Travel Behaviour and Society 45 (2026) 101362

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

What technologically proficient communities want from V2X: transport–environment implications from online discussions

Ondrej Havran [a,*], David Watling [a], Haibo Chen [a], Wen-Long Shang [a], Ye Liu [a], Chenxi Wang [a], Zhao Wang [a], Dingsong Cui [a], Dongyao Ji [a,b]

[a] Institute for Transport Studies, University of Leeds, Leeds LS2 9JT, United Kingdom
[b] School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou 215123, China

ARTICLE INFO

Keywords:
Bidirectional charging
Electric vehicles
Energy resilience
Artificial intelligence
Consumer behaviour

ABSTRACT

While bidirectional charging offers substantial environmental benefits, user acceptance through online social network discourse remains underexplored. This study analyses 11,454 comments to map perceptions of vehicle-to-grid (V2G), vehicle-to-house (V2H), and vehicle-to-load (V2L) using topic modelling and large language model (LLM) sentiment classification. The sample is characterised as a pre-mainstream, tech-savvy early-adopter community in which V2X is currently being evaluated, whose articulated priorities and concerns illuminate early-market dynamics. Nine topics were identified, with sentiment analysis achieving 81.8% accuracy through a cost-efficient model that outperformed premium alternatives. Overall sentiment was positive-leaning (39% positive, 33% neutral, 28% negative), revealing a clear preference hierarchy: users prioritise personal resilience (V2L/V2H) over grid services (V2G), while fleet applications received strong approval. Beyond confirming known barriers (compensation expectations, battery concerns, and minimum charge requirements), this study uncovered user-driven insights, including the cognitive burden of V2G management, cost, health, and safety comparisons with alternatives such as gas generators, and repurposing older electric vehicles (EVs) for storage. Findings inform design, product, and communication strategies targeted at the early-market segment, while demonstrating scalable methods for monitoring opinions on emerging transportation technologies.

1. Introduction

The electrification of transport marks a pivotal shift in the global energy system, with the potential to substantially cut greenhouse gas emissions and improve urban air quality. The transport sector is responsible for about one quarter of global energy-related carbon dioxide (CO_2) emissions, according to the International Energy Agency (IEA, 2024), making its decarbonisation essential to meeting international climate goals. In response, the adoption of electric vehicles (EVs) has accelerated rapidly, with sales reaching nearly 14 million in 2023 and projected to rise to 17 million in 2024, while the global fleet is expected to expand eightfold by 2035 (IEA, 2024). At the same time, this rapid electrification reshapes electricity demand profiles, introducing new environmental and systemic challenges. EVs consumed about 180 terawatt-hours (TWh) of electricity in 2023, representing 0.5% of global demand, yet this share is expected to rise to 6–8% by 2035 (IEA, 2024). Without managed charging, the rising electricity demand from EVs could intensify peak loads, prompting greater reliance on fossil-fuelled generation and eroding the anticipated environmental gains. Concurrently, vast quantities of renewable electricity continue to be curtailed because it cannot be stored or absorbed into the grid (Bird et al., 2016), representing a lost opportunity for emissions reduction. Aligning transport electrification with clean energy utilisation, therefore, requires intelligent, flexible energy systems that can smooth demand

Abbreviations: AC, Alternating Current; AI, Artificial Intelligence; API, Application Programming Interface; BERTopic, Bidirectional Encoder Representations from Transformers; DC, Direct Current; EV, Electric Vehicles; GW, Gigawatt; HEMS, Home Energy Management System; kWh, Kilowatt-hour; LDA, Latent Dirichlet Allocation; LFP, Lithium-iron Phosphate; LLMs, Large Language Models; MMR, Maximal Marginal Relevance; MWh, Megawatt-hour; NLP, Natural Language Processing; OSNs, Online Social Networks; PV, Photovoltaic; SoC, State-of-charge; ToU, Time-of-use; TWh, Terawatt-hour; UGC, User Generated Content; UMAP, Uniform Manifold Approximation and Projection; VADER, Valence Aware Dictionary and sEntiment Reasoner; V2G, Vehicle-to-Grid; V2H, Vehicle-to-House; V2L, Vehicle-to-Load; V2X, Vehicle-to-Everything, V1G, Smart Unidirectional Charging; DIY, Do It Yourself.

* Corresponding author.
E-mail address: o.havran@leeds.ac.uk (O. Havran).

https://doi.org/10.1016/j.tbs.2026.101362
Received 6 November 2025; Received in revised form 9 June 2026; Accepted 21 July 2026
Available online 27 July 2026

peaks, store surplus renewables, and enable low-carbon mobility at scale.

While smart unidirectional charging (V1G) enhances charging efficiency through optimised scheduling, EVs continue to function as a load on the grid. Bidirectional charging technologies, collectively referred to as vehicle-to-everything (V2X), extend this capability by allowing EVs to also discharge stored energy back to the grid (V2G), to households (V2H), or to external loads (V2L), among others. This dual functionality transforms vehicles from passive energy consumers into active, distributed energy resources capable of absorbing excess renewable generation, reducing peak electricity demand, and supplying zero-emission backup power.

Consequently, V2X represents a critical technology for integrating transport and energy systems, improving grid flexibility, and maximising the environmental benefits of vehicle electrification. Yet realising these environmental gains hinges fundamentally on widespread user adoption and sustained participation. If users are reluctant to enable energy export due to concerns about battery degradation, mobility constraints, or insufficient compensation, the environmental advantages of V2X may remain theoretical rather than operational. Recognising the importance of this understanding, researchers have increasingly examined public perceptions of bidirectional charging, predominantly through structured methods such as questionnaires, interviews, and customer surveys (Geske and Schumann, 2018; van Heuveln et al., 2021; Mehdizadeh et al., 2023; Dean and Kockelman, 2024; Khezri et al., 2024). While these methods have proven valid and reliable when designed carefully (Greenberg and Weiner, 2014), they typically elicit individual reflections to predefined questions rather than spontaneous, socially constructed opinions. Nevertheless, as Moussaïd et al. (2013) argue, people often form views through informal online discussions where peer interactions shape beliefs and technology acceptance emerges collectively (Klein and Kleinman, 2002); hence, relying solely on structured methods risks missing organically formed perspectives and innovations that develop through everyday online exchanges.

This study addresses this gap by adopting Rogers' Diffusion of Innovations framework (Rogers et al., 2014), extended with Moore's (1998) chasm concept, to analyse naturally occurring discourse from online social networks (OSNs) and complement existing survey-based research. We collected approximately 17,000 comments covering V2G, V2H, and V2L discussions through March 2025, of which 11,454 remained after preprocessing, creating the first comprehensive V2X online social network dataset to our knowledge. Although these technologies are attracting growing interest and shifting from experimental ideas to practical, deployable systems, they are not yet mainstream, and the users actively seeking out and discussing them constitute a pre-mainstream, tech-savvy community. Reddit serves as a rich source of this discourse, with its topic-specific subreddits and technically engaged user base (Proferes et al., 2021) concentrating precisely on this segment. To extract sentiment polarity across key themes, the study integrates large language models (LLMs) for sentiment classification and systematically evaluates multiple models across cost tiers to establish a scalable framework for domain-specific sentiment analysis. Considering that online samples are non-random and may not represent broader populations (Reveilhac et al., 2022), this approach complements rather than replaces conventional surveys, which elicit individual responses to predefined questions rather than capturing the socially negotiated, unprompted priorities that emerge through peer discourse. While this methodological approach offers unique insights into organically formed perspectives, it also introduces platform-specific biases and geographic heterogeneity that require careful interpretation.

2. Literature review

The following sections first examine the technical capabilities and applications of V2X **(2.1)**, **(2.2)**, **(2.3)**; then review existing research on public perception and acceptance **(2.4)**, before discussing the methodological approaches – topic modelling **(2.5)**, sentiment analysis **(2.6)** – that this study employs to analyse the online discourse landscape. Finally, Section 2.7 introduces the Diffusion of Innovations framework and Moore's (1998) chasm extension, establishing the pre-mainstream early market as the theoretical lens for interpreting online tech-savvy community discourse, concluding with an identification of the specific research gaps (**2.8**) this study addresses.

2.1. V2G

V2G technology transforms electric vehicles into distributed energy storage assets that can stabilise grids with high renewable penetration. By aggregating EV batteries to absorb excess renewable generation and discharge during peak demand, V2G provides grid services (frequency regulation, peak shaving, and load balancing) traditionally supplied by fossil fuel plants (Rao et al., 2025). This enables renewable integration while displacing carbon-intensive generation. Studies demonstrate substantial environmental potential: Boström et al. (2021) showed Spain's complete vehicle electrification could enable renewable self-reliance through 3.45 billion m2 of solar photovoltaic (PV), whilst Sassi et al. (2021) found Morocco could achieve 7.7 GW (GW) of V2G storage by 2030, reducing dependence on fossil fuel-balancing assets. Recent life cycle assessments further quantify these benefits: Ma et al. (2025) found V2G could reduce China's annualised emissions by 8.7–26.9 million tonnes (2021–2060), while Wohlschlager et al. (2024) demonstrated 50–200% operational emission reductions compared to uncontrolled charging in Germany. V2G also substitutes stationary battery capacity (117 GWh), reducing raw material demands (Wohlschlager et al., 2024).

2.2. V2H

V2H operates at the household level, using EV batteries to supply residential electricity demand. While V2G focuses on grid stabilisation, V2H prioritises household energy autonomy and resilience, particularly during outages and peak pricing periods (Varajão et al., 2017; Eltohamy et al., 2025). When integrated with rooftop solar, V2H allows households to store excess daytime generation for evening use, maximising renewable self-consumption and reducing fossil fuel dependence (Ghias et al., 2025). Studies demonstrate that V2H systems paired with solar PV and home energy management can reduce grid dependence by over 60% while creating revenue opportunities through energy arbitrage (Satpathy et al., 2025). Importantly, aggregated V2H adoption produces collective benefits beyond individual households. When many homes simultaneously reduce peak demand through V2H, this alleviates grid stress during critical periods (Buonomano, 2020), creating environmental benefits similar to V2G but emerging from decentralised household decisions rather than centralised grid coordination.

2.3. V2L

V2L represents the most accessible among the three solutions, enabling vehicles to power external loads through standard alternating current outlets without requiring a complex bidirectional charging infrastructure (Letcher and Britton, 2025). Operating at relatively low voltage levels (e.g., 120 V) compared to V2H and V2G systems (e.g., 240 V), V2L transforms EVs into versatile mobile power sources suitable for diverse applications, including construction sites, camping, outdoor events, and disaster relief scenarios where portable power is essential or grid access is limited. The technology's integration into vehicle design through onboard chargers offers significant advantages, making it more cost-effective for immediate implementation while avoiding the expense of additional external equipment and installation requirements. However, this onboard approach also constrains output power levels, with commercially available V2L systems typically providing 2.2–3.6 kW (kW) of power capacity. Despite this limitation, current power levels are

sufficient for critical applications such as providing backup power in rural areas with limited grid support and serving as clean alternatives to diesel or gasoline generators (Tian et al., 2024).

2.4. Social acceptance

As stressed earlier, public acceptance ultimately determines whether V2X technologies achieve their environmental potential, as consumer attitudes shape adoption rates, which in turn influence investment decisions and policy development (Davis, 1989; Ajzen, 1991; Rogers et al., 2014). Existing research, primarily derived from structured surveys, has identified several consistent patterns in how the general population evaluates these technologies. Together, this body of work provides a baseline against which this study compares early adopter discourse, allowing for an examination of whether early adopters' priorities align with or diverge from the broader market expectations identified in academic findings. Considering quantitative studies first, Geske and Schumann (2018) surveyed 611 German vehicle users, finding that a guaranteed minimum state-of-charge (SoC) at departure (i.e., a reserved residual driving range) increases V2G participation more than monetary incentives. Mehdizadeh et al. (2024) surveyed 929 Norwegian car users, finding that trust, perceived usefulness, and ease of use contribute to adoption, though non-EV users reported less favourable attitudes. Their earlier work (Mehdizadeh et al., 2023) found Norwegians required compensation equivalent to ~ 72% of average monthly electricity bills (≈$144 at 2021 prices) and a minimum SoC of ~ 71%. Furthermore, studies comparing V2X applications show households value V2H more than V2G: Dean and Kockelman (2024) found Americans willing to pay $280 for V2L and $776 for V2H, with only 51.3% accepting V2G during emergencies if compensated at $0.70 per mile of temporarily reduced range and guaranteed a minimum residual driving range of 50 miles, while Khezri et al. (2024) found Swedish drivers expressed greater interest in V2H than V2G. In light of qualitative studies, van Heuveln et al. (2021) interviewed twenty Dutch EV drivers, finding that V2G acceptance depends on financial compensation, transparent information, and user control, while range anxiety, discomfort, and battery degradation deter uptake. Similarly, Hu et al. (2025) reported that private EV owners prioritising battery longevity often express concerns about potential accelerated degradation from V2G usage, whereas more technologically confident users demonstrate reduced apprehension. Lastly, several systematic reviews have synthesised these findings: Liu et al. (2025) reviewed 87 related studies and identified the main antecedents influencing V2G acceptance as those related to the product, the individual, and the economy, while Goncearuc et al. (2024) categorised 23 barriers into autonomous (e.g., privacy and range anxiety), dependent (e.g., charging control), linkage (e.g., low EV penetration), and driver barriers (e.g., market entry or cybersecurity).

2.5. Topic modelling

Research reveals a methodological imbalance in EV studies, with Secinaro et al. (2022) finding that 76% of 254 consumer behaviour studies used quantitative "top-down" approaches, compared to Bryła et al. (2023), who identified just six of 44 adoption studies that utilised "bottom-up" qualitative techniques. In response, recent EV-related studies have examined public opinion on OSNs (Ruan and Lv, 2022; Ruan and Lv, 2023; Pani et al., 2023; Liao et al., 2024). Given the exponential growth of user-generated content (UGC) on OSNs, manually analysing thousands of comments would be prohibitively time-consuming. Topic modelling addresses this challenge by using computational algorithms to identify significant themes within textual collections through patterns of word co-occurrence, clustering related terms into coherent groups that reveal hidden structures without requiring prior knowledge of the content. While EV studies historically relied on Latent Dirichlet Allocation (LDA) (Liao et al., 2019; Pani et al., 2023; Qin et al., 2024), a probabilistic model that assumes documents contain mixtures of topics based on word co-occurrence patterns, Bidirectional Encoder Representations from Transformers (BERTopic) has emerged as a more effective topic modelling tool in natural language processing (NLP) applications, employing transformer-based embeddings that capture deep contextual and semantic nuances (Grootendorst, 2022). Despite this methodological potential, only a few studies have applied topic modelling to analyse EV charging discourse on OSNs. Tang et al. (2024) used LDA on Chinese social networks to identify five themes, including infrastructure, green travel, and battery technology, finding concerns about charging speeds and facility malfunctions alongside positive responses to fast charging, whereas Ashby et al. (2025) employed BERTopic to analyse 97,168 Twitter posts (2018–2022), identifying nine themes spanning technology, infrastructure, policy, costs, and environmental issues. Both studies found sentiment polarised around infrastructure quality, positive toward fast charging and new deployments, and negative toward broken chargers, cost increases, and access inequities. However, to the author's knowledge, no existing research has applied topic modelling to OSNs discourse specifically on bidirectional charging.

