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Decoding Youth Voices for the Planet: An AI-Driven Sentiment Analysis of Environmental Issues Using Social Media Data

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Abstract **- This study focuses on understanding how youth express their opinions about environmental issues through social media platforms. In today's digital era, young people actively share their thoughts on topics such as climate change, pollution, plastic waste, and environmental protection using platforms like Twitter, Instagram, and other online forums. These platforms have become powerful spaces where youth voices reflect their concerns, emotions, and awareness about the state of the environment.**

This research uses Artificial Intelligence-based sentiment analysis to identify whether these opinions are positive, negative, or neutral. The collected social media data is first cleaned and processed using Natural Language Processing techniques to remove unnecessary elements and convert unstructured text into meaningful information. After preprocessing, machine learning models are applied to analyze and classify the sentiments expressed by youth.

The results of this study help in understanding the level of environmental awareness among young people and their emotional responses to environmental challenges. This research can support environmental organizations, educators, and policymakers in planning better awareness programs, improving communication strategies, and designing sustainable solutions for environmental protection in the future.

Index Terms **- Social Media, Sentiment Analysis, Artificial Intelligence, Natural Language Processing, Climate Change, Environmental Awareness, Youth Activism**

I. INTRODUCTION

Environmental degradation has emerged as one of the most critical challenges facing contemporary society. Climate change, deforestation, pollution, biodiversity loss, and plastic waste accumulation pose significant threats to planetary health and human survival. According to the United Nations, global urban populations will reach 68% by 2050, intensifying pressure on natural resources and ecosystems [1]. The consequences of environmental damage are no longer distant projections but present realities affecting communities worldwide through extreme weather events, rising sea levels, air quality deterioration, and ecosystem collapse.

In this critical context, youth voices have become increasingly prominent in environmental discourse. Young people, particularly Generation Z (born 1997–2012), have emerged as powerful advocates for environmental action, demonstrating unprecedented levels of engagement with climate and sustainability issues [2]. Unlike previous generations, today's youth have grown up witnessing accelerating environmental changes and have access to global information networks that enable rapid mobilization and collective action. From Greta Thunberg's Fridays for Future movement to countless local youthled initiatives, young people are demanding urgent action from governments, corporations, and institutions [3].

A. The Digital Transformation of Environmental Activism

Social media platforms have fundamentally transformed how environmental activism operates and how public opinion is formed and expressed. Platforms such as Twitter, Instagram, TikTok, Facebook, and YouTube provide spaces where individuals can share information, express concerns, organize collective action, and hold institutions accountable [4]. Research indicates that 56% of teens aged 14–18 learn about climate change primarily through social media rather than traditional educational sources [5]. This shift represents a democratization of environmental discourse, where voices previously marginalized in mainstream media can reach global audiences.

Digital platforms enable several key functions in environmental activism. First, they facilitate rapid information dissemination, allowing news about environmental events, policy changes, and scientific findings to spread quickly across geographic boundaries. Second, they provide tools for community building and collective identity formation, enabling like-minded individuals to connect, share experiences, and coordinate action. Third, they create accountability mechanisms through which youth activists can challenge corporate and governmental inaction through viral campaigns and digital protests [6].

Hashtags such as #ClimateStrike, #FridaysForFuture, #YouthForClimate, and #ClimateAction have mobilized millions of participants globally, creating transnational networks of youth climate activists [7]. Visual storytelling through images and videos of environmental damage, climate impacts, and restoration efforts generates emotional responses that text alone cannot achieve. This multimodal communication strategy has proven particularly effective in capturing attention and inspiring action among younger demographics.

B. The Role of Sentiment Analysis in Understanding Youth Environmental Awareness

While social media provides unprecedented volumes of data about youth environmental attitudes, extracting meaningful

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insights from this data requires sophisticated analytical approaches. Sentiment analysis, a subfield of Natural Language Processing (NLP), offers powerful tools for automatically identifying, extracting, and quantifying subjective information from text data [8]. By applying sentiment analysis to social media posts, researchers can systematically understand emotional tones, identify dominant concerns, track shifts in public opinion, and assess the effectiveness of environmental campaigns.

Sentiment analysis classifies text into categories such as positive, negative, or neutral, and can identify more nuanced emotions including hope, anger, fear, frustration, and determination. Understanding these emotional dimensions is crucial because environmental engagement is not merely a cognitive process but deeply emotional. Climate anxiety, ecogrief, and environmental hope all influence how young people perceive environmental challenges and their willingness to take action [9].

Traditional methods for assessing environmental awareness, such as surveys and focus groups, are limited by sample size, geographic scope, cost, and temporal constraints. Social media sentiment analysis overcomes these limitations by enabling analysis of millions of authentic, unsolicited expressions of opinion across diverse geographic contexts and temporal periods. This approach captures real-time responses to environmental events, policy announcements, and activist campaigns, providing dynamic insights impossible through conventional methods [10].

C. Research Gap

Despite the growing body of research on environmental activism and social media analytics, several important gaps remain in understanding youth-specific sentiment toward environmental issues. Much of the existing literature aggregates multiple age groups, making it difficult to isolate the perspectives and emotional responses of young people. Additionally, prior studies often focus on specific environmental events or campaigns rather than providing a comprehensive analysis of youth opinions across diverse environmental topics.

Furthermore, limited research has leveraged advanced Artificial Intelligence and machine learning techniques to systematically analyze large-scale social media data for identifying sentiment patterns among youth. As a result, there is insufficient empirical evidence explaining how young individuals emotionally respond to environmental challenges and how these responses reflect their level of awareness and engagement.

