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Social acceptance dynamics and predictive scenario analysis of waste management policy ☆

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Highlights

- An integrated model of sentiment analysis, topic modeling, and SHAP with IPCC-aligned climate scenario prediction
- Analysis of over 7000 Macedonian tweets on waste issues from 2023 to 2025
- Identified landfill discourse as a dominant source of negative public sentiment
- Demonstrated potential 70% GHG reduction under Macedonia's mitigation measures scenario
- Highlighted a critical gap between policy goals and societal acceptance in waste management issues

Abstract

The objective of this study is to explore the intersection of public discourse and climate policy related to the waste management sector in the Republic of Macedonia. By integrating natural language processing (NLP) techniques, specifically sentiment analysis, topic modeling, and SHapley Additive exPlanations (SHAP), with scenario-based climate modeling aligned with IPCC guidelines, the research aims to assess the social acceptance and environmental potential of national waste strategies. The findings, from the analysis of X (formerly Twitter) data collected between October 2023 and April 2025, reveal a consistent predominance of negative sentiment, particularly toward opening new standardized landfills, with sharp sentiment peaks following local environmental events. The topic modeling results identify the landfill discourse as a dominant theme, with subtopics linked to public fear, mistrust and environmental health concerns. At the same time, the mitigation scenario projections indicate that full implementation of Macedonia's planned waste measures (mainly opening of new standardized landfills) could result in a 70% reduction in GHG emissions by 2050, compared to a scenario with no measures. However, the widespread public disapproval toward key policy components, as evidenced in digital discourse, shows an inconsistency between technical feasibility and social acceptance. The study demonstrates the utility of a dual methodological lens to assist in a more responsive, inclusive, and sustainable policy design. It advocates for the institutionalization of digital discourse monitoring and transparent sentiment interpretation in public environmental governance, especially important in underrepresented regions like the Western Balkans.

Introduction

Waste management has long been recognized as a constant policy and infrastructure challenge in the Republic of Macedonia. Although the legal framework has made significant advancements, especially following the adoption of a comprehensive set of harmonized waste-related laws in 2021, the implementation landscape remains fragmented and hindered by infrastructural, institutional, and sociopolitical obstacles. Key legislation such as the Law on Packaging and Packaging Waste [1], Law on Batteries and Accumulators [2], Law on Management of Electrical and Electronic Equipment and Waste Electrical and Electronic Equipment [3], Law on Management of Additional Waste Streams [4] and the Law on Extended Producer Responsibility [5], represent alignment with EU directives and mark a strategic shift toward modern waste governance. Nevertheless, the gap between regulatory aspirations and practical execution is particularly evident in the limited progress on establishing regional sanitary landfills and in the low public acceptance of necessary reforms.

The issue of insufficient public awareness and acceptance of waste management practices is not a new one. As early as the 2008–2020 National Waste Management Strategy [6], institutional reports pointed to deep-rooted social and perceptual barriers. These included widespread tolerance of illegal dumping, limited understanding of the concept and benefits of standardized landfilling, and high rates of non-payment for waste collection services. Importantly, as stated in the Strategy,

resistance to reform has been driven more by mistrust, fear, and lack of information than by cost concerns. Additionally, the Strategy points to sociological phenomena such as “Not in My Backyard” and “Not During My Term”, which reflect the intensity of these public attitudes, often resulting in delays or outright obstruction of critical infrastructure development. Notably, for example, the planned regional landfills in the Southwestern region were cancelled due to sustained public opposition, illustrating how deeply social dynamics influence environmental outcomes.

Despite the recognition of these issues across multiple planning cycles, recent documents such as the Waste Management Plan 2021–2031 still highlight the persistent lack of a national communication strategy and weak civil society capacities in public awareness. Four years after its adoption, no dedicated national strategy for public communication has been implemented. Although almost two decades have passed since these issues were first formally recognized, there has been little progress in the systematic understanding of why citizens oppose waste-related investments. No quantitative analysis has been conducted to assess which segments of the population are dissatisfied, what specific concerns they express, or which waste-related topics dominate public discourse. Besides, the lack of insight into the emotional and thematic structure of public opinion continues to hinder effective reform. That is particularly relevant given the growing urgency of integrating environmental sustainability with social equity. Furthermore, while technical models project emissions and costs, they often miss the legitimacy gap that arises from public mistrust, emotional resistance and local management problems. These blind spots significantly limit the development of evidence-based communication strategies and policy responses.

