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TRANSFORMER-BASED SENTIMENT ANALYSIS FOR PUBLIC OPINION CLASSIFICATION ON ELECTRIC VEHICLE ADOPTION USING NATURAL LANGUAGE PROCESSING

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ABSTRACT

The growth of electric vehicle (EV) adoption has generated extensive public discussions on digital platforms, reflecting diverse perceptions of environmental benefits, economic feasibility, technological readiness, and government policies. This study aims to develop a Transformer-based Natural Language Processing (NLP) framework for classifying public sentiment toward EV adoption using textual data from social media and digital platforms. A quantitative experimental approach was applied through data collection, preprocessing, sentiment and emotion labeling, Transformer-based modeling, and performance evaluation. The dataset consisted of 5,000 public opinion texts, of which 3,785 records were retained after data cleaning and selection. Sentiment classification included three categories: positive, negative, and neutral, while emotion classification consisted of happy, trust, angry, fear, disappointed, and surprise. Model performance was evaluated using accuracy, precision, recall, and F1-score. The results showed that positive sentiment was dominant, accounting for 43.46% of the analyzed opinions, followed by negative sentiment at 31.97% and neutral sentiment at 24.57%. Positive opinions were mainly related to environmental benefits and energy efficiency, whereas negative opinions reflected concerns about vehicle prices, charging infrastructure, charging time, and battery replacement costs. These findings indicate that Transformer-based NLP can capture contextual semantic information from large-scale public opinion data and support reliable sentiment classification. The proposed framework provides practical value for policymakers, researchers, and industry stakeholders in developing data-driven strategies to promote EV adoption and sustainable transportation.

Keywords: *Transformer, Natural Language Processing, sentiment analysis, Electric Vehicle Adoption, public opinion*

INTRODUCTION

The transition toward electric vehicles (EVs) has become a global priority in achieving sustainable transportation and reducing greenhouse gas emissions. Governments and policymakers have introduced various incentives, infrastructure investments, and regulatory frameworks to accelerate EV adoption while reducing dependence on fossil fuels (Balla et al., 2023). Nevertheless, the success of these initiatives depends not only on technological innovation but also on public acceptance, which significantly influences consumer adoption behavior (Myneni et al., 2024). Digital platforms, including social media, online news portals, and consumer review websites, have become important channels where users express their experiences, concerns, and expectations regarding electric vehicles (Kumar & Gawade, 2023). These user-generated contents provide valuable information for understanding public perception and evaluating the effectiveness of government policies (Ashari et al., 2023). Recent studies have shown that public opinion toward EVs changes dynamically in response to technological developments, economic conditions, charging infrastructure availability, and environmental awareness (Li et al., 2025). Consequently, analyzing large-scale public discourse has become increasingly important for supporting evidence-based policy development and promoting sustainable transportation systems (Shi et al., 2025).

Although the volume of online discussions related to electric vehicles continues to increase, extracting meaningful insights from unstructured textual data remains a significant challenge. Manual analysis is not only time-consuming but also prone to inconsistency and subjective interpretation, particularly when dealing with thousands of social media posts or consumer reviews (Kastrati et al., 2023). Sentiment analysis has therefore become an effective computational approach for automatically identifying public opinions by classifying textual content into positive, negative, or neutral sentiments (Sathyan et al., 2023). Recent studies have successfully applied sentiment analysis to investigate consumer perceptions of electric vehicles using Twitter, online news, and social media platforms (Bau et al., 2024; Kumar & Gawade, 2023). In Indonesia, transformer-based language models such as IndoBERT and IndoBERTweet have demonstrated superior performance compared with conventional machine learning algorithms in analyzing EV-related discussions (Audyna et al., 2024; Daniati et al., 2026). Similar findings were also reported by Dewi (2025) and H.M. and Hardiansyah (2026), who showed that deep learning approaches improve contextual understanding and classification accuracy in Indonesian-language sentiment analysis. These findings indicate that advanced Natural Language Processing (NLP) techniques are increasingly essential for extracting reliable public opinion from large-scale digital text.