2.6. Sentiment analysis

Sentiment analysis extracts opinions, attitudes, and emotions from text, and researchers often combine it with topic modelling to understand both what people discuss and how they feel about it. The field has evolved through distinct stages. Early approaches relied on lexicon-based tools like Valence Aware Dictionary and sEntiment Reasoner (VADER) (Hutto and Gilbert, 2014), which became popular for OSNs analysis (Suresha and Tiwari, 2021; Ruan and Lv, 2022), though they struggled with context-dependent language. Machine learning methods improved accuracy by learning from labelled datasets, but required extensive training data. Artificial Intelligence (AI) represents the latest advancement in this field, with LLMs serving as an advanced form of transfer learning models. Unlike earlier approaches that required extensive training on labelled datasets, LLMs can often classify sentiment directly through prompting, making them efficient and effective solutions across different types of text (Zhang et al., 2023). The contemporary LLM landscape is characterised by rapid innovation, with technology companies continuously releasing models across different performance and cost tiers. Cost-efficient models such as Gemini-2.0-flash, DeepSeek, GPT-4o Mini, and Claude-3-Haiku offer accessible entry points, while more expensive models, including Gemini-1.5-Pro, GPT-4o, Claude-3-Opus, and Grok, provide enhanced capabilities for complex analytical tasks. To illustrate the price disparity, GPT-4o Mini costs approximately $0.15 per million input tokens versus Claude-3-Opus at $15, a 100-fold difference (as of April 2025). Despite this diversity of available models, EV research studies have typically relied on single LLM implementations to determine sentiment polarity (Fu et al., 2025; Yu et al., 2025), which limits robustness, as model performance can vary across different text types (Chang et al., 2024).

2.7. Diffusion of Innovations, early adopters and online discourse

Understanding user acceptance of emerging transport–energy technologies requires situating their discourse within a theoretical account of how innovations spread. Rogers et al. (2014) Diffusion of Innovations framework distinguishes five adopter categories, consisting of innovators (≈2.5%), early adopters (≈13.5%), early majority (≈34%), late majority (≈34%), and laggards (≈16%), differentiated by the time at which members adopt an innovation relative to the rest of the population. Egmond et al. (2006c) consolidate these into two strategically meaningful blocs, including an early market of innovators and early adopters with a visionary attitude, and a mainstream market of the early and late majority, and laggards who are more pragmatic. Early adopters are vision-driven and motivated by future opportunities, willing to bear the bugs and setbacks of an innovation newly arrived on the market in

pursuit of strategic advantage, whereas mainstream adopters hold a more pragmatic attitude oriented towards current problems, adopting only once an innovation offers a reliable, affordable solution that minimises discontinuity with their existing operations (Moore, 1998; Egmond et al., 2006b).

Because the two blocs evaluate innovations by such different criteria, diffusion does not unfold smoothly across them, producing what Moore (1998) calls the "chasm" between the early and mainstream markets. Crossing it is the commercial test that determines whether an emerging technology scales or stalls; indeed, Li et al. (2025) identify the gap between early adopters and the early majority as the widest and most distinct of those separating adjacent adopter categories. Egmond et al. (2006a) show what a failure to cross it looks like in practice, many sustainable-energy products, including solar water heaters and photovoltaic systems, stall not because the underlying technology is poor, but because they remain incomplete in Moore's (1998) sense, failing to meet the pragmatic needs of the mainstream.

Moore (1998) describes crossing the chasm as a staged process that begins by winning a single, well-defined beachhead segment before expanding outward. This study treats the early-adopter community studied here as Moore's early market, the staging ground whose priorities must be understood and won first, and whose references and feedback condition any subsequent crossing toward the pragmatic mainstream. Its technology enthusiasts serve as a test bed where the product is refined and debugged, making their articulated evaluations directly actionable for product and policy refinement.

Although these technologies are attracting growing interest and shifting from experimental ideas to practical, deployable systems, they are not yet mainstream (Caban et al., 2026); V2G, in particular, remains mostly confined to utility pilot schemes (Shang et al., 2026). So anyone using V2X today is, by definition, part of the small pre-chasm early market. The Reddit commenters analysed here are accordingly treated as a source of early-adopter discourse on V2X, prospective adopters in Rogers' knowledge and persuasion stages alongside already-adopting pioneers of closely adjacent technologies such as electric vehicles, residential solar, and home-energy management systems. Reddit offers a practical window into this community. The platform's own audience research reports that 53% of its users say they are the first in their friend group to buy new gadgets, a larger share than users of TikTok, YouTube, or Twitter, and 60% regularly recommend new products to people they know (Reddit, 2023). These behaviours match the opinion-leader profile that Rogers et al. (2014) links to early adopters. Academic research also supports this picture, with Proferes et al. (2021) finding that Reddit users are typically tech-savvy and that topic-specific subreddits bring these users together to discuss emerging technologies.

Analysing online discourse offers methodological advantages beyond simply sampling early markets' perspectives. Even when structured research methods include early adopters, predefined questions constrain what respondents articulate, and individual reflection differs from socially constructed opinions (Moussaïd et al., 2013). In contrast, analysing naturally occurring "chatter" provides more efficient access to innovation insights, as users spontaneously articulate solutions, barriers, and requirements in peer-to-peer contexts, avoiding researcher influence effects such as Hawthorne bias (Cook, 1962; Muis et al., 2020) while preserving contextual richness (e.g., tone, analogies, and counterarguments) often absent from structured surveys (Swain and King, 2022). This reveals unanticipated themes and user-developed innovations that researcher-structured instruments might miss.

2.8. Research gap

Despite growing research on V2X acceptance **(2.4)**, existing studies rely predominantly on "top-down" methods like surveys and interviews that may miss spontaneous, organically formed perspectives. As noted in **(2.5)**, "bottom-up" analyses of UGC have only recently emerged for general EV charging infrastructure, with no dedicated study examining online user discourse on bidirectional technologies specifically. This gap is critical: V2X's environmental potential, from grid decarbonisation to renewable integration, depends fundamentally on user adoption, yet research lacks insight into how technologically engaged communities spontaneously discuss these technologies in unstructured contexts. This study addresses this gap by analysing online V2X discourse using BERTopic and multiple LLMs for sentiment analysis, drawing on Rogers' Diffusion of Innovations framework and Moore's chasm **(2.7)** to interpret findings as evidence of priorities and concerns within the pre-mainstream, tech-savvy community in which V2X is currently being evaluated. By examining these naturally occurring discussions, this research informs design, product, and communication strategies targeted at this early market, the prerequisite, in Moore's (1998) framework, for any subsequent broadening towards mainstream consumers.

2.9. Research questions

RQ1: What are the primary themes discussed by users regarding V2X technologies in online communities? [This identifies the substantive topics that dominate discourse among these technologically engaged early adopters, revealing which aspects of bidirectional charging resonate most strongly.].

RQ2: What is the sentiment of users toward V2G, V2H, and V2L? [Sentiment distributions across the three V2X applications reveal potential adoption barriers and enablers as perceived within this early-adopter community.].

RQ3: How do user discussions compare to barriers identified in academic literature? [Comparing the themes emerging from user discussion with barriers documented in structured survey studies tests whether existing academic frameworks capture the priorities voiced by engaged early adopters.].

RQ4: Which LLMs demonstrate superior performance for V2X sentiment analysis? [Evaluating multiple LLMs across cost and performance tiers establishes best practices for scalable sentiment analysis in transportation research, enabling cost-effective monitoring of user discourse on emerging technologies and informing methodological choices for future OSNs-based studies in transport and environmental domains.].

3. Methodology

The methodology for this study, as illustrated in Fig. 1, comprises four main steps: (1) data collection and preprocessing, (2) topic modelling, (3) sentiment analysis, and (4) interpretive analysis.

3.1. Data collection and preprocessing

We collected comments from posts across 33 EV-related subreddits using PRAW v7.7.1 (Reddit Application Programming Interface [API]) with no timeframe restrictions (through March 2025). Following established practices (Chen and Tomblin, 2021), posts were retrieved using three sorting methods ("new", "hot", and "top") to ensure comprehensive coverage. All data were anonymised and publicly available, consistent with ethical research standards (Wu et al., 2025). The preprocessing pipeline removed comments that were null, empty, or marked as [removed]/[deleted]. Comments shorter than five words were excluded to avoid vague inputs. Regular expressions filtered generic content ("Thanks for the info") and boilerplate text (bot signatures). Additional cleaning removed URLs, emojis, Reddit markdown, and quoted text. After these steps, the dataset was reduced from ~ 17,000 collected comments to 11,544. To ensure discourse authenticity, we leveraged Reddit's intrinsic 'human–machine' regulation system, where automated tools (e.g., AutoModerator) and volunteer moderators proactively remove commercial spam and other undesirable content (Jhaver et al., 2019). While this system is intended to substantially reduce systemic corporate advertising, we performed a final keyword

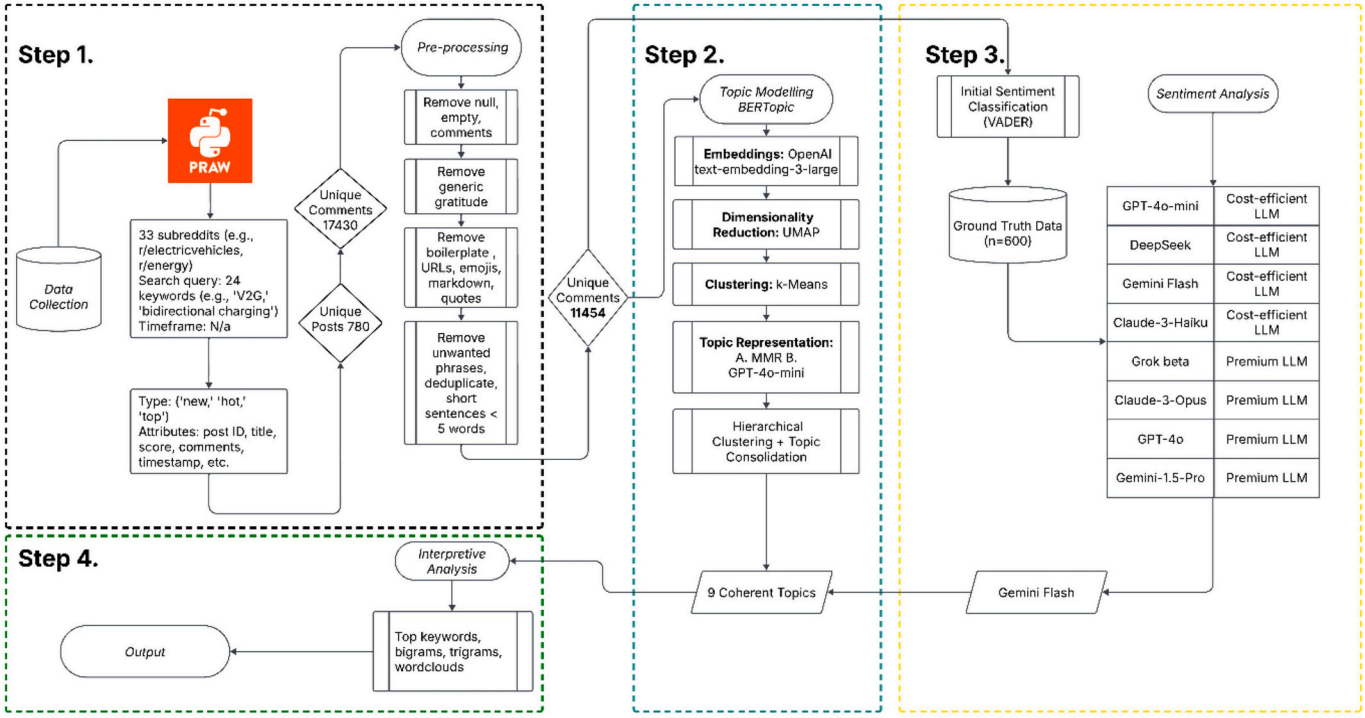


Fig. 1. Pipeline overview: reddit-based topic modelling and sentiment analysis on V2X-related discussions.

validation to detect residual promotional indicators (e.g., 'promo code', 'discount', 'promotion'). We found no evidence of promotional content that would artificially steer both sentiment and discussion topics. A final manual screening identified and excluded 90 irrelevant entries, producing a cleaned and final dataset of 11,454 comments for analysis.

3.2. Topic modelling

This study subsequently employed BERTopic (Grootendorst, 2022) for topic identification, chosen over traditional LDA approaches for its superior performance in capturing semantic nuances through transformer-based embeddings. Table 1 details the five-stage configuration. Ultimately, topic quality was assessed using coherence (CV) and diversity metrics implemented through the Gensim library (Řehůřek, 2011). In addition, Chi-square analysis was conducted to examine associations between topics and subreddit communities.

3.3. Sentiment analysis

We evaluated eight LLMs for sentiment classification accuracy across three classes: positive, negative, and neutral. Two independent annotators manually labelled 600 comments, sampled using stratified sampling (200 per class) via VADER, a method inspired by Borg and Boldt (2020). This sample size aligns with recent LLM benchmarking research, such as Maceda et al. (2023), which utilised a 600-sample "gold standard" to effectively validate GPT-4's performance on complex social media text and further doubles the 300-comment validation sets used in comparable studies (e.g., Havran et al., 2025). Inter-annotator agreement was assessed using Cohen's kappa (Gwet, 2014). A third annotator resolved disagreements. Additionally, we applied zero-shot prompting (Sahoo et al., 2024) with role-playing instructions (OpenAI, 2024b) and temperature = 0 for deterministic, reproducible results. Complete prompt engineering details, including system instructions, are provided in Appendix A: **LLM Sentiment Analysis Protocol** to ensure full reproducibility of the presented sentiment classification approach. Model performance was compared using accuracy, precision, recall, F1-macro, and Cohen's kappa. Statistical significance was assessed using McNemar's test. The best-performing model was

Table 1
Summary of the methodological stages in the topic modelling pipeline.