Accordingly, the application of natural language processing (NLP) techniques to environmental discourse analysis has emerged as a promising approach to address these knowledge gaps. Recent studies have demonstrated that the most effective approaches combine sentiment analysis with topic modeling to capture both thematic content and emotional responses, while temporal analysis reveals how environmental discourse evolves in response to events and policies [8,9]. Research has applied NLP techniques to analyze global news sentiment on environmental issues, revealing temporal sentiment trends that align with major environmental events, policy announcements, and international agreements [10]. These studies combine sentiment scoring with Latent Dirichlet Allocation (LDA) topic modeling to examine correlations between environmental news sentiment and low-carbon economy transitions, providing insights into how media coverage shapes public perception. Additionally, advanced sentiment and emotion analysis of social media environmental posts reveals complex patterns in public environmental discourse, demonstrating the utility of combining multiple analytical approaches to understand public attitudes [11]. Moreover, NLP-based analysis of environmental policy reveals significant democratic responsiveness, demonstrating that when public opinion prioritizes environmental issues, European governments respond with more ambitious renewable energy policies [12].

Against this backdrop, the Macedonian case presents a pressing context where these analytical tools can offer valuable insights. In this line, the failure to advance regional sanitary landfills is not simply

a matter of financing or engineering, it is a failure of communication, participation, and legitimacy. With Macedonia also committing to broader environmental goals through strategies such as the National Plan for Waste Prevention 2022–2028 [13] and the Draft National Sludge Management Strategy [14], understanding public discourse becomes an essential step toward designing responsive and inclusive waste governance.

This paper addresses these gaps through a dual-focus approach. First, it analyzes public discourse on waste management in Macedonia using advanced NLP techniques, sentiment analysis and topic modeling, applied to social media data. This component aims to uncover the dominant themes, emotional tones, and sociopolitical framings that shape citizen attitudes toward waste governance. Second, it evaluates the realistic trajectory of greenhouse gas (GHG) emissions in the waste sector through 2050 under two scenarios: a Without Measures (WOM) scenario, assuming no further policy interventions, and a With Measures (WM) scenario, incorporating all currently proposed policies, including the development of regional standardized landfills and enhanced recycling practices.

Thus, the objective of this paper is to examine the alignment between public sentiment and waste policy trajectories, by merging social media discourse analytics with scenario-based emissions modeling, assessing how societal acceptability and environmental performance converge or diverge in shaping sustainable waste governance. By integrating the Intergovernmental Panel on Climate Change IPCC-compliant emission modeling with discourse analytics, the study not only quantifies the mitigation potential of current strategies but also explores whether these policy pathways align with public sentiment and perceived legitimacy.

Understanding this alignment, or lack thereof, is critical. If the proposed emissions reductions are technically feasible but socially contested, the likelihood of successful implementation diminishes. Conversely, scenarios that reflect both environmental effectiveness and public support offer a more robust foundation for sustainable policy design. As such, this paper contributes to both the scientific evaluation of mitigation pathways and the social dimensions of policy acceptance, an essential convergence for effective and inclusive reform of the waste sector.

Section snippets

Social media data

The media play a central role in informing the public about global events, particularly in areas where audiences lack direct knowledge or experience. Previous studies have demonstrated how media coverage can influence public debate through agenda-setting and directing public attention to specific subjects [15]. However, with the rapid development of information and communication technologies, social media platforms have fundamentally transformed how people interact, share information, and …

Methodology

This research methodology combines social media discourse analysis with environmental impact assessment to offer a comprehensive perspective on waste management in Macedonia. This dual framework enables the simultaneous investigation of environmental outcomes and public acceptability, two dimensions that are often treated separately but are critically interdependent in the context of sustainable waste governance.

As illustrated in Fig. 1, the dual-track framework integrates social, …

Results

A total of 12,344 tweets related to waste management were collected, including 5135 retweets. To ensure the analysis focused on original content and avoided duplication, only the 7209 unique tweets were included in the study. …

Discussion

The objective of this research was to assess how public sentiment and thematic discourse around waste management in the Republic of Macedonia align with the country's climate mitigation trajectories. Specifically, we sought to understand what citizens feel and how these sentiments may affect the implementation of the WM scenario, which projects a striking 70% reduction in GHG emissions by 2050, using IPCC-based modeling. In this way, the research fulfils a significant gap in understanding how …

Conclusion

This research integrates NLP techniques with scenario-based climate modeling to assess the dual challenge of technical feasibility and societal acceptability in waste management. The findings reveal a dominant negative sentiment toward waste management in Macedonia, especially concerning landfilling practices, a key component of Macedonia's planned mitigation strategy. That reflects a public acceptability problem that may hinder the implementation of technically feasible, but socially disputed …

CRediT authorship contribution statement

Marija Stojcheva: Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation. **Aleksandra Dedinec:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aleksandar Dedinec:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jana Prodanova:** Writing – review & editing, Writing …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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