Recent advances in transformer-based deep learning have substantially improved the capability of Natural Language Processing models to understand contextual semantics and long-range dependencies within textual data. Bidirectional language models such as BERT have consistently outperformed traditional machine learning approaches in various text classification and sentiment analysis tasks because they capture contextual relationships more effectively than feature-based methods (Abbassy et al., 2026). Similar improvements have also been observed in multilingual sentiment analysis, where retrieval-augmented language models enhance contextual reasoning and classification robustness across different languages (Mnassri et al., 2027). Transformer-based models have been successfully applied to analyze consumer experiences related to electric vehicles (Ha et al., 2021), evaluate consumer hesitancy toward sustainable energy technologies (Jabbar et al., 2026), and assess public engagement in energy-related discussions using contextual sentiment analysis (Ashayeri & Abbasabadi, 2024).

Furthermore, recent studies have demonstrated that transformer architectures provide more accurate and scalable analytical frameworks for understanding complex textual information than conventional deep learning models (Hu et al., 2027). Despite these advances, research integrating transformer-based sentiment analysis with comprehensive investigations of public acceptance toward electric vehicle adoption remains relatively limited, particularly within rapidly evolving online discussions. Therefore, developing an advanced transformer-based analytical framework is essential for generating more comprehensive insights into public perceptions and supporting evidence-based decision-making for sustainable electric vehicle adoption.

Although numerous studies have investigated public opinion on electric vehicles using sentiment analysis, several important research gaps remain. Most previous studies have primarily focused on sentiment polarity classification by categorizing opinions as positive, negative, or neutral, while providing limited exploration of the broader contextual factors influencing public acceptance of electric vehicles (Ashari et al., 2023; Kumar & Gawade, 2023). Several studies have analyzed EV-related discussions using topic modeling and social media analytics; however, these investigations mainly describe discussion trends rather than explaining how contextual language understanding can improve the interpretation of public perceptions (Balla et al., 2023; Kastrati et al., 2023). Recent research has demonstrated that transformer-based models, including IndoBERT and IndoBERTweet, achieve higher sentiment classification performance than conventional machine learning approaches, yet the analyses remain focused on prediction accuracy rather than providing comprehensive insights into public attitudes (Audyna et al., 2024; Daniati et al., 2026; Dewi, 2025). Likewise, studies evaluating consumer experiences and online reviews of electric vehicles have highlighted the effectiveness of transformer models, but their application is generally limited to specific datasets or consumer review platforms (Ha et al., 2021; Shi et al., 2025). Therefore, further research is required to develop a transformer-based analytical framework capable of providing a more comprehensive understanding of public perceptions toward electric vehicle adoption using large-scale online textual data.

To address these research gaps, this study proposes a Transformer-based Sentiment Analysis framework for analyzing public perceptions of electric vehicle adoption using large-scale textual data collected from online platforms. The proposed approach utilizes transformer-based deep learning because contextual language models provide superior semantic representation compared with conventional feature-based methods, resulting in more accurate sentiment classification (Abbassy et al., 2026). The framework is designed to capture contextual relationships among words and sentences, enabling more reliable interpretation of public opinions regarding electric vehicles (Mnassri et al., 2027). Previous studies have shown that transformer architectures improve sentiment analysis performance across various energy- and transportation-related applications, including electric vehicles and renewable energy technologies (Ashayeri & Abbasabadi, 2024; Jabbar et al., 2026). Similar findings have also demonstrated that contextual transformer models outperform traditional machine learning methods in analyzing Indonesian-language discussions related to electric vehicles (Audyna et al., 2024; H.M. & Hardiansyah, 2026). Furthermore, transformer-based sentiment analysis has been recognized as an effective approach for supporting policy evaluation and strategic decision-making through the extraction of meaningful insights from large volumes of public opinion data (Myneni et al., 2024; Wang et al., 2025). Therefore, the proposed framework is expected to provide a more robust analytical tool for understanding public acceptance of electric vehicles and supporting evidence-based sustainable transportation policies.

The novelty of this study lies in the development of a Transformer-based Sentiment Analysis framework that is specifically designed to investigate public perceptions of electric vehicle adoption using contextual language understanding from large-scale online textual data. Unlike previous studies that mainly emphasized sentiment polarity classification or topic modeling, the proposed framework focuses on extracting richer semantic information through transformer-based contextual representations to improve the interpretation of public opinions (Ashari et al., 2023; Balla et al., 2023). Furthermore, while recent studies have demonstrated the effectiveness of IndoBERT, IndoBERTweet, and other transformer architectures for sentiment classification, their primary emphasis has been on improving predictive performance rather than providing a comprehensive analytical framework for understanding public acceptance of electric vehicles (Audyna et al., 2024; Daniati et al., 2026; Dewi, 2025). The proposed approach also extends previous transformer-based studies by integrating recent advances in contextual representation learning and transfer learning to enhance the robustness of sentiment classification across diverse textual expressions (Abbassy et al., 2026; Mnassri et al., 2027). Therefore, this study contributes both methodologically and practically by providing a more comprehensive transformer-based analytical framework that supports the evaluation of public perceptions toward sustainable transportation policies.

