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Electrifying urban mobility: Unveiling expert insights on electric quadricycles through topic modelling and sentiment analysis

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ABSTRACT

Electric quadricycles offer significant potential for enhancing sustainable urban mobility due to their compact design and efficiency. To effectively shape this sustainable future, it is vital to understand the associated trends and challenges. Accordingly, this study analysed expert reviews of 13 heavy and light electric quadricycles by implementing an advanced topic modelling approach to identify dominant themes and examined sentiment polarity across reviews using artificial intelligence. The study revealed eight key topics: design and technology, driving experience, urban mobility and acceptance, performance, battery and efficiency, pricing options, market and production, and classification and regulations. Additionally, the assessment quantified experts' positive and negative perceptions of specific elements within these topics. The findings indicate that (1) the majority of discussions focused on design and technology, (2) experts frequently appreciated spacious interiors, innovative swappable battery solutions, and agile and playful driving characteristics, (3) negative sentiments primarily pertained to safety, comfort, purchase price, and build quality, and (4) overall, experts held optimistic views regarding the role of electric quadricycles in urban mobility. These insights support a data-driven and user-centred approach to electric quadricycle design, assisting manufacturers and policymakers in advocating for electric quadricycles as practical solutions for sustainable urban mobility of the future.

1. Introduction

Urbanisation is accelerating globally, with 56 % of the world's population, approximately 4.4 billion people, now residing in urban areas [64]. This trend is projected to intensify, with forecasts indicating that nearly 70 % of the global population will inhabit cities by 2050. This rapid urban expansion generates significant challenges, including deteriorating air quality, excessive noise pollution, spatial constraints, and escalating traffic congestion. European cities exemplify these pressures, where traffic delays have exceeded pre-COVID levels in 42 % of urban centres. Drivers in major metropolitan areas such as London, Paris, and Rome now experience over 100 h of annual congestion-related delays[50].

The pervasive reliance on private vehicles in urban areas exacerbates these issues. Private cars are inherently space-intensive, demanding at least three times more room than public transit and ten times more than bicycles [45]. The problem is particularly acute for sport utility vehicles (SUVs), which need roughly 10 % more parking space than medium-sized cars. Moreover, the preference for larger and heavier vehicles is growing. According to the International Energy Agency [27], SUV sales reached about 20 million units in 2023, over half of the total market for the first time, and this preference is increasingly evident among electric vehicles (EVs) as well, with >55 % of new electric car registrations being SUVs. Paradoxically, as vehicle sizes grow, average car occupancy rates continue to decline. In European urban settings, car occupancy averages between a mere 1.20 and 1.90 individuals per trip [14].

Such a surge in larger, heavier, and less energy-efficient vehicles intensifies demand for oil, electricity, and critical minerals used in the production of batteries. Ultimately, this amplifies the environmental burden, as road transport already accounts for the largest share of transport-related greenhouse gas (GHG) emissions. In 2022, road transport in the EU accounted for 73.2 % of the sector's emissions, while urban mobility alone generated approximately 40 % of global carbon

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dioxide (CO_2) emissions from passenger transport [15]. This combination of underutilised vehicle capacity, short typical urban travel distances, and constrained urban space underscores an urgent need for more sustainable, compact, and efficient urban transport solutions. Despite measures such as high-occupancy vehicle (HOV) lanes and ride-sharing programmes, low-occupancy vehicles still account for a significant portion of short urban trips.

Electric quadricycles (hereinafter referred to as 'EQs') have emerged as a promising alternative, directly addressing many of the challenges in urban mobility. These vehicles blend the weather protection and cargo capacity of traditional cars with the compact footprint and energy efficiency characteristics of motorcycles. Within the European Union's L-category classification, EQs are categorised into L6e (light quadricycles, max. 45 km/h) and L7e (heavy quadricycles, up to 90 km/h). They can occupy as little as one-third of the space of a standard passenger vehicle and consume significantly less energy compared to other conventional electric cars. This inherent efficiency helps reduce the environmental burden of urban transport.

Despite their considerable potential to revolutionise urban transportation, academic research on EQs remains notably limited, predominantly focusing on technical aspects such as safety, performance, and ride comfort, with only a few studies addressing public perceptions and evaluation of the acceptance factors. This represents a critical gap, as successful technology adoption hinges not only on technical feasibility but also on user acceptance and market perception. While substantial research has explored public attitudes toward conventional electric vehicles and other micromobility options, the social dimensions of EQs adoption require further academic investigation. The limited number of public acceptance studies that exist face significant methodological challenges. Current research has predominantly relied on traditional methods such as surveys and interviews based on stated preferences, rather than analysing organic, user-generated content that reflects genuine experiences and opinions. To the authors' knowledge, no studies have applied natural language processing (NLP) techniques to systematically analyse user-generated content (UGC) related to EQs, representing a missed opportunity to leverage the wealth of online discussions, reviews, and evaluations that could provide deeper insights into user perceptions and experiences. This study addresses this empirical gap by systematically analysing expert reviews of EQs using advanced natural language processing techniques. The study employs Bidirectional Encoder Representations from Transformers (BERTopic), a state-of-the-art transformer-based topic modelling framework, combined with Large Language Model (LLM)-based sentiment analysis to extract meaningful insights from 95 automotive expert reviews covering 13 distinct EQ models. This research makes three key contributions: (1) It provides the first comprehensive analysis of expert perceptions of EQs, addressing a significant empirical gap in the literature; (2) it evaluates the application of novel and advanced NLP techniques (BERTopic coupled with LLM sentiment analysis) in the automotive domain; and (3) it generates actionable insights for the user-centred design and development of EQs, directly informing product development and market strategies.

The paper is structured as follows: Section 2 provides a comprehensive literature review covering micromobility, EQ research, and NLP applications in automotive contexts. Section 3 presents the methodology, including data collection and analysis procedures. Section 4 presents the results, Section 5 provides a thorough discussion, Section 6 discusses the implications for EQ design and development, and Sections 7 and 8 conclude with limitations and future research directions.

2. Literature review

2.1. Micromobility solutions

Micromobility solutions have emerged as a response to the aforementioned challenges, offering more space-efficient and environmentally sustainable alternatives than conventional vehicles. Research has consistently demonstrated that electric micromobility devices can significantly reduce urban congestion while meeting most urban trip requirements [67]. This expansive concept encompasses various vehicle types, from e-scooters and e-bikes to compact microcars, each addressing different segments of urban mobility needs and contributing to a diversified transportation ecosystem [42]. Understanding public perception is crucial for the successful adoption of micromobility, as user attitudes and acceptance directly influence the uptake of technology and market success, regardless of technical superiority or policy support. Extensive research has examined public perceptions of various micromobility solutions, including e-scooters [30, 39], e-bikes [34,56], and shared mobility systems [37], revealing critical insights into adoption barriers, safety concerns, and usage patterns. However, while specific electric micromobility solutions have received considerable attention within academia from both technical and perceptual perspectives, electric quadricycles from a perceptual standpoint remain underexplored despite their potential.

2.2. Electric quadricycles: technical and regulatory context

While the terminology and regulatory frameworks for EQs vary internationally, ranging from 'micro-mobility' in Japan to 'neighbourhood electric vehicles' in the United States (US), this study focuses on the context of the European Union (EU). Concentrating on the EU's standardised L-category classification, as set out in Regulation (EU) 168/2013, allows a more systematic analysis without the complexity introduced by cross-national regulatory fragmentation. Under this framework, EQs are divided into two main categories: (a) L6e – Light Quadricycle: A four-wheeled vehicle with a mass not exceeding 425 kg (excluding the driver and propulsion batteries) and a maximum design speed of 45 km/h; (b) L7e – Heavy Quadricycle: A four-wheeled vehicle exceeding the specifications of L6e, with a mass not exceeding 450 kg for passenger transport or 600 kg for goods transport; some subcategories have maximum design speeds up to 90 km/h. These speed limitations have significant implications for where EQs can legally operate within European road networks. In the United Kingdom (UK), vehicles are required to have a maximum design speed of at least 25 mph (40 km/h) for motorway use, whereas in Germany and France, a speed of over 60 km/h is required. This means that light quadricycles, limited to 45 km/h, cannot legally use these high-speed roads; however, faster and heavier quadricycles may qualify. Outside the EU, countries such as Japan and the United States restrict EQ access to high-speed roads, with most jurisdictions prohibiting its use on motorways and expressways due to its limited speed capabilities.

2.2.1. Licensing requirements

Licensing requirements for EQs differ across categories and countries. For example, in France, light quadricycles like the Citroën Ami can be driven from the age of 14 without a full driving licence. In the UK, similar light quadricycles require an AM moped licence and can be driven from the age of 16. In contrast, L7 heavy quadricycles, such as the Renault Twizy (heavy version), require a standard car licence (category B), with a minimum age of 17 or 18, depending on the country [12]. Given the less stringent licence requirements, their accessibility expands the potential user demographic beyond traditional car owners (e.g., elderly users who may encounter difficulties obtaining or maintaining conventional car driving licences). Regarding countries outside the EU, Japan imposes stricter restrictions, typically requiring a standard driving licence at the age of 18 for micromobility vehicles. This requirement is similar to that in the US, where requirements vary by state, ranging from 16 to 18 years of age, with standard licensing requirements. This positions the EU's approach as relatively permissive internationally, particularly for L6e vehicles, which can be driven from age 14–16 with minimal licensing requirements in many member states.

2.2.2. Design characteristics and urban advantages

EQs represent a specific segment within the broader micromobility landscape, occupying a unique position between motorcycles and conventional cars. Like motorcycles, EQs are compact (usually a two-seater with two doors) and agile, making it easy to navigate urban areas and requiring significantly less parking space. In fact, EQs can occupy as little as one-third of the space of a standard passenger vehicle, presenting an effective solution to reduce land-use pressure in cities [60]. Their lighter weight results in considerably lower energy consumption during the use phase of their lifecycle, with some EQs consuming as little as 0.06 kWh/km [2]. As a result, this lower energy consumption significantly reduces operating costs for users. Unlike other micromobility options, EQs feature enclosed cabins. This crucial attribute protects occupants from adverse weather conditions and substantially enhances overall safety due to a more robust physical barrier. Additionally, EQs typically provide more cargo space than other micromobility solutions, making them better equipped for transporting groceries, personal belongings, or small goods for delivery services. Overall, EQs represent an ideal choice for individuals across a broader age spectrum seeking a compact yet functional vehicle for urban commuting, families requiring a practical option for short trips, and businesses needing effective last-mile delivery solutions in urban settings.

