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Analyzing YouTube users' comments on climate change issues presented through immersive mixed reality using sentiment analysis and network analysis tools

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The use of modern technologies, including Immersive Mixed Reality (IMR) technologies, to present information on climate change has become essential due to their ability to simplify information and increase interaction with it. Hence, the current study aimed to explore YouTube users' engagement with climate change issues presented using (IMR) technologies by using both sentiment analysis and network analysis tools. It adopted a mixed method methodology (quantitative and qualitative analysis), analyzing the five most-popular videos that utilized IMR to deliver environmental content on The Weather Channel on YouTube. A range of analytical software was used to analyze the data collected. Specifically, Communalytic was used to collect comments, Gephi was used to analyze social networks, and NetworkX in Python was employed to calculate engagement metrics such as degree centrality and network density. TextBlob and VADER were also employed to analyze sentiment and classify comments as positive, negative, or neutral. Additionally, data analysis was used to study engagement dynamics within comments, analyze the evolution of engagement over time, and classify comment patterns based on writing style. The results showed that videos depicting severe weather events achieved the highest engagement rates, reflecting the emotional impact of the content on the audience. Social network analysis results indicated that most engagement was concentrated in a limited number of comments. Sentiment analysis revealed variations between analysis tools. VADER shows greater sensitivity to negative sentiment than TextBlob, underscoring the importance of using multiple analysis tools to ensure classification accuracy.

KEYWORDS

sentiment analysis, network interaction, immersive mixed reality, climate change, YouTube

1 Introduction

The recent Los Angeles wildfires, which occurred on January 12, are a prime example of the increasing risks posed by climate change. They destroyed thousands of buildings, displaced hundreds of thousands of people, and caused significant human and material losses (Sky News Arabia, 2025). These fires are attributed to extreme weather conditions exacerbated by climate change, contributing to rising temperatures and persistent drought, creating an ideal environment for the unprecedented spread.

UN Secretary-General António Guterres pointed out that the period from 2014 to 2024 was the warmest in terms of temperatures. He stated, "We are witnessing a climate breakdown right before our eyes" (United Nations, 2024). A subsequent report issued in January by the Copernicus Climate Change Service projected that could be the second or third warmest year on record, with global warming likely to exceed 1.5 °C during the period 2024–2028 (Copernicus Climate Change Service, 2024). Hence, it is obvious that this phenomenon is serious and deserves careful study.

Therefore, we can say that using new technology, including Immersive Mixed Reality (IMR) technology, helps people experience what climate change might bring. In this regard, IMR, as a pioneering technology, can fill the chasm between reality and imagination. In such continuity, virtuality grows while you get farther away from the reality environment point, and reality grows while you get farther away from the virtual environment point (Akbay and Deniş Çeliker, 2023).

Meijers et al. (2023) found that VR can successfully teach people about what climate change issues mean by offering a realistic experience, which might raise their awareness of the expected threats. Because VR features are interactive and give a first-person view, users can experience what climate change risks are like, which may raise their awareness of environmental issues (Iyer, 2022). At the same time, several studies revealed that VR simulations of sea level rise and melting glaciers helped the public recognize the effects of climate change over many years, which raised their awareness of environmental problems (Thoma et al., 2023).

Generally, IMR helps to capture people's attention, teach them more, and motivate them to behave in ways that benefit the environment. Using this information, the current study aims to examine YouTube comments on climate change topics from "The Weather" Channel, which used IMR technologies. In particular, it tries to understand what they feel and how they interact with these videos. As a result of this analysis, it may help using IMR to educate people about climate change and encourage everyone to care for the environment.

2 Literature review

The review of literature is split into two main areas. The first includes literature on using new technology such as IMR, AR, and VR in climate issues, while the second focuses on the literature on analyzing audience sentiment and relationship networks through YouTube comments, as follows:

2.1 Literature review on using new technology such as IMR, AR, and VR in presenting climate issues

Wang and Kim (2022) endeavored to address prevailing misconceptions on climate change that hamper mitigation actions. They investigated the possibilities of mixed reality (virtual reality and augmented reality) in conveying the consequences of climate change. A pilot study was conducted using the conceptualized mixed reality system. The participants demonstrated increased willingness for sustainable action after using the mixed reality system. The findings showed high stress levels and high ratings of immersion after system use. The work identifies the great potential of climate change contextualization by virtue of mixed reality systems. Thoma et al. (2023) endeavored to investigate the influence of immersive mixed reality technology on better climate change awareness. The findings indicated that showing a simulation of Aletsch Glacier's melt by use of virtual reality significantly improved environmental awareness compared with conventional presentation, but no significant difference was noted on attachment to nature or climate change skepticism. The findings validated that simple or abstract virtual reality spaces have the potential for pro-environmental mindsets.

Tisoglu et al. (2025) described the technology of IMR and its connection to interactive responses of climate change content. Their analysis was framed against an educational environment of technology, pedagogy, and content. The findings report that IMR has the potential to function as effective technology for on-going community education, particularly in combination with constructivist approaches, such as inquiry-based learning, and using characteristics of the system, for instance, interactive approaches, for facilitating interaction and engaging people.

Regarding applying augmented reality (AR) technology on digital content on climate change, Heemsbergen et al. (2022) carried out a study on how AR helps provide better decision-making on climate issues. The results of the study showed that AR complements the environmental awareness of individuals and thereby supports the process of decision-making. Likewise, Van Gevelt et al. (2023) aimed to see how AR would support awareness on climate change hazards by visualizing potential future extreme weather events. The results indicated that participants have a good level in their knowledge on climate hazards because of IMR technology and became more motivated to adopt preventative acts. Lo and Tsai (2022) examined the potential of promoting water-saving habits following the presentation of augmented reality (AR) technology. The findings of the study revealed that the AR technology-exposed participants were more likely to generate water-saving habits than those exposed to traditional media. Grassini and Ratcliffe (2023) also emphasized the use of virtual reality (VR) for promoting environmental awareness. The authors highlighted the capability of VR and AR in providing virtual environmental information from different vantage points, for instance, promoting the use of virtual tours as a less damaging approach of minimizing the environmental degradation of using traditional traveling.

In studying climate-themed digital media and virtual reality technology's impact, Pi et al. (2025) aimed to determine how VR experiences with high degrees of immersion affect individuals' perceptions and behaviors concerning climate change challenges. The

results were that climate-themed VR experiences with high degrees of immersion have the potential to increase awareness and elicit positive environmental behaviors. Zhongyao et al. (2024) found that emotional considerations feature significantly in facilitating deeper understanding of sustainable-development challenges based on how VR technology is used. According to this study, the use of such disruptive technology served to improve "emotional awareness" of climate challenges. In another such study, Iyer (2023) studied the use of VR technologies among the efforts of the United Nations by evaluating 12 VR productions linked to Sustainable Development Goals. The analysis established that applying such technology improved awareness on climate issues.

Other researchers looked at how VR impacts our feelings toward the environment and the responses that flow from climate change. The researchers looked at 277 participants by having them read news articles, see a normal video, or see a VR video of wildfires. The findings showed that those who viewed VR felt more aware of space and felt more negatively, but those feelings made them more aware of climate change's dangers. In the same sequence, Thoma et al. (2023) examined how people learn about climate change and the environment through VR compared to traditional media. The researchers examine how much realism was needed in the virtual setting to impact the audience. All study cases indicated that environmental understanding increased after the experience. The research found that VR had a stronger influence on people's attitudes toward the environment than traditional media. Additionally, Xu et al. (2022) examined whether a VR application could be created to teach people about climate change. Results proved that VR can successfully be used to increase awareness of climate change and future environmental problems. At the same time, Huang et al. (2020) used ecological modeling, procedural modeling, and VR to build an experience that shows how forests might change because of climate change. The results showed that using virtual representations of future forests can improve our understanding of how climate change affects ecosystems.