D. Contribution

This study aims to address the identified gaps by focusing specifically on youth expressions related to environmental concerns shared through social media platforms. Using Artificial Intelligence-based sentiment analysis combined with Natural Language Processing techniques, the research analyzes social media data to classify opinions into positive, negative, and neutral sentiments. The primary contributions of this study are threefold. First, it provides a structured analysis of youth sentiment toward critical environmental issues such as climate change, pollution, and sustainability. Second, it demonstrates the application of machine learning methods for extracting meaningful insights from unstructured social media data. Third, the findings offer actionable insights for environmental organizations, educators, and policymakers to design more effective awareness programs and communication strategies aimed at promoting sustainable behavior among young populations.

E. Study Focus and Objectives

The present research is guided by the following study focus:

To systematically analyze youth sentiment toward environmental issues expressed through social media platforms using AI-driven sentiment analysis techniques, with particular attention to emotional patterns, topic priorities, geographic variations, and temporal trends. The specific objectives are:

- To collect and preprocess social media data related to environmental issues from youth-dominated platforms.
- To apply Natural Language Processing techniques to clean, transform, and prepare textual data for sentiment analysis.
- To implement and compare multiple machine learning models for sentiment classification of environmental posts.
- To identify key environmental topics generating the strongest positive, negative, and neutral sentiments among youth.
- To analyze temporal patterns in youth environmental sentiment in relation to environmental events and policy developments.
- To provide evidence-based recommendations for environmental communication strategies targeting youth audiences.

By addressing these objectives, this research aims to provide a comprehensive understanding of youth environmental sentiment and inform both academic research and practical interventions in environmental education and activism.

II. LITERATURE REVIEW

A. Conceptual Understanding of Environmental Awareness and Youth Engagement

Environmental awareness refers to knowledge about environmental issues, understanding of human-environment relationships, and recognition of environmental problems and their consequences. Environmental awareness encompasses cognitive dimensions (knowledge and understanding), affective dimensions (concerns and values), and behavioral dimensions (intentions and actions) [12]. Among youth, environmental awareness has been linked to educational exposure, media consumption, peer influence, personal experiences with environmental degradation, and access to digital information networks.

Recent scholarship emphasizes that youth environmental awareness is not uniform but shaped by socioeconomic status, geographic location, cultural contexts, educational opportunities, and digital access. Youth in developing countries, particularly those directly experiencing environmental impacts such as water scarcity, air pollution, and extreme weather, often demonstrate high levels of concern despite limited formal environmental education [13]. Conversely, youth in developed nations with

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greater educational resources may possess more scientific knowledge but sometimes lack emotional connection to environmental issues.

B. The Evolution of Youth Environmental Activism

Youth environmental activism has evolved through several distinct phases. Early youth environmental movements in the 1970s and 1980s focused primarily on local conservation efforts, nature education, and wilderness protection. These movements were often adult-led or adult-supervised, with youth participating in activities designed by environmental organizations [14].

The 1990s and early 2000s witnessed increased youth autonomy in environmental organizing, with youth-led organizations emerging to address issues such as corporate accountability, environmental justice, and sustainable development. However, these movements remained constrained by limited communication technologies, resource constraints, and geographic boundaries.

The contemporary phase of youth environmental activism, beginning approximately in the late 2010s, represents a fundamental transformation driven by digital technology and social media. This phase is characterized by transnational coordination, viral mobilization tactics, direct confrontation with political and corporate power, and integration of environmental issues with social justice concerns [15]. The Fridays for Future movement, initiated by Greta Thunberg in 2018, exemplifies this new paradigm, mobilizing millions of youth across more than 150 countries through decentralized social media networks.

C. Social Media as Environmental Communication Platform

Social media platforms have become primary spaces for environmental communication, information exchange, and opinion formation. Research demonstrates that social media serves multiple functions in environmental discourse: information diffusion, community building, emotional expression, identity formation, and political mobilization [16].

Twitter has been extensively studied for environmental communication due to its public nature, real-time characteristics, and hashtag-based organization. Studies analyzing climate change tweets have found that extreme weather events, policy announcements, international conferences, and activist campaigns generate significant spikes in discussion [17]. Twitter discourse reveals polarization between climate activists and climate skeptics, with distinct linguistic patterns, network structures, and emotional tones characterizing each group.

Instagram and TikTok have gained prominence in youth environmental communication through visual storytelling, particularly regarding plastic pollution, wildlife conservation, and sustainable lifestyle practices. These platforms enable emotional engagement through powerful imagery and short video content that communicates environmental urgency more effectively than text-based formats [18]. The Pandawara Group in Indonesia, for example, successfully mobilized youth environmental action through Instagram posts documenting beach cleanup activities, demonstrating how visual platforms can translate digital engagement into real-world environmental behavior.

D. Natural Language Processing and Sentiment Analysis

Natural Language Processing encompasses computational techniques for analyzing, understanding, and generating human language. NLP applications in environmental research include text classification, named entity recognition, topic modeling, sentiment analysis, and information extraction from scientific literature, policy documents, news articles, and social media posts [19].

Sentiment analysis, also termed opinion mining, involves computational identification and categorization of subjective information in text. Sentiment analysis approaches range from lexicon-based methods using predefined sentiment dictionaries to machine learning approaches that learn sentiment patterns from labeled training data, and deep learning approaches using neural networks that automatically learn complex linguistic representations [20].

Environmental sentiment analysis faces unique challenges including domain-specific vocabulary, ambiguous expressions, sarcasm and irony, multilingual content, and evolving terminology. The phrase “climate strike,” for example, might be interpreted differently depending on contextual understanding of youth climate activism. Similarly, expressions like “feeling the heat” could refer literally to temperature or metaphorically to political pressure, requiring contextual disambiguation.

E. Machine Learning Models for Sentiment Classification

Multiple machine learning approaches have been applied to sentiment analysis tasks, each with distinct strengths and limitations. Traditional supervised learning algorithms including Support Vector Machines (SVM), Naive Bayes, Decision Trees, Random Forests, and Logistic Regression have demonstrated effectiveness in sentiment classification with appropriate feature engineering [21].