2.2.3. Technical limitations and challenges

Despite their advantages, EQs face specific technical limitations and challenges. A significant concern is the absence of mandated crashworthiness standards for L-category vehicles under current European Union regulations, unlike traditional M-category vehicles [9]. This regulatory gap means EQs are not obligated to undergo rigorous crash testing or integrate crucial active and passive safety features (e.g., crumple zones, airbags, electronic stability control). While research on improving EQ safety is ongoing [13], this lack of standardisation remains a notable barrier to consumer confidence and safety perception. Furthermore, while generally more affordable than new Battery Electric Vehicles (BEVs), the purchase price of EQs remains relatively high compared to smaller transportation alternatives, such as e-scooters or e-bicycles. This pricing can deter budget-conscious consumers seeking affordable urban mobility options. Lastly, the simplistic design and lightweight materials often result in elevated vibration levels, negatively impacting passenger comfort and the overall driving experience. These vibrations affect components such as tyres, suspension systems, and chassis elements and directly impact passengers through the seats, pedals, and steering wheel [61].

2.3. Electric quadricycle research landscape

Research on EQs encompasses technical, market, and perception studies, though the field remains relatively limited compared to mainstream electric vehicle research. The existing literature can be categorised into three main areas: technical performance, market potential, and public perception.

2.3.1. Technical performance research

Most research concerning EQs has historically focused on technical aspects, particularly safety and performance characteristics. Safety and crashworthiness studies have examined structural integrity and occupant protection in L-category vehicles [13,18,29], while ride comfort and performance research has addressed vibration issues and overall vehicle dynamics [1,61], identifying specific technical challenges, such as elevated vibration levels resulting from the use of lightweight materials and simplified suspension systems. Other studies have compared energy consumption and operational characteristics across different EQ models (e.g., [2]).

2.3.2. Market potential research

Market potential studies provide the most promising evidence for EQ adoption. Gebhardt et al. [19] conducted a comprehensive analysis using 960,619 trips from the German National Household Travel Survey, demonstrating that small, lightweight electric vehicles could replace up to 76 % of conventional car trips and account for 50 % of overall car mileage. Other investigations have revealed that substituting traditional cars with smaller vehicles can enhance traffic throughput and reduce travel times [38], while incorporating autonomous microcars can further improve road capacity while reducing congestion [59]. Additional studies evaluated EQs from a cost optimisation perspective (e.g., [41]).

2.3.3. Public perception and acceptance research

While limited compared to technical studies, emerging research has begun to examine public attitudes toward EQs. A cross-cultural, large-scale survey study reveals a significant interest, with approximately 50 % of respondents across Germany, France, Denmark, and Japan expressing a willingness to use light electric vehicles/quadricycles, particularly for short trips and leisure activities, and as complementary vehicles [6]. However, major barriers include safety concerns and uncertainty about ownership models. Empirical studies with actual users provide valuable insights into adoption patterns through in-depth interviews. Research with 34 mini-EV owners in China revealed distinct demographics: predominantly older, often retired men with high household incomes, with notably <50 % holding conventional driving licences [36]. A key appeal of these vehicles in China is that they often do not require a licence, giving mobility to those who cannot drive standard cars. Additionally, users emphasised convenience, low cost, and perceived safety benefits of low-speed operation as primary motivations. The study showcased that most users transitioned from using e-bikes to public transit. A structured survey analysis by Zhao et al. [66] reveals distinct satisfaction drivers for mini-EV owners versus non-mini-EV owners in China. Mini EV users prioritise "ease of driving" and manoeuvrability, demonstrating purely pragmatic motivations with little interest in status symbolism, unlike conventional EV owners who emphasise charging infrastructure and prestige considerations. Lastly, through expert reviews and an online survey, Ewert et al. [16] identified both opportunities and challenges for public acceptance. While acknowledging urban benefits such as space efficiency and environmental improvements, industry experts express concerns about a potential modal shift away from active transportation and road safety issues associated with lightweight construction.

2.4. Topic modelling & sentiment analysis

Traditional approaches to assessing consumer perceptions have historically relied on surveys and focus groups, but the proliferation of digital content has enabled researchers to leverage NLP techniques to extract insights from vast amounts of UGC [5]. Among these NLP techniques, topic modelling has emerged as a particularly powerful approach for systematic content analysis. Topic modelling represents an automated analytical technique that identifies the most significant themes within collections of textual documents by examining patterns of word co-occurrence, clustering related terms into coherent subject groups that reveal hidden structures in large datasets without requiring prior content knowledge.

In automotive research, topic modelling has been extensively employed to uncover latent themes within diverse datasets. Latent Dirichlet Allocation (LDA) has served as the foundational approach, enabling researchers to group semantically related terms into coherent topics across large volumes of unstructured text data [58]. For instance, Liao et al. [35] applied LDA to 7492 online reviews of the US automotive industry from 2020, 2021, and 2022 to explore recent trends in the US automotive industry, while Pani et al. [48] employed LDA on tweets collected from multiple countries to decode public discourse and

sentiment shifts around electric mobility over time.

The methodological landscape has progressively evolved toward more sophisticated topic modelling techniques (e.g., Non-Negative Matrix Factorisation [NMF] or Top2Vec), offering enhanced granularity and contextual understanding. Notably, BERTopic, a relatively recent method, has garnered significant interest in the field of natural language processing due to its oftentimes superior performance compared to other topic modelling techniques. BERTopic [21] is an advanced topic modelling technique that employs transformer-based embeddings and clustering algorithms to uncover the underlying themes in the expert reviews analysed in this study. Transformer-based embeddings convert textual data into high-dimensional vector spaces, positioning semantically similar texts closer together and effectively capturing deep contextual and semantic nuances. Clustering algorithms subsequently group these embeddings based on their proximity in the vector space, enabling the identification of distinct themes or topics within the dataset [40]. Avetisyan et al. [4] demonstrated that BERTopic outperformed LDA in analysing 1602 tweets, successfully identifying seven coherent topics (e.g., promotion and service, mobility, acceptance) related to micromobility in the US.

Sentiment analysis, a computational technique that automatically determines the emotional tone and opinion polarity within textual data, has become increasingly crucial for understanding consumer attitudes and experiences in automotive contexts. Often employed in conjunction with topic modelling, sentiment analysis enables researchers to not only identify what consumers are discussing but also how they feel about specific automotive themes and issues. By classifying text into distinct sentiment classes (e.g., positive, negative, neutral), this approach enables researchers to quantify subjective opinions and track emotional responses across large-scale datasets, providing valuable insights into brand perception, product satisfaction, and market dynamics, while revealing the sentiment patterns associated with various automotive topics. In automotive sentiment research, studies have historically employed lexicon-based approaches (e.g., Linguistic Inquiry and Word Count [LIWC], Valence Aware Dictionary and sEntiment Reasoner [VADER], and AFINN). For instance, Ruan and Lv [53] utilised VADER to assess public perceptions of electric vehicles on Reddit, drawing on a large-scale corpus spanning from 2011 to 2020. In a subsequent cross-platform study, Ruan and Lv [54] extended this analysis by comparing EV discussions across Twitter and Reddit using multiple lexicon-based approaches, including AFINN, VADER, and LIWC, analysing over 3.4 million Reddit posts and 7.3 million tweets collected over a decade. While effective for basic polarity detection, these rule-based methods assign sentiment scores based on fixed word lists, without considering how the meanings of words change depending on context, sarcasm, domain-specific jargon, or sentence structure, which can lead to misclassification. To address this limitation, researchers have advanced beyond static dictionaries to train classifiers on labelled data and utilised machine learning methods for sentiment classification [7]. More recently, transformer-based deep-learning models, such as BERT and its derivatives and instruction-tuned LLMs, have enhanced automotive sentiment analysis by capturing context, sarcasm, and domain-specific nuances [57,62].

2.5. Research gap

Within the micromobility options available to the public, EQs have received the least attention in academic research from a public acceptance perspective so far. To the authors' knowledge, only a few studies have assessed the public acceptance of these vehicles, with methods being limited to either structured surveys or in-depth reviews. This represents a significant methodological gap, as the literature review demonstrates that user-generated content, particularly social media data, serves as a valuable source for topic modelling and sentiment analysis in automotive research, providing insights into consumer preferences and informing product improvements. Automotive expert reviewers, who produce content for automotive magazines and specialised platforms, offer a suitable data source for EQ analysis, considering that these reviews typically contain detailed technical assessments, nuanced user-experience evaluations, and comprehensive comparisons. Furthermore, Dewenter and Heimeshoff [10] demonstrate that expert reviews have a significant influence on vehicle adoption decisions, underscoring both their credibility and practical relevance for understanding market acceptance. This paper addresses a critical gap by being the first to apply state-of-the-art topic modelling and sentiment analysis methods to expert-generated reviews of electric quadricycles, offering more profound insights into how these vehicles are evaluated across different dimensions (e.g., safety, comfort, usability, design, and recent trends). This study addresses these gaps by conducting the first systematic analysis of expert reviews targeting electric quadricycles, analysing 95 reviews across 13 distinct EQ models (representing both L6e and L7e categories). By applying BERTopic and LLM-based sentiment analysis to this comprehensive corpus, the research uncovers detailed insights into how automotive experts perceive and evaluate EQs across different vehicle configurations and design elements.

Research Questions:

RQ1: What are the dominant themes in expert reviews of EQs?

RQ2: What sentiments do experts express regarding these themes?

RQ3: How can the insights gained inform the user-centred design and development of EQs?