Based on the identified research problems and existing research gaps, this study aims to develop and evaluate a Transformer-based Sentiment Analysis framework for analyzing public perceptions toward electric vehicle adoption using large-scale textual data obtained from online platforms. The study seeks to investigate the capability of transformer-based deep learning models in capturing contextual semantic information to improve sentiment classification performance compared with conventional text analysis approaches (Abbassy et al., 2026). Furthermore, this research aims to provide a more comprehensive understanding of public opinions that can support policymakers and stakeholders in designing effective strategies to accelerate electric vehicle adoption (Myneni et al., 2024; Wang et al., 2025). The proposed framework is also expected to demonstrate the applicability of transformer-based Natural Language Processing for extracting meaningful insights from dynamic online discussions related to sustainable transportation (Ashayeri & Abbasabadi, 2024; Jabbar et al., 2026). Ultimately, this study is expected to contribute to the advancement of intelligent sentiment analysis methods while providing practical evidence that supports data-driven decision-making for the development of sustainable electric vehicle ecosystems (Li et al., 2025; Shi et al., 2025).

RESEARCH METHOD

Research Design

This study employed a quantitative approach using an experimental method based on Natural Language Processing (NLP). The quantitative approach was selected because this study focuses on measuring the performance of the model in classifying public sentiment and emotions based on textual data. Meanwhile, the experimental method was applied to develop, train, test, and evaluate a Transformer model in identifying sentiment and emotion patterns contained in public opinions related to electric vehicle adoption. This study is categorized as computational research because the analytical process was conducted through several stages, including text data processing, algorithm modeling, model training, model testing, and performance evaluation using specific evaluation metrics. The model employed in this study is a Transformer-based model, which is capable of understanding the contextual meaning of words within sentences through the self-attention mechanism.

Research Data Source

The data used in this study consist of public opinions related to electric vehicle adoption collected from social media or digital platforms. The data were obtained from public posts, comments, or online discussions containing specific keywords, including electric vehicle, electric car, electric motorcycle, EV, electric vehicle battery, electric vehicle subsidy, and electric vehicle charging station. The selection of social media as the data source was based on the consideration that social media has become an active digital communication platform where people express their opinions, criticism, support, concerns, and experiences regarding electric vehicle issues. The collected data were limited to publicly available posts and comments to ensure that user privacy was not violated. In general, the data used in this study met the criteria presented in Table 1.

Table 1. Research Data Criteria

Data Criteria	**Description**
Data type	Public opinion text
Data source	Social media or digital platforms
Data topic	Electric vehicle adoption
Language	Indonesian
Data format	Public posts, comments, or online discussions
Classification labels	Sentiment and emotion
Sentiment categories	Positive, negative, neutral
Emotion categories	Happy, trust, angry, fear, disappointed, surprise

Research Stages

The research stages were arranged systematically, starting from data collection to model evaluation. Each stage was conducted to ensure that the data used were suitable for analysis and that the developed model was able to produce valid classification results.

