0.495	0.112	3.764	< 0.001***
H1d	Green Self-Identity (GSI) → Social Norms (SN)	0.591	0.121	4.179	< 0.001***
H4a	Green Halo Effect (GHE) → Intention (INT)	0.961	0.049	19.701	< 0.001***
H4b	Attitude (ATT) → Intention (INT)	0.231	0.113	1.601	0.109
H4c	Social Norms (SN) → Intention (INT)	−0.227	0.125	−1.431	0.152

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

values are methodologically expected given the small sample size ($N=151$) combined with the hypothetical nature of the non-users group model but are highly defensible given the strong CFI and TLI scores (Kenny et al., 2015). Furthermore, an SRMR of 0.100 indicates some unmodeled variance, which is an expected limitation when modeling complex, hypothetical intentions for a group lacking direct experiential anchors.

The standardized path coefficients provide a clear narrative of the expectations of non-users. The results confirm that Green Self-Identity remains a powerful foundational predictor, significantly predicting general attitudes ($\beta=0.495$), susceptibility to social norms ($\beta=0.591$), and the expectation of a Green Halo Effect ($\beta=0.452$).

However, the evaluation of the final behavioral outcome revealed a primary enabling factor. The anticipated Green Halo Effect acted as the strongest significant predictor of Intended Public Transport Usage ($\beta=0.961$, $p<0.001$). In this optimized model, the direct influence of general Attitude became statistically insignificant ($\beta=0.231$, $p=0.109$), as did subjective Social Norms ($\beta=-0.227$, $p=0.152$). This highlights a profound theoretical insight: for individuals outside the transit network, preexisting general attitudes toward buses are insufficient to trigger a shift in behavior. Instead, the “green branding” and modern image of the electrified fleet act as the primary, dominant lever capable of attracting them into the system. A comprehensive summary of all tested structural paths, including their standardized estimates and significance levels, is detailed in Table 9.

To provide a deeper methodological evaluation, a single-stage NCA

was conducted using the latent factor scores extracted from the finalized non-user structural model. Because the non-users model does not include physical evaluation variables (BCA and SAT), this NCA solely evaluated the direct predictors of INT to identify any critical thresholds for intended modal shift.

The results perfectly corroborated the SEM findings, identifying the expected Green Halo Effect as a primary limiting factor ($d=0.490$). This substantial effect statistically indicates that if a non-user fails to perceive the new buses as an environmental and technological upgrade, it is practically impossible to trigger their intention to adopt public transit. Crucially, general Attitude ($d=0.066$) and Social Norms ($d=0.028$) completely failed to reach the necessity threshold ($d>0.10$).

The combination of the SEM and NCA results provides a striking contrast to the current users model. For non-riders, positive underlying attitudes cannot compensate for a lack of eco-modern appeal. This highlights the Green Halo Effect as a highly prominent predictor for non-users, making the electric (and fleet modernization) “halo” a highly critical necessary condition for expanding system-wide transit ridership.

7. Discussion

The primary objective of this study was to investigate how the electrification of an urban bus fleet influences public transport adoption. By extending the TPB with the GHE and GSI, and evaluating both current users and non-users through SEM and NCA, this research provides a comparative understanding of transit behavior.

The findings confirm that the predictors of modal shift differ fundamentally based on an individual's prior physical exposure to the electrified fleet. For both groups, GSI acts as a foundational predictor, shaping general attitudes, susceptibility to social norms, and the perception of the green halo. For current users, electrification produces a “sensory priming” effect, where eco-conscious riders physically evaluate the vehicle more positively. Their path to increased usage frequency is multifaceted, driven by underlying attitudes, physical satisfaction, and the psychological pull of the GHE. However, the NCA revealed a crucial boundary: actual physical comfort (BCA) is a critical necessary condition ($d=0.462$) for post-ride satisfaction. Conversely, for non-users within this sample, classic behavioral predictors (general ATT and SN) collapsed into insignificance. Instead, the anticipated GHE emerged as the strongest model-based predictor and a major limiting factor ($d=0.490$) for future adoption intentions. Given the modest subsample size, these non-user dynamics are appropriately designated as exploratory.