3. Methods

3.1. Data collection

As illustrated in the first step of Fig. 1, this analysis collected and analysed reviews on EQs from a diverse range of reputable automotive media outlets, including online automotive magazines (i.e., Autocar.co.uk), general technology and innovation websites (i.e., Theverge.com), specialised electric vehicle websites (i.e., Insideevs.com), and professional YouTube review channels (Fully Charged Show). Established outlets such as Autocar and Car and Driver were included, given their long-standing influence in the automotive journalism domain. At the same time, emerging but increasingly influential platforms such as Electrifying.com and InsideEVs were also retained, as they specialise in electric mobility and provide detailed, up-to-date coverage of small EVs sometimes overlooked by traditional magazines. A systematic search was conducted using both specific model names (e.g., 'Citroën Ami review', 'Microlino review', 'XEV Yoyo test drive', 'Opel Rocks-e review', 'Silence S04 review') and generic keywords (e.g., 'electric quadricycle review', 'urban microcar review', 'L7e vehicle test', 'light quadricycle review', 'heavy quadricycle comparison'). Due to the limited availability of English-language reviews, this study expanded its collection to include reviews in German, Greek, Spanish, and other European languages, which were subsequently translated using automated translation tools, namely DeepL. The selection criteria for these sources were based on their objectivity. This excluded personal blog posts or any clearly promotional content. The review had to also provide a substantive evaluation of the vehicle, exceeding a simple news announcement. Typically, this meant full driving reviews or long-term test reports. The reviews span publications from 2021 to 2024, capturing expert discourse during a specific stage of the EQ market's maturity. As a result, the final dataset contained 95 reviews, of which 52 relate to the L7 category and the remaining 43 to the L6 category. The following brands represented the L7 category: Microlino, XEV YOYO, Silence S04, and City Transformer CT-1. Conversely, the L6 category was represented by Solar Squad EV, Citroën Ami, Opel Rocks-e, Fiat Topolino, Estrima Biró, Eli Zero, DoGood, and SWAPA. The selected 13 models represent the vast majority of EQs that have undergone significant expert evaluation and were available on the European market or announced for imminent release during the data collection period.

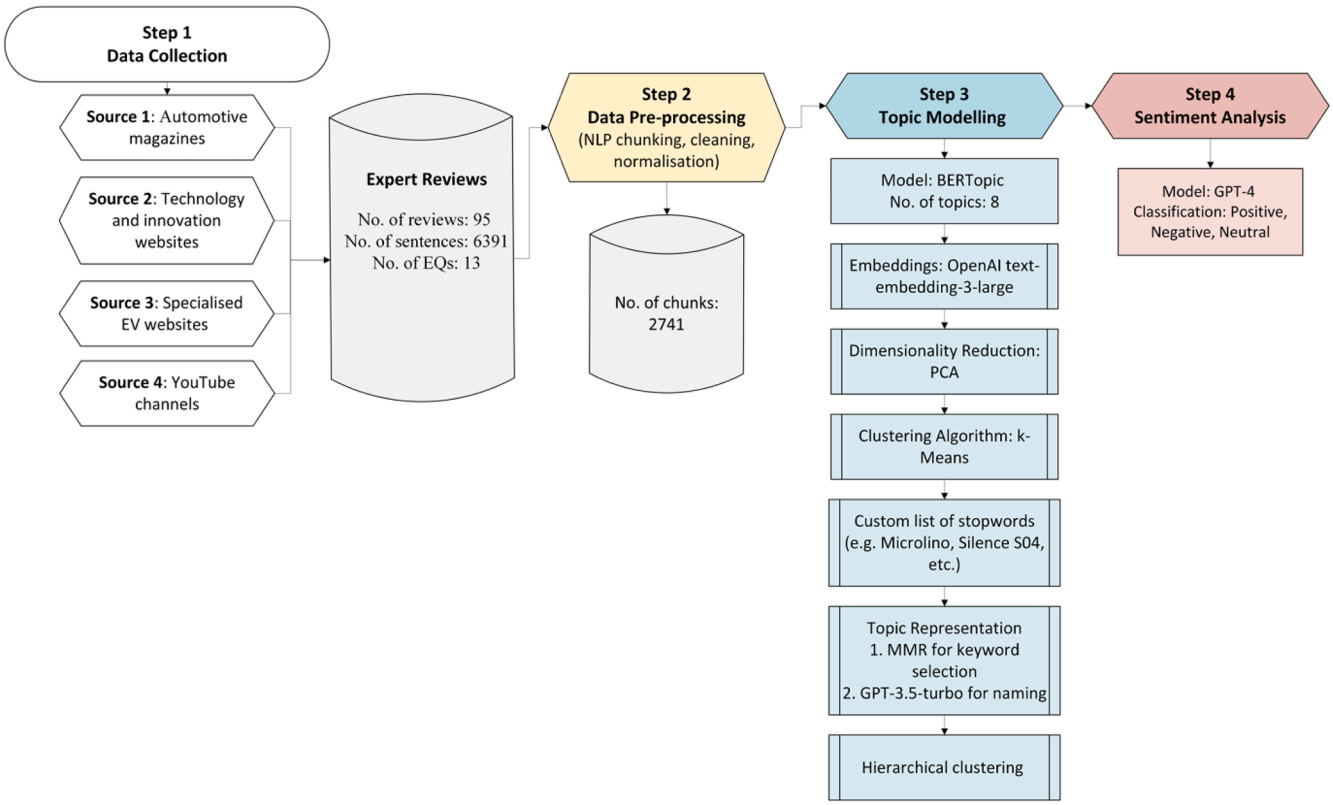

Fig. 1. Research Workflow.

3.2. Data pre-processing

In topic modelling, one common approach for text segmentation is to break the text down into separate sentences. However, this method is unsuitable for the objectives of this analysis, as sentiments and contextual meanings often extend across multiple sentences. For example, consider the phrase: 'This quadricycle has no airbags. That is not great.' Separating these sentences means this study loses the cohesive sentiment and context they convey. Furthermore, unified ideas are often expressed across multiple sentences within reviews and separating them would disrupt the continuity of thought. To address this, the following analysis employed an NLP chunking method that groups semantically related sentences into coherent chunks (see Step 2 in Fig. 1). According to Safjan [32], this method is effective for tasks requiring a good understanding of semantic context and topic continuity, including sentiment analysis. This method divides the text into chunks based on semantic understanding, specifically by detecting significant shifts in the topics of sentences. The study used cosine similarity to assess the level of semantic similarity between consecutive sentences. This was achieved by calculating the cosine of the angle between their vectors in a multi-dimensional space, resulting in a value ranging from 0 (entirely dissimilar) to 1 (identical). Specifically, this study generated vector representations of sentences using the *all-mpnet-base-v2* model, a practical option for sentence similarity tasks [25]. Sentences were classified as belonging to the same coherent segment when their cosine similarity surpassed a threshold of 0.6 [43]. Through iterative experimentation with various threshold values, it was determined that a threshold of 0.6 yielded the most coherent segments since setting the threshold too low resulted in grouping sentences that were not sufficiently related, leading to overly large chunks that combined distinct ideas and diluted semantic specificity. Conversely, setting the threshold too high caused excessive fragmentation, splitting semantically related sentences into separate chunks and disrupting the context flow. As a result, out of 6391 individual sentences, 2741 coherent chunks were created. Each chunk averages 2.15 sentences. While Lalitha et al. [33] define "coherent chunks" as two or more semantically connected sentences, this analysis produced a notable number of single sentences. This deviation arises from the nature of the chunking methodology, where single sentences that did not meet the semantic similarity threshold (cosine similarity $>$ 0.6) with adjacent sentences were left unmerged to preserve their meaning. Consequently, while "chunk" traditionally implies multi-sentence segments, this study adopts a broader definition to include both multi-sentence and single-sentence segments. Lastly, by using suitable Python libraries (i.e., pandas, re, and NLTK), several common preprocessing steps were involved, namely (1) contraction expansion, (2) hyphen and dash removal, (3) currency symbol conversion, (4) abbreviation expansion (e.g., 'EV' to 'electric vehicle'), (5) whitespace normalisation, (6) uniform resource locator (URL) and ellipsis removal, (7) unit formatting, (8) quotation mark removal, and (9) punctuation cleaning.

3.3. Topic modelling

As shown in Step 3 of Fig. 1, by leveraging the modular architecture of BERTopic, this analysis generated embeddings for the pre-processed chunks, facilitating semantic representation, using OpenAI's *text-embedding-3-large* model [47]. This model produces 3072-dimensional embeddings that capture deep contextual meanings of the text. Embeddings from the OpenAI model generally outperform traditional techniques, such as BERT and Term Frequency-Inverse Document Frequency (TF-IDF), in benchmark studies [49]. In particular, *text-embedding-3-large* has achieved a higher Massive Text Embedding Benchmark (MTEB) score of 64.6 % compared to other available models [47]. The MTEB score evaluates a model's performance across a range of embedding tasks (i.e., classification, clustering, and reranking) [44], reflecting its ability to capture nuanced relationships within the text.

The dimensionality of the constructed embeddings was subsequently reduced using Principal Component Analysis (PCA), which was set to six

components. After the PCA, the dimensionally reduced embeddings were clustered using the K-means algorithm with the number of clusters set to forty-seven. Initially, this study experimented with Uniform Manifold Approximation and Projection (UMAP) for dimensionality reduction and Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) for clustering due to its ability to identify outliers and find clusters of varying densities. However, HDBSCAN consistently classified 460 out of 2741 sentences (16.8 %) as outliers. Manual inspection revealed that the vast majority of these outliers contained valuable sentiment information rather than genuinely anomalous data, with only a small fraction consisting of fragmentary text. Given the substantial potential for data loss, K-means clustering was employed to ensure that all chunks were assigned to topics and retained potentially informative content. While this approach may result in some sentences being assigned to suboptimal topics [21], the trade-off was considered preferable to discarding nearly one-sixth of the dataset. Additionally, this analysis created a custom list of stopwords, primarily consisting of brand names and other terms that held no informative value within the topics (e.g., Microlino, Silence S04, Estrima Birò). These custom stopwords were added to the default English stopwords provided by the CountVectorizer. This study subsequently implemented a multi-aspect topic modelling technique that generated numerous representations for each topic. To identify the most indicative words per topic, the study utilised Maximal Marginal Relevance (MMR), which selects keywords by balancing relevance to the topic and diversity among the selected terms [8]. The diversity parameter was set to 0.3, aiming to strike a balance between the relevance and diversity of the chosen keywords. This setup captured the key terms while minimising redundancy in topic representations. Additionally, this study utilised OpenAI's *GPT-3.5-turbo* model via the OpenAI Application Programming Interface (API) to generate concise and descriptive labels for each topic. By providing the model with the leading keywords, topic labels consisting of up to five words were generated, which improved the clarity of the identified topics (see an illustrative example in Fig. 2). Finally, the study conducted hierarchical topic modelling to consolidate similar topics and reduce their overall count.

Lastly, the assessment gauged the quality of the generated topics using two widely recognised metrics: topic coherence and topic diversity. The review applied normalised pointwise mutual information to measure topic coherence for each model (NPMI). This coherence metric produces scores ranging from −1 to 1, where 1 signifies perfect coherence between topic words, while −1 indicates total incoherence. Conversely, topic diversity quantifies the proportion of unique words across all topics, with values from 0 to 1; 0 signifies redundancy, while 1 indicates a wide variety among topics [11]. Both metrics were calculated using the Gensim library [52]. Upon assessing the quality of the generated topics by the BERTopic model, the analysis observed a topic coherence score (NPMI) of 0.1941 and a topic diversity score of 0.8375. The positive coherence score indicates that the top words within each topic are semantically related, reflecting a meaningful association among them. The high topic diversity score of 0.8375 signifies that 83.75 % of the top keywords across all topics are unique. This high level of diversity is desirable in the context of the project, as it ensures a broad coverage of themes in the expert reviews without significant redundancy.