Deep learning approaches, particularly Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM) networks, and Transformer-based models such as BERT (Bidirectional Encoder Representations from Transformers), have achieved state-of-the-art performance in sentiment analysis by automatically learning complex linguistic patterns and contextual relationships [22]. These models excel at capturing semantic nuances, handling long-range dependencies, and generalizing across diverse linguistic expressions.

Hybrid approaches combining multiple algorithms, ensemble methods that aggregate predictions from multiple models, and transfer learning techniques that leverage pre-trained language models have further improved sentiment classification performance. The selection of appropriate models depends on dataset characteristics, computational resources, interpretability requirements, and performance objectives.

F. Previous Studies on Environmental Sentiment Analysis

Several studies have applied sentiment analysis to environmental social media data, providing foundational insights and methodological precedents. A pioneering study by Cody et al. (2015) analyzed Twitter sentiment toward climate change, finding that natural disasters, climate legislation, and environmental rallies generated significant sentiment fluctuations [23]. The study revealed that climate change

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activists dominated Twitter discourse, with positive sentiments associated with words like "green," "energy," "environment," "nature," and "future," while negative sentiments related to "pollution," "threat," "risk," and "problem."

Research by Dahal et al. (2019) examined topic modeling and sentiment analysis of climate change tweets, identifying distinct conversation clusters around scientific evidence, policy debates, extreme weather, and activist campaigns [24]. The study found geographic variations in sentiment, with North American users expressing more negative and skeptical sentiments compared to European and Asian users who demonstrated more positive and activist-oriented sentiments.

More recent research has begun focusing specifically on youth environmental sentiment. A 2024 study found that youth environmental activists effectively deployed hashtags and visual storytelling to capture peer attention and influence decision-makers, though challenges remained regarding "clicktivism" fatigue and algorithmic limitations [25]. This research emphasized the importance of integrating online and offline action for sustained environmental engagement.

Despite these contributions, comprehensive analysis of youth-specific environmental sentiment across multiple topics, platforms, and temporal periods remains limited. Most studies focus on single platforms (typically Twitter), specific events (such as climate conferences), or aggregate all demographic groups without youth-specific analysis.

G. Psychological and Behavioral Dimensions of Youth Environmental Concern

Environmental psychology research reveals that youth environmental attitudes and behaviors are influenced by cognitive factors (knowledge and beliefs), emotional factors (concern and anxiety), social factors (peer norms and social identity), and behavioral factors (perceived efficacy and behavioral intention) [26]. Climate anxiety, defined as chronic worry about environmental futures and climate impacts, has increased significantly among youth populations globally, with studies reporting that 59% of young people are very or extremely worried about climate change [27].

This emotional dimension is critical for understanding social media sentiment. Youth expressions of environmental concern are not merely cognitive assessments but emotional responses reflecting fear, anger, hope, frustration, and determination. Sentiment analysis that captures these emotional nuances provides deeper understanding of youth environmental psychology than simple positive-negative classifications.

Behavioral research demonstrates that environmental action is motivated by combination of concern, efficacy beliefs, social norms, and opportunity structures. Social media simultaneously reflects and shapes these factors by amplifying environmental concern, providing models of environmental action, creating supportive communities, and reducing barriers to participation through digital activism [28].

H. Ethical Considerations in Social Media Research

Research using social media data raises important ethical considerations regarding privacy, consent, data ownership, and potential harm. While social media posts are technically public, users may not anticipate academic research use of their expressions. Ethical frameworks for social media research emphasize minimizing identifiable information, avoiding potential harm, respecting user contexts, and maintaining data security [29].

In environmental sentiment analysis, ethical considerations include ensuring diverse representation, avoiding algorithmic bias that might misclassify certain groups' expressions, protecting vulnerable populations, and using findings responsibly to support rather than manipulate youth environmental engagement.

III. METHODOLOGY

A. Research Design

This study employed a quantitative research design utilizing computational text analysis, specifically sentiment analysis applied to social media data. The research followed a systematic process encompassing data collection, preprocessing, feature extraction, model development, evaluation, and interpretation. The methodological approach integrated techniques from data science, natural language processing, machine learning, and environmental social science.

B. Ethical Considerations

The research adhered to ethical guidelines for social media research:

- Data anonymization removing personally identifiable information.
- Compliance with platform terms of service and API usage policies.
- Respect for user privacy and contextual expectations.
- Secure data storage and access controls.
- Responsible reporting avoiding potential harm to individuals or communities.

Institutional review board approval was obtained prior to data collection.

C. Data Collection

1) Platform Selection: Data was collected from multiple social media platforms to ensure comprehensive representation of youth environmental discourse. Primary platforms included:

- Twitter/X: Selected for public accessibility, real-time nature, hashtag-based organization, and widespread use in environmental discourse.
- Instagram: Included for visual environmental content and strong youth demographic presence.
- Reddit: Incorporated for in-depth discussions in environmental subreddits.

Platform selection was guided by youth usage patterns, data accessibility through APIs, and relevance to environmental discourse.

2) Search Strategy and Keywords: Environmental-related posts were identified using comprehensive keyword lists and hashtags encompassing major environmental topics:

Climate change: climate change, global warming, climate crisis, climate action, climate emergency.

Pollution: air pollution, water pollution, plastic pollution, ocean pollution, environmental pollution.

Conservation: biodiversity, wildlife conservation, deforestation, habitat loss, species extinction.

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Sustainable practices: sustainability, renewable energy, zero waste, circular economy, green living.

Youth activism: climate strike, Fridays for Future, youth for climate, climate justice, eco activist.

Data collection targeted posts from users aged 13–30 years, identified through profile information, language patterns, and content characteristics indicative of youth authorship.