Stage	Method	Key Parameters	Rationale
Embeddings	OpenAI text-embedding-3-large (OpenAI, 2024a)	*Dimensions: 3,072*	Captures deep semantic relationships between sentences for accurate topic formation
Dimensionality Reduction	Uniform Manifold Approximation and Projection (UMAP)	*n_components = 10, n_neighbors = 13, min_dist = 0.0, metric='cosine', and random_state = 42*	Preserves local structure while enabling efficient clustering in lower-dimensional space
Clustering	k-means	*k = 50 (tested 25, 50, 75, 100)*	Provides balanced topic granularity without excessive fragmentation
Representation	Maximal Marginal Relevance (MMR; Carbonell and Goldstein, 1998) + GPT-4o-mini	*diversity = 0.5, stop_words="english", min_df = 10, max_df = 0.8, ngram_range=(1, 2)*	Generates varied yet representative keywords and interpretable topic labels
Consolidation	Hierarchical clustering + manual semantic review	—	Reduces redundancy and merges semantically similar topics while preserving distinctiveness

applied to classify the entire dataset. Additionally, chi-square tests of independence were conducted to examine associations between sentiment classes and discussion topics. Lastly, to assess the stability of classification under prompt variation, this study additionally compared three prompt variants, including the original production prompt, a stripped version without domain framing or role instructions, and a few-shot version augmented with six worked examples (two per sentiment class) on the same 600 manually labelled comments.[1] Full prompt texts are provided in Appendix A**: LLM Sentiment Analysis Protocol**.

3.4. Interpretive analysis

For each topic, we extracted top keywords (n = 15), bigrams, and trigrams, generating word clouds for visualisation. Representative quotes were paraphrased to prevent identification. Monetary values include clarifying context in square brackets for international/longitudinal comprehension.

4. Results

This section begins with an exploratory data analysis of the dataset, followed by the distinct topics identified through topic modelling, detailing their key sub-themes and prevalence. A comparison of sentiment analysis models follows and, finally, analyses of both overall and topic-level sentiment distributions.

4.1. Exploratory data analysis

As shown in Fig. 2, discussion of bidirectional charging has expanded markedly in recent years, reflecting the technology's growing visibility and commercial maturity. Discussion is highly concentrated, with the five most active subreddits accounting for over 70% of all comments, led by r/electricvehicles. The average comment length of 63.2 words indicates detailed exchanges rather than superficial engagement. The dataset comprises 4,164 unique contributors with a median contribution of 1.0 comments (mean: 2.75). While 58.5% contributed a single comment, a dedicated core of 7.9% made 11 + comments, accounting for 38.2% of total volume. The top 1% of contributors generated 21.2% of all comments. This broad base ensures the dataset captures diverse perspectives from both casual observers and regular engagers.

4.1.1. Topic modelling

The BERTopic model first identified 50 distinct topics. Through a systematic evaluation of topic relationships and proximity clustering via hierarchical clustering analysis, the original topics were consolidated into nine thematically coherent topics: (1) Energy Resilience, (2) Remuneration, (3) Hardware, (4) Market Landscape, (5) Charging Standards, (6) V2X Preferences, (7) Battery Longevity, (8) Solar Integration, and (9) Electric School Buses. The authors observed a CV of 0.81 and a topic diversity score of 0.53, meaning that the topics are highly coherent, with words within each topic being strongly related, and moderately diverse, indicating a reasonable balance between distinctiveness and overlap among topics.

4.1.2. Correlation analysis

Chi-square analysis consequently revealed significant associations between topics and subreddit communities ($\chi^2 = 7826.51$, $p < 0.001$, Cramér's V = 0.29), indicating that different aspects of bidirectional charging are discussed within distinct online communities with specialised interests. Several notable patterns emerge from the standardised residuals analysis. Solar Integration demonstrates the strongest community specialisation, being heavily over-represented in r/solar (std. residual = 36.67) and r/enphase (25.35), whilst being significantly under-represented in the general r/electricvehicles community (−13.93). Conversely, market-landscape discussion was over-represented in brand-centric subreddits (r/Rivian and r/teslamotors). Economic/participation aspects (remuneration) were more prominent in r/energy and r/cars, while hardware/wiring issues were concentrated in r/evcharging. Ultimately, charging-standards discussions clustered in r/leaf and battery-longevity debates in r/Futurology.

4.1.3. Topic breakdown

Fig. 3 provides the breakdown of topic distribution across the dataset. **Energy Resilience** emerged as the most prevalent theme, with discussions consistently framing EV batteries as dual-purpose assets capable of supporting both mobility and household energy needs, particularly during power outages. The emphasis on “home” and “house” in Fig. 4 illustrates that resilience is most often imagined at the domestic scale. Users frequently described powering essential appliances during outages for days, including refrigerators, freezers, lights, and even heating, ventilation, and air conditioning (HVAC) systems. Comparisons with alternative backup systems were likewise featured prominently (e.g., dedicated home batteries or gas/hydrogen generators), evaluating trade-offs in cost, capacity, and reliability. V2L emerged as a particularly accessible entry point, with participants describing how simple 12 V inverter setups could keep refrigerators, freezers, or other essentials running during outages.

At the community scale, **Electric School Buses** were also framed as powerful enablers of energy resilience. Although this was the smallest topic, it extended the household-focused vision of resilience toward public infrastructure and fleet-scale solutions. Users noted that school buses, which are idle for much of the day, could serve as distributed energy storage units, providing emergency backup power to schools, shelters, or the grid during peak demand. Discussions frequently referenced real-world implementations, such as Dominion Energy's planned deployment of electric school buses in Virginia, United States (US), and the Beverly, Massachusetts, V2G Program.

Remuneration discussions centred on compensation for V2X participation through direct payments, energy arbitrage, and alternative benefits. The core economic logic involved charging EVs during low-cost periods and discharging during high-demand peaks, arbitraging electricity price differentials. Octopus Energy's Powerloop pilot (launched ~ 2018, involving 130 + households in the United Kingdom [UK]) provided a frequently cited example, with participants reportedly saving up to £840 annually using Nissan Leaf EVs and bidirectional chargers to strategically time charge–discharge cycles. For solar owners, V2G/V2H became particularly relevant as net metering shifted from retail-rate credits to wholesale-only payments, prompting debates over whether storing excess solar in EV batteries for self-consumption delivered greater value than grid export. Alternative incentives, including free equipment installation, workplace charging, and parking benefits, also featured prominently.

A substantial share of the discussion focused exclusively on **Battery Longevity**. Users examined how repeated charge–discharge cycles in V2G and V2H applications might accelerate degradation. Chemistry considerations were mentioned, with lithium iron phosphate (LFP) batteries often highlighted for their durability, with emerging alternatives such as sodium-ion or “million-mile” batteries discussed as potential enablers of large-scale V2X deployment. Another recurring subtheme concerned warranty coverage, with questions about whether manufacturers would explicitly cover degradation. Users were also debating “second life” uses for retired EVs as home storage units.

Hardware revolved around the technical requirements for enabling bidirectional charging. Online users focused on transfer switches, which ensure safe switching between power sources, and inverters, which convert EV battery direct current (DC) to alternating current (AC), as well as main breakers that protect wiring from overloads. Further

[1] At the time of this robustness check, the original model (Gemini-2.0-flash) was no longer available through the API, so the prompt-variation analysis was conducted using its upgraded successor (Gemini-2.5-flash).

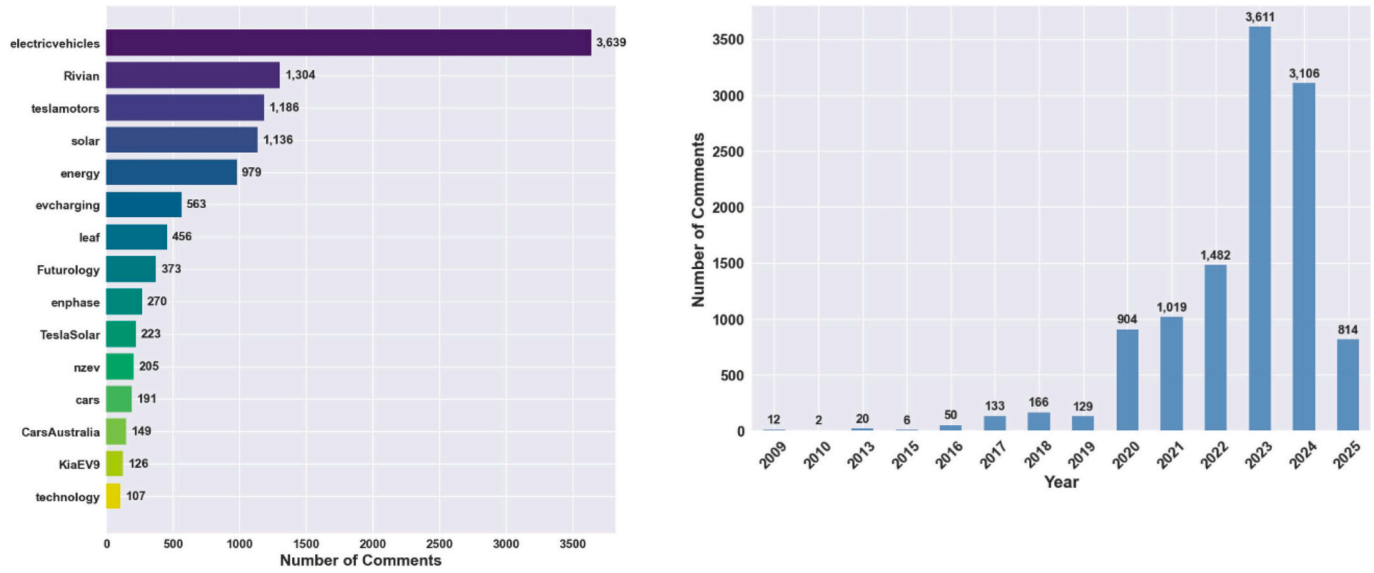


Fig. 2. Exploratory data analysis. Left: Top 15 subreddits, right: comments by year.

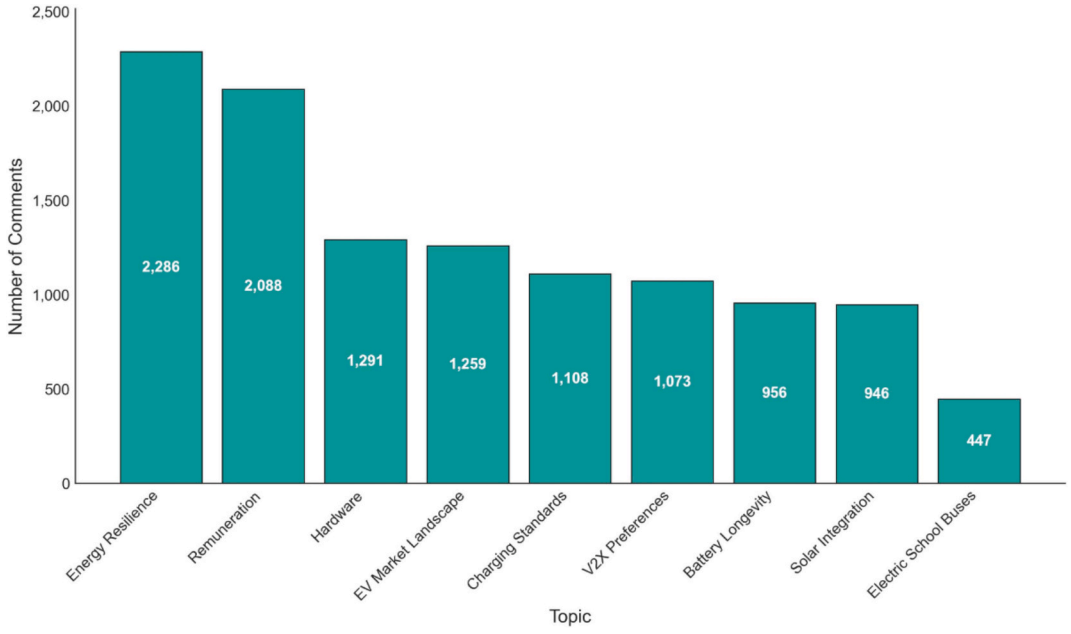
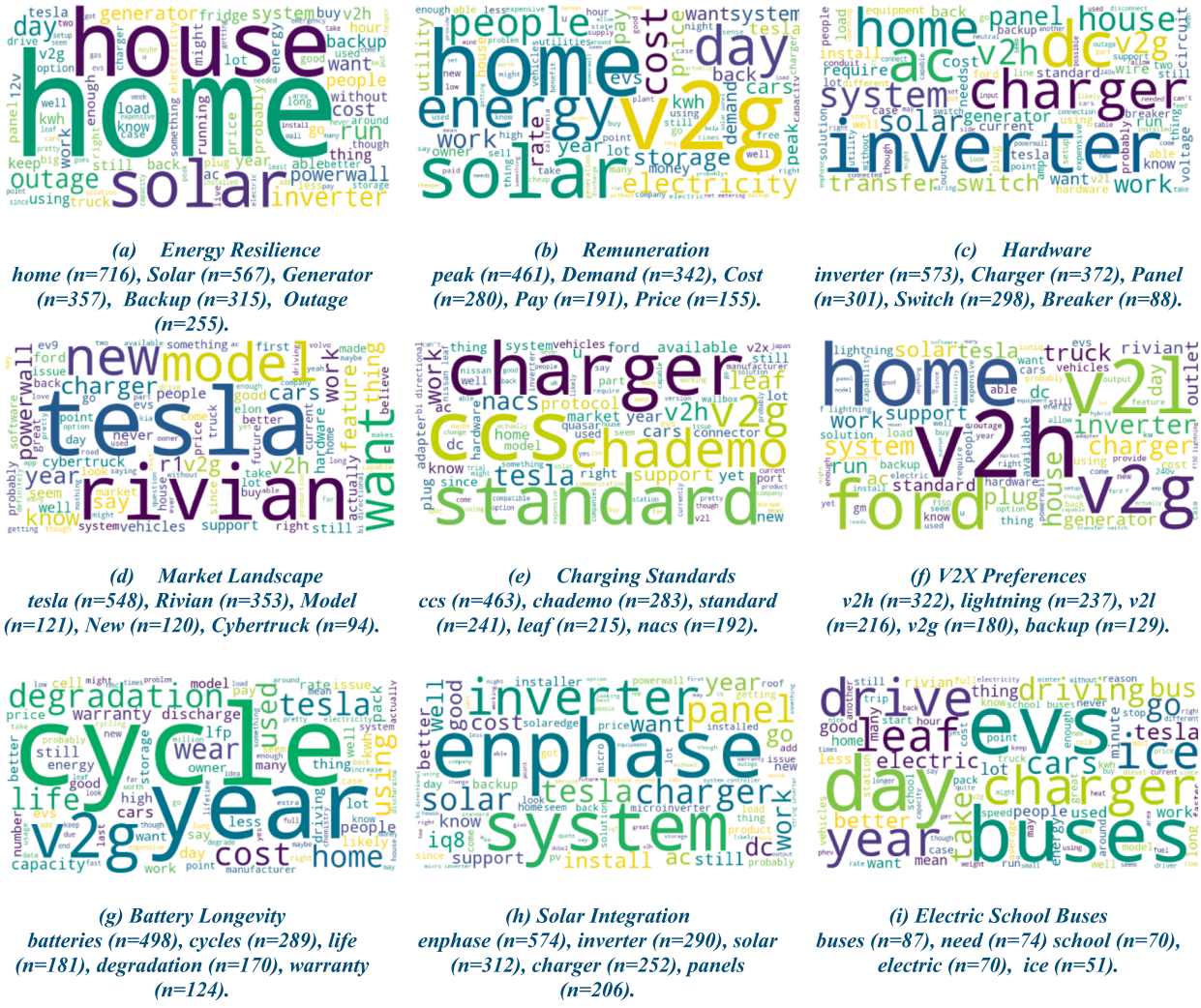


Fig. 3. Distribution of topics.

hardware considerations encompassed wiring infrastructure, main electrical panels, and sub-panels serving as distribution boards, together with voltage specifications critical for safe bidirectional transfer between vehicles and household systems. Notably, the "inverter" keyword appeared frequently not only within this topic but also across others such as Energy Resilience, V2X Preferences, and Solar Integration (see Fig. 4), reflecting its central focus in V2X discourse. **Solar Integration** extended these hardware-focused discussions into the broader context of renewable energy and vendor ecosystems. This topic highlighted how inverters, batteries, and bidirectional chargers intersect with solar PV systems and third-party technologies. Discussions heavily focused on Enphase vs Tesla ecosystems (e.g., Powerwall batteries, inverters, and apps), with users weighing the pros and cons of "all-in-one" ecosystems for seamless integration compared to mixing brands. Other brands like Wallbox, Sol-Ark, EG4, Franklin, SolarEdge, and Emporia are mentioned as alternatives.