2.2 Literature review on the analysis of audience sentiment and relationship networks through YouTube comments

Abdel Rahman and Rabie (2024) investigated user reactions to 14 COP28 summit videos on YouTube by analyzing comments and using network and sentiment analysis. They examined 6,888 comments. The results revealed that comment networks could differ in size and levels of engagement on every YouTube channel. The BBC had the most touchpoint videos in the study sample. There were more positive German comments than there were English or French comments in the results. Singha et al. (2024) investigated how YouTube comments reflect people's attitudes toward videos, supporting creators in understanding their viewers. The author relied on six different machine learning algorithms. In the same context, Singh and Dhayani (2024) examined how sentiment analysis works in YouTube movie reviews using machine learning. The better model made it more accurate and effective to understand all kinds of emotions found in movie comments, with an accuracy of 92%. Adhikari et al. (2023) investigated YouTube users' feelings toward climate change content by applying sentiment analysis techniques, which helped companies and creators understand their viewers better and produce large amounts of climate content more efficiently.

Al Fathir et al. (2023) examined how users reacted to videos that discussed the prohibition of music. The study pointed out that to analyze audience sentiment effectively, data has to be accurate and preprocessed correctly. Rochadiani (2023) investigated how YouTube users feel about ChatGPT. A big set of user comments from YouTube was gathered, and afterward, unnecessary information was removed. The study used TextBlob and VADER tools to classify comments. The results showed that most users had positive feelings toward ChatGPT, reflecting widespread acceptance of the technology.

Shevtsov et al. (2023) aimed to analyze political interaction networks across Twitter and YouTube. The study relied on linking Twitter and YouTube networks through cross-posting videos on Twitter to analyze voter sentiment. The results showed a close connection between comment communities on Twitter and YouTube, as users in the same Twitter community tend to post links to YouTube videos. Ma and Huo (2022) sought to analyze the echo chamber effect on the spread of health misinformation on social media, focusing on the mechanism behind this effect. The study relied on the social contagion mechanism to examine the influence of imitation, intergroup interaction, and reciprocal behavior on TECE. A social network of user comments and responses was constructed based on comments on a YouTube video about the COVID-19 vaccine. The results showed a weak echo chamber effect on the spread of misinformation about the COVID-19 vaccine.

After reviewing the previous literature, it is clear that research on using IMR, VR and AR technologies to address climate change issues and analyze user engagement on social media platforms is witnessing significant development. Several studies have focused on the role of VR and AR in raising awareness and stimulating emotional and behavioral responses to climate change. On the other hand, some studies have focused on the importance of using VR to enhance understanding and raise awareness of environmental issues. Other studies have confirmed that virtual simulation can be a powerful tool for deepening understanding of climate risks and Preparedness to take preventive measures. Regarding audience sentiment analysis on YouTube, some research papers have revealed that comments reflect not only individual attitudes but also the dynamics of interactions within social networks. Besides, various academic productions have stressed social network analysis for describing environmental information diffusion on YouTube.

Despite the advances of these studies, it is still lacking in terms of how users interact with IMR technology as they talk about climate issues on social media. As much as VR has been targeted by earlier studies, they have not fully tackled how IMR or AR contributes to enhancing the attitude of the masses toward the online climate change material. Although numerous studies have investigated what YouTube audiences perceive concerning various topics, few have incorporated sentiment and social network analysis to interpret environmental discussions. In order to solve this problem, the present study tries to analyze climate change commentary on YouTube to determine how IMR technology affects these interactions. In addition, it utilizes network analysis and sentiment analysis tools to learn interaction patterns and audience attitudes toward environmental materials aided by such technology.

2.3 The scope of the study

Recently, IMR has risen significantly as mediums for informing the masses on climate change concerns, eliciting more participation and awareness of these matters than conventional media outlets

(Heemsbergen et al., 2022). Along these lines, numerous academic journals have validated that augmented reality (AR) provides the promise of increasing people's reaction to environmental issues by triggering emotional and logical responses among its consumers (Meijers et al., 2023). Further, Elgammal et al. (2025) theorized that interactive realities that mimic climate change effects have the potential to affirm popular understanding of the need for sustainable environmental stewardship. Nevertheless, insight into how AR technology affects popular attention and involvement in climate matters is limited.

Concurrently, the volume of research examining the discourse of YouTube users regarding environmental issues is evidently on the rise. In this context, numerous studies have indicated that emotional expressions and discussions on social media platforms can assist in identifying the environmental concerns that resonate with audiences (Abdel Rahman and Rabie, 2024). Furthermore, Singha et al. (2024) and Elgammal (2025) demonstrated that artificial intelligence methodologies can facilitate the analysis of YouTube viewers' perspectives, thereby enhancing our comprehension of public reactions to diverse topics. Conversely, Shevtsov et al. (2023) observed that the utilization of social media has the potential to monitor the interplay between environmental news and related subjects. Nevertheless, a gap persists in comprehending the correlation between Information Mediation Responsibility (IMR) and individuals' engagement with climate-related matters on YouTube.

For this reason, this study aims to fill this gap in climate change studies by analyzing YouTube users' comments on climate change supported by IMR technologies, by using sentiment analysis in addition to network analysis tools to discover the nature of digital engagement dealing with these issues. In this regard, our main question is: To what extent do IMR technologies impact YouTube users' engagement with climate change issues, network patterns, and the nature of the emotions associated with them?

The current study importance lies in its contribution to the field that combines IMR technologies and digital interaction with environmental issues. It focuses on how IMR-based environmental content influences both users' feelings and their actions. This study also seeks to improve analytical tools used to study audience interaction with digital environmental content, combining sentiment analysis with social network analysis to uncover user behavioral patterns on YouTube. In addition, the study results can be used to develop more effective environmental communication strategies, which help content creators, environmental organizations, and government agencies understand the nature of audience interaction with IMR-enabled environmental content to design more effective awareness media campaigns. Furthermore, the study results can be important for environmental decision-makers, who can utilize these findings to understand how audiences interact with digital environmental content. This approach can improve awareness and communication strategies on climate issues.

3 Study questions

> *RQ1*: What is the user engagement level with the YouTube videos under study?
>
> *RQ2*: What is the nature of the network connections between users who participated in climate change discussions on the YouTube videos under study?
>
> *RQ3*: What are the prevailing sentiments in YouTube users' comments on climate change issues that rely on using IMR technologies?

4 Methodology

The study population consists of all videos posted on "The Weather Channel" on YouTube that discuss climate change issues using IMR technologies. This channel was selected for several methodological and practical considerations. It represents a pioneering and reliable model for employing IMR and immersive media technologies to address climate change issues, ensuring a high level of consistency and precision in data analysis. Furthermore, limiting the focus to a single channel reduces the variance in editorial standards and production methods across different platforms, allowing for a more accurate examination of the phenomenon, free from the distortion of external factors. This focus is viewed as a preliminary step toward building a knowledge base that can be expanded in the future through comparative studies that include other platforms, enhancing the chances of generalization and broadening the scope of findings. Furthermore, due to the novelty of technology, it was impossible to find channels that had been used to produce climate-related content with the same large number of comments. For the study sample, the authors selected the most-viewed videos on this channel by clicking the "Popular" option, and then they chose the first five videos. The high level of views of these videos indicates the effectiveness of IMR technology in engagement rate.

The following are details of the analytical study sample:

Based on Table 1, the total number of comments on the study sample videos was 39,873, with 39.1 million views. This study is descriptive. It relied on a mixed-methods approach, combining quantitative and qualitative content analysis to understand YouTube users' engagement with climate change issues presented using IMR technologies. The authors analyzed the comments and interaction patterns on the selected videos. They applied sentiment analysis using AI tools to classify user attitudes (positive, negative, or neutral). In addition, social network analysis was also used to study the links between comments and determine the prevalence of environmental discussions within the digital community.