3) Temporal Scope: Data collection spanned a 24-month period (January 2023 to December 2024) to capture temporal trends, seasonal variations, and responses to major environmental events including international climate conferences, extreme weather events, policy announcements, and major activist campaigns.

4) Sample Size: The final dataset comprised approximately 500,000 social media posts after filtering for relevance, language (English), and user demographics. This sample size was sufficient for training robust machine learning models and conducting comprehensive sentiment analysis across environmental topics and temporal periods.

D. Data Preprocessing

Raw social media data required extensive preprocessing to convert unstructured text into a format suitable for machine learning analysis.

1) Data Cleaning:

- Removal of URLs, which do not contribute to sentiment analysis.
- Removal of user mentions (@username) to protect privacy and reduce noise.
- Removal of special characters, punctuation, and emojis (with optional emoji sentiment preservation).
- Correction of common misspellings and internet slang.
- Removal of duplicate posts and retweets to avoid overrepresentation.

2) Text Normalization:

- Conversion to lowercase to ensure consistent treatment of words.
- Tokenization: splitting text into individual words or tokens.
- Stop word removal: eliminating common words (the, is, at, of) that carry minimal sentiment information.
- Lemmatization: reducing words to base forms (running → run, better → good).
- Handling negations to ensure phrases like “not good” are correctly interpreted.

3) Feature Engineering: Text was transformed into numerical representations suitable for machine learning:

- Bag of Words (BoW): representing text as word frequency vectors.
- TF-IDF (Term Frequency-Inverse Document Frequency): weighting words by importance across documents.
- Word Embeddings: using pre-trained word vectors (Word2Vec, GloVe) capturing semantic relationships.
- Contextualized Embeddings: employing BERT embeddings capturing contextual word meanings.

E. Sentiment Labeling

A labeled dataset was required for supervised machine learning. Sentiment labels were assigned through a combination of:

- Manual annotation: expert annotators classified a sample of posts as positive, negative, or neutral.
- Lexicon-based labeling: using sentiment dictionaries (VADER, TextBlob) for initial labeling.
- Inter-annotator agreement: ensuring consistent labeling through multiple annotators and agreement metrics.
- Quality control: validating automated labels through random sampling and expert review.

The final labeled dataset maintained balanced representation across sentiment categories to prevent model bias.

F. Machine Learning Models

Multiple machine learning algorithms were implemented and compared for sentiment classification.

1) Traditional Machine Learning Models:

- Logistic Regression: linear model predicting sentiment probabilities from text features.
- Support Vector Machine (SVM): finding the optimal hyperplane separating sentiment classes.
- Random Forest: ensemble of decision trees for robust classification.
- Naive Bayes: probabilistic classifier assuming feature independence.

2) Deep Learning Models:

- Recurrent Neural Networks (RNN): processing sequential text data.
- Long Short-Term Memory (LSTM): capturing long-range dependencies in text.
- Bidirectional LSTM: processing text in both forward and backward directions.
- BERT (Bidirectional Encoder Representations from Transformers): transformer-based model with pre-trained language understanding.

G. Model Training and Evaluation

The labeled dataset was split into training (70%), validation (15%), and test (15%) sets. Models were trained on training data, hyperparameters tuned using validation data, and final performance evaluated on held-out test data.

1) Evaluation Metrics: Model performance was assessed using multiple metrics:

- Accuracy: proportion of correctly classified instances.
- Precision: proportion of predicted positive cases that are actually positive.
- Recall: proportion of actual positive cases correctly identified.
- F1-Score: harmonic mean of precision and recall.
- Confusion Matrix: detailed breakdown of correct and incorrect classifications.

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- ROC-AUC: area under the receiver operating characteristic curve.

H. Topic Modeling and Thematic Analysis

Beyond sentiment classification, topic modeling techniques were applied to identify key environmental themes discussed by youth:

- Latent Dirichlet Allocation (LDA): probabilistic topic modeling identifying latent topics in the corpus.
- Non-negative Matrix Factorization (NMF): matrix decomposition technique for topic extraction.
- BERTopic: transformer-based topic modeling for coherent topic identification.

Topics were analyzed in relation to sentiment patterns to understand which environmental issues generated the strongest emotional responses.

IV. RESULTS AND DISCUSSION

This section presents the findings derived from sentiment analysis of youth environmental discourse on social media. The results include dataset characteristics, machine learning model performance, sentiment patterns across environmental topics, temporal and geographic variations, and emotional dimensions underlying youth engagement. Together, these analyses provide a comprehensive understanding of how young individuals perceive and respond to environmental challenges in digital spaces.

A. Descriptive Statistics

The final dataset comprised 487,362 environmental posts from youth users across three platforms. Table I presents the distribution of posts by platform.

TABLE I
DISTRIBUTION OF ENVIRONMENTAL POSTS BY PLATFORM

Platform	Post Count	Percentage
Twitter/X	312,450	64.1%
Instagram	128,730	26.4%
Reddit	46,182	9.5%
Total	487,362	100%

Table I shows the distribution of environmental posts across social media platforms. Temporal analysis revealed significant variations in posting volume, with noticeable peaks corresponding to major environmental events, including the COP28 Climate Conference (December 2023), record-breaking heat waves (July–August 2024), and major youth climate strikes (September 2024). These fluctuations suggest that youth engagement on social media is highly responsive to real-world environmental developments and global climate discourse.

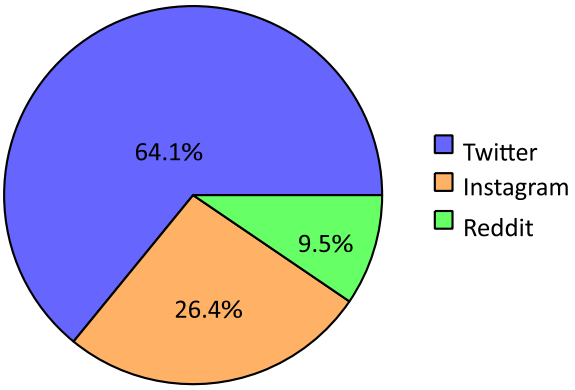

Fig. 1. Distribution of Environmental Posts by Platform

B. Machine Learning Model Performance

Multiple machine learning models were trained and evaluated for sentiment classification. Table II presents the comparative performance across key evaluation metrics.