Market Landscape captured automakers in their approaches to bidirectional charging. Tesla dominated these discussions, followed by Rivian, Ford's F-150 Lightning and Hyundai/Kia's E-GMP. Beyond specific brands, users reflected on market readiness and whether V2X was a mainstream purchase factor or a secondary consideration behind range, price, and performance.

Charging Standards emphasised that the viability of bidirectional charging is not only a matter of hardware or automaker strategy but also of interoperability and standardisation. Connector systems formed a core theme, with the Combined Charging System (CCS) widely regarded as the most likely pathway for future V2X deployment (users frequently referred to the ISO 15118–20 – an international standard that enables bidirectional power transfer and advanced communication between EVs and charging infrastructure [ISO, 2022]). By contrast, CHAdeMO was frequently cited as the first standard to enable V2G at scale, especially through the Nissan Leaf, but was seen as declining in relevance outside



(a) Energy Resilience
home (n=716), Solar (n=567), Generator (n=357), Backup (n=315), Outage (n=255).

(b) Remuneration
peak (n=461), Demand (n=342), Cost (n=280), Pay (n=191), Price (n=155).

(c) Hardware
inverter (n=573), Charger (n=372), Panel (n=301), Switch (n=298), Breaker (n=88).

(d) Market Landscape
tesla (n=548), Rivian (n=353), Model (n=121), New (n=120), Cybertruck (n=94).

(e) Charging Standards
ccs (n=463), chademo (n=283), standard (n=241), leaf (n=215), nacs (n=192).

(f) V2X Preferences
v2h (n=322), lightning (n=237), v2l (n=216), v2g (n=180), backup (n=129).

(g) Battery Longevity
batteries (n=498), cycles (n=289), life (n=181), degradation (n=170), warranty (n=124).

(h) Solar Integration
enphase (n=574), inverter (n=290), solar (n=312), charger (n=252), panels (n=206).

(i) Electric School Buses
buses (n=87), need (n=74) school (n=70), electric (n=70), ice (n=51).

Fig. 4. Thematic word cloud matrix key topics, with word size proportional to term frequency.

Japan. Meanwhile, Tesla's North American Charging Standard (NACS) was frequently discussed in relation to CCS.

Lastly, **V2X Preferences** captured how users compared the relative value of different bidirectional applications. A recurring theme was the perception that V2L delivers most of the practical benefits (powering appliances, tools, or essential loads) at minimal cost. V2H was framed as a premium solution, enabling whole-home backup and integration with heat pumps or HVAC systems, though installation requirements such as transfer switches and high costs were frequently raised. V2G was seen as the most ambitious application, but discussions highlighted its dependence on utilities, regulatory frameworks, and standardisation efforts.

4.2. Model performance evaluation

Following topic identification, sentiment analysis was performed to evaluate the emotional tone across these themes. 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, which resulted in a value of 0.884, indicating almost perfect agreement according to Cohen's scale (Gwet, 2014). Regarding the 46 comments where the two annotators did not reach a consensus, a third annotator was brought in to resolve the disagreements by providing a final decision for each disputed comment.

Following the inter-annotator agreement check, this study assessed the stability of classification under prompt variation. Across the three prompt variants, accuracy varied by less than one percentage point (spread = 0.7 pp), and Cohen's kappa against the manual ground truth was substantively unchanged ($\kappa = 0.643–0.652$). Pairwise McNemar tests detected no statistically significant differences between any pair of prompts (all $p > 0.7$). The classification is therefore robust to reasonable rewording of the instruction.

Table 2 presents a comprehensive evaluation of nine models across multiple performance metrics. Surprisingly, the cost-efficient Gemini-2.0-flash achieved the highest accuracy (81.8%), significantly outperforming most competitors, including premium models such as GPT-4o (76.3%) and Claude-3-Opus (70.7%). McNemar's test revealed that Gemini-2.0-flash significantly outperformed five of the eight comparison models ($p < 0.05$), with only DeepSeek showing statistically equivalent performance ($p = 0.932$). Table 3 reveals Gemini-2.0-flash's class-specific strengths and weaknesses. The model excelled at detecting negative sentiment (F1 = 0.90) and showed high recall for positive sentiments (94%) but struggled most with neutral sentiment classification (F1 = 0.76). This pattern suggests extreme sentiments are more easily identifiable than neutral positions in bidirectional discussions. Based on these results, all subsequent sentiment analyses employ Gemini-2.0-flash classifications.

4.3. Sentiment trends across topics

Fig. 5 presents the sentiment composition across discussion themes.

Table 2
Accuracy comparison of cost-efficient vs. Premium LLMs on sentiment classification.

Category	Model	Accuracy	Precision	Recall	F1-Macro	Cohen's K	McNemar p-value†
Cost-Efficient	Gemini-2.0-flash	0.818	0.823	0.830	0.818	0.729	–
	DeepSeek	0.815	0.839	0.804	0.814	0.717	0.932
	GPT-4o Mini	0.792	0.831	0.776	0.788	0.68	0.236
	Claude-3-Haiku	0.782	0.783	0.781	0.782	0.669	0.076
Premium	Gemini-1.5-Pro	0.773	0.776	0.785	0.771	0.662	0.014*
	GPT-4o	0.763	0.836	0.740	0.753	0.634	0.018*
	Claude-3-Opus	0.707	0.796	0.703	0.709	0.551	< 0.001***
	Grok	0.695	0.825	0.683	0.693	0.529	< 0.001***

Dataset: N = 600 comments. Ground Truth Distribution: Neutral (37.5%), Negative (35.2%), Positive (27.3%). †McNemar's test comparing each model against Gemini Flash. Significance levels: *p < 0.05, ***p < 0.001.

Table 3
Per-class performance of best-performing model (Gemini flash).

Category	Precision	Recall	F1-Score	Support
Negative	0.92	0.87	0.9	211
Neutral	0.85	0.68	0.76	225
Positive	0.7	0.94	0.8	164
Overall	0.82	0.83	0.82	600

A chi-square test of independence confirmed significant differences in sentiment distribution across topics, χ^2 (16, N = 11,454) = 640.99, p < 0.001, indicating that emotional tone varied systematically rather than by chance. As illustrated, overall sentiment was positive-leaning, with favourable or neutral opinions dominating most themes. Almost half of the discussions concerning Energy Resilience and Remuneration were positive, while Battery Longevity attracted the most negative reactions. Technical topics like Hardware and Charging Standards were largely neutral, indicating a fact-based exchange of opinions rather than emotional engagement. These differences show that user optimism concentrates where benefits are tangible and personal, whereas uncertainty about cost and durability drives negative emotion.

4.3.1. *The social prioritisation of household energy resilience*

Interpretive analysis revealed that positive sentiment was mainly driven by a prioritisation of energy security and self-reliance, with discussions consistently framing EVs as a solution for household energy resilience, particularly in regions experiencing frequent grid disruptions (see Fig. 6). This perspective was reinforced by users' focus on maximising the utility of an underutilised asset. Participants frequently noted that cars remain parked most of the time, framing the EV's large battery as an existing resource that could be leveraged more effectively. This was particularly relevant for multi-EV households who expressed interest in differential vehicle usage, dedicating one for transportation while utilising another for stationary energy storage *("I can't wait for V2H to become more common; if we had two EVs and some solar panels, one could easily keep the house running overnight while the other stayed charged for daily driving")*. A central and persuasive argument was the clear economic advantage of an EV over a dedicated home battery, highlighting its high relative advantage compared to standalone storage systems (Rogers et al., 2014). Users performed direct comparisons, with one stating, *"My car has a 78-kWh battery, and to get the same amount of storage using Powerwalls, I would need more than five of them, which would cost around twenty thousand USD."* Because the EV battery has already

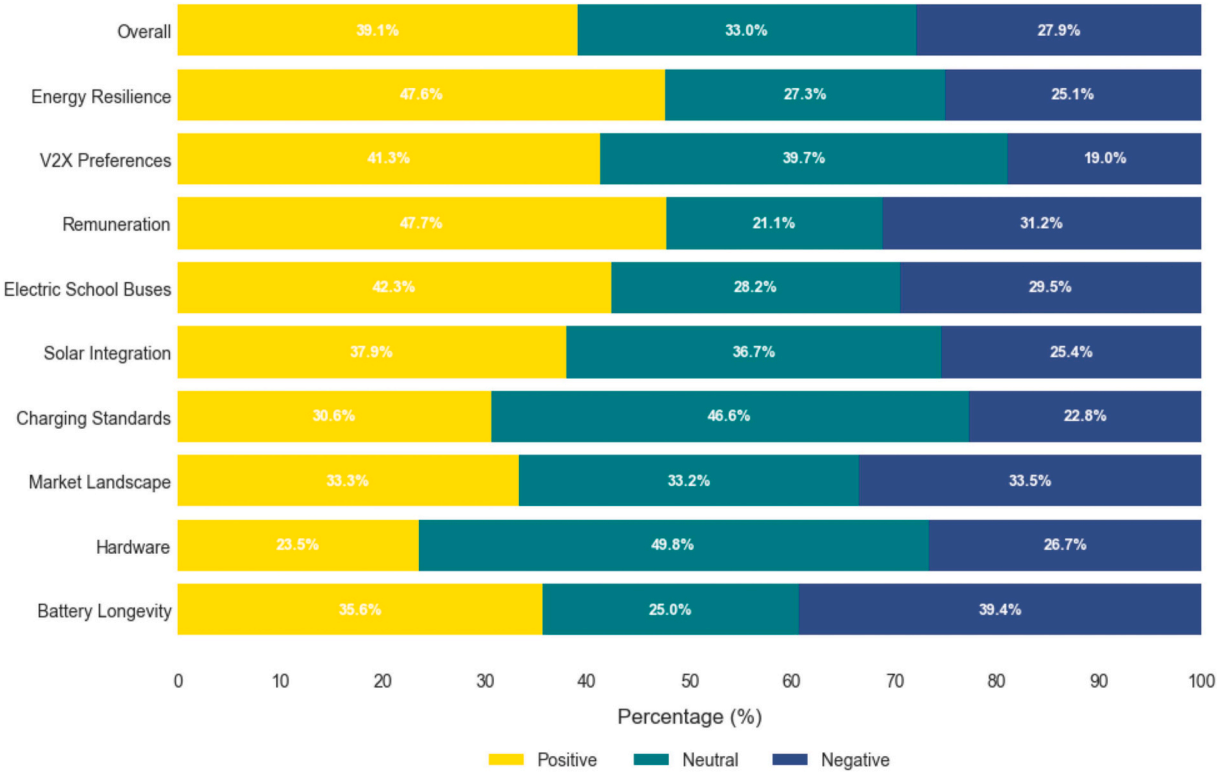


Fig. 5. Sentiment distribution across topics.

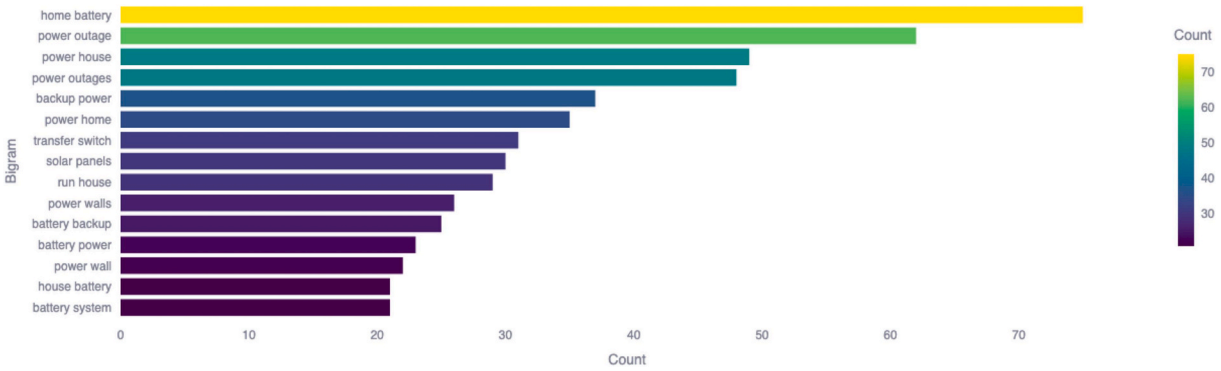


Fig. 6. The list of 15 most frequent bigrams in a positive class concerning Energy resilience.

been purchased for transportation purposes, participants perceived using it for home energy storage as essentially "free" or highly cost-efficient – an example of inverse sunk cost reasoning, where an existing paid-for asset makes the additional benefit feel costless (Thaler, 1980). Illustrative examples of the inverse sunk cost reasoning include, for example: *"The battery is already paid for because I needed the car anyway, so using it to back up the house just feels like free storage sitting there…"; or "Why would I spend thousands on a home battery when my EV is already parked outside with a massive one, I have already paid for?"* This logic extended beyond the household sphere, with users recognising electric school buses, with their predictable schedules and high battery capacities, as ideal assets for community-level grid support and resilience *("I'm proud to see Oakland leading the way with Zum's V2G school buses; they are not only cleaning the air and protecting kids' health but also turning electric buses into mobile power grids that can keep communities safe during extreme weather")*. Despite this optimism, the analysis also uncovered significant psychological barriers related to control and complexity. A core concern was the anxiety over having insufficient charge for mobility needs, with users questioning, *"Why would I let my car's battery run down if I might not be able to recharge it afterwards? Also, what if I suddenly need it?"* This highlights a critical tension between the vehicle's primary and secondary functions. While some proposed mitigations, like setting a minimum charge threshold, others emphasised the mental burden of active management (Sweller, 1988). As one user noted, *"It feels like extra planning for me to handle…Unless that process is automated, I am not sure it would be worth the effort."*.