Regarding the analytical tools that were used in the current study, they are as follows:

- Social network analysis

Network analysis aims to study YouTube user interaction to understand the spread of AR-enabled climate issues in the digital community. Comments were collected via Communalytic, and analysis was conducted using Gephi to visualize networks, as well as NetworkX in Python to calculate metrics such as centrality, clustering, and network density, providing deeper insight into the structure of discussions and the extent of user interconnectedness.

- Sentiment analysis

Sentiment analysis was used in this study to categorize YouTube users' opinions regarding environmental IMR videos into positive,

TABLE 1 Description of the analytical study sample.

Video name	Broadcasting date	Views number	Comments number	QR code
1- A tornado hits the weather channel	20/7/2018	11 M	16,121	
2- The dangers of storm surge	10/10/2018	7.8 M	1,391	
3- The dangers of flash flooding	24/10/2019	7.6 M	6,092	
4- Why hurricane categories make a difference	8/8/2013	6.6 M	8,123	
5- Experience storm surge like you never have before	9/10/2018	6.1 M	8,146	
Total		39.1 M	39,873	

neutral, and negative. Comments were collected via Communalytic and subjected to sentiment analysis using NLP algorithms, which helped measure audience acceptance and engagement with the content.

- Analyzing interaction data and user comments

Data analysis was used to analyze the interaction dynamics within comments and understand audience responses to IMR-enabled environmental videos. The analysis included elements such as the distribution of comments and likes, the evolution of interaction over time, the ratio of the responses to original comments, comment classification (informative, argumentative, emotional), and Semantic Network analysis of frequent words, revealing the most common topics in discussions about climate.

Regarding the study scales, the current study relied on a set of scales as follows:

1 Social network analysis (SNA): It measures the degree of influence and interaction between users by visually representing the digital relationships between comments and users. Hence, this analysis allows an understanding of the discussion patterns spread and the centrality of individuals within the digital network. Among the most important metrics used are:
   - o Degree centrality: reflects the number of links that connect each user to others, as users with high centrality are more influential in spreading and receiving information and shaping general trends.
   - o Modularity class: Measures the cohesion of the network of relationships between users, dividing them into interconnected groups. This helps us understand the evolution of discussions and the extent of divergent opinions on climate change.
   - o Network density: Indicates the level of interconnectedness between users. The higher the density, the more interaction there is, while a lower density indicates dispersed or divergent discussions.
   - o Network diameter: Reflects the extent of the discussions spread. A larger diameter indicates extended conversations between users who are not directly connected, while a smaller diameter indicates rapid interaction and the direct spread of ideas.
2 Sentiment analysis: The current study relied on the TextBlob library for text processing and sentiment analysis within video comments. This tool provides accurate sentiment classification based on two main factors:
   - o Polarity: This value measures a sentence's positive or negative sentiment, ranging from −1 (completely negative) to +1 (completely positive). The closer the value is to zero, the more neutral or unspecified the sentiment. The authors will employ this indicator in the current study to understand the general sentiment trends within climate and IMR commentary.
   - o Subjectivity: It measures the extent to which a statement relies on personal opinions or feelings rather than objective facts, ranging from 0 (completely objective) to 1 (completely subjective). Higher values indicate that users are expressing their personal opinions rather than providing reliable information. The authors will use this indicator to determine whether discussions about climate change on YouTube are based on objective evidence or reflect personal biases and impressions.

To enhance the reliability of the study results, an initial automated categorization was implemented by using the Communalytic platform (which includes VADER for natural language processing and TextBlob for sentiment analysis). In addition, the authors used both Google Perspective API and Detoxify to detect toxicity and civility. However, relying only on automated analysis can overlook some contextual and cultural nuances. For this reason, the authors depended on independent statistical experts to verify the consistency of the results between the automated output and human interpretation.

In the same sequence, the authors utilized the double-coding method as one of the best practices in content analysis. Two authors coded the data and calculated the agreement coefficient by using Cohen's Kappa. The values were within the acceptable limits. This, in turn, refers to the significant consistency between the coders. Generally, this approach, which combines automated software and human revision, improves the accuracy of the study results.

5 Study results

5.1 The results of network analysis of user comments on the YouTube videos under *analysis*

5.1.1 General statistical data for user comments

Figure 1 shows that the "Tornado Hits the Weather (IMR)" video recorded the highest engagement rate in terms of the number of comments, exceeding 16,000. The "Experience Storm Surge Like You Never Have Before" video received the lowest engagement rate, with a significantly lower number of comments compared to other videos under study. The general distribution of comments also reveals a clear disparity in the level of engagement between the different videos, as comments were concentrated on a limited number of videos, while some videos received only a limited engagement rate.

Figure 2 shows that "The Dangers of Flash Flooding" received the highest number of likes, exceeding 200,000, followed by the video "A Tornado Hits the Weather (IMR)" with approximately 150,000 likes. In contrast, the video "Experience Storm Surge Like You Never Have Before" received the fewest likes compared to the other videos. This disparity indicates differences in the content attractiveness and its impact on the audience. Furthermore, it appears that videos that addressed severe weather phenomena received greater engagement.

The graph in Figure 3 shows the trends in engagement on YouTube comments on climate change issues supported by IMR technologies over time, which distinguishes between original comments (in red) and responses (in orange). The same graph shows that engagement was relatively low and stable until 2017, followed by gradual increases in some comments and responses, with significant peaks recorded during 2018, 2019, and 2020. Engagement peaked in 2020, with an average of 800 comments received in 1 day. After that, engagement gradually declined, with relatively low activity continuing until 2024.

These time peaks reflect user responses to specific climate change-related events. The decline in engagement after 2020 could also

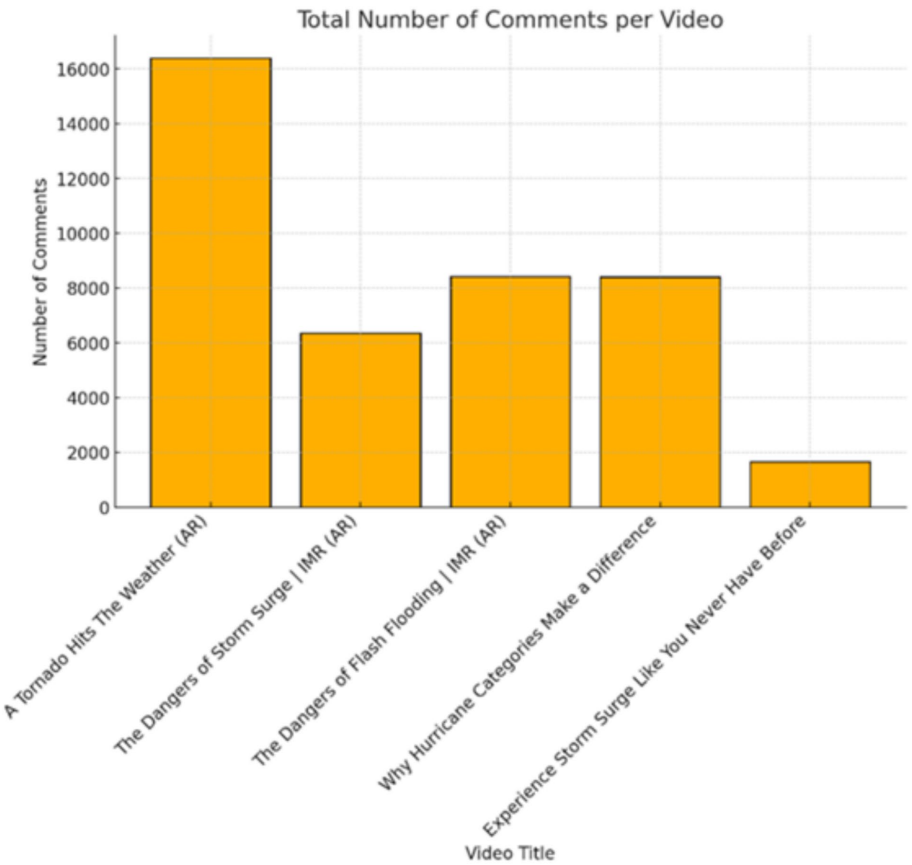

FIGURE 1
Distribution of the total number of comments per video.