3.4. Sentiment analysis

3.4.1. Model selection

The analysis harnessed the capabilities of generative artificial intelligence (AI), particularly LLM, to analyse the sentiments conveyed in each topic. With the introduction of Generative Pre-trained Transformer (GPT) models, sentiment analysis has become considerably more effective, which is crucial for comprehending and addressing vast amounts of UGC. These models excel in recognising and assessing sentiment across different contexts, effectively managing ambiguities, negations, slang, and modern abbreviations. A study by Kheiri and Karimi [28] underscores the effectiveness of GPT-related models, showing that they outperform traditional machine learning methods in analysing sentiment from social media posts, particularly tweets, by over 22 % in F1 score. This metric combines precision and recall, providing a balanced evaluation of a model's accuracy [44]. Research by Krugmann and Hartmann [31] found that the new GPT-4 multimodal model generally surpassed GPT-3.5 and Llama 2 in three-class classification tasks. Moreover, GPT-4 performs better in evaluating non-social media texts at various levels of granularity (i.e., document or sentence level) and achieves high accuracy in zero-shot settings, demonstrating its suitability for tasks that require no prior training data. Since this study works with three sentiment classes – neutral, positive, and negative – uses non-social media texts at various levels of granularity, and requires no prior training data, GPT-4 makes it an ideal choice for exploring the polarity of reviewers' opinions concerning EQs. It is worth noting that while GPT-4 offers substantial benefits for sentiment analysis, maintaining consistent results remains a vital issue. In this analysis, the temperature parameter was set to zero, which, according to OpenAI [46], controls the creativity or randomness of the text generated by the model. A higher temperature, such as 0.8, leads to greater diversity and creativity in responses, whereas a lower temperature, like 0.2, focuses the output more tightly. By setting the temperature to zero, the analysis eliminated randomness in the model's responses, making the model completely deterministic.

3.4.2. Prompt engineering

By linking GPT with the project's Jupyter environment via the OpenAI API, this study carried out sentiment classification using a prompt specifically crafted to categorise sentences into three sentiment categories: positive, negative, and neutral (refer to Fig. 3). The review noted that changes to the prompt had a significant impact on the

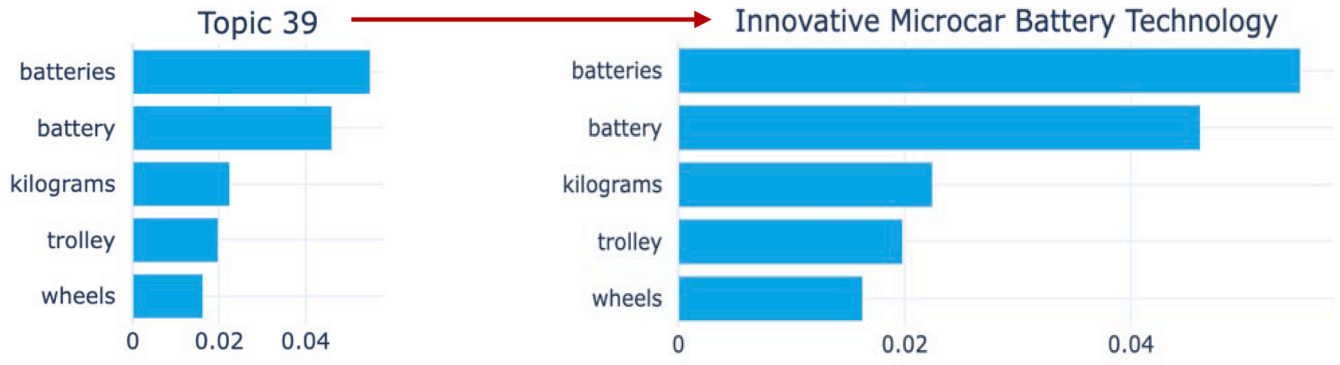

Fig. 2. Generated Topic Label using GPT-3.5-turbo.

Analyse the following sentences from expert reviews on various electric quadricycles and assign a sentiment score from 0 to 2, where 0 signifies negative sentiment, 1 indicates neutral sentiment, and 2 corresponds to positive sentiment. In situations where the sentiment is difficult to classify, provide your best estimation of the sentiment score based on the overall tone.

Fig. 3. Initial Prompt Design.

model's effectiveness. Using the referenced prompt, numerous sentences with moderate sentiment were incorrectly classified as neutral. To refine this approach, a sample of ten sentences that had been categorised as neutral by the first prompt but exhibited moderately negative or positive sentiment was collected (i.e., 'These are mostly settings, especially for the ventilation, which makes a sound like a hair dryer at full power.'). The analysis then tested alternative prompt formulations to improve classification accuracy. The revised prompt, shown in Fig. 4, successfully distinguished neutral sentences, reassigning them to the correct sentiment categories and enhancing overall accuracy.

3.4.3. Sentiment evaluation

To assess the accuracy of the model's predictions, this study first created a set of ground-truth labels that would serve as a reference standard for benchmarking its output. A stratified random sampling technique was employed on 300 sentences, ensuring proportional representation for each sentiment class: 150 neutral, 90 positive, and 60 negative sentences. Two independent annotators were appointed to assign the ground-truth labels. To assess the level of agreement between the annotators, the inter-annotator agreement was computed using Cohen's kappa, yielding a value of 0.7766, indicating substantial agreement according to Cohen's scale [22]. When disagreements arose, the annotators held discussions to align on the correct ground-truth labels. Using the consensus ground-truth labels alongside the model's predictions, this study evaluated the performance of the sentiment classification model using four frequent metrics for topic modelling, including accuracy, precision, recall, and F1-score [51]. The model achieved an overall accuracy of 90.33 %, demonstrating its effectiveness in classifying sentiments in reviews concerning EQs. Table 1 displays each sentiment class's precision, recall, and F1 score, along with the number of instances (support) for each category.

Positive Sentiment Classification: The positive class demonstrates exceptional performance with perfect precision (1.00), meaning every sentence predicted as positive was indeed positive, eliminating false positive errors. Combined with a recall of 0.87, this yields the highest F1-score (0.93) among all classes. The 0.87 recall indicates that while the model correctly identifies 87 % of positive sentences, it incorrectly classifies 13 % as neutral. This performance profile reflects a highly conservative yet accurate approach to detecting positive sentiment. **Negative Sentiment Classification**: The negative class exhibits well-balanced performance with precision (0.88) and recall (0.85) values closely aligned, resulting in an F1-score of 0.87. This indicates that the model correctly identifies 85 % of negative sentences while maintaining 88 % accuracy in its negative predictions. The marginally higher precision compared to recall suggests a slightly higher number of false negatives than false positives, consistent with the model's conservative classification strategy. **Neutral Sentiment Classification**: The neutral class exhibits a distinctive performance pattern, with the highest recall (0.95) but the lowest precision (0.85), resulting in an F1-score of 0.89. The high recall demonstrates the model's ability to capture 95 % of genuinely neutral sentences, while the lower precision reveals that 15 % of sentences classified as neutral actually contain sentiment. This pattern indicates the model's tendency to default to neutral classification when sentiment indicators are ambiguous.

Table 1
Performance Overview of Sentiment Classification.

Class	Precision	Recall	F1-Score	Support
Negative	0.88	0.85	0.87	62
Neutral	0.85	0.95	0.89	134
Positive	1.00	0.87	0.93	104
Accuracy			**0.90**	**300**

The confusion matrix in Fig. 5 corroborates these findings by revealing systematic error patterns across all sentiment classes. For neutral sentences, 127 out of 134 (94.8 %) were correctly classified, while seven negative and 14 positive sentences were misclassified as neutral, explaining the neutral class's high recall but reduced precision.

Please analyse the following sentence derived from expert reviews on various electric quadricycles and assign a sentiment score from 0 to 2 using the following exact mapping:
0: Negative sentiment (criticism or dissatisfaction)
Example: The vehicle's battery life is terrible, and it constantly needs recharging.
1: Neutral sentiment (objective statements without positive or negative connotations)
Example: The car has a range of 100 miles on a single charge.
2: Positive sentiment (praise or satisfaction)
Example: I absolutely love the sleek design and exceptional performance.
Base your assessment on the overall tone and content of the sentence."
Important: Use the sentiment scores exactly as defined above. Do not use any other mapping or include any labels or explanations. Answer with just the sentiment score (0, 1, or 2). Do not include any other text.

Fig. 4. Improved Prompt Design.

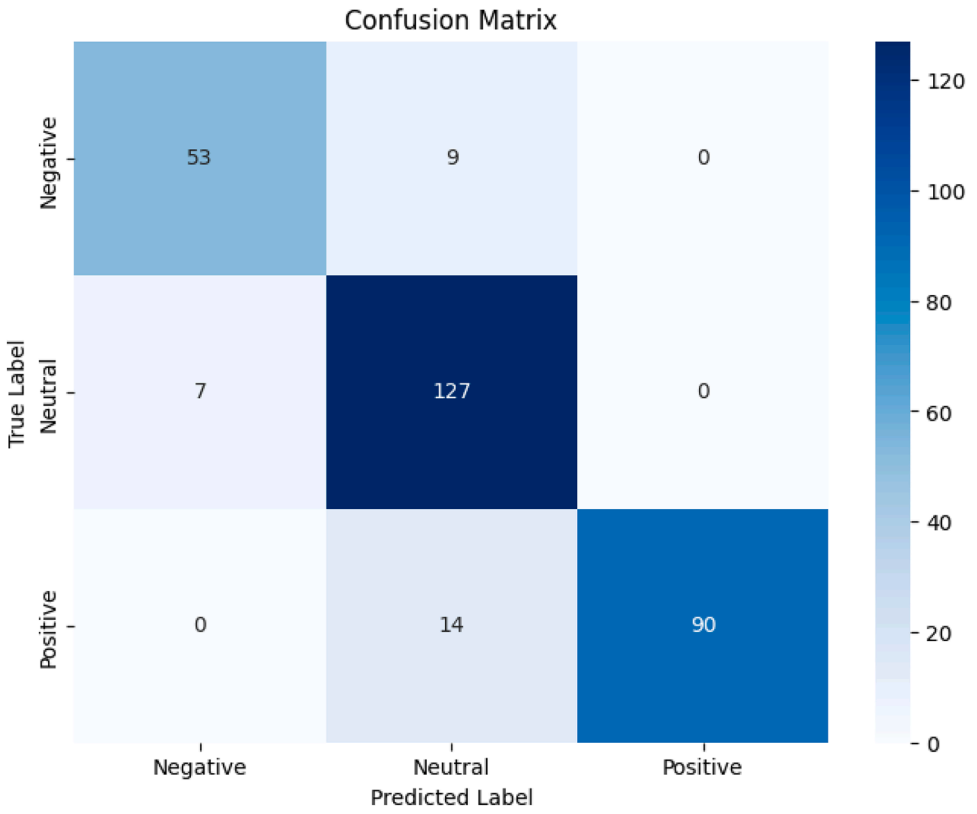

Fig. 5. Confusion Matrix for Sentiment Classification.