These theoretical insights translate into several critical, actionable implications for Public Transport Authorities (PTAs) and Public Transport Operators (PTOs). First, regarding passenger recruitment, the findings suggest a hypothesis for future pilot programs: PTAs could test leveraging the Green Halo Effect as a strategic rebranding tool. Because preexisting attitudes toward buses are often stigmatized among non-users, we hypothesize that traditional marketing campaigns emphasizing routes or service frequencies might struggle to encourage a modal shift. Instead, testing communication strategies that heavily spotlight the zero-emission, modern, and technologically advanced nature of the electric fleet could prove beneficial. By positioning the battery electric bus as a disruptive, premium urban service in targeted field experiments, authorities could systematically evaluate whether this approach successfully cuts through entrenched biases and fosters the psychological “halo” needed to attract habitual private car users.

Second, regarding operational strategy and passenger retention, PTOs must recognize that a green label cannot compensate for a poor physical ride. The NCA statistically demonstrated that physical comfort is a critical necessary condition for passenger satisfaction. Therefore, fleet maintenance protocols must fundamentally evolve. While operators typically focus on battery health, charging logistics, and powertrain efficiency, equal operational priority must be given to preserving the vehicle's superior dynamic qualities by suppressing cabin noise,

vibrations, and harshness (NVH). Additionally, PTOs should invest in specialized eco-driving and safety training for bus operators to manage the high instant torque of electric motors, ensuring smooth acceleration and deceleration. If an electric bus rattles or provides a jerky ride, the current passenger's satisfaction will hit a hard ceiling, neutralizing the behavioral benefits of electrification.

Finally, at the broader policy level, the physical deployment of electric buses offers an opportunity to test spatial visibility effects. Rather than isolating new electric fleets on low-ridership peripheral routes, authorities could design field experiments that prioritize deployment on highly visible, congested urban corridors where the contrast with conventional traffic is starkest. We hypothesize that this would maximize the fleet's exposure to non-users, potentially accelerating the expectation paradigm and reinforcing public transport's new identity. Ultimately, these suggestions, ranging from differentiated public awareness campaigns targeting the Green Halo Effect to strategic corridor deployments, serve as hypotheses derived from our behavioral models. Future research involving controlled pilot programs and field experiments is necessary to empirically validate these strategies and quantify their actual impacts on ridership.

This study is not without limitations. First, the cross-sectional nature of the survey data captures a specific snapshot in time, precluding strict causal inferences between psychological constructs and usage behaviors. Future research should employ longitudinal designs to track whether the Green Halo Effect decays as electric buses become normalized. Additionally, because the study evaluates the deployment of brand-new vehicles replacing an aging diesel fleet, it is difficult to entirely decouple the positive psychological impacts of electrification from a general "novelty effect" associated with modern interiors and improved amenities. Second, the relatively small sample size of the non-user group (N=151), combined with the self-selected online survey design, which inherently introduces a sampling bias toward younger and more technologically engaged demographics, and intention-based behavioral outcomes, suggests that the Expectation Paradigm findings should be interpreted as exploratory and must be validated with broader demographic samples in future studies. Finally, reliance on self-reported usage changes introduces potential recall bias; integrating objective transit smart-card data alongside psychological surveys would provide a more robust measure of actual behavioral shift. Furthermore, the reliance on a single-item indicator for overall satisfaction limits the ability to empirically capture its internal measurement error within the structural framework, which future studies could address by incorporating multi-item global satisfaction scales.

CRediT authorship contribution statement

Efstathios Triantafyllidis: Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Andreas Nikiforiadis:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Vasilina Klimi:** Writing – original draft, Formal analysis, Data curation. **Annie Kortsari:** Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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