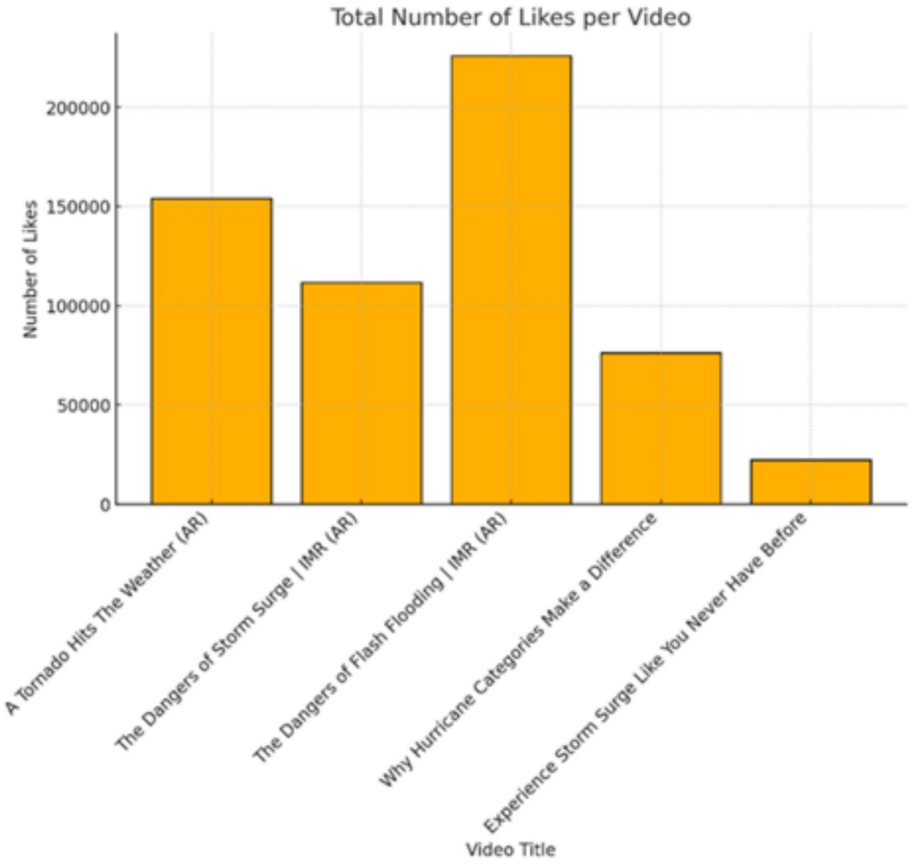

FIGURE 2
Distribution of the total number of likes per video.

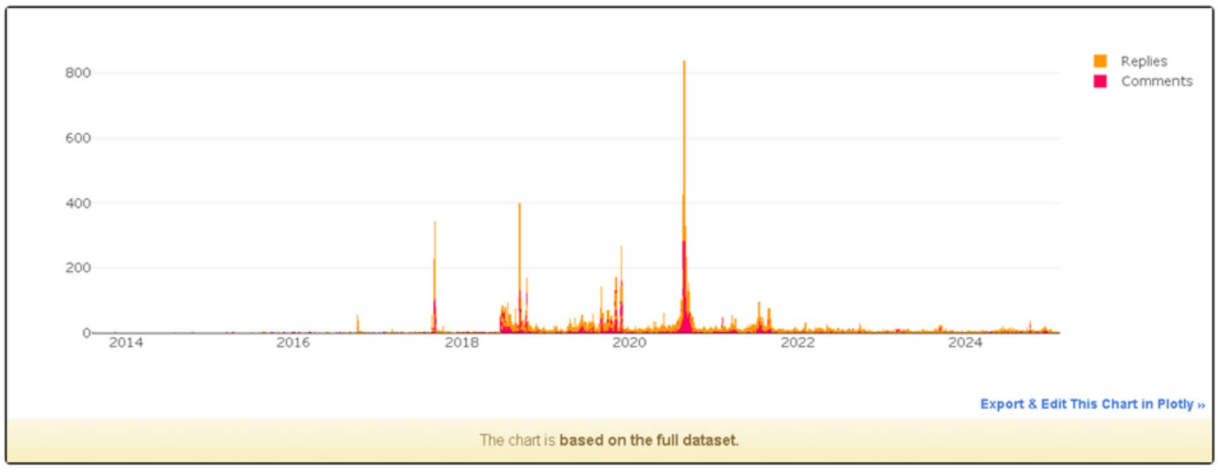

FIGURE 3
Analysis of the interaction development (comments and responses) over time.

be linked to changes in YouTube policies, a decline in interest in IMR content in this area or shifts in audience interests.

Figure 4 shows an uneven distribution of likes across comments, with most comments receiving very few interactions, while a small percentage receive thousands or tens of thousands of likes. This distribution reflects a strongly left-skewed pattern, indicating that most engagement is concentrated on a limited number of comments, while the rest remain largely unengaged. The high concentration of likes in a small percentage of comments can be explained by the phenomenon of "preferential stacking," whereby early engagement boosts the visibility of comments and attracts further attention, creating a self-reinforcing cycle that continues to increase engagement.

Figure 5 shows that most posted comments (64.8%) are original, while replies to comments constitute 35.2% of total engagement.

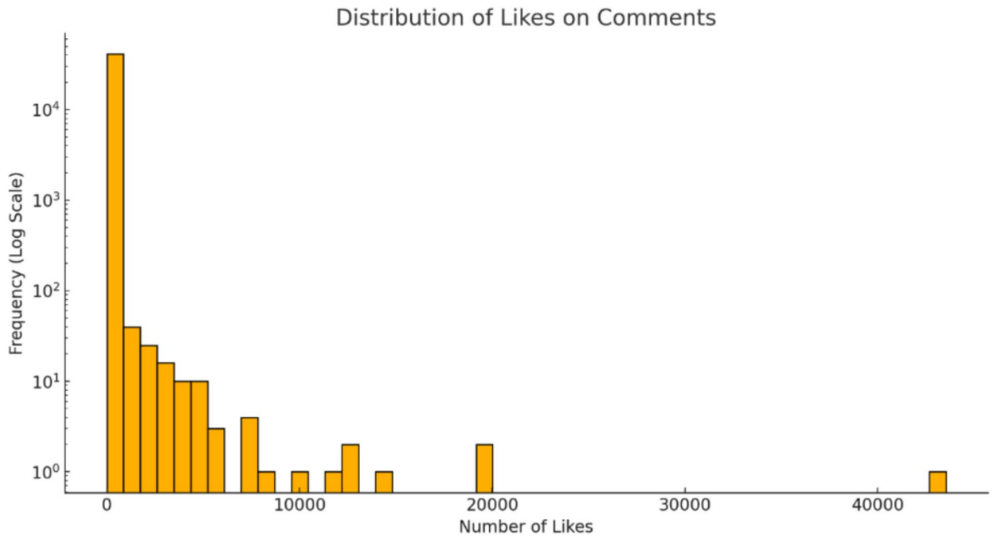

FIGURE 4
Distribution of likes according to comments.