4.3.2. Consumer expectations and the economic viability of grid participation

Users across the dataset actively debated the economics of participation, frequently performing granular cost-benefit calculations. Stated expectations typically ranged from four to ten times standard electricity rates, with specific examples of $0.50-$2.00/kWh during peak demand periods, rates 5–20 times higher than typical off-peak prices. These expectations centred on "charge low, discharge high" arbitrage logic: charging during off-peak hours or with excess solar (at $0.03-$0.10/kWh) and discharging during expensive peaks ($0.40-$0.50+/kWh), potentially turning EVs into revenue generators. Considering the solar owners in particular, bidirectional charging offered a way to maximise self-consumption rather than exporting at declining net metering rates, which many users complained about. Alternative compensation models, including free equipment installation, workplace charging access, and complimentary airport parking, proved particularly attractive to leaseholders prioritising immediate utility over long-term battery value *("I lease my cars, so I'm not worried about battery wear. If airport parking were free and they guaranteed the same or higher charge on return, I'd definitely go for it")*. However, substantial scepticism characterised responses to existing proposals. Users dismissed monthly payments of $10–15, or annual totals of around $120, explicitly compared by some to *'less than a Netflix subscription'*, as insufficient relative to costs. Users objected that after accounting for upfront infrastructure for bidirectional chargers and additional charge cycles annually, low net earnings (cited values ranged from $1 to $3/day) failed to justify battery degradation risks. Sarcastic remarks about narrow differentials *("Buying at $0.03 per kilowatt-hour and selling at $0.08 per kilowatt-hour, that tiny profit is hardly worth the effort")*, reflected perceptions that proposed rates inadequately motivated participation: *"No one is going to give up their driving range for some abstract idea of grid stability or for a mere hundred dollars a year."* This observation closely aligns with the Prospect Theory (Kahneman and Tversky, 1979), where the potential losses (battery wear, loss of range) loom larger than the small, uncertain gains offered by utilities. This rational assessment was further compounded by a violation of Perceived Fairness (Adams, 1963), with users raising concerns about utilities 'disproportionately benefiting' by paying wholesale rates while charging retail. Many suggested simpler demand-response charging could achieve similar grid benefits without expensive bidirectional infrastructure: *"Demand-response charging already provides most of the same benefits without needing an expensive inverter."*.

4.3.3. Battery longevity: Divergent interpretations

The Battery Longevity topic demonstrated the highest proportion of negative sentiment, yet a deeper analysis reveals a polarisation driven by asymmetric information and divergent risk perception, rather than a uniform consensus. Approximately 40% of users expressed concerns about accelerated degradation from additional cycling (see Fig. 7), with particular emphasis on replacement costs and warranty implications. One participant calculated potential economic impacts: *"I have seen replacement cost estimates of around twelve thousand dollars for a Tesla battery, roughly the price of a small new car, so if V2G reduces the lifespan from twelve years to six, that is a serious expense."* Concerns likewise extended to whether daily household power consumption would void manufacturer warranties or exceed expected cycle life parameters. Contrasting sharply, approximately 35% held opposing views grounded in different technical interpretations. These users emphasised that shallow discharge cycles (10–20% depth of discharge) contribute minimally to overall degradation: *"The impact of V2G on battery wear is greatly exaggerated. LFP batteries can last for up to ten thousand full cycles."* Some users further argued that V2G participation could even optimise battery health by maintaining lower average SoC levels, citing research suggesting potential health improvements of 8.6–12.3% over annual operation periods. References to emerging "million-mile" battery technologies reinforced optimistic assessments of V2G compatibility with long-term battery durability. Additionally, discussions of older EVs revealed an alternative value proposition for degraded batteries. Users identified cost advantages in repurposing vehicles with reduced capacity for stationary storage applications: *"You can pick up an older Nissan Leaf with a 30-kWh battery for around three thousand pounds, and even if the battery is down to about sixty per cent health, it still offers roughly 14 kWh of usable energy. That is about the same storage as a Tesla Powerwall, which costs close to eight thousand pounds installed. For that price difference, using*

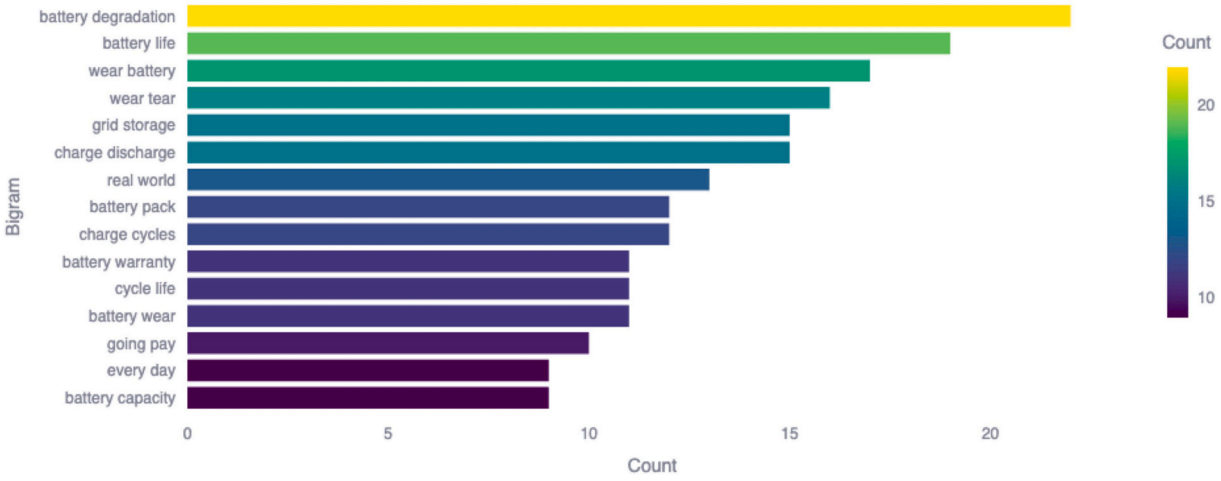


Fig. 7. The list of fifteen most frequent bigrams in a negative class concerning battery longevity.

a used EV for home energy storage seems like a much better deal, especially if it can still handle short local trips.".

4.3.4. User autonomy and the social hierarchy of V2X adoption

V2H attracted stronger interest than V2G, reflecting users' prioritisation of household energy security over grid services: *"Why would anyone send power back to the grid during an outage? The whole point is to keep your own home running."* Other users indicated that V2H availability would serve as a prerequisite for considering V2G participation, suggesting a sequential adoption pathway: *"I want to see V2H become available first; I would think about trying V2G after that."* V2L functionality generated consistently positive responses due to its straightforward implementation and immediate practical applications for outdoor activities and emergency scenarios. Users emphasised V2L's economic advantages, noting that it avoids the substantial infrastructure investments required for home integration: *"I would rather have a simple, low-cost setup like V2L. I do not need to power the entire house."* This staged pattern clearly mirrors diffusion processes where simpler, lower-effort innovations precede more complex ones as users gradually build confidence (Rogers et al., 2014). It is worth noting that some commenters even questioned the fundamental value proposition of bidirectional charging relative to conventional backup solutions, with portable gas generators cited as simpler, lower-cost alternatives for infrequent outages *("Despite all the hype around V2H, I just don't get it. How can a finite battery compete with an infinite natural gas generator?")*. Additionally, several users expressed a preference for portable power stations, describing these devices as more flexible options for occasional power needs compared to the perceived complexity and investment required for full bidirectional vehicle integration (see Fig. 8). In contrast, others defended EV-based systems against gas generator use, emphasising their superior safety and zero-emission operation: *"There is no risk of carbon monoxide poisoning, and an EV can safely stay on in the garage while supplying power to the house."* Discussions from disaster-prone regions also revealed particular urgency, with users noting recurring shortages of backup generators during preventative utility shutoffs *("During planned power shutoffs, backup generators are often impossible to find, so having an EV that can power the home becomes a huge advantage")*.

4.3.5. Hardware requirements and implementation approaches

Hardware discussions maintained a primarily neutral sentiment as users detailed technical specifications and system requirements. However, negative sentiment emerged around implementation costs and complexity. Commenters consistently identified significant expenses for bidirectional systems, including inverters ($3,000-$7,500) [representing a significant barrier at roughly 1–2 months' household income for middle-income earners], transfer switches, complex wiring configurations, and electrical panel modifications. One representative assessment stated, *"People do not seem to realise how expensive this will be; I estimate it could cost anywhere from three to six thousand dollars to set up."* In response, many users adopted interim "do-it-yourself" (DIY) approaches

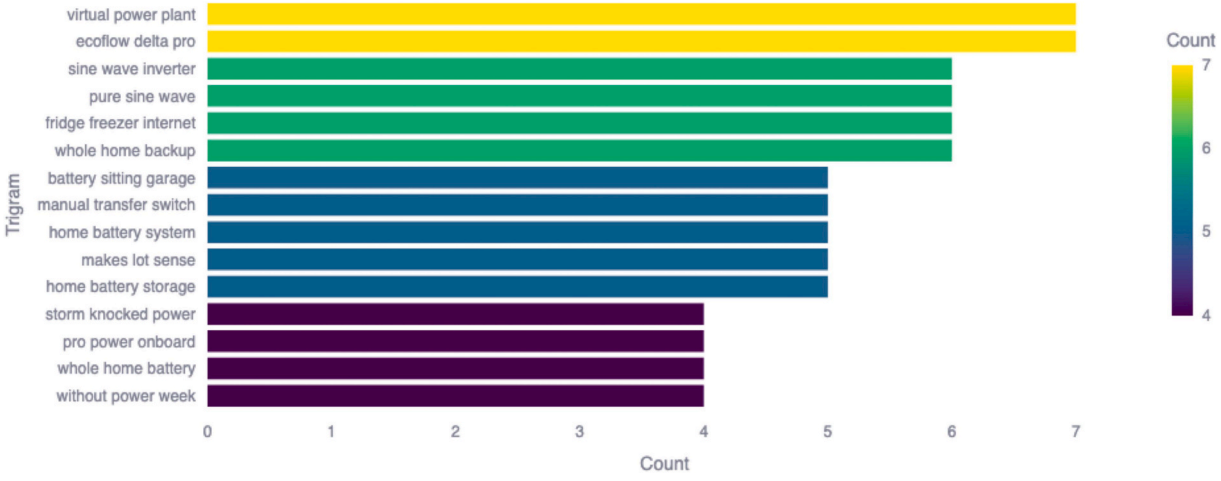


Fig. 8. The list of the fifteen most frequent trigrams in a positive class concerning Energy Resilience. Note: "ecoflow delta pro" (a high-capacity portable power station) appears frequently, suggesting users favour alternative solutions.

utilising aftermarket 12 V inverters ($70-$250) connected to vehicle auxiliary batteries. These configurations enable users to power essential appliances during outages by maintaining vehicle operation to sustain DC-DC converter function: *"You can draw around 1,700 W from the auxiliary system, which is enough to keep a refrigerator running. There is no need to spend ten times more on a full V2H installation."* Commenters characterised these solutions as practical alternatives while awaiting more affordable bidirectional systems. High anticipation also surrounded Enphase's IQ Bidirectional EV Charger for its promised V2H/V2G integration, yet frustration mounts over persistent release delays and backwards compatibility concerns, with users fearing stranded investments in older Enphase hardware unable to support the new charger without costly upgrades.

4.3.6. Standards development and vehicles featuring V2X

Alongside CHAdeMO, representing the primary V2G-capable protocol due to the Nissan Leaf's pioneering implementation, the discussions demonstrated increased optimism following the International Organisation for Standardisation (ISO) 15118–20. Users anticipated that protocol standardisation would accelerate manufacturer adoption and position V2G capability as a competitive differentiator by 2025. Many users expressed a clear expectation that bidirectional charging would be a standard feature in their next electric vehicle, often describing it as an essential capability rather than an optional add-on. As a result, the Ford F-150 Lightning and Tesla Cybertruck received positive recognition for V2H/L implementation. However, Tesla's broader product line generated criticism (see Fig. 9), with users interpreting limited bidirectional charging support as strategic positioning to promote Powerwall sales (Tesla's home battery storage system), noting that *"V2H is a feature I definitely want in my next EV, but I doubt Tesla will include it because it would compete directly with their Powerwall business…"* Kia and Hyundai earned favourable mentions for practical V2L functionality, while the Nissan Leaf was consistently recognised across discussions for being an early V2G adopter, though users noted limitations in its implementation, such as restricted charging infrastructure compatibility. References to manufacturers, including Rivian, BMW, BYD, and Polestar, predominantly reflected future expectations rather than current capabilities, indicating that users actively monitor market development and anticipate expanded availability as technical and regulatory frameworks mature.

5. Discussion

Before turning to specific findings, authors emphasise that all strategic and policy implications drawn below are scoped to the early-market, the pre-mainstream, tech-savvy community analysed here and are not presented as universally applicable. Following Moore's (1998) logic, recommendations appropriate for this segment are a precondition for, but qualitatively distinct from, those required to cross the chasm into the mainstream.

5.1. Methodological reflection

Correlation analysis confirmed that V2X discussions cluster within specialised Reddit communities rather than distributing evenly, aligning with Ruan and Lv's (2022) observation that subreddit communities emphasise distinct EV discourse dimensions. Evaluating eight LLMs further revealed that cost-efficient models can outperform premium alternatives for domain-specific sentiment classification, enabling scalable OSNs monitoring. In particular, Gemini-2.0-flash substantially outperformed several costlier models, contrasting with studies like Tohidi et al. (2025) that found no significant performance differences among GPT-4o, Gemini 2.0 Flash, and Claude 3.7 Sonnet for Persian text. Our results align with Walke (2025), who demonstrated Gemini 2.0 Flash's high accuracy in classifying EV adoption news headlines, confirming its robustness for mobility-related discourse. This finding has practical implications: researchers can achieve high-quality sentiment analysis at substantially lower computational costs, making large-scale OSNs analysis more accessible for transportation research.