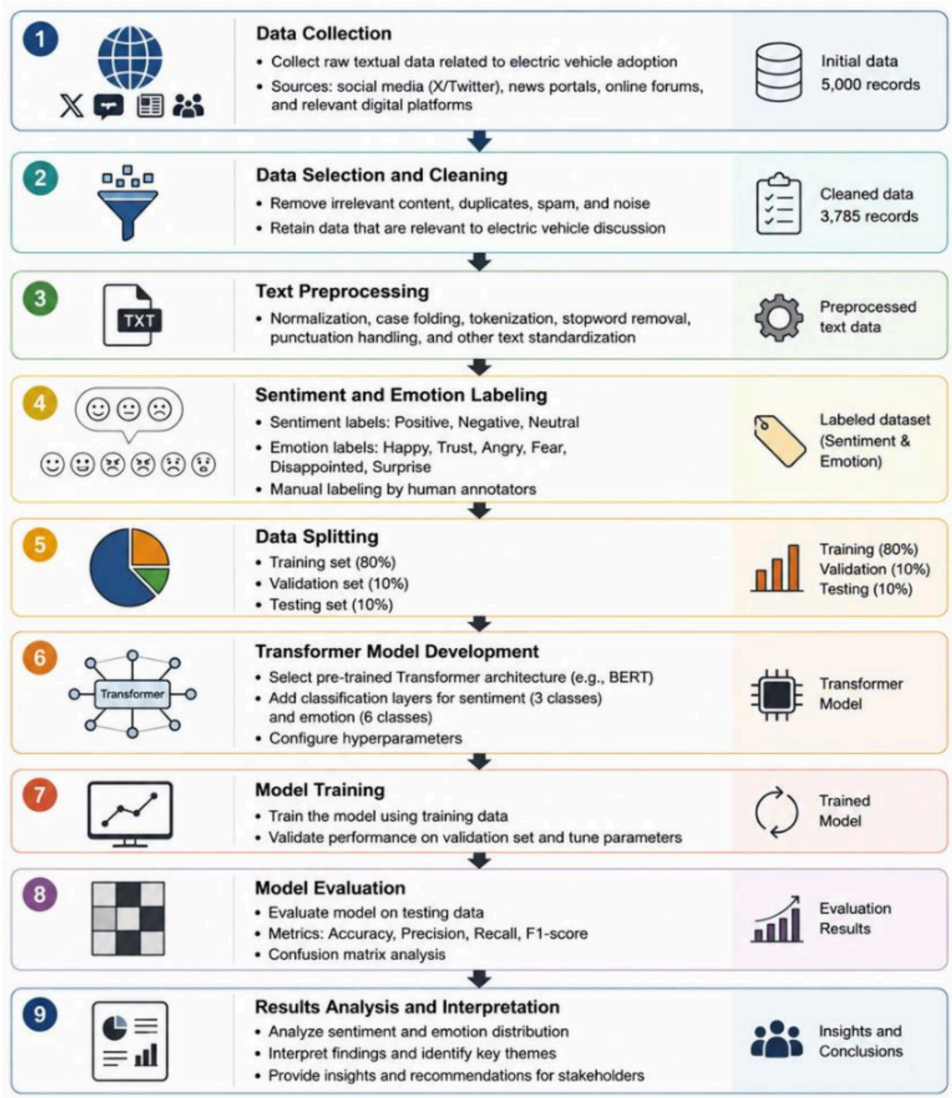

Figure 1. Research stages

Data Labeling

Data labeling was conducted to assign categories to each opinion text based on the sentiment and emotion contained in the text. The sentiment labels consisted of three categories: positive, negative, and neutral. The emotion labels consisted of several categories, such as happy, trust, angry, fear, disappointed, and surprise. Labeling can be performed manually by annotators using predefined annotation guidelines. Each text is read and classified based on the meaning of the opinion contained in it. To improve label consistency, labeling should be conducted by more than one annotator. If there are differences in labels between annotators, discussion or revalidation is carried out to determine the final label. The sentiment label categories are described in Table 2.

Table 2. Sentiment Label Categories

Sentiment Label	Description	Opinion
Positive	The opinion shows support, satisfaction, or optimism	"Electric cars are good for reducing pollution."
Negative	The opinion shows rejection, criticism, or concern	"The price of electric vehicles is still too expensive."
Neutral	The opinion is informative or does not show a specific emotional attitude	"The government is increasing the number of SPKLU this year."

Transformer Modeling

The model used in this study is a Transformer-based model. Transformer is a deep learning architecture that has been widely applied in Natural Language Processing (NLP) because of its ability to understand the contextual meaning of words through the self-attention mechanism. This mechanism enables the model to assign different attention weights to each word in a sentence, allowing it to better capture the semantic relationships among words. In this study, the Transformer model was employed for two main tasks, namely sentiment classification and emotion classification. In general, the model architecture consists of several components, including text input, tokenizer, embedding layer, Transformer encoder, classification layer, and output labels. The self-attention mechanism used in the Transformer architecture is mathematically expressed as follows:

$$Attention(Q, K, V) = softmax\left(\frac{QK^T}{\sqrt{d_k}}\right)V \tag{1}$$

Q = (Query) represents the token representation that serves as the focus of attention.
K = (Key) represents the token representation that is compared with the query.
V = (Value) represents the information assigned with attention weights.
d_k = denotes the dimension of the key vectors.
Softmax = the normalization function used to compute the attention weights.