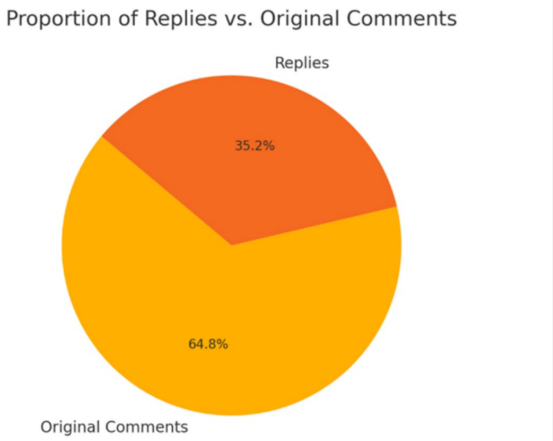

FIGURE 5
Proportion of replies vs. original comments.

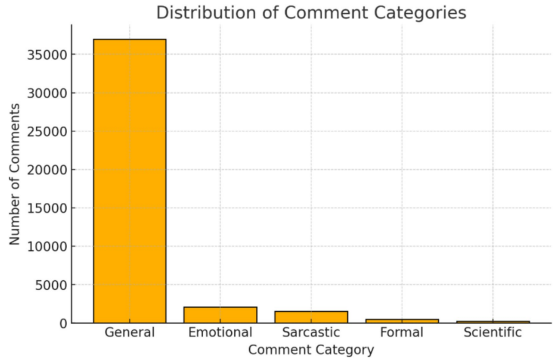

FIGURE 6
Distribution of categories.

Figure 6 shows that the "general" category represents the highest percentage, exceeding 35,000 comments, while other categories, such as emotional, sarcastic, formal, and scientific, constitute a very low percentage. This pattern demonstrates that most engagement on the videos under study revolves around "general" comments, not categorized under a specific theme. This indicates that users tend to express their opinions directly rather than using specialized expressions.

5.2 Semantic distribution of user comments on climate change videos

Figure 7 shows a semantic similarity 3D map between YouTube comments on climate change topics, created using the Communalytic tool. This map depended on the HDBScan algorithm to cluster comments into 446 semantic clusters based on the semantic similarity between texts. These results can be interpreted as follows:

The large number of centered points in the middle indicates a high semantic similarity between most of the comments. This means that users are discussing similar topics about climate change.

Some clusters appear outside the focus, reflecting comments with different concepts or responses that are less closely related to the discussion.

The analysis consisted of 39,873 comments, with 11,400 comments classified as outliers, indicating that some comments did not fit into any main semantic cluster.

The Davies-Bouldin index, which measured the quality of clustering, was 0.441, with lower values indicating better and more differentiated clustering.

Interaction Figures 8–12 show that most of the comments on the videos were individual and independent, with users preferring to express their opinions without engaging in extended discussions. However, some Figures 9–12 showed interaction clusters, reflecting a particular interest in specific topics within the video. This pattern led

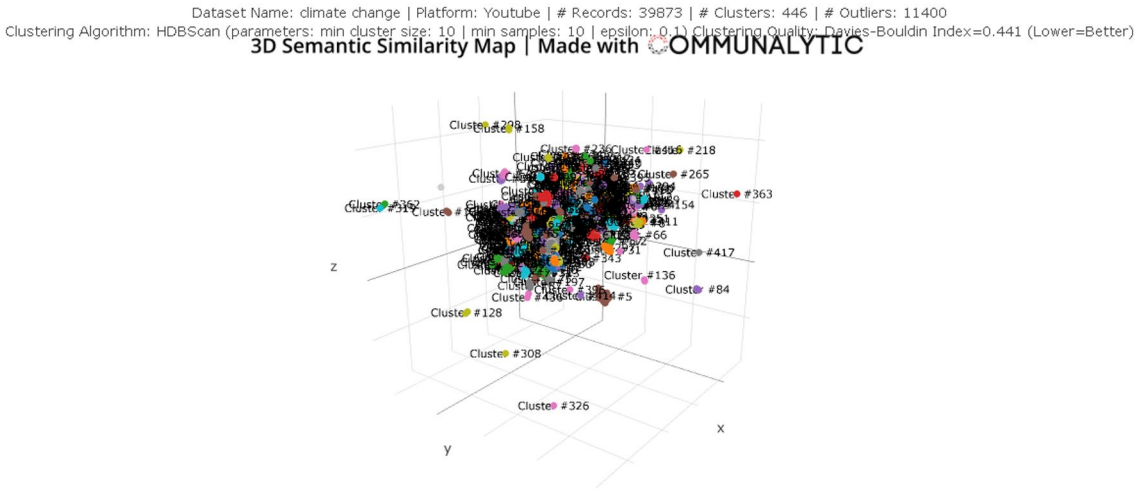

FIGURE 7
3D semantic similarity map.

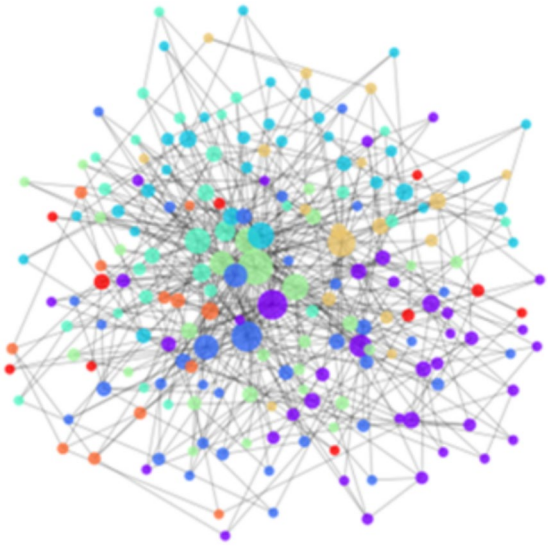

FIGURE 8
Network analysis of the first video titled "A Tornado Hits the Weather Channel".

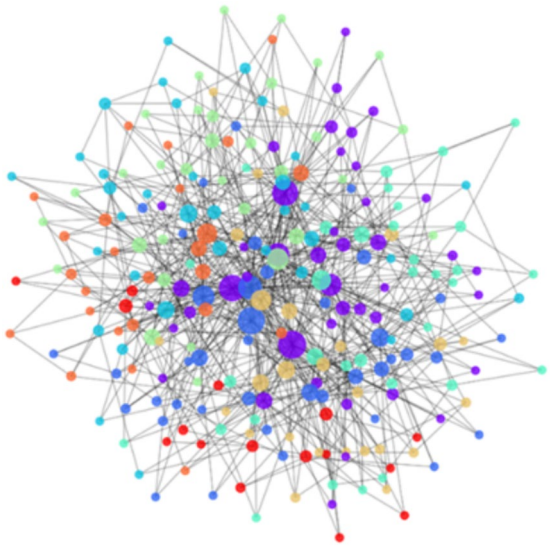

FIGURE 9
Network analysis of the second video titled "The Dangers of Storm Surge".

to the emergence of sub-conversations among viewers. It also indicates that some topics stimulated group interaction while others remained within the framework of independent participation. This distribution also confirms that the nature of the content plays a role in shaping interaction patterns, as certain factors, such as the attractiveness of the topic and its relevance to viewers' experiences, can lead to increased interaction and discussion among users.

Figure 13 clearly shows that the most used emojis include interactive emotions such as 😂, 😐, ❤️, and 🙂, reflecting an informal and perhaps sarcastic tone in some comments. Symbols associated with climate phenomena, such as 🌪️, 🌧️, and ⛈️, confirm the relevance of comments to the discussed content. In contrast, using symbols such as 💀, 🚫, and 🔥🌪️🌧️⛈️ indicates discussions about disaster risks or skepticism about the authenticity of the content. This diversity in interaction reflects a mix of emotions, sarcasm, and seriousness in addressing climate change issues, which helps understand the audience's response to IMR in presenting environmental issues and the impact of emotions on the reception of digital content.