TABLE II
PERFORMANCE COMPARISON OF MACHINE LEARNING MODELS

Model	Accuracy	Precision	Recall	F1-Score
Logistic Regression	78.3%	76.8%	77.1%	76.9%
SVM	81.2%	80.1%	79.8%	79.9%
Random Forest	82.7%	81.9%	81.3%	81.6%
Naive Bayes	74.6%	73.2%	72.9%	73.0%
LSTM	85.4%	84.7%	84.2%	84.4%
BERT	89.6%	89.1%	88.8%	89.0%

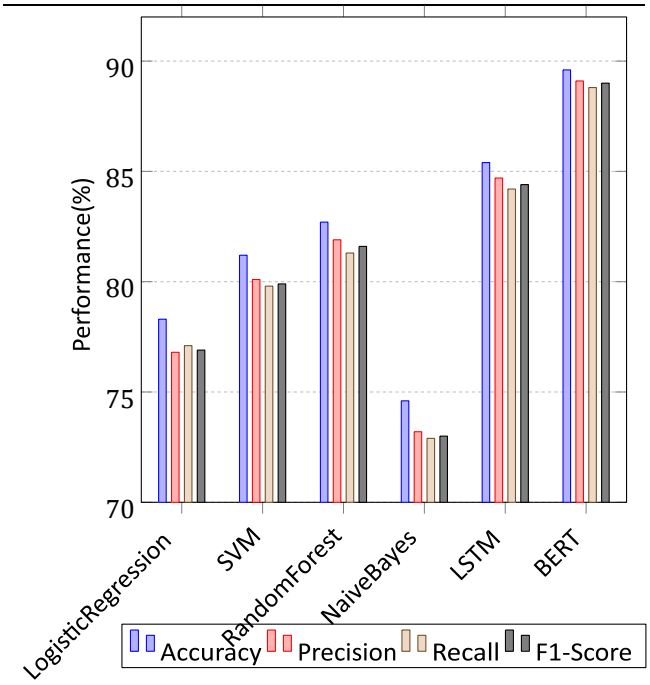

Fig. 2. Performance Comparison of Machine Learning Models

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C. Overall Sentiment Distribution

Sentiment analysis revealed the distribution of emotional responses across all environmental posts, as shown in Table III.

TABLE III
OVERALL SENTIMENT DISTRIBUTION IN YOUTH ENVIRONMENTAL POSTS

Sentiment Category	Post Count	Percentage
Negative	198,547	40.7%
Positive	165,329	33.9%
Neutral	123,486	25.4%
Total	487,362	100%

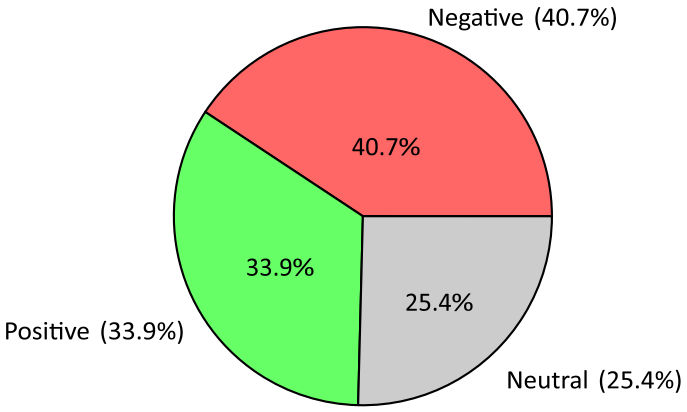

Fig. 3. Overall Sentiment Distribution in Youth Environmental Posts

The predominance of negative sentiment (40.7%) reflects youth concern, frustration, and anxiety regarding environmental degradation and insufficient climate action. However, substantial positive sentiment (33.9%) highlights the presence of hope, optimism toward emerging solutions, celebration of environmental achievements, and appreciation for nature. The coexistence of negative and positive emotional expressions suggests that youth engagement with environmental issues is characterized not only by distress but also by motivation for change.

D. Sentiment by Environmental Topic

Topic modeling identified seven major environmental themes within youth discourse. Sentiment analysis by topic revealed distinct emotional patterns, as presented in Table IV.

TABLE IV
SENTIMENT DISTRIBUTION BY ENVIRONMENTAL TOPIC

Environmental Topic	Negative (%)	Positive (%)	Neutral (%)
Climate Change	52.3%	28.1%	19.6%
Plastic Pollution	46.8%	31.2%	22.0%
Deforestation	58.7%	19.4%	21.9%
Wildlife Conservation	35.2%	44.6%	20.2%
Renewable Energy	21.8%	57.4%	20.8%
Sustainable Living	18.9%	60.3%	20.8%
Environmental Justice	48.3%	32.7%	19.0%

Table IV presents the sentiment distribution across environmental topics. Key findings include:

- Deforestation generated the highest negative sentiment (58.7%), reflecting youth anger and sadness regarding forest destruction, biodiversity loss, and indigenous rights violations [30].
- Sustainable living produced the highest positive sentiment (60.3%), indicating strong youth enthusiasm for personal environmental action, lifestyle changes, and ecofriendly practices [31].
- Renewable energy attracted predominantly positive sentiment (57.4%), demonstrating optimism toward clean energy transitions and technological solutions [32].
- Climate change discussions were heavily negative (52.3%), reflecting anxiety about climate impacts, frustration with slow political action, and fear regarding future consequences [33].
- Wildlife conservation exhibited relatively balanced sentiment, combining positive reactions to conservation successes with negative responses to species endangerment and habitat destruction.