5.2. Household energy resilience resonates

Discussions revealed two distinct strategies in multi-vehicle households: (a) dedicating one EV to mobility and another to stationary storage, and (b) repurposing older vehicles with degraded batteries primarily for energy services while maintaining limited mobility. This second strategy extends existing research (Dean and Kockelman, 2024) by highlighting a novel pathway for integrating end-of-life EVs into household resilience, potentially reframing the used EV market around energy storage value rather than purely mobility. Frequent informal cost–capacity comparisons among the mentioned power backup solutions have rarely been captured by researchers in top-down studies. A corresponding implication could involve presenting EVs in cost-per-kWh terms, highlighting their relative affordability and making the option appear more tangible and cost-effective. This mode of comparison could be particularly appealing to audiences already familiar with energy storage, such as the solar community – both for households that already own solar panels and could benefit from additional storage without purchasing a home battery and for those considering solar adoption in the future, where the combined value of solar plus EV-based storage could be emphasised. The debates contrasting EVs with gas generators offer framing V2H not only as economically competitive but also as

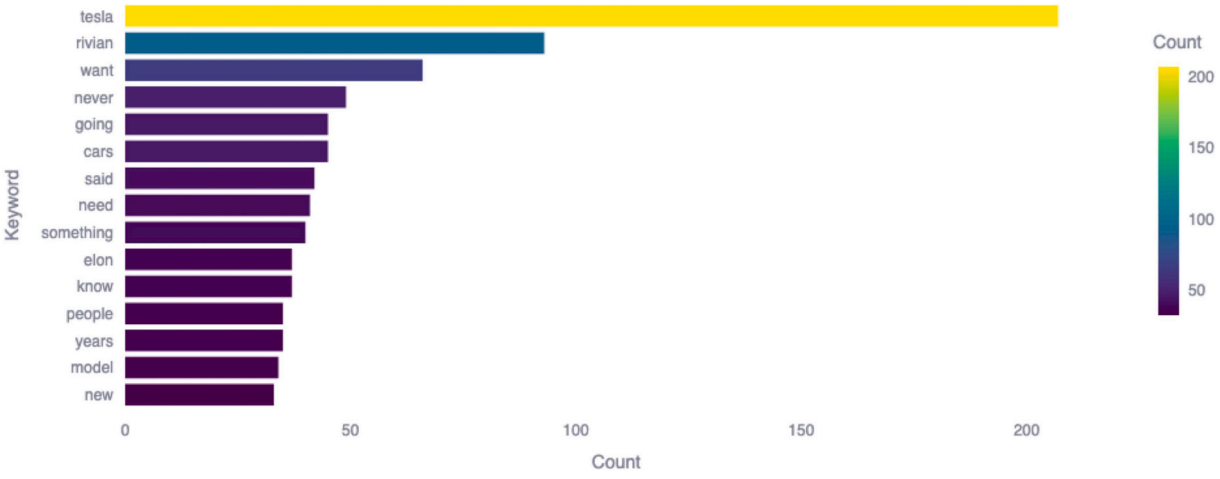


Fig. 9. The list of fifteen most frequent keywords in a negative class concerning the EV Market Landscape.

superior in health and safety. These framings rest on what Rogers et al. (2014) terms relative advantage, the degree to which an innovation is perceived as better than what it replaces, and specifically its low-cost and economic-profitability dimensions. For an energy-literate segment such as this one, cost-per-kWh comparisons and the health and safety advantages over gas generators are therefore the most effective messaging levers for this segment.

5.3. Private benefits vs. Collective gains

Households consistently favour V2H over V2G, aligning with studies showing Swedish drivers prefer household applications (Khezri et al., 2024) and that only Norwegian and Finnish buyers pay premiums for V2G capability (Noel et al., 2019). This preference pattern reflects asymmetric value distribution, meaning that V2G delivers collective environmental benefits, energy integration, peak demand reduction, and avoided fossil fuel generation, while costs (e.g., range anxiety, battery degradation concerns, and cognitive burden) remain concentrated at the household level. While users acknowledge the environmental benefits of V2G *("It can help turn EVs into mobile storage units for renewable energy generated by solar and wind power the impact of V2G seems to be immense…it can help put a big dent in emissions"),* they perceive V2H or V2L as providing tangible personal benefits (e.g., powering home during an outage, running appliances while camping), whereas V2G offers primarily abstract, systemic gains they cannot directly capture. However, this observed preference hierarchy may partly reflect Reddit's platform characteristics, with two possible factors likely contributing to this potential bias. First, Reddit discussions often centre on concrete advice, lived experiences, and evaluations of what "works" in practice, aligning with personally actionable concerns (Lu, 2024). V2G, on the contrary, involves utility partnerships, regulatory frameworks, and grid-scale coordination that individual users cannot unilaterally implement, making it less conducive to peer-to-peer knowledge exchange. Second, the discussed preference for household applications (V2L/V2H) over grid services (V2G) may also partly reflect overrepresentation of users from regions where (a) recent grid disruptions made home resilience salient (e.g., California wildfires or Texas winter storms) and (b) unfavourable net metering changes increased self-consumption value (refer to **5.4** for further details).

Despite this potential selection bias, fleet applications, particularly electric school buses, attracted overwhelmingly positive sentiment regarding V2G, identifying fleets as the natural niche for grid services. Fleet-focused V2G programmes, targeting school districts, municipal vehicles, and commercial operations, can demonstrate environmental benefits at scale in controlled settings, generating longitudinal data to address degradation concerns. Such programmes should actively involve this segment as visible demonstrators rather than treat it as a passive audience, the form of demonstration Egmond et al. (2006b) identify as most effective for an internally-motivated early market. For early-market entry to individual users, companies should prioritise V2L/V2H as the primary value proposition. V2H adoption may prove particularly compelling in outage-prone regions where conventional backup solutions experience supply shortages, offering both personal resilience and environmental advantages through fossil fuel generator displacement.

5.4. Compensation and geographic context

Users identified compensation exceeding battery degradation costs as a crucial condition for V2G participation. This insight aligns with findings from multiple studies (van Heuveln et al., 2021; Goncearuc et al., 2024; Liu et al., 2025), but unlike traditional surveys reporting preferences for "proper compensation" (Kester et al., 2019), monthly payments of "100-1,000 SEK" (Khezri et al., 2024), or 72% electricity bill reductions (~$144; Mehdizadeh et al., 2023), tech-savvy communities demonstrated arbitrage-focused logic, a level of energy-economics fluency characteristic of a technically engaged, solar-aware early-adopter segment rather than of the general consumer population.

Importantly, these compensation expectations are substantially shaped by local tariff structures, grid reliability conditions, and regulatory frameworks that differ across jurisdictions. Users in regions with high ToU differentials (e.g., peak rates exceeding $0.40/kWh versus off-peak below $0.10/kWh) discussed substantial arbitrage opportunities, whereas participants in flat-rate pricing regions (common across the southeastern US) questioned V2G's economic viability (e.g., *"The electric rate is low and it is flat across the day, so no money to be made here…")*. Net metering policy changes particularly influenced solar owners, with some jurisdictions transitioning from retail-rate credits to wholesale-only compensation (e.g., the frequently cited case was California's NEM 3.0[2]), intensifying interest in V2H for self-consumption maximisation, with users explicitly framing V2H as compensation for lost export revenue. Grid reliability contexts also shaped value perceptions, where users in outage-prone regions (California wildfire zones, Texas winter storm areas, or hurricane-affected Atlantic coastal regions) overwhelmingly emphasised house resilience applications, whereas participants from grid-stable regions redirected their focus toward economic arbitrage rather than resilience: *"I'm from Germany; here the power system is quite stable, so that is not a real concern, however, the price difference between buying and selling electricity is > 20 cent/kWh, so to use the car's energy when there is no PV production would be attractive if it is not too expensive to manage."*.

Interestingly, participants (particularly leaseholders who exhibited lower degradation concerns) also discussed non-monetary incentives, suggesting opportunities for innovative business models where commercial establishments (airport parking operators and shopping centres) act as V2G intermediaries by offering context-specific benefits like free equipment installation, workplace charging access, or premium parking privileges.

Overall, discussions about remuneration illustrated the Rational Choice Theory (Becker, 1976) in practice, with users acting as sophisticated economic actors systematically weighing costs and benefits to maximise expected utility. Nevertheless, the geographic heterogeneity suggests that effective industry responses must be jurisdiction-specific rather than universal. Effective targeting, therefore, requires jurisdiction-specific instruments. In high ToU differential markets, transparent cost-benefit calculators factoring in real-time electricity rates, degradation costs, and participation duration would resonate with arbitrage-focused early adopters. In flat-rate or grid-stable regions, V2H self-consumption and resilience value propositions are likely more compelling than V2G economic arguments. Non-monetary incentives (airport parking, workplace charging) may prove particularly effective for leaseholders across all contexts, given their lower degradation concerns. Lastly, although a subset of users flagged hardware cost, Egmond et al. (2006b) caution that broad subsidies suit an internally-motivated early market poorly, since these actors largely adopt regardless, incentives reward purchases that would have happened anyway, producing a substantial free-rider effect. Any fiscal support is therefore better directed as a specific investment subsidy, not broad subsidies.

5.5. Control, automation and cognitive burden

Besides the aforementioned compensation, control over discharge limits to ensure adequate charge for driving needs has been identified as equally critical for reducing adoption barriers. Users consistently cited 70–80% minimum SoC thresholds, closely matching the 71% found in Norwegian research (Mehdizadeh et al., 2023). Nevertheless, mental burden **(4.3.1)** affecting the user intervention presents itself as a barrier

[2] *California's NEM 3.0 (Net Energy Metering), effective April 2023, is a net billing tariff that drastically reduces solar export compensation by ~75% compared to NEM 2.0.*

to adoption that prior studies' models failed to capture. This cognitive burden dimension reveals a limitation in dominant technology acceptance frameworks. Models such as the Technology Acceptance Model (Davis, 1989) or its extension in the form of the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003) emphasise perceived usefulness and ease of use at the point of adoption but do not capture the ongoing cognitive cost of active system management post-adoption. Online users articulated this explicitly, expressing reluctance to "babysit" discharge schedules or manually override SoC thresholds. Rational Choice Theory (Becker, 1976) likewise fails to account for the disutility of sustained cognitive effort required to realise corresponding benefits. This finding suggests that V2G adoption is constrained not only by economics or feasibility but also by the cognitive friction of maintaining participation, a behavioural barrier that automation must address to enable scale.

Industry actors already recognise this challenge: Octopus Energy implements intelligent battery management systems in the United Kingdom that automatically guarantee minimum charge levels (Octopus Energy, 2025), while Bosch's connected energy management platform employs predictive algorithms balancing user preferences, mobility needs, and system conditions (Bosch Mobility, 2025). Therefore, standardising the 70–80% threshold across platforms with emergency override options would meet expectations articulated by this pre-mainstream early-market segment, while automated systems that learn individual driving patterns and dynamically adjust discharge limits reduce friction without requiring continuous user intervention.

5.6. Battery impact – polarised debate

Battery degradation emerged as a major concern, consistent with previous research (van Heuveln et al., 2021; Khezri et al., 2024; Hu et al., 2025), yet others counter-argued, citing minimal wear and potential battery lifespan extension through optimal charge cycling. This polarisation reflects the tech-oriented characteristics of Reddit's user base and aligns with patterns identified by Hu et al. (2025), who observed that private EV owners prioritising long-term battery value expressed strong degradation concerns, whereas technically knowledgeable participants downplayed risks. The technically proficient nature of Reddit users (Proferes et al., 2021) was further evident in their forward-looking perspective, with some participants expressing optimism that emerging "million-mile" battery technologies could render degradation concerns obsolete, demonstrating an awareness of technological trajectories that currently exceed demonstrated commercial capabilities. This divergence also mirrors mixed findings in the scientific literature; while studies like Thingvad et al. (2021) quantify degradation under V2X duty cycles, others like Wang et al. (2016) suggest that well-designed cycling strategies can mitigate or offset ageing. However, addressing the degradation uncertainty still requires transparent, data-driven approaches. Therefore, real-time battery health monitoring systems providing clear, actionable degradation data could resolve the information asymmetry driving this early-adopter debate. Initiatives like the UK-funded BEVScanV2X project are developing cost-effective diagnostic tools that monitor battery health and provide usage recommendations to extend lifespan and maximise financial returns (Department for Energy Security and Net Zero, 2023). Equally critical is transparent warranty communication, as uncertainty over V2X participation coverage was a recurring adoption deterrent. Manufacturers should explicitly specify how bidirectional use affects warranty terms. Strategic market entry pathways could leverage this polarisation. Prioritising lease customers, who demonstrate lower degradation anxiety, creates opportunities for positive early experiences that may influence broader adoption as testimonials circulate. However, given the mixed scientific evidence, educational campaigns must be grounded in robust, longitudinal field data. As empirical evidence on real-world V2X degradation accumulates, transparent communication of findings, including both risks and mitigation strategies, will be essential for reducing uncertainty and enabling informed adoption decisions.

5.7. The absence of a privacy debate

Interestingly, no comments in the dataset explicitly addressed privacy concerns commonly highlighted in prior V2G research (Goncearuc et al., 2024; Bakhuis et al., 2025), a finding that contrasts sharply with the existing literature. While this may partly reflect the characteristics of Reddit users as those with a higher tolerance for uncertainty and risk, this absence should be interpreted cautiously. Pseudonymous online environments like Reddit, in which users operate under usernames rather than real identities (Proferes et al., 2021), may shape what risks are articulated. As Suler (2004, p. 322) notes, the so-called "dissociative anonymity" characteristic of such platforms allows individuals to *"separate their actions online from their in-person lifestyle and identity"*, potentially reducing the perceived personal relevance of risks tied to identifiable real-world consequences.

5.8. Technological maturity

User perceptions reflect a technology in transition. Many participants framed V2H and V2G as confined to pilot projects and niche demonstrations, viewing adoption as distant. However, discussions increasingly referenced concrete market progress: established brands offering V2X capability, upcoming model releases, commercial charger manufacturers, and standardised communication protocols. This shift indicates growing awareness that V2X is moving from experimentation toward structured commercialisation. Egmond et al. (2006b) hold that, for an internally motivated early market, the most effective intervention is the removal of institutional barriers. The discourse suggests this removal is already underway; participants frequently referenced the emerging standards and regulatory mandates that are dismantling precisely these barriers, with regulatory frameworks confirming the trajectory. For instance, Europe's Alternative Fuels Infrastructure Regulation mandates compliance with ISO 15118-20 by 2027, while the US has established UL-certified charger requirements and National Electrical Manufacturers Association (NEMA) permitting standards.