5.3 Analyzing comment content using machine learning (topic modeling)

The interaction network in Figure 14 represents the relationship between the most frequently used words in YouTube comments about climate change based on a Topic Modeling analysis. Figure 14 also shows the correlation of words based on their

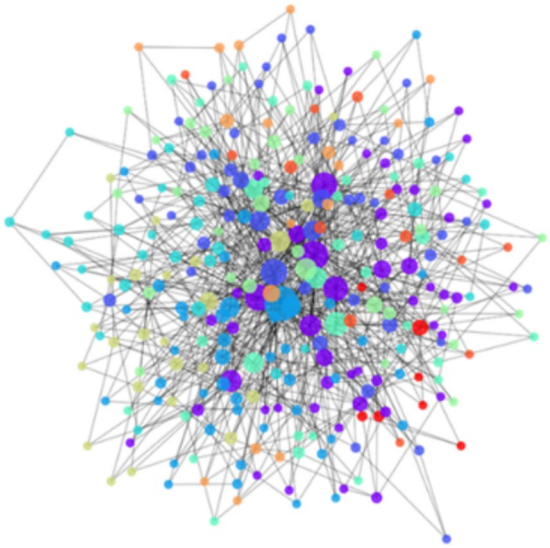

FIGURE 10
Network analysis of the third video titled "The Dangers of Flash Flooding".

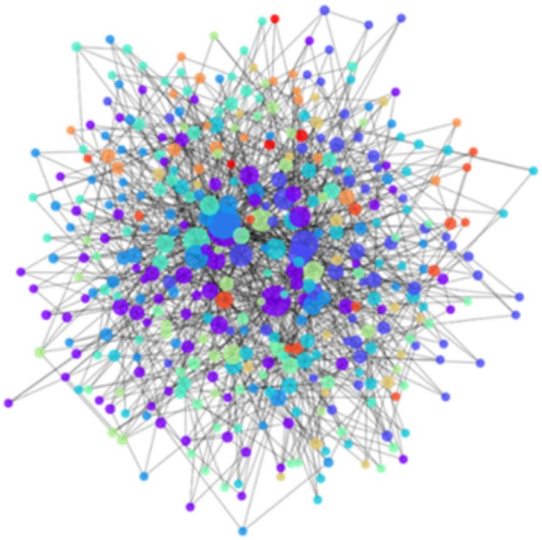

FIGURE 12
Network analysis of the fifth video titled "Experience Storm Surge Like You Never Have Before".

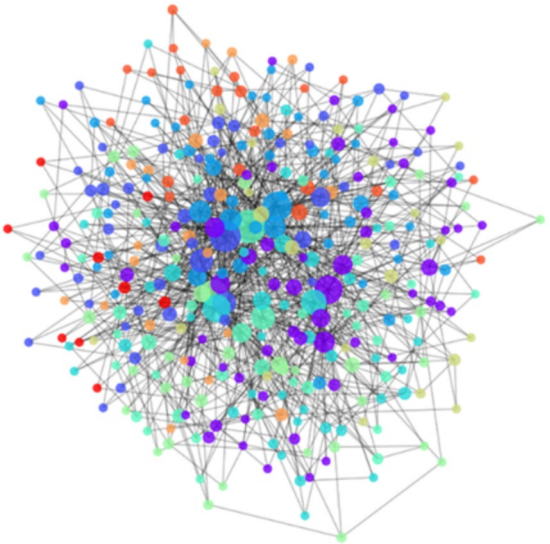

FIGURE 11
Network analysis of the fourth video entitled "Why Hurricane Categories Make a Difference".

frequency of co-occurrence, with larger nodes, such as "tornado" and "weather," indicating the most central topics in the discussions. In addition, other semantic clusters are built, including those that involve keys like "storm" and "flood." On the other hand, some users feel in an emotional way, such as "cool" or "wow," to display different types of reactions to what they see. Because people respond to the news with different opinions, the discussion often moves from scientific details to playful comments and even humorous reactions. The connection among these three terms often leads to questions about the reliability of content. Such analysis points out that co-connection networks are important for capturing trends in digital connections. The order of nodes and the strength of ties show how closely words are connected, which helps to understand the dynamics of digital discussions about environmental issues.

Table 2 indicates that using VADER and TextBlob shows a sentiment analysis of comments on climate videos, showing a discrepancy in sentiment classification. VADER classified 23.95% of English comments as negative, 36.68% as neutral, and 39.37% as positive. On the other hand, TextBlob recorded a lower percentage of negativity (17.51%), with a higher neutral comments' percentage (45.96%) and positive comments (36.53%). This difference reflects VADER's greater sensitivity in sentiment classification compared to TextBlob due to the differences in language and context analysis mechanisms.

For the other languages (Portuguese, French, German), the percentage of neutral comments exceeded 91%, with a significant decrease in negative and positive sentiments, indicating users' tendency toward neutrality or the difficulty of analytics tools in classifying sentiment in these languages. On the contrary, English comments showed a clearer contrast between positive and negative sentiments, reflecting a stronger emotional response to climate change content supported by IMR technologies. These results underscore the importance of using multiple analytics tools to ensure accurate assessment, considering linguistic and cultural differences in the expression of digital sentiment.

Based on Table 3, 34 comments on climate change issues were analyzed by the RuSentiment tool. The results reveal that most comments (55.88%) were neutral, 35.29% expressed positive sentiments, while the percentage of negative sentiments was low (8.82%). This distribution indicates that engagement with climate content in Russian is characterized by a predominance of neutrality, which may reflect the nature of the discussion on the topic or the limited sample analyzed.

The same table also shows a similar pattern to what was found in other languages except English, where users tended to express their

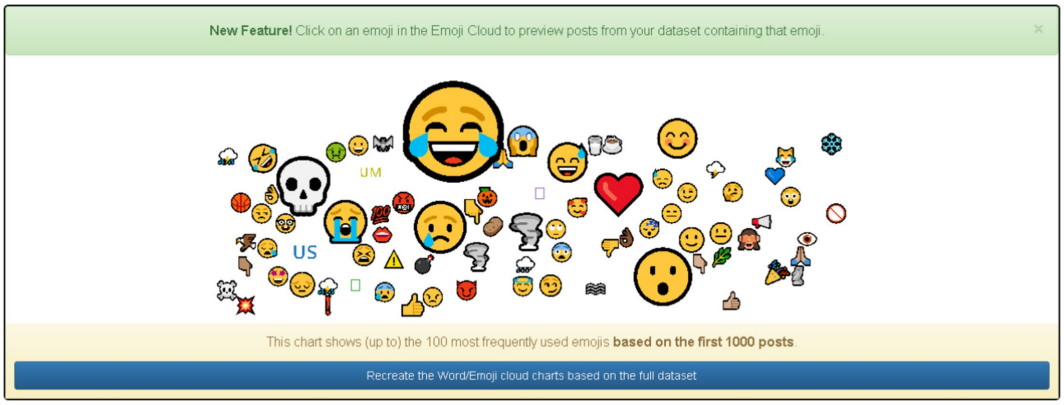

FIGURE 13
Emoji Cloud (frequency of emoji characters in the dataset) generated by Communalytic. https://communalytic.org/.