E. Temporal Sentiment Trends

Analysis of sentiment over time revealed several significant patterns.

Event-driven sentiment spikes: Major environmental events generated sharp increases in posting volume and sentiment shifts. The September 2024 Global Climate Strike produced a 34% increase in positive sentiment as youth shared experiences of collective action and solidarity.

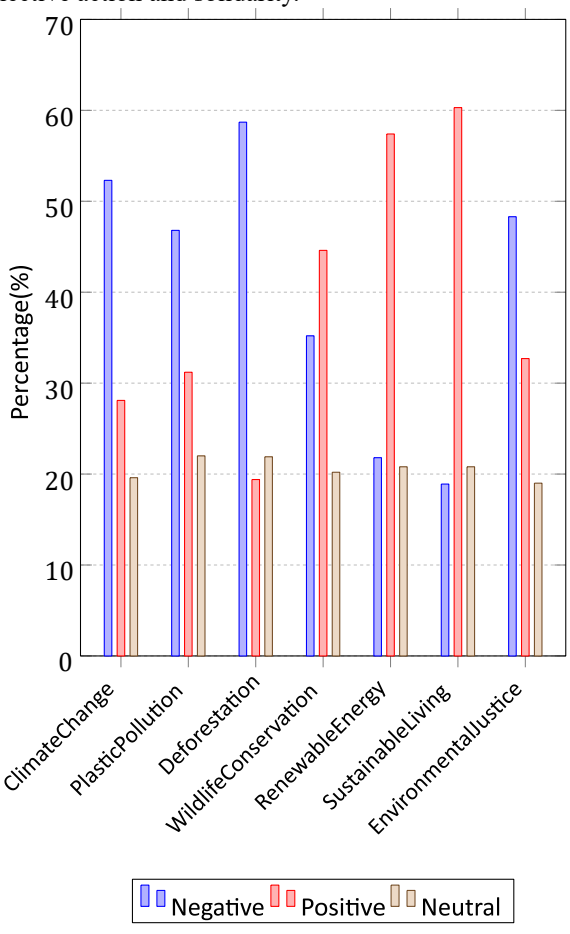

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Fig. 4. Sentiment Distribution by Environmental Topic

Seasonal variations: Summer months (June–August) showed increased negative sentiment corresponding to discussions of heat waves, wildfires, and extreme weather. In contrast, spring months demonstrated higher positive sentiment associated with nature appreciation and Earth Day celebrations.

Sustained concern: Despite temporal fluctuations, baseline negative sentiment regarding climate change remained consistently high (above 45%) throughout the study period, indicating persistent youth anxiety about environmental futures.

F. Geographic Variations in Sentiment

Analysis of user location data (where available) revealed notable geographic differences in environmental sentiment. Regions directly experiencing climate impacts—such as coastal areas vulnerable to sea level rise and regions affected by droughts and floods—displayed higher negative sentiment and more urgent language.

Developed nations with strong environmental movements, particularly in Scandinavia and Western Europe, demonstrated more balanced sentiment characterized by both concern and optimism about solutions. Emerging economies showed diverse patterns, with urban youth expressing high environmental awareness while simultaneously highlighting tensions between development priorities and environmental protection.

G. Linguistic Patterns and Key Phrases

Natural language analysis identified characteristic linguistic markers associated with each sentiment category.

Negative sentiment posts frequently included:

- "climate crisis," "climate emergency," "environmental destruction"
- "too late," "not enough," "inaction," "failure"
- "devastating," "catastrophic," "terrifying," "heartbreaking"
- "future generations," "running out of time," "point of no return"

Positive sentiment posts frequently included:

- "climate action," "renewable energy," "sustainable solutions"
- "making a difference," "hope," "progress," "innovation"
- "together," "community," "movement," "change is possible"
- "inspiring," "empowering," "beautiful nature," "protecting our planet"

Neutral sentiment posts typically contained:

- Factual information, statistics, and scientific findings
- Educational content about environmental issues
- Announcements of events, policies, and initiatives
- Technical discussions of environmental technologies

H. Emotional Dimensions Beyond Positive-Negative

Fine-grained emotion analysis using multi-class classification identified emotional tones extending beyond a simple polarity framework:

- Fear/Anxiety (23.4%): climate anxiety, future-oriented concern, and intergenerational responsibility
- Anger/Frustration (18.7%): directed toward governments, corporations, and perceived inaction
- Hope/Optimism (16.2%): confidence in solutions, youth movements, and renewable energy
- Sadness/Grief (12.3%): eco-grief related to species loss and environmental destruction
- Determination/Empowerment (10.8%): commitment to action and collective mobilization
- Pride/Inspiration (8.1%): celebration of environmental achievements and activist success
- Overwhelm/Helplessness (6.9%): feelings of powerlessness and uncertainty about individual impact

This emotional diversity demonstrates that youth environmental sentiment cannot be reduced to binary categories but instead reflects a complex psychological landscape shaped by social, ecological, and generational factors.

I. Comparison with Non-Youth Environmental Discourse

Comparative analysis with posts from older demographic groups revealed several distinguishing characteristics of youth environmental communication:

- Higher emotional intensity, with stronger sentiment polarization.
- Greater use of activist language, movement framing, and calls to action.
- More solution-oriented discussions despite elevated climate anxiety.
- Increased reliance on visual and multimedia communication formats.
- Strong emphasis on peer networks, generational identity, and intergenerational justice.

V. DISCUSSION

This section interprets the findings of the study in relation to existing literature, psychological theory, and environmental communication research. The discussion examines the implications of youth sentiment patterns, evaluates the effectiveness of the analytical approach, and considers broader societal, cultural, and ethical dimensions of AI-driven environmental research.