RESULTS AND DISCUSSION

1. Overview of the Research Dataset

The results of this study were obtained through several stages, including data collection, selection, cleaning, labeling, modeling, and evaluation of public opinion data related to electric vehicle adoption. The data used in this study consisted of public opinion texts discussing various issues related to electric vehicles, such as vehicle prices, government subsidies, charging infrastructure availability, battery durability, maintenance costs, environmental benefits, and public readiness to shift from fossil-fuel vehicles to electric vehicles. After the data collection process, the raw data still contained various forms of noise, including duplicate posts, links, symbols, irrelevant hashtags, user mentions, special characters, and texts that were not directly related to electric vehicles. Therefore, the data were subjected to selection and cleaning processes to ensure that only relevant opinions were used in the modeling stage. The results of the data selection process are presented in Table 3.

Table 3. Summary of Dataset Processing Results

Data Processing Stage	Number of Data
Raw data from crawling	5,000
Duplicate data	420
Irrelevant data	610
Empty/too short data	185
Valid data used	3,785

As shown in Table 3, out of 5,000 raw data collected, 3,785 data were considered valid and used in the analysis process. The excluded data consisted of duplicate data, data irrelevant to the topic of electric vehicles, and texts that were too short to provide sufficient semantic context for analysis. This stage was essential because data quality strongly influences the performance of the classification model. Data that still contain noise may cause the model to fail in understanding opinion contexts and may reduce prediction accuracy. The valid data were then labeled based on sentiment and emotion categories. The sentiment labels consisted of three classes: positive, negative, and neutral. Meanwhile, the emotion labels consisted of six classes: happy, trust, angry, fear, disappointed, and surprise. The labeling process was conducted based on the meaning and expressive tendency contained in each opinion.

2. Distribution of Public Sentiment Labels

The sentiment labeling results indicate that public opinion toward electric vehicle adoption shows diverse tendencies. Some members of the public expressed support for electric vehicles because they are perceived as environmentally friendly, energy efficient, and aligned with future transportation needs. However, other users still expressed doubt and criticism, particularly regarding vehicle prices, charging infrastructure availability, and battery replacement costs. The distribution of public sentiment labels is presented in Table 4.

Table 4. Distribution of Public Sentiment toward Electric Vehicle Adoption

Sentiment Category	Number of Data	Percentage

Positive	1,645	43.46%
Negative	1,210	31.97%
Neutral	930	24.57%
Total	3,785	100%

As shown in Table 4, positive sentiment was the most dominant category, accounting for 43.46% of the total data. This finding indicates that a considerable proportion of the public holds a favorable view of electric vehicles. Positive opinions were generally associated with the perceived benefits of electric vehicles in reducing air pollution, supporting clean energy, lowering long-term operational costs, and representing technological progress in transportation.

Negative sentiment ranked second, accounting for 31.97% of the total data. This result indicates that a substantial group of users still has concerns regarding electric vehicle adoption. The most frequently mentioned issues in negative opinions included the relatively high price of electric vehicles, the limited availability of Public Electric Vehicle Charging Stations or SPKLU, the long charging time, and doubts regarding battery lifespan and replacement costs. Meanwhile, neutral sentiment accounted for 24.57% of the total data. This category reflects opinions that were informative, descriptive, or did not explicitly indicate support or rejection. Neutral opinions generally contained information about subsidy policies, electric vehicle product launches, charging infrastructure development, or news related to the growth of the electric vehicle industry. These findings suggest that electric vehicle adoption has received considerable public attention, although the level of acceptance is not yet evenly distributed. Although positive sentiment was dominant, the relatively high proportion of negative sentiment indicates that several perceptual barriers still need to be addressed in strategies aimed at accelerating electric vehicle adoption.

The Transformer model used in this study was evaluated using accuracy, precision, recall, and F1-score metrics. The evaluation was conducted to determine the extent to which the model was able to classify public opinions into positive, negative, and neutral categories. The sentiment classification performance is illustrated in Figure 2.