The positive class analysis confirms the perfect precision observed in Table 1: all sentences predicted as positive were indeed positive, with zero false positives. However, 14 positive sentences were misclassified as neutral, directly accounting for the 0.87 recall value. Similarly, negative sentences showed 53 out of 62 (85.5 %) correct classifications, with 9 misclassified as neutral, aligning precisely with the 0.85 recall in Table 1. A closer evaluation of the misclassified sentences revealed distinct patterns in the model's errors. The model often misidentified positive and negative sentences as neutral, especially when sentiments were implied rather than explicitly articulated. For instance, sentences such as 'With 230 litres (8.1 cubic feet) of cargo room in the back, you have more than enough for the weekly shopping run…' were incorrectly tagged as neutral by the model despite clearly conveying a positive sentiment regarding ample storage space. This suggests the model might have difficulty recognising positive sentiments expressed through factual statements lacking overtly positive language. Likewise, negative sentiments communicated subtly or softened by contextual information were also misclassified as neutral. An example includes the sentence, 'The steering is not power assisted, but you get used to it' which presents a negative point tempered by a conciliatory comment, causing the model to label it as neutral. The tendency to misclassify positive and negative sentiments as neutral indicates that the AI model adopts a conservative approach.

3.5. Methodological replicability

This methodology can be systematically adapted across different research contexts and domains. For data collection, researchers should establish domain-specific credibility criteria for expert sources and maintain minimum quality thresholds for content depth. The semantic chunking approach requires adjusting cosine similarity thresholds based on text characteristics. BERTopic's modular architecture allows flexible algorithm selection. While this study employed PCA and K-means clustering, researchers may prefer UMAP and HDBSCAN, among others, depending on their dataset characteristics and research objectives. In addition, while this study used OpenAI's text-embedding-3-large for semantic understanding, different corpora may benefit from alternative models. Google's gemini-embedding-001 is currently a top-performing model on the MTEB leaderboard; for multilingual corpora, robust open alternatives that produce aligned embeddings across 50+ languages could include, for example, paraphrase-multilingual-mpnet-base-v2 [26].

Regardless of algorithmic choices, topic quality assessment remains crucial. However, coherence metrics and diversity scores serve merely as proxies for topic model performance, not ground truth measures. These metrics have notable limitations, including sensitivity to topic word counts, and can be misleading. Therefore, researchers should also manually inspect topics to assess semantic coherence and thematic relevance within their specific domain context. For sentiment analysis, this study utilised GPT-4, but other LLMs (e.g., Gemini, Grok, DeepSeek, etc.) may yield superior results for different corpora or domains. Depending on the corpus and research objectives, researchers could consider experimenting with alternative models and validating their performance against domain-specific ground truth annotation.

4. Results

4.1. Topic modelling

The BERTopic model first identified 47 distinct topics from 2741 chunks. Nonetheless, hierarchical clustering and dendrogram visualisation indicated that several topics were alike. These similarities were manually evaluated, and topics were merged based on their semantic relationships and proximity in the dendrogram. This process identified eight distinct topics: Design, Technology, Driving Experience, Urban Mobility and Acceptance, Performance, Battery and Efficiency, Pricing Options, and Market and Production. Upon further examination, a substantial overlap between Design and Technology emerged, as

reviewers frequently mentioned physical design aspects alongside technological features. Given that both technology-related topics had similarity scores exceeding 0.70 in terms of various themes concerning design, the authors opted to merge them. Additionally, topics related to Classification and Regulations were initially scattered across different clusters. However, they shared a common concern regarding classification and legislative matters, prompting the study to consolidate them into a separate Classification and Regulations topic to emphasise their significance. As a result, eight topics were identified, namely (1) Design and Technology, (2) Driving Experience, (3) Urban Mobility and Acceptance, (4) Performance, (5) Battery and Efficiency, (6) Pricing Options, (7) Market and Production, and (8) Classification and Regulations.

Fig. 6 illustrates the distribution of topics across reviews. Notably, Design and Technology emerged as the most prevalent topic (30 %), whereas Classification and Regulations ranked last with 4.9 %.

To complement the distribution shown in Fig. 6, Table 2 summarises the key sub-themes within each topic. Considering the most discussed topic, experts paid a lot of attention to the dimensions ('In terms of dimensions, the Microlino is small. Very small. It's just 2.5 m long and 1.5 m wide…'). Besides the compactness of EQs, reviewers frequently highlighted emerging trends in engineering design. These comments ranged from addressing unique seating arrangements ('We have got staggered seating, so the passenger seat is actually behind the driver like in a McLaren F1.'), and unconventional door designs ('One of the coolest features is its single front opening door.'; 'Inside, you will find removable doors.'; 'For cost reasons, the two doors, including the hinges, are also identical and therefore open in opposite directions.') to a shape-shifting chassis that allows the EQ to narrow from 1.4 m to approximately 1 m for enhanced agility ('Unlike other microcars, the CT1 shape-shifting chassis sets it apart.'). Some experts also addressed the additive manufacturing processes, with some manufacturers leveraging 3D printing technology to produce components such as body panels, rims, and dashboards, thereby enabling shorter manufacturing development times and greater customisation for users to personalise designs ('These elements, such as the wide door panels, are created using 3D printing. Numbers, letters and self-designed patterns should not be a problem.'). In contrast, others adopted a cost-effective modular production strategy that involves segmenting the vehicle into interchangeable components ('Interestingly, the body panels are identical at both the front and back, allowing Citroën to save on production costs. It also makes the car cheaper to insure because the parts are interchangeable; just swap the lights around! Everything is mirrored, including the doors.').

Table 2
Overview of Topics and Associated Sub-Themes.

Main Topic	Sub-themes
Design and Technology	Exterior (i.e., dimensions, frame, wheels); interior (i.e., dashboard, seats, materials); space; technology (i.e., infotainment screens, connectivity solutions, heating, ventilation, and air conditioning [HVAC]).
Driving Experience	Safety (i.e., anti-lock braking system [ABS], airbags, crumple zones); noise, vibrations, and harshness (NVH); handling.
Urban Mobility and Acceptance	Public attitudes; benefits of EQs in urban settings; acceptance challenges.
Performance	Range, acceleration, and speed across various environments (e.g., urban areas, highways, hilly landscapes).
Battery and Efficiency	Battery size and range; charging methods; battery chemistries; battery innovations.
Pricing Options	Vehicle cost; subsidies; financing options.
Market and Production	Manufacturing locations; distribution plans; pricing strategies.
Classification and Regulations	Legal classifications; driving regulations; safety standards.

The second most discussed topic, Driving Experience (18 %), revealed that safety emerged as one of the key sub-themes, as shown in Table 2. This observation was to be expected, considering the absence of stringent safety requirements for L7 and L6 and the frequent debate in the literature surrounding this phenomenon [13,18,29]. Typically, safety-related comments were as follows: ('Braking from the four discs is rather light due to the absence of assistance and its ABS…'; 'In the structural and mechanical parts, we distinguish the self-supporting body with safety bars for side and frontal collisions.'; 'The driver has a steering wheel without an airbag…'). Building on this, the reviewers frequently commented on how aspects like suspension stiffness, sound insulation, and body structure influence the NVH characteristics. The prominence of NVH in the context of EQs also aligns with the unique challenges these vehicles face due to their lightweight and compact design [1]. Illustrative comments were ('Logically, it is a car with hard

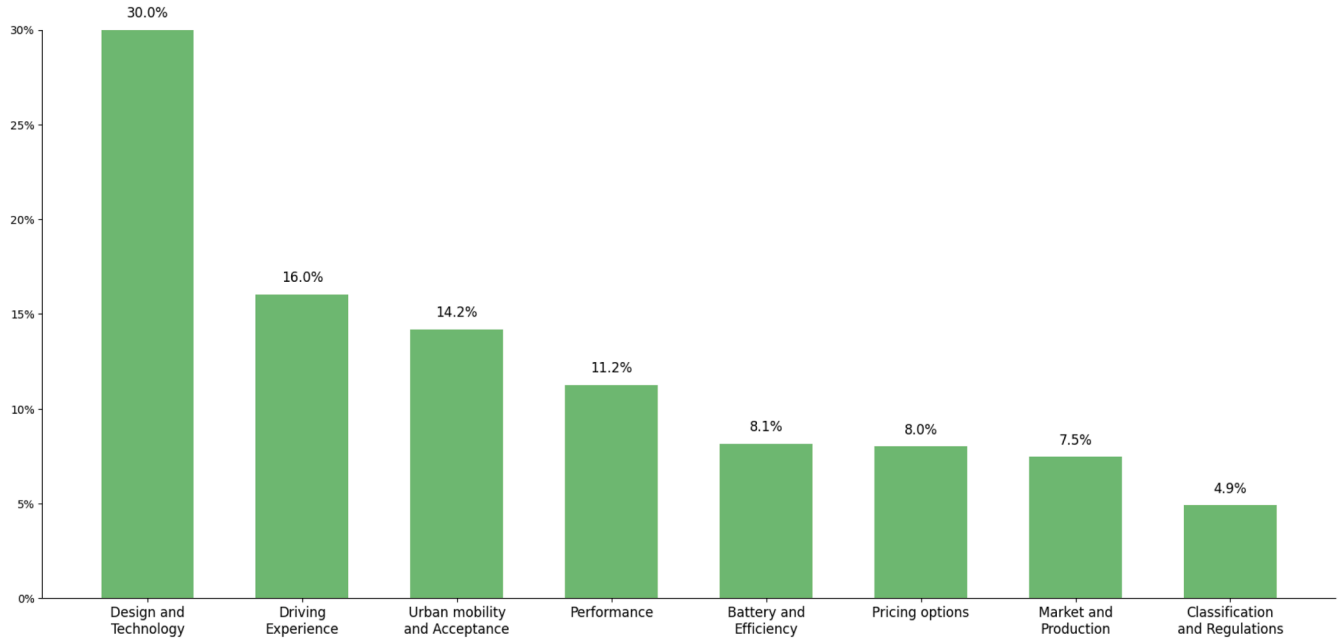

Fig. 6. Proportion of Topics Identified in the Reviews.

suspensions, since with such a short wheelbase, all the bumps reach the interior.'; 'The suspension is also hard because, between the low weight of the vehicle and the two engines located in the rear wheel hubs, it could not be otherwise.').