A. Youth Environmental Sentiment as Expression of Climate Anxiety and Hope

The predominance of negative sentiment (40.7%) in youth environmental posts reflects documented increases in climate anxiety among younger generations. Climate anxiety represents a rational response to objectively threatening environmental conditions rather than psychological pathology [34]. Youth negative sentiment expresses legitimate concerns about environmental degradation, frustration with inadequate political responses, anger at corporate inaction, and fear about future consequences that will disproportionately affect their generation.

However, substantial positive sentiment (33.9%) demonstrates that youth environmental discourse is not characterized by despair alone. Positive expressions reflect hope in collective

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action, optimism about technological solutions, pride in environmental achievements, and determination to create change. This coexistence of anxiety and hope represents an adaptive psychological response enabling sustained engagement rather than paralysis [35].

The research findings validate psychological theories of environmental concern emphasizing that emotional responses motivate action. Youth expressing both negative emotions (energizing concern) and positive emotions (sustaining hope) demonstrate engagement patterns conducive to long-term environmental activism rather than burnout or apathy.

B. Implications of BERT Model Performance

The superior performance of the BERT model (89.6% accuracy) compared to traditional machine learning approaches demonstrates the importance of contextualized language understanding for accurate sentiment analysis. Environmental discourse contains complex linguistic features including domain-specific terminology, figurative language, irony, and contextual meaning that simpler models struggle to capture.

The BERT model's capacity to understand contextual word meanings enables accurate interpretation of phrases that might otherwise be ambiguous. For example, "feeling the heat" might refer literally to extreme temperatures or metaphorically to political pressure, requiring contextual disambiguation. Similarly, activist slogans, hashtags, and movement-specific language require contextual understanding for accurate sentiment classification.

From a practical perspective, the availability of highperforming pre-trained models like BERT democratizes advanced sentiment analysis, enabling environmental organizations, educators, and researchers without extensive machine learning expertise to analyze social media data. Transfer learning approaches allow these models to be fine-tuned for specific applications with relatively modest computational resources and training data.

C. Topic-Specific Sentiment Variations Reveal Communication Opportunities

Significant sentiment variations across environmental topics suggest strategic opportunities for environmental communication. Topics generating predominantly positive sentiment (renewable energy, sustainable living) represent entry points for engaging youth who might feel overwhelmed by climate anxiety. These topics enable youth to envision solutions, take personal action, and experience self-efficacy rather than helplessness [36].

Conversely, topics generating strongly negative sentiment (deforestation, climate change) require communication approaches that acknowledge emotional reality while providing pathways to action. Dismissing or minimizing youth anxiety through overly optimistic messaging may alienate engaged youth, while dwelling exclusively on negative aspects without solutions may contribute to paralysis.

Environmental communication research demonstrates that effective messaging balances problem recognition with solution presentation, emotional validation with empowerment, and individual action with collective mobilization [37]. The sentiment patterns identified in this research provide an empirical foundation for developing such balanced communication strategies.

D. The Power and Limitations of Digital Environmental Activism

The findings illuminate both strengths and limitations of social media as a platform for youth environmental engagement. Social media enables rapid information sharing, community building, emotional expression, and mobilization that would be impossible through traditional communication channels. Viral environmental campaigns can shift public discourse, pressure institutions, and inspire offline action at scales previously unattainable [38].

However, concerns about "clicktivism" or "slacktivism" suggest that digital engagement may substitute for rather than complement substantive environmental action. Research indicates that social media activism is most effective when integrated with offline action, institutional engagement, and sustained organizing rather than isolated digital gestures [39]. The high volume of environmental posts identified in this research raises questions about the relationship between digital expression and behavioral impact.

Furthermore, social media algorithms may create echo chambers where environmentally engaged youth primarily encounter like-minded perspectives rather than engaging diverse viewpoints. While such communities provide important social support and identity validation, they may limit persuasive communication with less-engaged or skeptical audiences [40].

E. Geographic and Cultural Considerations

While this study focused primarily on English-language posts, environmental sentiment is shaped by geographic, cultural, and socioeconomic contexts. Youth in regions directly experiencing severe climate impacts (island nations facing sea level rise, regions experiencing desertification, communities affected by extreme weather) may express different sentiment patterns than youth in regions where climate change feels more distant or abstract [41].

Cultural factors influence environmental values, relationships with nature, and modes of expressing concern. Collectivist cultures may emphasize community and intergenerational responsibility, while individualist cultures may focus on personal action and individual rights. Religious and philosophical traditions shape environmental ethics and motivation for environmental protection [42].

Socioeconomic factors also matter. Youth with economic security may have greater capacity to prioritize environmental concerns and engage in environmental activism compared to youth facing immediate economic pressures. Environmental justice perspectives emphasize that environmental burdens and benefits are inequitably distributed, with marginalized communities disproportionately affected by environmental degradation while having less capacity to influence environmental policy [43].

Future research should expand beyond English-language analysis to examine multilingual environmental sentiment, incorporate diverse geographic contexts, and attend to

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intersections between environmental concern and social justice issues.

F. Ethical Considerations in AI-Driven Sentiment Analysis

The application of AI and machine learning to social media data raises important ethical considerations. While this research adhered to ethical guidelines through data anonymization and privacy protection, broader questions remain about surveillance, data ownership, and algorithmic accountability.

Social media users, particularly youth, may not fully understand how their data is collected, analyzed, and utilized. While environmental sentiment analysis conducted for academic and educational purposes may seem benign, the same technologies could be applied for purposes that might not align with users' interests, such as targeted advertising, political manipulation, or social control [44].

Algorithmic bias represents another concern. Machine learning models trained on biased data may reproduce and amplify existing inequalities. If training data overrepresents certain demographic groups, geographic regions, or linguistic patterns, resulting models may perform poorly for underrepresented groups. Ensuring diverse, representative training data and conducting fairness audits are essential for equitable AI applications [45].