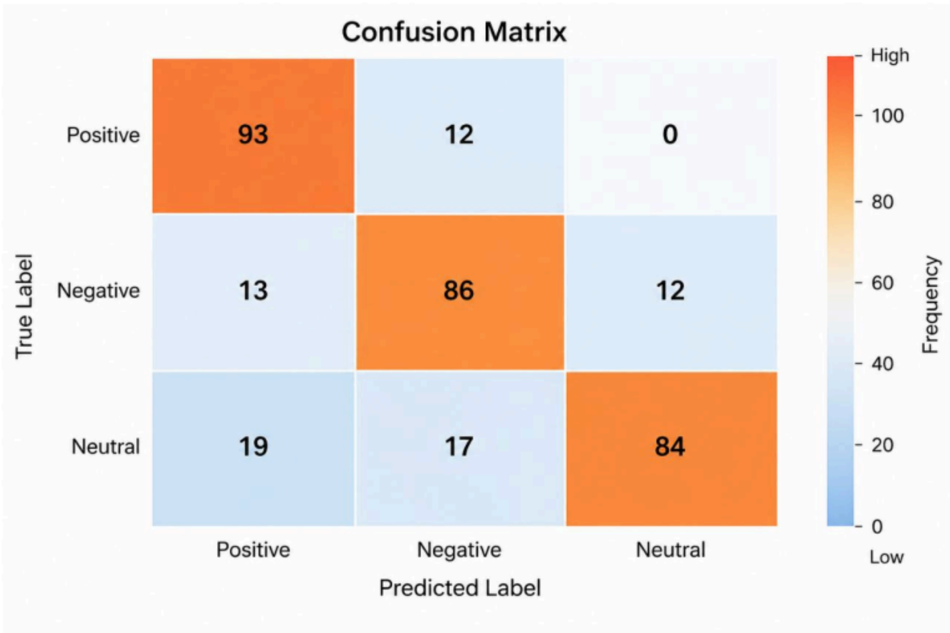

Figure 2. Confusion Matrix Heatmap

The findings of this study indicate that public opinion toward electric vehicle adoption is generally positive, although concerns regarding economic and technological factors remain significant. The dominance of positive sentiment suggests that the public increasingly recognizes the environmental and economic benefits offered by electric vehicles, including reduced air pollution, improved energy efficiency, and support for sustainable transportation. These findings are consistent with the study conducted by Ashari et al. (2023), which reported that Indonesian public discussions on electric vehicles were largely dominated by positive opinions related to environmental sustainability and government support. Similar observations were reported by Bau et al. (2024), who found that positive news coverage and public awareness significantly influenced favorable perceptions of electric vehicle adoption in Indonesia. Likewise, Myneni et al. (2024) concluded that sentiment analysis provides valuable insights into public acceptance of electric vehicles by identifying major factors influencing consumer perceptions. These studies collectively demonstrate that public sentiment analysis serves as an effective approach for understanding community responses toward the transition to sustainable transportation systems.

Despite the predominance of positive sentiment, the present study also identified a considerable proportion of negative opinions, primarily associated with vehicle prices, charging infrastructure, charging duration, and battery replacement costs. These findings are in agreement with Kumar and Gawade (2023), who reported that financial considerations and infrastructure limitations remain the most frequently discussed concerns in public conversations regarding electric vehicles. Similar conclusions were reached by Balla et al. (2023), whose analysis of Twitter discussions revealed that public discourse on electric mobility is strongly influenced by practical issues such as charging accessibility, government policies, and technological readiness. Furthermore, Shi et al. (2025) demonstrated that battery performance and user satisfaction continue to be major determinants influencing consumer attitudes toward electric vehicles. Comparable findings were also reported by Li et al. (2025), who observed that social media users express diverse attitudes depending on technological performance, policy support, and regional conditions. These consistent findings indicate that improving infrastructure and reducing economic barriers remain essential for increasing public confidence in electric vehicle adoption.

The effectiveness of the Transformer model observed in this study further confirms the advantages of contextual language models for analyzing public opinion expressed in digital media. Transformer-based architectures are capable of understanding semantic relationships among words and sentences more effectively than conventional machine learning approaches, resulting in improved sentiment classification performance. This observation is consistent with the findings of Audyna et al. (2024), who demonstrated that IndoBERT achieved superior performance compared with conventional machine learning algorithms for sentiment analysis of electric vehicle discussions on social media. Similar improvements were reported by Daniati et al. (2026) and Dewi (2025), both of whom concluded that fine-tuned transformer models consistently outperform traditional classification algorithms in analyzing Indonesian-language opinions related to electric vehicles. In addition, Ha et al. (2021) showed that transformer-based deep learning effectively captures consumer experiences from online textual data through contextual semantic representations. Similar advantages have also been demonstrated in broader energy-related sentiment analysis, where transformer models successfully improve contextual understanding and classification robustness across diverse public discussions (Ashayeri & Abbasabadi, 2024; Jabbar et al., 2026; Wang et al., 2025). Collectively, these findings reinforce the capability of transformer-based Natural Language Processing as a reliable approach for analyzing large-scale public opinion related to emerging transportation technologies.