The subject of Urban Mobility and Acceptance (14.2 %) primarily illustrates public perceptions and preferences about EQs, specifically highlighting the distinct practicality benefits EQs offer for urban mobility compared to other modes of mobility (i.e., M1 category vehicles, scooters, bikes, etc.) and their contribution to minimising the urban traffic footprint, whilst also addressing various acceptance-related challenges and limitations faced by EQs in urban settings ('Americans do not like tiny cars. Some fear they may not be safe. Some people think they'll look silly driving them. Others say they are bad values, offering far less than a normal car without actually saving you much money.').

Table 2 further illustrates that Performance, with 11.2 %, comprises sub-themes related to range, acceleration, and speed across various driving environments. Although EQs are primarily designed for urban use, automotive experts often tested them beyond city settings, such as on highways and in hilly terrains, to evaluate their performance limits and real-world capabilities ('If you live in a flat city, the Rocks-e performs well for a vehicle of this class, but it can get a little frustrating in a hilly place like Stuttgart.'). Conversely, Battery and Efficiency subsequently reveals several unique technological innovations. Notably, reviewers highlighted the significance of the swappable battery systems featured in certain EQs. For example, the Silence S04, which was frequently mentioned, is designed with two swappable batteries, each with a capacity of approximately 5 kWh, enabling a total range of around 150 km. Each battery weighs 41 kg and can be replaced in approximately 30 s. Additional innovative features discussed included integrated solar panels. This is exemplified by just one of the EQs within this study, namely Solar Squad EV, which can provide an additional 22 km (13.6 mi) of range on sunny days in the Netherlands with the support of the embedded solar panels on the roof.

Pricing Options and Market and Production present many financial options for these EQs, which are frequently examined. In the studied reviews, these financing options ranged from the so-called Battery-as-a-Service (BaaS), which allows EQ owners to purchase the EQ without the battery ('A customer who opts to buy the S04 without the batteries, in other words, chooses to lease them instead will pay 30 % less for the car itself.'), car-sharing schemes ('Ami will also be available for rental in Paris via Free2Move, the PSA group's car-sharing service. The rates will be the same as for the 550 Citroën C Zero and Peugeot iOn already available: €0.26 to 0.39 per minute with or without the subscription at €9.90 per month and, respectively, €40 to 60 for 24 h.') to standard leasing agreement ('Fiat is offering its Topolino at €58.90 per month over 36 months and 15,000 km, i.e., 5000 km per year, without a deposit.').

Lastly, the topic that received the least discussion (4.9 %) was Classification and Regulations. A note of caution is due here since safety-related regulations were also mentioned across Driving Experience and Urban Mobility and Acceptance; hence, the distribution is likely to be higher among the reviews. Besides the safety-related regulations, the topic revolves around the other legal and regulatory frameworks governing EQs, including their categorisation (L6e, L7e) and usage restrictions, as illustrated in the previous table. Interestingly, licence requirements-related discussions dominated, with reviewers frequently pointing out the fact that EQs can be driven by younger individuals, with L6e models accessible to 14- or 15-year-olds with a moped license and L7e models requiring a B1 or standard driving licence for drivers aged 16 and above ('It is not a car, but in terms of regulations, it is a quadricycle, and it is sold in both the L6e version without a licence and with a top speed of 45 km/h and the L7e, which requires a type B driving licence and can reach 85 km/h.').

4.2. Sentiment analysis

Fig. 7 highlights that while nearly half of the feedback remains neutral, positive sentiment demonstrates a significant level of approval for EQs, while a smaller but notable proportion of negative sentiment signals some dissatisfaction.

Building on the overall proportions in Fig. 7, Fig. 8 breaks down sentiment distributions across individual topics. Specifically, Fig. 8 reveals that the Driving Experience is the only topic where negative sentiment (35.5 %) surpasses positive sentiment (27.9 %), indicating substantial concerns among reviewers. In contrast, Urban Mobility and Acceptance exhibit a predominantly positive sentiment (55.8 %), suggesting strong approval of these vehicles' suitability for urban environments. The topic of Design and Technology presents a significant positive sentiment (32.3 %) alongside a notable negative sentiment (21.5 %), reflecting a diversity of opinions. Similarly, Performance and Pricing Options garner positive sentiments but are accompanied by considerable negative feedback, highlighting areas needing improvement. The remaining topics, including Battery and Efficiency, Market and Production, and Classification and Regulations, are characterised primarily by neutral sentiments, indicating objective assessments without pronounced positive or negative opinions.

5. Discussion

5.1. Interior space and customisation

An unexpected finding was the strong positive feedback regarding **interior space, ample storage**, and **luggage capacity**, as experts noted ('We were very impressed by the luggage space, which reaches 230 litres and comfortably fits all the day's shopping.'; 'Once aboard, though a six-footer like me found there was plenty of space.'). The perceived sense of spaciousness was further attributed to the incorporation of **expansive glass surfaces** and **panoramic roofs**, which many experts praised for improving overall visibility ('But we can discuss the astonishing visibility. I feel like I am outside driving this thing. There is so much glass and visibility in every direction that you hardly even need the mirrors.'). This finding aligns with broader research on consumer preferences in electric vehicle adoption, where interior space consistently emerges as a key factor in decision-making. For instance, a study by Xu et al. [65] found that the interior space was among the most frequently discussed topics in users' word-of-mouth comments on the AutoHome website regarding BYD's new energy vehicle (NEV). Similarly, by analysing online consumer reviews, Gong et al. [20] discovered that, besides appearance, space was an aspect consumers paid the most attention to when considering EVs. Nevertheless, this spatial advantage becomes more pronounced when contrasted with other micromobility alternatives, where practicality constraints have generated negative user feedback. Research on e-scooters consistently identifies limited or absent cargo capacity as a significant disadvantage, with studies by Mesimäki and Lehtonen [42] and Sanders et al. [55] highlighting storage limitations as barriers to broader adoption. The superior storage capacity of EQs, therefore, represents a distinct competitive advantage within the micromobility ecosystem.

Beyond spatial aspects, **customisation options** captivated experts. These ranged from interchangeable door panels and cockpit designs ('The decorative plastic parts of the doors can be removed and replaced with blades of another colour or custom designs, thus giving a completely personalised character.') to innovative door concepts that facilitated ease of entry and exit in tight urban spaces. For example, some models featured front-facing doors, with some experts saying ('The idea here is that you can park nose in into a parking space, pop that door open and jump straight out onto the pavement safely.') while others plan to introduce scissor doors ('City Transformer is planning to offer an optional roof box to expand the luggage capacity of the mini EV and a fancy scissor doors upgrade, saving even more space as they rotate

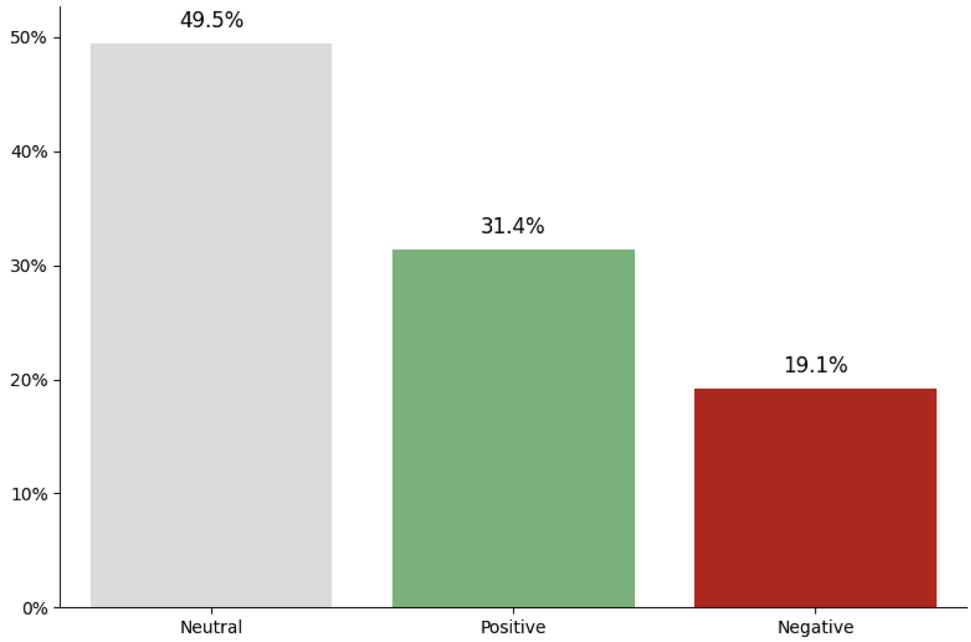

Fig. 7. Overall Proportion of Positive, Neutral, and Negative Sentiments.