6. Conclusion

The accelerating shift toward electric mobility presents both opportunities and challenges for decarbonising transport and energy systems. While bidirectional charging technologies have the potential to transform EVs from passive loads into distributed energy assets that absorb excess renewable generation, reduce peak fossil fuel generation, and enable grid flexibility, realising these environmental benefits depends fundamentally on user acceptance across the stages of market diffusion. Despite this, user-centred evidence, particularly from informal, early-stage discourse derived from OSNs, remains absent from the literature. This study addresses that gap by analysing Reddit discussions within a pre-mainstream, tech-savvy community, using BERTopic modelling and LLM-based sentiment classification on over 11,400 comments from more than 4,000 contributors. Overall sentiment was positive-leaning, with optimism concentrated in topics offering tangible personal benefits (e.g., energy resilience and remuneration), while uncertainty persists regarding battery degradation and implementation complexity. Methodologically, this study contributes a low-cost, reproducible pipeline that pairs BERTopic with multi-LLM sentiment benchmarking and demonstrates that cost-efficient models can exceed classification accuracy compared to premium alternatives for domain-specific transport discourse and reveals that the resulting classifications remain stable across reasonable prompt variations.

In line with previous research, this study found that the pre-mainstream community likewise demonstrate a clear preference hierarchy based on a rational assessment of value, viewing V2L as an immediate, low-cost entry point for essential needs, followed by V2H for

household resilience and renewable energy self-consumption. V2G ranks last, with adoption being conditional on guaranteed SoC and compensation that outweighs degradation risks. Battery degradation discourse is polarised rather than uniformly negative, with lease customers and technically knowledgeable users expressing lower anxiety, yet transparent battery health monitoring emerged as a desired feature across the sample.

Beyond confirming findings from structured surveys, this analysis reveals additional insights that show how this early-market segment differs from the mainstream along several specific dimensions. Reddit users exhibit higher technical tolerance, engaging with DIY V2L set-ups, hardware integration debates, higher risk and uncertainty tolerance, downplaying battery degradation and expressing forward-looking optimism about emerging "million-mile" battery technologies; arbitrage-oriented economic reasoning alongside non-monetary compensation preferences (parking perks, workplace charging) among leaseholders; peer-to-peer benchmarking including repurposing degraded EVs as cost-effective stationary storage and cost-capacity comparisons against home batteries and gas generators in which carbon monoxide risk and backup-solution shortages were raised. Even within this segment, however, pragmatic counter-arguments surfaced, including the cognitive burden of actively managing V2G, scepticism about whether proposed compensation justifies the effort, and preferences for simpler alternatives such as gas generators, portable power stations, or V2L-only set-ups. This study further deviates in the absence of a privacy debate, although, as discussed, that is likely attributable to OSNs' nature rather than to their pre-mainstream risk-tolerant nature. Read together, findings are not directly transferable to the mainstream, that is, the early majority of more cautious adopters who follow innovators and early adopters in the diffusion curve, and who require stable business cases, plug-and-play installation, and visible adoption trends before committing. This gap is what Moore (1998) terms the chasm, and bridging it would require targeting a narrow beachhead niche of mainstream adopters with a distinct policy mix rather than extending the recommendations developed for this pre-mainstream segment (e.g., Egmond et al. [2006b] recommend for the mainstream "cash-on-the-barrelhead" subsidies, covenants, energy labels, and market-leader messaging stressing comfort, reliability and quality over novelty). The arbitrage logic, technical fluency, degradation tolerance, and DIY orientation that characterise this sample are unlikely to resonate with mainstream adopters. Instead, they are likely to be deterred by the very incompleteness that even this study's pre-mainstream sample flagged, like unclear compensation, complex and expensive hardware, unsettled warranty terms, and immature standardisation. Nevertheless, barriers rooted in early-adoption conditions, such as regulatory uncertainty and high hardware costs, may diminish naturally as institutional frameworks mature and economies of scale take effect.

Overall, this study proposes a set of implications targeted specifically at the pre-mainstream market. For this segment, the most relevant interventions are jurisdiction-specific cost-benefit calculators that match the arbitrage-oriented reasoning observed in the sample; non-monetary incentives such as workplace charging and parking benefits, which resonate particularly with leaseholders; transparent battery-health monitoring; cost-per-kWh framing of EVs against alternatives such as home batteries and gas generators, with health and safety advantages emphasised; and a staged deployment pathway beginning with V2L for outdoor and emergency use, followed by V2H in outage-prone regions and V2G in fleet settings such as electric school buses and municipal vehicles.

Several limitations warrant acknowledgement. This study deliberately focuses on the pre-mainstream, tech-savvy community discourse rather than representative mainstream samples. Reddit's demographic (tech-savvy), geographic (US-centric), and linguistic (English-only) characteristics introduce biases that limit generalisability to broader populations. The sample reflects users' perspectives characterised by higher technical tolerance, greater willingness to experiment with emerging technologies, and platform-specific discourse patterns. The findings should therefore be interpreted strictly as descriptions of early-market priorities, not as predictors of mainstream attitudes. Future research could validate findings through cross-platform analyses (X, specialised forums); implement longitudinal studies as V2X matures commercially; examine region-specific platforms to capture diverse geographical perspectives; and incorporate stakeholder views from manufacturers, policymakers, and infrastructure operators. Despite these limitations, this study demonstrates that analysing pre-mainstream discourse provides indispensable strategic value by complementing structured methods with spontaneous, peer-negotiated insights, enabling the proactive, user-centred interventions essential for accelerating V2X adoption and transport system decarbonisation.

CRediT authorship contribution statement

Ondrej Havran: Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **David Watling:** Writing – review & editing, Supervision, Conceptualization. **Haibo Chen:** Supervision, Project administration, Funding acquisition, Conceptualization. **Wen-Long Shang:** Writing – review & editing. **Ye Liu:** Writing – review & editing. **Chenxi Wang:** Conceptualization. **Zhao Wang:** Conceptualization. **Dingsong Cui:** Conceptualization. **Dongyao Ji:** Writing – review & editing.

Funding

This work was part of the ePowerMove project co-funded by the European Union under Grant Agreement ID: 101192753. ePowerMove aims to optimise energy usage by integrating advanced charging infrastructure with smart grid technologies. However, views and opinions expressed are those of the authors only and do not necessarily reflect those of the European Union or European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible.

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.

Acknowledgements

The authors would like to thank the anonymous reviewers for their constructive and insightful feedback, which substantially improved the quality and clarity of this manuscript. The corresponding author also extends his gratitude to our team members for their valuable contributions and collaborative efforts throughout the development of this work. Lastly, the corresponding author dedicates this work to the memory of his father.

Appendix A:. LLM sentiment analysis protocol

.

Table 4
LLM models and parameters used in sentiment analysis.

Model	Provider	Model identifier	Temperature	Max tokens
GPT-4o-mini	OpenAI	gpt-4o-mini	0.0	10
GPT-4o	OpenAI	gpt-4o	0.0	10
Claude 3 Haiku	Anthropic	claude-3-haiku-20240307	0.0	10
Claude 3 Opus	Anthropic	claude-3-opus-20240229	0.0	10
Gemini Flash	Google	gemini-2.0-flash	0.0	10
Gemini 1.5 Pro	Google	gemini-1.5-pro	0.0	10
DeepSeek Chat	DeepSeek	deepseek-chat	0.0	10
Grok Beta	xAI	grok-beta	0.0	10

Table 5
Prompt design.

"Act as a sentiment analysis expert and classify the overall sentiment of this Reddit comment about Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H) or Vehicle-to-Load (V2L) technology as positive, negative, or neutral, focusing on the main tone (return only the sentiment label): '{text}'"

Table 6
Configuration and prompt variants used in the sensitivity analysis.

Variant	Prompt Text
Configuration	Model: Gemini-2.5-flash. Temperature: 0. Reasoning mode: disabled. Max tokens: 10.
Production (original)	"Act as a sentiment analysis expert and classify the overall sentiment of this Reddit comment about Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H) or Vehicle-to-Load (V2L) technology as positive, negative, or neutral, focusing on the main tone (return only the sentiment label): '{text}'"
Stripped	"Classify the sentiment of the following text as positive, negative, or neutral. Return only the label.\n\nText: '{text}'"
Few-shot	"Act as a sentiment analysis expert and classify the overall sentiment of this Reddit comment about Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H) or Vehicle-to-Load (V2L) technology as positive, negative, or neutral, focusing on the main tone. Return only the sentiment label.Examples:Comment: 'V2G is honestly the most exciting EV feature — being able to power my house and earn money from the grid is incredible.' Sentiment: positive Comment: 'Finally a use for the giant battery sitting in my driveway. Bidirectional charging is the future.' Sentiment: positive Comment: 'Cycling the battery this much is going to absolutely destroy its lifespan. No thanks.' Sentiment: negativeComment: 'Just another way for utilities to use your car as a free battery. Hard pass.' Sentiment: negativeComment: 'V2G uses bidirectional inverters to send DC power from the battery back to the grid as AC.' Sentiment: neutralComment: 'Currently V2H requires a specific charger and is only available on certain models in select regions.' Sentiment: neutral Comment: '{text}'Sentiment:"

References

Adams, J.S., 1963. Towards an understanding of inequity. J. Abnorm. Soc. Psychol. 67 (5), 422.

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50 (2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T.

Ashby, C., Weir, D., Fussey, P., 2025. Understanding public views on electric vehicle charging: a thematic analysis. Transp. Res. Interdiscip. Perspect. 29, 101325. https://doi.org/10.1016/j.trip.2025.101325.

Bakhuis, J., Barbour, N., Chappin, É.J.L., 2025. Exploring user willingness to adopt vehicle-to-grid (V2G): a statistical analysis of stated intentions. Energy Policy 203, 114619. https://doi.org/10.1016/j.enpol.2025.114619.

Becker, G.S., 1976. The Economic Approach to Human Behavior. University of Chicago Press.

Bird, L., Lew, D., Milligan, M., Carlini, M.E., Estanqueiro, A., Flynn, D., Gomez-Lazaro, E., Holttinen, H., Menemenlis, N., Orths, A., Eriksen, P.B., Smith, C.J., Söder, L., Sørensen, P., Altiparmakis, A., Yasuda, Y., Miller, J., 2016. Wind and solar energy curtailment: a review of international experience. Renew. Sustain. Energy Rev. 65, 577–586. https://doi.org/10.1016/j.rser.2016.06.082.

Borg, A., Boldt, M., 2020. Using VADER sentiment and SVM for predicting customer response sentiment. Expert Syst. Appl. 162, 113746. https://doi.org/10.1016/j.eswa.2020.113746.

Bosch Mobility, 2025. Connected energy management for electric vehicles. Available at: https://www.bosch-mobility.com/en/solutions/software-and-services/connected-energy-management-for-electric-vehicles/ [Accessed 24 Oct 2025].

Boström, T., Babar, B., Hansen, J.B., Good, C., 2021. The pure PV-EV energy system – a conceptual study of a nationwide energy system based solely on photovoltaics and electric vehicles. Smart Energy 1, 100001. https://doi.org/10.1016/j.segy.2021.100001.

Bryła, P., Chatterjee, S., Ciabiada-Bryła, B., 2023. Consumer adoption of electric vehicles: a systematic literature review. Energies 16, 205. https://doi.org/10.3390/en16010205.

Buonomano, A., 2020. Building to vehicle to building concept: a comprehensive parametric and sensitivity analysis for decision making aims. Appl. Energy 261, 114077. https://doi.org/10.1016/j.apenergy.2019.114077.

Caban, A., Lukszo, Z., Scholz, G., 2026. Evolution of V2G acceptance: a review of influencing factors over time. Energy Rep. 15, 109169.

Carbonell, J., Goldstein, J., 1998. The use of MMR, diversity-based reranking for reordering documents and producing summaries. In: Proc. 21st Annu. Int. ACM SIGIR Conf. Res. Dev. Inf. Retr., 335–336.

Chang, Y., Wang, X., Wang, J., Wu, Y., Yang, L., Zhu, K., Chen, H., Yi, X., Wang, C., Wang, Y., Ye, W., Zhang, Y., Chang, Y., Yu, P.S., Yang, Q., Xie, X., 2024. A survey on evaluation of large language models. ACM Trans. Intell. Syst. Technol. 15 (3), 39. https://doi.org/10.1145/3641289.

Chen, K., Tomblin, D., 2021. Using data from Reddit, public deliberation, and surveys to measure public opinion about autonomous vehicles. Public Opin. Q. 85 (S1), 289–322. https://doi.org/10.1093/poq/nfab021.

Cook, D.L., 1962. The Hawthorne effect in educational research. Phi Delta Kappan 44 (3), 116–122.

Davis, F.D., 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. 13 (3), 319–340. https://doi.org/10.2307/249008.

Dean, M.D., Kockelman, K.M., 2024. Assessing public opinions of and interest in bidirectional electric vehicle charging technologies: a U.S. perspective. Transp. Res. Rec. 2678 (12), 1889–1904. https://doi.org/10.1177/03611981241253608.

Department for Energy Security and Net Zero, 2023. V2X innovation programme: Phase 1 projects. GOV.UK. Available at: https://www.gov.uk/government/publications/v2x-innovation-programme-successful-projects/v2x-innovation-programme-phase-1-successful-projects [Accessed 24 Oct 2025].

Egmond, C., Jonkers, R., Kok, G., 2006a. A strategy and protocol to increase diffusion of energy related innovations into the mainstream of housing associations. Energy Policy 34 (18), 4042–4049.

Egmond, C., Jonkers, R., Kok, G., 2006b. One size fits all? Policy instruments should fit the segments of target groups. Energy Policy 34 (18), 3464–3474.

Egmond, C., Jonkers, R., Kok, G., 2006c. Target group segmentation makes sense: if one sheep leaps over the ditch, all the rest will follow. Energy Policy 34 (17), 3115–3123.

Eltohamy, M.S., Tawfiq, M.H., Ahmed, M.M.R., Alaas, Z., Mohammed, B., Ahmed, I., Youssef, H., Raouf, A., 2025. A comprehensive review of vehicle-to-grid (V2G) technology: technical, economic, regulatory, and social perspectives. Energy Convers. Manag. X 27, 101138. https://doi.org/10.1016/j.ecmx.2025.101138.