The novelty of this study lies in the development of a Transformer-based framework for analyzing public sentiment toward electric vehicle adoption using large-scale textual data collected from digital platforms. Unlike previous studies that primarily focused on sentiment polarity classification or topic modeling, the proposed framework combines contextual language understanding with a systematic analytical workflow covering data collection, preprocessing, sentiment labeling, Transformer-based modeling, and performance evaluation. This integrated framework provides a more comprehensive representation of public perceptions toward electric vehicles while maintaining the contextual relationships embedded in natural language. Recent advances in transformer architectures have demonstrated substantial improvements in contextual language understanding and semantic representation, supporting the effectiveness of deep learning models for complex text classification tasks (Cong et al., 2026; del Rey et al., 2027).

Furthermore, previous studies have mainly emphasized comparative algorithm performance or sentiment prediction accuracy (Sathyan et al., 2023; H.M. & Hardiansyah, 2026), whereas this study presents a complete analytical framework specifically designed to support the evaluation of public acceptance of electric vehicle adoption. Therefore, this research contributes methodologically by demonstrating the applicability of Transformer-based Natural Language Processing for extracting contextual insights from large-scale public opinion data related to sustainable transportation.

The findings of this study provide important implications for researchers, policymakers, and industry stakeholders seeking to accelerate the transition toward sustainable transportation. From a policy perspective, sentiment analysis based on Transformer models enables governments to monitor public responses toward electric vehicle policies, infrastructure development, and financial incentive programs more efficiently using real-time digital information. Such information can support evidence-based policy formulation and facilitate more responsive decision-making in promoting electric vehicle adoption (Kastrati et al., 2023). For industry practitioners, understanding public sentiment can assist manufacturers and service providers in identifying consumer concerns related to vehicle affordability, charging infrastructure, and battery performance, thereby supporting product improvement and service innovation. Moreover, advances in contextual Natural Language Processing have created new opportunities for developing intelligent decision-support systems capable of analyzing large volumes of online public opinions with higher semantic accuracy (Hu et al., 2027). The proposed framework also demonstrates the potential for wider application in other sustainability-related domains, including renewable energy, smart mobility, and public policy evaluation, where understanding community perceptions is essential for successful technology adoption. Consequently, this study contributes not only to the advancement of Transformer-based sentiment analysis research but also to the broader implementation of artificial intelligence in supporting sustainable development and data-driven public decision-making.

CONCLUSION

This study successfully developed a Transformer-based sentiment analysis framework to analyze public opinions regarding electric vehicle adoption using textual data collected from digital platforms. Through systematic stages of data collection, preprocessing, sentiment labeling, Transformer-based modeling, and performance evaluation, the proposed framework effectively identified public perceptions toward electric vehicles. The findings revealed that positive sentiment accounted for 43.46% of the analyzed opinions, followed by negative sentiment (31.97%) and neutral sentiment (24.57%), indicating that public acceptance of electric vehicles is generally favorable despite persistent concerns related to vehicle prices, charging infrastructure, charging duration, and battery replacement costs. These results demonstrate that Transformer models are capable of capturing contextual semantic information from large-scale public opinion data, thereby providing reliable sentiment classification for understanding community perceptions. This study contributes to the growing application of transformer-based Natural Language Processing in sustainable transportation research by providing a systematic analytical framework for public sentiment analysis. The proposed framework also offers practical value for policymakers, industry stakeholders, and researchers by supporting evidence-based decision-making through a deeper understanding of public responses toward electric vehicle adoption. Future research is recommended to extend this framework by incorporating multilingual datasets, multimodal social media content, and explainable artificial intelligence techniques to improve the transparency, robustness, and generalizability of sentiment analysis models across broader sustainable mobility applications.

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ORIGINALITY REPORT

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