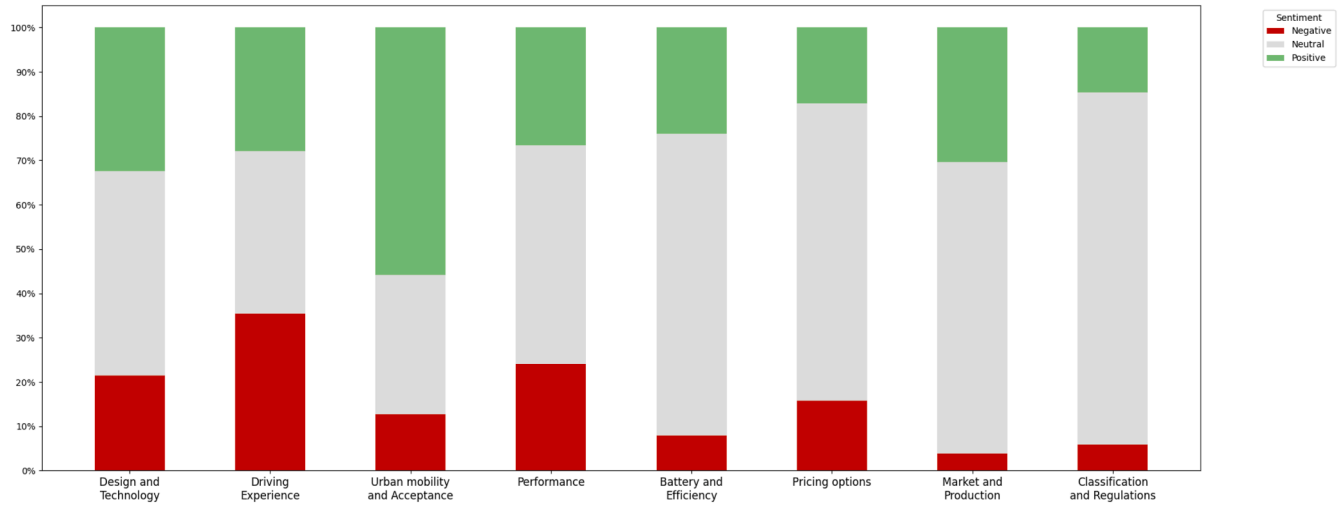

Fig. 8. Sentiment Distribution Across Identified Topics.

upwards.'). Experts also appreciated modular features like optional removable doors ('Inside, you'll find removable doors. Why don't all vehicles have removable doors? You can remove them on sunny days.') and user-centric, cost-effective technology solutions such as portable Bluetooth speakers replacing built-in audio systems ('You get a portable Bluetooth speaker. This may be one of my favourite design highlights inside the car.'). Notably, to the authors' knowledge, no prior research has systematically examined end-user sentiments regarding these specific attributes, offering a unique perspective on what individuals appreciate in EQs' design.

5.2. Build quality and HVAC issues

However, the examined EQs faced criticism, particularly regarding their **build quality.** These findings align with Anwar et al. [3]'s aspect-based sentiment analysis of electric motorcycles, which similarly identified poor build quality as a notable source of negative sentiment among users. Reviewers frequently noted that the vehicles used inferior materials, especially rigid hard plastic, giving the interiors a cheap feel ('It is made of sturdy hard plastic, but it looks very cheap, which would be fine if the Microlino cost half as much.'). Moreover, what is typically not an issue in conventional vehicles, experts often raised concerns about heating, ventilation, and air conditioning regarding EQs, particularly pointing out the absence of air conditioning and the issues of noisy, inefficient, and non-adjustable heating and ventilation systems. This issue resulted in uncomfortable cabin temperatures and difficulties with window defogging ('There is, of course, no air conditioning nor even real ventilation with nozzles towards the passengers, only a very noisy demisting and heating function for the windscreen.').

5.3. Joyful driving vs. safety concerns

Furthermore, many described the driving experience as **fun** and **playful**, emphasising these EQs' **agile**, stable, go-kart-like handling abilities ('It is a completely joyful thing to potter around town in'; 'It is really joyous and playful, and that is what I want in a city car.'). Short

turning circles made these vehicles especially enjoyable, particularly in urban environments with tight spaces ('This is a true city cruiser, nothing more; its steering is a breeze, its turning circle is <8 m, and its dynamics are comfortable enough for city traffic.'). The frequent emphasis on fun and joyful driving experiences in automotive reviews of EQs aligns, for instance, with research on powered two-wheelers (PTWs). Will et al. [63] found that the most important reason to own or choose a PTW is the driving experience, i.e., experiencing fun and freedom, echoing the "fun" and "playful" characteristics that reviewers consistently highlighted for EQs. Both micromobility solutions are characterised by their ability to deliver experiential mobility beyond pure utility, combined with urban manoeuvrability advantages like easier parking and agile handling in tight spaces.

Nonetheless, the most frequently cited concerns were about **insufficient safety features** – an issue noted in earlier studies [17,23]. In particular, frequently cited concerns related to braking performance, the absence of airbags, and the lack of advanced assistance systems ('And because the lattice frame vehicle lacks any crumple zones or safety features (yes, there aren't even airbags), we decide to turn around.'; 'As we said before, you have to press hard on the brake pedal to slow down. There is no ABS, as usual in microcars, which are governed by different rules than cars, but also no driver assistance or passive safety systems beyond the seat belts.'). Due to the limited safety features, reviewers often express feelings of vulnerability when navigating roads alongside larger vehicles like trucks and SUVs ('So, when you are cruising around in a cabin scooter at sixty miles an hour between trucks, buses and SUVs and are being shaken like a cube in a plastic cup, fear is sitting next to you on that uncomfortable seat, and there is nothing there to calm you down – no airbag, no crumple zone, no good brakes.'). This heightened safety awareness among European automotive experts contrasts markedly with the findings of Ling et al. [36], where all Chinese mini-EV users reported feeling "very safe", despite 47 % having experienced crashes during ownership. This divergence suggests that experienced automotive reviewers possess greater awareness of conventional vehicle safety standards and the risks associated with operating lightweight vehicles in mixed traffic environments, whereas actual users, particularly elderly populations, prioritise the perceived safety improvements over their previous modes (such as e-bikes).

The analysis further revealed that manufacturers are aware of these issues and are proactively working to improve safety features, a commitment further bolstered by positive feedback from industry experts. These safety features include, for instance, an ABS ('To ensure that the safety of the occupants does not suffer, the production models will rely on all conventional assistance systems such as Electronic Stability Programme [ESP] and ABS, which is not mandatory for this vehicle class.'). Manufacturers also incorporate advanced structural designs, such as monocoque frames, aluminium exoskeletons, and high-strength steel chassis, which further enhanced experts' perception of safety ('It is the first vehicle in its class to be equipped with a self-supporting monocoque frame, offering it increased levels of safety and dynamic driving.'; 'First, look at this aluminium exoskeleton. This car has crash safety far beyond what is required for an L6 microcar with full crash structures front and rear.').

5.4. Comfort (NVH)

Additional issues included the **rigid suspension** and **minimal seat padding**, which intensified vibrations and discomfort on uneven surfaces, particularly cobblestone streets, aligning with Vella et al.[61]'s findings. This study clarifies how experts perceive these shortcomings ('The suspension is fine on smooth streets and handles well enough around turns, but over cobblestone roads, which are frequent in old cities in Europe where the Microlino would be at its best, otherwise, the ride gets rather jarring.'; 'What else is noticeable when driving for a longer time? Well, there is not much suspension comfort with a wheelbase of just under 5.1 feet. A pothole finder spontaneously comes to mind. At least cobblestones and potholes are passed on to the inside.'). Many experts also noted **insufficient sound insulation** ('I do not think there is much soundproofing back there, so you can hear it whine. I am used to it because I have driven a fair number of electric vehicles, but it sounds like a London Underground tube train to me.'), and **steering difficulties** due to the absence of power assistance and self-centring mechanisms ('The non-power steering is heavy, making parking manoeuvres a bit difficult.').

5.5. Urban suitability of EQs

A strong consensus emerged that EQs are **well-suited for city driving.** They offer an entertaining and purpose-built experience for daily commuting, make navigating urban environments easier, and simplify finding parking spaces, making them a suitable option for city dwellers ('While cars, in general, are emerging in some cities, a new breed of electric microcars is trending. They are cheaper to own, easier to park, consume less public space and energy and manoeuvre around obstacles that would otherwise block big SUVs and snarl traffic.'). This observation aligns closely with other studies, such as those by Bauer et al.[6], which have demonstrated that EQs are often viewed as ideal for short trips and errands, serving as a secondary vehicle rather than a primary one. Similarly, the study of Zhao et al. [66] showed that ease of driving and manoeuvrability were the strongest contributors to overall satisfaction among EV adopters. Experts regularly emphasised their benefits compared to conventional two-wheelers ('It's also a good deal safer than an e-scooter or bike given the UK's variable driving standards, not to mention weather.'). This mirrors the sentiments in the study by Ling et al. [36], which observed that Chinese mini-EV users often transitioned from e-bikes to EQs due to a greater sense of comfort and increased carrying capacity. Moreover, the reviewers frequently experienced significant attention and **favourable public responses** during the vehicle tests ('The smile it puts on people's faces as you drive by is absolutely infectious.'; 'It's impossible to count the number of smiles, outstretched fingers, and thumbs up during our short Parisian escapade at the wheel.'). On the contrary, some reviewers pointed out limitations affecting the practicality of these EQs, with some emphasising that despite their small size, these vehicles **lack the agility of bikes** or scooters to navigate through traffic and find easy parking, limiting their effectiveness in congested areas ('You're still getting stuck in traffic when the shoulder isn't wide enough to squeeze past, and you're still left searching for parking…'). Prior studies [38,59] have theoretically demonstrated that EQs hold the potential to ease congestion issues; however, the findings of this study highlight that this benefit is not yet realised in practice.

5.6. Performance limitations

The majority agreed that the performance is acceptable and **sufficient for daily use in urban settings** ('The maximum speed is limited to 85 km/h and the official autonomy is 149 km, more than enough for the daily urban trips of a normal person.'), although some often noted the **limited speed capabilities** of EQs, particularly **on ring roads, urban expressways**, and **motorways**, noting that these vehicles can disrupt traffic flow ('Driving it in the crazy traffic of Bucharest full of aggressive drivers that driveway too fast, the Microlino's power output just barely allowed me to keep up without being honked at every two seconds.'; 'Do not think about highways, not even those with a 55 mph, 90 km/h speed limit. The power is just not there.'). Some also noted a significant decrease in the range when driving around hilly terrains or in cold conditions ('But after a good climb of about 20 km, the battery went from 97 % to 33 %. Of course, not all customers will probably climb passes with their YOYO, but during a second phase of use in urban conditions with a bit of peri-urban over about 30 km, the battery went from 100 % to 70 %.'). Although the study by Topaç et al. [60] assessed microcar performance through simulations, this study reveals real-world

challenges, including limited effectiveness on motorways and in hilly or cold conditions.