Transparent reporting of methodological choices, model limitations, and potential biases enables critical evaluation and responsible interpretation of findings. Environmental organizations and policymakers utilizing AI-driven sentiment analysis should do so with awareness of these ethical dimensions and a commitment to equitable, respectful engagement with youth communities.

G. Key Interpretations

Overall, the findings suggest that youth environmental sentiment is characterized by a dynamic interplay between concern and optimism, reflecting both awareness of environmental threats and belief in transformative solutions. The strong performance of advanced language models further demonstrates the potential of AI-driven approaches for capturing nuanced public discourse. Together, these insights highlight the importance of emotionally intelligent communication strategies and responsible technological applications in supporting meaningful youth engagement with environmental challenges.

VI. Practical Implications and Recommendations

A. For Policymakers

Government agencies and policy institutions can benefit from understanding youth environmental priorities, concerns, and emotional responses. Policymakers should:

- Recognize youth environmental sentiment as legitimate democratic expression deserving serious consideration.
- Incorporate youth perspectives into climate policy development and environmental planning.
- Communicate policy decisions transparently, acknowledging youth concerns and explaining rationales.
- Create formal mechanisms for youth participation in environmental governance.
- Respond substantively to youth climate activism rather than dismissing or co-opting their demands.

B. For Environmental Organizations

Environmental NGOs and advocacy groups can leverage social media sentiment insights to refine communication strategies, identify resonant messaging, and engage youth effectively. Organizations should:

- Develop content strategies balancing problem recognition with solution presentation.
- Utilize visual storytelling and multimedia formats preferred by youth audiences.
- Create opportunities for youth participation in campaign design and implementation.
- Integrate digital engagement with offline organizing and sustained activism.
- Monitor social media sentiment as a feedback mechanism for campaign effectiveness.

C. For Environmental Educators

Environmental education programs should acknowledge and validate youth emotional responses to environmental challenges rather than dismissing climate anxiety as irrational. Educators can create spaces for emotional expression while providing tools for constructive action, balancing problem awareness with solution exploration.

Curriculum development should incorporate topics generating positive sentiment (renewable energy, sustainable living) as entry points while addressing difficult topics (climate change, deforestation) with appropriate emotional support. Projectbased learning enabling students to take meaningful environmental action can channel anxiety into empowerment.

D. For Social Media Platforms

Social media companies have a responsibility to facilitate constructive environmental discourse while mitigating harms. Platforms should:

- Combat environmental misinformation and climate denialism through fact-checking and authoritative information.
- Amplify credible environmental information and youth climate activism.
- Provide mental health resources for users experiencing climate anxiety.
- Design algorithms promoting diverse perspectives rather than echo chambers.
- Protect youth privacy while enabling meaningful environmental engagement.

E. For Future Research

This study opens multiple avenues for future investigation:

- Longitudinal studies tracking sentiment changes over extended periods to understand evolving youth environmental attitudes.

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- Multilingual analysis examining environmental sentiment across diverse linguistic and cultural contexts.
- Behavioral validation investigating relationships between expressed sentiment and actual environmental behaviors.
- Intervention studies testing whether sentiment-informed communication strategies enhance environmental engagement.
- Cross-platform analysis examining how environmental discourse varies across different social media platforms.
- Intersectional analysis exploring how environmental sentiment intersects with other social identities and justice concerns.

VII. LIMITATIONS

This research has several limitations requiring acknowledgment. First, analysis was restricted to English-language posts, limiting generalizability to non-English-speaking youth populations. Second, demographic identification relied on profile information and linguistic patterns, which may contain inaccuracies. Third, sentiment analysis captures expressed attitudes but not necessarily privately held beliefs or actual behaviors.

Fourth, the study focused on public social media posts, excluding private communications where youth might express different sentiments. Fifth, platform APIs provide incomplete data access, potentially introducing sampling biases. Sixth, the rapid evolution of social media platforms, linguistic practices, and environmental discourse means the findings reflect a specific historical moment.

Finally, while machine learning models achieved strong performance, misclassification errors remain, particularly for ambiguous posts, sarcasm, and complex emotional expressions. Interpretation of findings should account for these limitations.

VIII. CONCLUSION

This research demonstrates the power of AI-driven sentiment analysis for understanding youth environmental attitudes expressed through social media. By analyzing nearly 500,000 posts using advanced Natural Language Processing and machine learning techniques, this study reveals a rich emotional landscape of youth environmental engagement characterized by both anxiety and hope, concern and determination, fear and inspiration.

The findings validate youth climate anxiety as a rational response to environmental crisis while also highlighting substantial positive sentiment reflecting hope, optimism, and commitment to action. The superior performance of the BERT model demonstrates the importance of contextualized language understanding for accurate sentiment classification, while topic-specific sentiment variations reveal strategic opportunities for environmental communication.

Social media has transformed environmental activism, providing youth with unprecedented platforms for expression, mobilization, and community building. Understanding sentiment patterns within these digital spaces enables environmental educators, organizations, and policymakers to engage youth more effectively, design communication strategies that resonate, and support constructive environmental action rather than despair or disengagement.

As environmental challenges intensify and youth voices grow louder, decoding these voices through sophisticated analytical techniques becomes increasingly important. This research contributes methodological approaches, empirical insights, and practical recommendations for leveraging AI to understand and support youth environmental engagement. By listening to youth voices for the planet, stakeholders can work toward environmental futures that reflect these hopes, address pressing concerns, and honor the determination to protect the planet.

The path forward requires integration of digital and offline action, emotional validation combined with empowerment, and recognition that youth are not merely future stakeholders but present actors in environmental transformation. Their voices, decoded through AI yet rooted in genuine concern and authentic hope, call for responses grounded in urgency, solidarity, and sustained commitment.

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