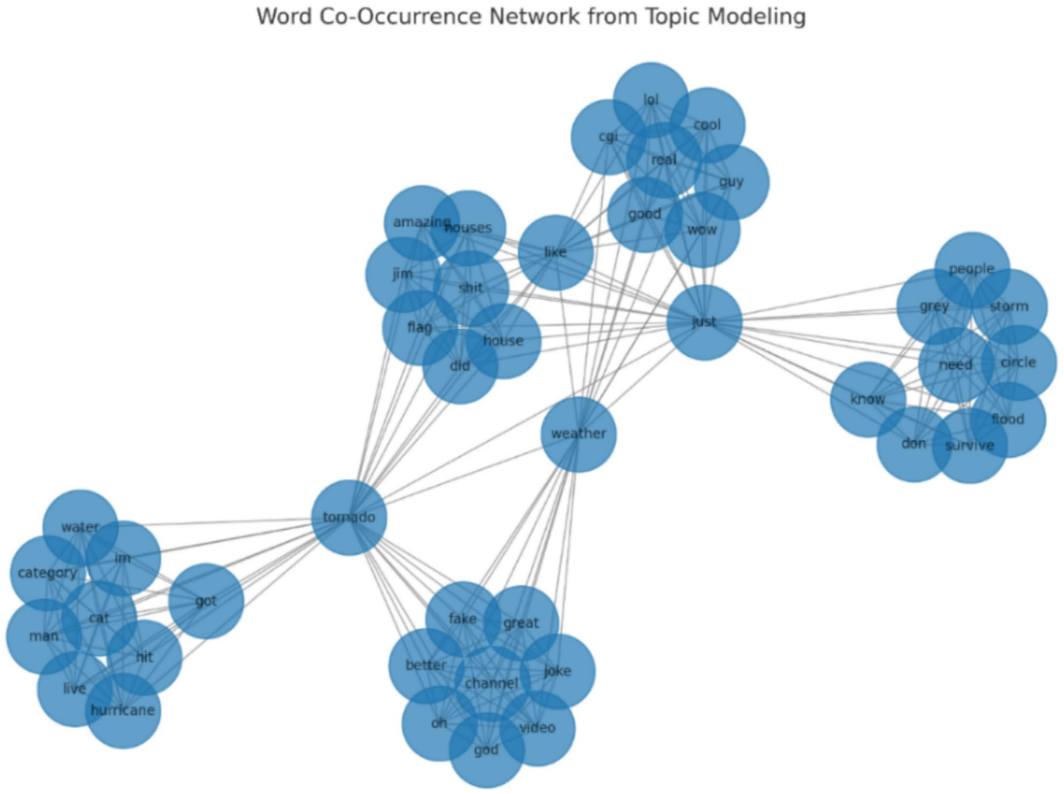

FIGURE 14
Representation of the vocabulary network according to the topic analysis.

opinions less emotionally compared to English comments, which showed higher levels of positive and negative sentiment. This difference may be due to cultural or linguistic factors that influence how opinions are expressed. Or, because of the prevalence of AR-based climate content in the Russian context. On the other hand, the low percentage of negative comments reflects a general acceptance of the content or the absence of strong reactions against it.

Figure 15 indicates that most of the comments appear close to zero, suggesting they are probably neutral. The results revealed that TextBlob is more sensitive at detecting negative sentiments than VADER. Usually, TextBlob describes most comments as neutral or negative, while VADER shows comments that are negative or positive as nearly the same. This difference is due to how the tools get their information: TextBlob uses dictionaries, whereas VADER includes algorithms that respond to changes in emotional expression. This result highlights the importance of employing mixed analytical tools for an accurate analysis of public sentiment on complex issues, such as climate change.

Table 4 shows that VADER and TextBlob agreed on classifying 3,481 comments as negative, 8,492 as neutral, and 7,956 as positive.

TABLE 2 Outputs of the Communalytic program for analyzing YouTube users' feelings toward climate change issues using augmented reality techniques.

Tool (Language)	# of Posts	Negative sentiment [−1.−0.05]	Neutral Sentiment (−0.05−0.05)	Positive Sentiment [0.05−0.1]
VADER (English/EN)	32,632	7,815 (23.95%)	11,971 (36.68%)	12,846 (39.37%)
VADER (Portuguese/PT)	459	15 (3.27%)	421 (91.72%)	23 (5.01%)
TextBlob (English/EN)	32,632	5,713 (17.51%)	14,997 (45.96%)	11,922 (36.53%)
TextBlob (French/FR)	320	8 (2.50%)	298 (93.12%)	14 (4.38%)
TextBlob (German/DE)	620	5 (0.81%)	609 (98.23%)	6 (0.97%)

*Based on the analysis of 34,074 out of 41,243 posts, the results are as follows.

TABLE 3 Sentiment analysis of russin comments using the RuSentiment tool.

Tool (Language)	# of posts	Negative sentiment (pos_score>0.5)	Neutral sentiment (neu_score>0.5)	Positive sentiment (pos_score>0.5)
RuSentiment (Russian/RU)	34	3 (8.82%)	19 (55.88%)	12 (35.29%)

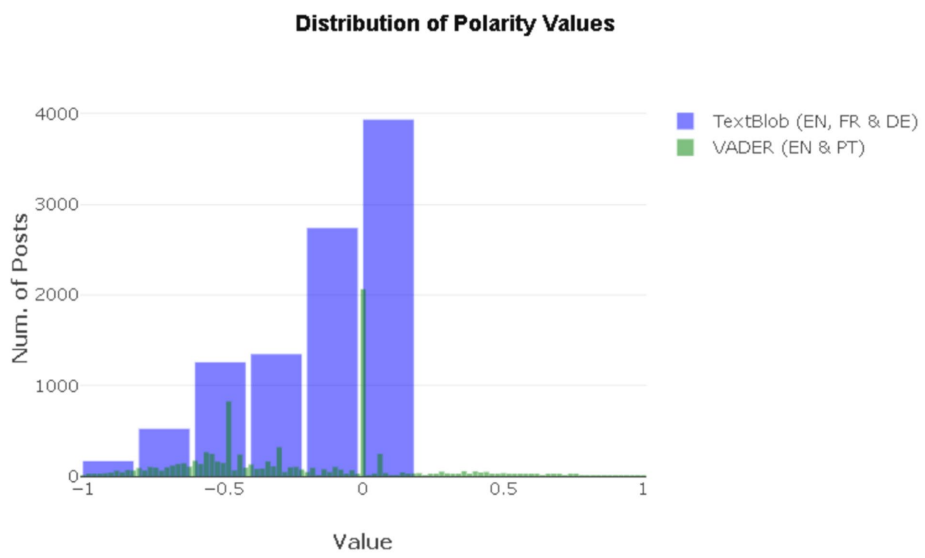

FIGURE 15
Distribution of polarity values for comments' sentiments using the TextBlob (represented in blue) and VADER (represented in green) tools.

TABLE 4 Confusion matrix comparing the sentiment classifications analyzed by VADER and TextBlob.

TextBlob/VADER	VADER – Negative [−1.−0.05]	VADER – Neutral (−0.05−0.05)	VADER – Positive [0.05.0.1]
TextBlob - Negative [−1.−0.05]	3,481	892	1,171
TextBlob - Neutral (−0.05−0.05)	2,673	8,492	3,541
TextBlob - Positive [0.05.0.1]	1,464	2,208	7,956

*The table shows both agreement and disagreement counts across sentiment labels as determined by VADER and TextBlob.

However, the analysis revealed that VADER classified 1,171 comments as positive. TextBlob classified them as negative, and vice versa for 1,464 comments. This result reflects the algorithms' differences in assessing the intensity and polarity of sentiment. This disparity suggests that VADER is more sensitive to words with a clear emotional tone, while TextBlob tends to classify a greater number of comments as neutral.

Regarding the content of the comments, users liked the visual techniques used, believing that the visual effects enhance the message delivery about climate change. Meanwhile, neutral comments reflected

a focus on descriptive content or disaster-related strategies without clearly expressing positive or negative sentiments. Furthermore, the sarcastic tone of comments indicates the public's acceptance of IMR technologies as a visual simplification tool.

On the other hand, negative comments expressed reservations about the excessive use of effects and the unrealism of some scenes, with some users criticizing the sensationalist effect of climate coverage. Several respondents pointed out that making climate phenomena less complicated with computer graphics could make the information less valuable and give the show an entertainment feel instead of a lesson. The results highlight that using various tools helps get a total picture of people's attitudes toward IMR and environmental content.