5.7. Flexibility of swappable batteries

The battery swapping system feature was frequently praised, with experts highlighting the convenience of removable batteries that can be swapped or transported, making charging **quick** and **flexible**, effectively eliminating the charging anxiety ('One of the most distinctive features of the Silence S04 compared to its competitors is its removable batteries with integrated handles and wheels so that they can be driven or transported like a trolley.'). Some portable battery models were recognised for their **versatile** applications, including energy storage features enabling users to power home appliances. These batteries were also commended for their ability to power various products in the brand's portfolio, including electric two-wheelers. Nevertheless, experts expressed concern regarding the weight of swappable batteries, noting that they are not as easily manoeuvrable ('Note that the battery is not as easy to drag or push as cabin baggage.'; 'It weighs about 40 kg, and you have to be mindful of the way the battery block is balanced when moving it around.'). Additionally, the lack of established **swapping station infrastructure** in some countries presents considerable challenges ('Now obviously there is no network yet of places where you can go and swap these batteries, so at the moment it is basically useless.'). While much of the focus on swappable battery technology has been on two-wheelers and buses [24], the analysis findings highlight its emerging applications and challenges regarding EQs.

5.8. Low running costs vs high purchase price

Low running costs and financing options like **BaaS** were positively noted ('It charges so cheaply I cannot believe that this car cost me under £3 when the train to London yesterday cost me over £32! So, it is <10 % of the cost of getting the train.', 'You can lease them from Silence, which reduces the cost of the vehicle by some 40 %. Nice touch!'). However, the analysis also indicates that these vehicles continue to exhibit relatively **high purchase prices**, with experts saying that there are other alternatives offered in a similar price range, offering more features, comfort and safety, making the EQs less appealing in comparison ('But the biggest thorn in the side of the YOYO is the Dacia Spring, which in its entry form is actually slightly cheaper, not to mention having two more seats, more range and a higher top speed.'). Experts contend that the elevated pricing does not correspond with the quality or features provided, thereby complicating the justification for potential consumers considering a purchase ('The price of €16,900 is a bitter disappointment compared to the €13,000 announced in 2021 and may have made the YOYO more difficult to reach, especially for younger customers.'; 'It costs at least €17,690; the "Pioneer" version we drove is only available from €22,690 (not eligible for BAFA funding). A lot of money – for an electric vehicle that feels like it is already a few years old.'). A deeper analysis shows that the high purchase price is partially attributed to the fact that in many countries, there is no availability of **government subsidies** for this particular vehicle class, which increases the financial burden ('This vehicle class does not receive any e-car subsidies. At best you will then qualify for the GHG quota, which brings in around €350 to 400 annually.'). This policy does not extend to all countries; for instance, Spain and France have well-established incentive programmes for EQs ('Thanks to the subsidies of the Moves III Plan and other tax deductions, the final cost of the vehicle can be considerably reduced; the entry-level version is around €6000, which makes the Silence S04 a more attractive option within the electric microcar market.'). These results corroborate the findings of Ewert et al. [16], emphasising the critical role of EQ-friendly incentives in promoting the widespread adoption of these vehicles. Interestingly, while Ling et al. [36] concur with the finding regarding low running costs, their study reveals a contrasting perspective on purchase price acceptability, with respondents perceiving the acquisition cost as reasonably affordable. This divergence can be attributed to the significantly lower price point in their study context (China), where interviewees paid an average of 15,409 RMB (≈ €1900) for a three-seat mini-EV, substantially below the European market prices discussed in this analysis. This price differential is further contextualised by Bauer et al.'s (2017) multi-country survey in Europe, which demonstrates that consumer price sensitivity remains a critical barrier to adoption: 51.3 % of potential buyers would pay at most €5000 for a light electric vehicle, with only 35.2 % willing to extend to €10,000, a threshold that places these vehicles in direct competition with entry-level A-segment conventional cars.

6. Implications

This study offers valuable insights for manufacturers, policymakers, and stakeholders in the EQs sector. EQs' design, safety, and market viability as sustainable urban mobility solutions can be improved by addressing the highlighted areas. Although EQs fall under categories with less rigorous safety regulations, manufacturers should aim to include safety features that exceed the basic standards. Incorporating advanced safety technologies – like ABS and robust structural designs, including monocoque frames and aluminium exoskeletons – has been consistently appreciated, providing experts with a sense of security during EQ testing. There is an evident necessity for increased safety features, which manufacturers are beginning to implement in their forthcoming EQ models. For instance, the Renault Twizy's successor, the Mobilize Duo, is scheduled for launch in 2025 and will feature an airbag. Similarly, the City Transformer CT-2, anticipated to begin production at the end of 2026, will include ABS, an ESP, airbags, blind spot warning, and a collision prevention system.

Additionally, experts often emphasised comfort-related concerns, especially regarding NVH. The rigid suspension systems and inadequate seat padding make driving uncomfortable, particularly on uneven urban roads. To tackle these challenges, manufacturers must persistently enhance suspension systems, upgrade seat ergonomics, and implement better cabin insulation. This also pertains to underperforming HVAC systems that often detract from driving comfort. The high purchase price of EQs, disproportionate to their features and quality, further poses a barrier to widespread adoption. This challenge is exacerbated in regions lacking government subsidies for EQs. Policymakers should consider extending EV incentives to include EQs, as demonstrated by Spain's Moves III programme, which offers substantial subsidies for EQ purchases. For instance, the programme provides up to €1400 without scrapping and €1600 with scrapping for the L6 category and higher amounts for the L7 category. EQs are inherently suited for urban environments due to their compact size and agility. Municipal governments can further lower overall costs by enacting supportive policies, such as decreasing parking fees and considering the space-saving benefits of EQs. The concept of battery-swapping technology in EQs is attractive due to its convenience and flexibility. However, the full potential of this technology is hindered by the lack of supporting infrastructure. To realise the benefits of battery swapping, investment in infrastructure is crucial. Considering the design of these portable batteries, lightness and interoperability were the two main desired features. The study also revealed that EQs are often perceived as fun and enjoyable to drive, with agile handling similar to that of go-karts. Manufacturers can leverage this emotional appeal in their marketing strategies, emphasising the unique driving experience and the positive public reactions EQs elicit. Emphasising characteristics like large glass surfaces for improved visibility, roomy interiors offering much greater storage than other micromobility options, and unique design features like tandem seating or unconventional door designs can attract consumers seeking a novel, practical and enjoyable way to navigate urban environments easily. Lastly, while EQs have limitations compared to traditional cars, they effectively serve their intended purpose as practical urban mobility tools. Marketing strategies should emphasise positioning EQs as a

valuable complement to conventional vehicles, specifically suited for short commutes and adept at manoeuvring within urban settings.

7. Limitations

This study offers important insights into experts' views of EQs, but its limitations should be recognised to frame the findings and inform subsequent research. Although expert reviews provide comprehensive feedback on the EQs, they may only partially reflect the broader range of user experiences and opinions. While selection criteria emphasised objectivity, the possibility of manufacturer influence or bias in expert reviews cannot be entirely eliminated, as automotive journalists may be influenced through press events, manufacturer relationships, or access to review vehicles. A natural extension of this work could involve applying the methodology to social media platforms such as X, which would enable the identification of any additional topics not captured in this analysis and examine potential differences in sentiment polarity that people express regarding these vehicles. Moreover, the reviewed material is mainly from European sources; thus, the findings might reflect cultural and regional biases specific to Europe, which could be irrelevant to other markets, such as North America, Asia, or regions with distinct regulatory frameworks, urban settings, and consumer behaviours. This geographical bias constrains the global relevance of the outcomes. Future research should strive to include reviews and data from a more varied array of regions to better identify diverse cultural and market-related factors. Furthermore, the number of reviews per model was not uniform; popular models like the Microlino were reviewed more extensively than other models like SWAPA. This could inadvertently weight the overall results towards the features and sentiments associated with the most frequently reviewed models. Additionally, reviews written in German, Spanish, and Greek were translated into English using automated tools (DeepL), which may have introduced minor inaccuracies in tone or nuance despite the high quality of machine translation. Although this study systematically searched across multiple outlets using predefined criteria, it is possible that not every eligible review was captured, and the dataset should therefore be regarded as near-comprehensive rather than exhaustive. Lastly, the GPT-4 prompt refinement process was conducted using only 10 sentences, which represents a limitation in our implementation rather than the methodology itself. While this small sample successfully addressed the model's conservative bias toward neutral classifications, a larger sample would have provided more robust evidence for prompt optimisation. However, the subsequent validation on 300 sentences, which showed substantial inter-annotator agreement (Cohen's kappa = 0.78) and 90.33 % accuracy, provides confidence in the overall sentiment classification approach.

8. Conclusion

This study examined trends and challenges related to EQs. By integrating state-of-the-art topic modelling with advanced AI-driven techniques for generating embeddings, refining topic labels, and determining sentiment polarity, this study identified a coherent, thematically diverse set of topics and accurately captured the nuanced perspectives of experts across reviews. This analysis identified eight key themes: design and technology, driving experience, urban mobility and acceptance, performance, battery and efficiency, pricing options, market and production, and classification and regulations.

Within these themes, both anticipated and unexpected outcomes were observed. Overwhelmingly positive feedback regarding spaciousness was somewhat unexpected, given initial assumptions. While reviewers consistently praised EQs' fun, agile handling, this study confirmed that safety remains a pressing concern. The study extended this understanding by identifying specific safety measures that reviewers found promising, thereby enriching the current body of knowledge on safety-related aspects of EQs. Comfort also remained a challenge, with rigid suspensions, weak sound insulation, and heavy steering placing additional strain on daily usability. The analysis also uncovered nuanced performance limitations, particularly in hilly or cold conditions, extending previous technical insights into real-world usage contexts. Moreover, while battery swapping has emerged as a promising innovation, these observations suggest that supporting infrastructure remains a key priority for its widespread adoption. Equally, although EQs boast low operational costs, their high upfront prices and limited policy support currently constrain market appeal and accessibility. Thus, while sentiment toward EQs was generally positive – experts valued their spacious interiors, emotive and modular designs, and low running costs – this study advances existing knowledge by showing that persistent practical limitations moderate user enthusiasm.

Addressing these challenges through targeted infrastructure development, more effective policy incentives and iterative product refinements will be critical to unlocking EQs' full potential. As urban landscapes continue to evolve, such measures will ensure that EQs remain not only relevant and appealing but also genuinely enhance sustainable mobility for a diverse range of users.

Data availability

The dataset is available on the Zenodo and can be accessed at https://doi.org/10.5281/zenodo.14501242.

CRediT authorship contribution statement

Ondrej Havran: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **David Watling:** Writing – review & editing, Supervision. **Haibo Chen:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Jin Liu:** Writing – review & editing. **Wen-Long Shang:** Writing – review & editing. **Chengcheng Xu:** Writing – review & editing. **Dimitri Margaritis:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Haibo Chen reports financial support was provided by European Union. If there are other authors, they 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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