Fu, T., Yu, S., Tan, S., 2025. Peer effect matters for the adoption of new energy vehicles: evidence from consumer sentiment analysis using Chat-GPT. Energy Econ. 148, 108692. https://doi.org/10.1016/j.eneco.2025.108692.
Geske, J., Schumann, D., 2018. Willing to participate in vehicle-to-grid (V2G)? Why not! Energy Policy 120, 392–401. https://doi.org/10.1016/j.enpol.2018.05.004.
Ghias, R., Ahmad, I., Rehman, H., Hasan, A., 2025. Advanced nonlinear control for a residential microgrid with renewable energy integration and electric vehicle backup. Energy 332, 136414. https://doi.org/10.1016/j.energy.2025.136414.
Goncearuc, A., De Cauwer, C., Sapountzoglou, N., Van Kriekinge, G., Huber, D., Messagie, M., Coosemans, T., 2024. The barriers to widespread adoption of vehicle-to-grid: a comprehensive review. Energy Rep. 12, 27–41. https://doi.org/10.1016/j.egyr.2024.05.075.
Greenberg, M.R., Weiner, M.D., 2014. Keeping surveys valid, reliable, and useful: a tutorial. Risk Anal. 34 (8), 1362–1375. https://doi.org/10.1111/risa.12250.
Grootendorst, M., 2022. BERTopic: Neural topic modeling with a class-based TF-IDF procedure. *arXiv preprint* arXiv:2203.05794. https://doi.org/10.48550/arXiv.2203.05794.
Gwet, K.L., 2014. Handbook of inter-rater reliability: The definitive guide to measuring the extent of agreement among raters. Advanced Analytics, LLC.
Havran, O., Watling, D., Chen, H., Liu, J., Shang, W.L., Xu, C., Margaritis, D., 2025. Electrifying urban mobility: Unveiling expert insights on electric quadricycles through topic modelling and sentiment analysis. Sustain. Futures 10, 101540. https://doi.org/10.1016/j.sftr.2025.101540.
Hu, Y., Birke, F.B., Ettema, D., 2025. Vehicle-to-grid, why not? An interview with battery electric vehicle users with various driving patterns in Utrecht, the Netherlands. Transp. Policy 164, 231–240. https://doi.org/10.1016/j.tranpol.2025.02.009.
Hutto, C., Gilbert, E., 2014. VADER: a parsimonious rule-based model for sentiment analysis of social media text. Proc. Int. AAAI Conf. Web Soc. Media 8, 216–225. https://doi.org/10.1609/icwsm.v8i1.14550.
International Energy Agency (IEA), 2024. Global EV outlook 2024. IEA, Paris. Available at: https://www.iea.org/reports/global-ev-outlook-2024 [Accessed 24 Oct 2025].
International Organization for Standardization (ISO), 2022. ISO 15118-20: Road vehicles — Vehicle to grid communication interface. Part 20: 2nd generation network layer and application layer requirements. ISO, Geneva. Available at: https://www.iso.org/standard/77845.html [Accessed 24 Oct 2025].
Jhaver, S., Birman, I., Gilbert, E., Bruckman, A., 2019. Human-Machine Collaboration for Content Regulation: the Case of Reddit Automoderator. ACM Trans. Comput.-Hum. Interact. 26 (5). https://doi.org/10.1145/3338243.
Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision under risk. Econometrica 47 (2), 263–291. https://doi.org/10.2307/1914185.
Kester, J., de Rubens, G.Z., Sovacool, B.K., Noel, L., 2019. Public perceptions of electric vehicles and vehicle-to-grid (V2G): Insights from a Nordic focus group study. Transp. Res. Part D: Transp. Environ. 74, 277–293. https://doi.org/10.1016/j.trd.2019.08.006.
Khezri, R., Steen, D., Anh Tuan, L., 2024. Willingness to participate in vehicle-to-everything (V2X) in Sweden, 2022—Using an electric vehicle's battery for more than transport. Sustainability 16, 1792. https://doi.org/10.3390/su16051792.
Klein, H.K., Kleinman, D.L., 2002. The social construction of technology: structural considerations. Sci. Technol. Hum. Values 27 (1), 28–52. https://doi.org/10.1177/016224390202700102.
Letcher, M., Britton, J., 2025. The role of electric vehicle-to-X in net zero energy systems: a comprehensive review. Energy Res. Soc. Sci. 122, 104021. https://doi.org/10.1016/j.erss.2025.104021.
Li, Z., Jiao, Y., Cheng, Y., Shen, Z., Zhou, M., 2025. Unlocking the power of peer influence: strategies for bridging the adoption chasm in new product diffusion. Manag. Decis. Econ. 46 (1), 361–377.
Liao, F., Molin, E., Timmermans, H., van Wee, B., 2019. Consumer preferences for business models in electric vehicle adoption. Transp. Policy 73, 12–24. https://doi.org/10.1016/j.tranpol.2018.10.006.
Liu, F., Wei, Z., Lin, Y., Huang, X., Li, Y., Huang, Y., Lim, M.K., 2025. Vehicle-to-grid technology acceptance for electric vehicle users: a systematic literature review and future research agenda. Int. J. Consum. Stud. 49 (3), e70065. https://doi.org/10.1111/ijcs.70065.
Lu, R., 2024. Audience design and pragmatic conceptions of moves and upvotes during advice-giving on Reddit. J. Pragmatics. https://doi.org/10.1016/j.pragma.2023.11.006.
Ma, S.C., Fan, Y., Yao, X., Fang, H., Xu, C., 2025. Cost and environmental impacts assessment of electric vehicles and power systems synergy: the role of vehicle-to-grid technology. Environ. Impact Assess. Rev. 114, 107899. https://doi.org/10.1016/j.eiar.2025.107899.
Maceda, L.L., Llovido, J.L., Artiaga, M.B., Abisado, M.B., 2023. December. Classifying sentiments on social media texts: a gpt-4 preliminary study. In: In Proceedings of the 2023 7th International Conference on Natural Language Processing and Information Retrieval, pp. 19–24. https://doi.org/10.1145/3639233.363935.
Mehdizadeh, M., Nayum, A., Nordfjærn, T., Klöckner, C.A., 2024. Are Norwegian car users ready for a transition to vehicle-to-grid technology? Transp. Policy 146, 126–136. https://doi.org/10.1016/j.tranpol.2023.11.014.
Mehdizadeh, M., Nordfjaern, T., Klöckner, C.A., 2023. Estimating financial compensation and minimum guaranteed charge for vehicle-to-grid technology. Energy Policy 180, 113649. https://doi.org/10.1016/j.enpol.2023.113649.
Moore, G.A., 1998. Crossing the CHASM. John Wiley & Sons.
Moussaïd, M., Kämmer, J.E., Analytis, P.P., Neth, H., 2013. Social influence and the collective dynamics of opinion formation. PLoS One 8 (11), e78433. https://doi.org/10.1371/journal.pone.0078433.
Muis, J., Klein, O., Dijkstra, G., 2020. Challenges and opportunities of social media research: using Twitter and Facebook to investigate far-right discourses. In: In: Researching the Far Right, pp. 147–163.
Noel, L., Carrone, A.P., Jensen, A.F., de Rubens, G.Z., Kester, J., Sovacool, B.K., 2019. Willingness to pay for electric vehicles and vehicle-to-grid applications: a Nordic choice experiment. Energy Econ. 78, 525–534. https://doi.org/10.1016/j.eneco.2018.12.014.
Octopus Energy, 2025. Octopus Power Pack: The UK's first vehicle-to-grid tariff. Available at: https://octopus.energy/power-pack/ [Accessed 24 Oct 2025].
OpenAI, 2024a. New embedding models and API updates. Available at: https://openai.com/index/new-embedding-models-and-api-updates/ [Accessed 24 Oct 2025].
OpenAI, 2024b. Best practices for prompt engineering with the OpenAI API. Available at: https://help.openai.com/en/articles/6654000-best-practices-for-prompt-engineering-with-the-openai-api [Accessed 24 Oct 2025].
Pani, A., Balla, S.N., Sahu, P.K., 2023. Decoding consumer-centric transition to electric mobility based on sentiment, semantic and statistical analysis. Res. Transp. Bus. Manag.e. 51, 101069. https://doi.org/10.1016/j.rtbm.2023.101069.
Proferes, N., Jones, N., Gilbert, S., Fiesler, C., Zimmer, M., 2021. Studying reddit: a systematic overview of disciplines, approaches, methods, and ethics. Soc. Media Soc. 7 (2). https://doi.org/10.1177/20563051211019004.
Qin, Q., Zhou, Z., Zhou, J., Huang, Z., Zeng, X., Fan, B., 2024. Sentiment and attention of the Chinese public toward electric vehicles: a big data analytics approach. Eng. Appl. Artif. Intell. 127, 107216. https://doi.org/10.1016/j.engappai.2023.107216.
Rao, S.P., Olusegun, T.S., Ranganathan, P., Kose, U., Goveas, N., 2025. Vehicle-to-grid technology: opportunities, challenges, and future prospects for sustainable transportation. J. Energy Storage 110, 114927. https://doi.org/10.1016/j.est.2024.114927.
Reddit, 2023. Reddit communities provide insight to new technologies. Available at: https://www.business.reddit.com/blog/reddit-communities-provide-insight-to-new-technologies [Accessed 22 Oct 2025].
Řehůřek, R., 2011. Fast and faster: A comparison of two streamed matrix decomposition algorithms. arXiv preprint arXiv:1102.5597. https://doi.org/10.48550/arXiv.1102.5597.
Reveilhac, M., Steinmetz, S., Morselli, D., 2022. A systematic literature review of how and whether social media data can complement traditional survey data to study public opinion. Multimed. Tools Appl. 81, 10107–10142. https://doi.org/10.1007/s11042-022-11985-8.
Rogers, E.M., Singhal, A., Quinlan, M.M., 2014. Diffusion of innovations. In: An Integrated Approach to Communication Theory and Research. Routledge, New York, pp. 432–448.
Ruan, T., Lv, Q., 2023. Public perception of electric vehicles on Reddit and Twitter: a cross-platform analysis. Transp. Res. Interdiscip. Perspect. 21, 100872. https://doi.org/10.1016/j.trip.2023.100872.
Ruan, T., Lv, Q., 2022. Public perception of electric vehicles on Reddit over the past decade. Commun. Transp. Res. 2, 100070. https://doi.org/10.1016/j.commtr.2022.100070.
Sahoo, P., Singh, A.K., Saha, S., Jain, V., Mondal, S., Chadha, A., 2024. A systematic survey of prompt engineering in large language models: Techniques and applications. arXiv preprint arXiv:2402.07927.
Sassi, H.B., Alaoui, C., Errahimi, F., Es-Sbai, N., 2021. Vehicle-to-grid technology and its suitability for the Moroccan national grid. J. Energy Storage 33, 102023. https://doi.org/10.1016/j.est.2020.102023.
Satpathy, P.R., Ramachandaramurthy, V.K., Krishnan, T.R.R., Padmanaban, S., 2025. Technological innovations and sustainable strategies for advancing electric vehicle performance and market integration. Energy Strateg. Rev. 60, 101790. https://doi.org/10.1016/j.esr.2025.101790.
Secinaro, S., Calandra, D., Lanzalonga, F., Ferraris, A., 2022. Electric vehicles' consumer behaviours: mapping the field and providing a research agenda. J. Bus. Res. 150, 399–416. https://doi.org/10.1016/j.jbusres.2022.06.011.
Shang, W., Chen, H., Watling, D., Ochieng, W., 2026. How far are we from the large-scale adoption of V2G technology? Eng. Manage. 13 (1), 240–245.
Suler, J., 2004. The online disinhibition effect. Cyber Psychol. Behavior 7 (3), 321–326. https://doi.org/10.1089/1094931041291295.
Suresha, H.P., Tiwari, K.K., 2021. Topic modelling and sentiment analysis of electric vehicles on Twitter data. Asian J. Res. Comput. Sci. 12 (2), 13–29.
Swain, J., King, B., 2022. Using informal conversations in qualitative research. Int. J. Qual. Methods 21. https://doi.org/10.1177/16094069221085056.
Sweller, J., 1988. Cognitive load during problem solving: effects on learning. Cognit. Sci. 12, 257–285. https://doi.org/10.1207/s15516709cog1202_4.
Tang, M.C., Cao, J., Fan, Z.X., Gong, D.Q., Xue, G., 2024. Public perceptions of EV charging infrastructure: a combined sentiment analysis and topic modelling approach. Stud. Inform. Control 33 (2), 59–72.
Thaler, R., 1980. Toward a positive theory of consumer choice. J. Econ. Behav. Organ. 1 (1), 39–60. https://doi.org/10.1016/0167-2681(80)90051-7.
Thingvad, A., Calearo, L., Andersen, P.B., Marinelli, M., 2021. Empirical capacity measurements of electric vehicles subject to battery degradation from V2G services. IEEE Trans. Veh. Technol. 70 (8), 7547–7557. https://doi.org/10.1109/TVT.2021.3093161.
Tian, S., Razeghi, G., Samuelsen, S., 2024. Assessment of vehicle-to-load in support of home appliances. J. Energy Storage 104, 114406. https://doi.org/10.1016/J.EST.2024.114406.
Tohidi, K., Dashtipour, K., Rebora, S., Pourfaramarz, S., 2025. A comparative evaluation of large language models for Persian sentiment analysis and emotion detection in social media texts. arXiv preprint arXiv:2509.14922.
Van Heuveln, K., Ghotge, R., Annema, J.A., van Bergen, E., van Wee, B., Pesch, U., 2021. Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle

drivers in the Netherlands. Travel Behav. Soc. 24, 34–45. https://doi.org/10.1016/j.tbs.2020.12.008.
Varajão, D., Araújo, R.E., Miranda, L.M., Lopes, J.P., Weise, N.D., 2017. Control of an isolated single-phase bidirectional AC–DC matrix converter for V2G applications. Electr. Power Syst. Res. 149, 19–29. https://doi.org/10.1016/j.epsr.2017.04.004.
Walke, K., 2025. Evaluating global news sentiment on electric vehicle adoption using Gemini 2.0. Available at SSRN 5371824. https://doi.org/10.2139/ssrn.5371824.
Wang, D., Coignard, J., Zeng, T., Zhang, C., Saxena, S., 2016. Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services. J. Power Sour. 332, 193–203. https://doi.org/10.1016/J.JPOWSOUR.2016.09.116.
Wohlschlager, D., Kigle, S., Schindler, V., Neitz-Regett, A., Fröhling, M., 2024. Environmental effects of vehicle-to-grid charging in future energy systems – a prospective life cycle assessment. Appl. Energy 370, 123618. https://doi.org/10.1016/j.apenergy.2024.123618.
Wu, X., Lam, C.S., Hui, K.H., Loong, H.H.F., Zhou, K.R., Ngan, C.K., Cheung, Y.T., 2025. Perceptions in 3.6 million web-based posts of online communities on the use of cancer immunotherapy: data mining using BERTopic. J. Med. Internet Res. 27, e60948. https://doi.org/10.2196/60948.
Yu, Q., Que, T., Cushing, L.J., Pierce, G., Shen, K., Kejriwal, M., Yao, Y., Zhu, Y., 2025. Equity and reliability of public electric vehicle charging stations in the United States. Nat. Commun. 16, 5291. https://doi.org/10.1038/s41467-025-60091-y.
Zhang, W., Deng, Y., Liu, B., Pan, S.J., Bing, L., 2023. Sentiment analysis in the era of large language models: A reality check. arXiv preprint arXiv:2305.1500.