6 Discussion and conclusion

According to the current study, videos about extreme weather events (for example, hurricanes and storms) received more engagement than those showing different topics. This finding is consistent with Elgammal et al. (2025), who highlight that IMR encourages learning about the environment and leads to better ways of caring for nature. The study also discovered that user engagement was stable until 2017, after that increased from 2018 to 2020, with significant peaks before a decline after 2020. This result shows the direct impact of environmental events that have been held in this period. This was consistent with Iyer (2023) study that indicated the need to update VR-based environmental content to keep the user engagement in a high level.

The results also revealed that about half of all engagements have a relevant with small percentage of comments. Which is consistent with the study of Heemsbergen et al. (2022), that confirmed that digital recommendation algorithms help in shaping engagement. Furthermore, the study's findings expose that users prefer to comment on posts by themselves rather than replying to other comments or having a conversation with others. This agrees with Adhikari et al. (2023), who sum up that comments on YouTube are more individualistic in nature than conversational.

YouTube comments semantic analysis by the HDBScan algorithm revealed 446 clusters into which comments are distributed based on semantic similarity, with 11,400 outliers that did not have any main cluster. Most comments were related to similar topics, while some clusters appear outside the focus, imitating variations in user responses. This result is consistent with Ma and Huo (2022), who found that YouTube comments might be shaped by digital echo chambers, resulting in conversations with diverse opinions on climate change issues.

The results from the network analysis of video comments also indicated that most comments were individual and independent, with users preferring to express their opinions without engaging in extended discussions. However, some of the Figures 9–12 show the formation of interaction groups around certain environmental issues, suggesting these topics piqued the interest of many individuals. In this regard, Singha et al. (2024) found through studying YouTube interaction networks that some subjects were discussed more frequently than others.

The analysis of the most frequently used emojis showed that interactions in the comments ranged from emotional to sarcastic and serious. This finding is consistent with Rochadiani (2023), who reported that analyzing emojis is useful for identifying users' emotional responses to video content. The current study revealed that the most common words in the comments related to weather disasters were associated with words like "tornado" and "weather," and strong excitement with "cool" and "wow." This result indicates the links in the semantic network between "fake," "channel," and "video," suggesting the trustworthiness of the displayed information. These findings are consistent with those by Shevtsov et al. (2023), who investigated the political interaction networks on YouTube. He found that the link between certain words in comments regarding specific topics clearly displays differences in public opinion about these topics.

Sentiment analysis results using VADER and TextBlob showed a discrepancy in sentiment classification, with VADER showing a negative sentiment rate of 23.95%, compared to 17.51% according to TextBlob. Comments in French, German, and Portuguese showed remarkably high neutral rates of more than 91%, indicating that comments in these languages were less intensive on an emotional level compared to English comments, which showed an increased emotional intensity level. The results support the findings of Kaushik et al. (2024), who showed that sentiment analysis is potentially dependent on the languages used and on the used classification models, and who thereby highlight the necessity of using various tools for achieving accurate assessments.

The findings also indicated that over half (55.88%) of the Russian comments contained neutral feelings. The proportion of positive feelings was 35.29%, and negative feelings were 8.82%. The findings of the present study tend to support that Russian-speaking users may have less openness in responding to environmental content on emotional grounds. The current study's results support recent research by AL Fathir et al. (2023), who determined that emotional expression on YouTube relies on cultural and linguistic considerations.

In analyzing sentiment classification, the researchers recorded a variance of results using VADER and TextBlob. Concretely, VADER showed a greater propensity for classifying negative commentary, whereas TextBlob labeled numerous of these comments as neutral. TextBlob labeled 1,171 of these comments as negative; TextBlob, however, labeled these as negative, due to varying algorithms applied by each program. This experience verifies the recommendation of Adhikari et al. (2023), who emphasized using a set of several sentiment analysis programs for the proper analysis of digital content.

Despite the significant potential of Immersive Mixed Reality (IMR) technologies, including augmented reality (AR) and virtual reality (VR), in achieving environmental engagement and enhancing communication, these technologies also pose serious challenges that need careful consideration. Overutilization of esthetically appealing elements may lead to an exaggerated feeling of excitement or convert the content material into entertainment that undermines its scientific credibility. Overemphasis on digital media might simultaneously coincide with superficial interpretations or superficial elaborations and, consequently, place undue cognitive loads on the audience and hinder them from perceiving the intended message (Koparan, 2025).

The results of network analysis show that IMR-supported content has a unique potential for raising the dynamics of group communication beyond simple person-to-person contacts by means of a complex system of interactive networks of commentary and replies. Kaplan-Rakowski and Meseberg (2019) emphasized the above conclusion by describing that

IMR embodies VR, AR, and MR as interconnected and identical entities by virtue of their interactive and immersive nature. The study by Yang et al. (2022) confirms that collaboration in an immersive virtual environment generates a more balanced degree of group participation in discussions and so has a beneficial impact on increased interaction and dialog compared to a traditional desktop workplace. The argument is in harmony with Social Presence Theory, which argues that newly evolving technologies like IMR and AR have the potential for generating a sense of group presence, leading to more significant person-to-person interactions in groups. It is also in line with the concept of Virtual Collective Consciousness, where collective awareness is created and built around shared themes in an immersive digital context.

6.1 Recommendations

The study recommends using IMR, VR, and AR technologies in Arabic channels to deliver interesting content to audiences, particularly in the environmental field. This contributes to stimulating stronger emotional responses to such content. At the same time, environmental content strategies must adapt to global climate events and change audience interests. The current study revealed that users publish their opinions independently rather than engage in lengthy discussions. Therefore, engagement strategies can be improved by fostering digital environments that stimulate group discussion.

It's essential to foster some degree of integration between media organizations, particularly in the Arab world, to help leverage modern technologies in the production of climate change-related content. This step is essential in light of the high cost of this issue, which ultimately contributes to reducing production costs, which are the primary reason for the Arab media's reluctance to use this technology in climate change news.

Additionally, the study recommends using multilingual sentiment analysis tools to ensure accuracy. It's also essential to enhance the digital libraries used for sentimental analysis by adding examples that consider cultural differences between people. In addition, it is recommended to develop a dedicated library for sentiment analysis of Arabic-language comments, which is still in its infancy to date. Despite some tools, such as Orange Data Mining, which seek to add Arabic to their libraries, experience confirms that it is extremely weak.

The current study recommends leveraging sentiment analysis, emojis, keywords, and interaction patterns to design environmental communication campaigns based on IMR technologies. It also recommends enhancing positive emotional dimensions and incorporating the most popular vocabulary among the audience, which can contribute to increased engagement. Networked interaction dynamics enable group discussions that can foster shared environmental awareness and support sustainable behaviors related to climate change issues.

Finally, there is still a need for further research aiming to explore how new technology, like IMR, VR& AR, will transform media production and its impact on the target audiences. Additionally, future studies should take into consideration the ethical implications of using immersive technologies (e.g., risk of emotional manipulation and misinformation through overly dramatized visualizations).

6.2 Limitation of the study

There are significant challenges associated with cross-linguistic sentiment analysis, including that there are no reliable tools for sentiment analysis in Arabic. In addition, when different languages are used in comments, there is some variation in analysis rates depending on the library tools used. Furthermore, it is hard to verify whether artificial intelligence can understand cultural differences and local expressions when participating in the digital realm. This perspective calls for enhancing sentiment analysis libraries with these contents to increase their reliability. In addition, Part of the limitation of this study can be attributed to the reliance on YouTube only, along with the analysis of five videos, which suggests further studies across other social media platforms.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving humans were approved by Research Center-Gulf University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was not required, for either participation in the study or for the publication of potentially/indirectly identifying information, in accordance with the local legislation and institutional requirements. The social media data was accessed and analyzed in accordance with the platform's terms of use and all relevant institutional/national regulations.

Author contributions

NE: Writing – original draft, Writing – review & editing. HM: Validation, Methodology, Writing – original draft. SH: Writing – review & editing, Data curation. HF: Writing – original draft, Resources, Visualization, Formal analysis. FA: Methodology, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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