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Innovative Framework based on Simulation and Generative AI for enhance Decision Making in Green Projects

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Abstract

This paper introduces an advanced simulator designed to assist decision-makers in strategically implementing smart cities and green infrastructure initiatives. Thanks to the innovative Strategic Engineering approach, based on Modeling and Simulation, Data Analytics and Artificial Intelligence our Simulator has the capacity to model human behavior, capturing a spectrum of cognitive responses to urban and industrial development projects and green initiatives. By simulating public sentiment as well as propaganda of different parties involved in these action, over different channels (Broadcasting, Press and Media) it is possible to recreate a realistic scenario and evaluate impact of media campaigns on people and key players. The use of Generative AI and in particular of LLMs is functional to create real communication content, analyze and synthetize responses and update population parameters by a sentiment analysis. By simulating different scenarios, BRAINS2 (Behavioral Response Analysis and Integrated Network Simulator for Sustainability) provides insights into how each communication channel influences public opinion, either fostering support or inciting opposition to the proposed sustainability initiatives.

Keywords: Modeling & Simulation: Human Behavior Modeling; Large Language Models; Sustainability; Social Media Analysis

1. Introduction

Sustainability has become a critical concern in urban planning and development, as cities worldwide face escalating challenges related to environmental degradation, resource depletion, and climate change. The need for sustainable solutions is pressing, with green infrastructure projects and smart city initiatives offering promising pathways to mitigate these issues. However, the successful implementation of these initiatives hinges not only on their technical and economic feasibility but also on the perception and acceptance by the public (Molloy et al., 2022).

Public perception of sustainability initiatives is influenced by various factors, including awareness, understanding, and trust in the proposed projects. Effective communication plays a crucial role in shaping these perceptions, as it helps inform, educate, and engage communities. Conversely, poor communication leads to misunderstandings, resistance, and even opposition, jeopardizing the success of sustainable initiatives. Moreover, cognitive biases significantly influence how people perceive and

react to information about sustainability. Our minds are susceptible to cognitive biases that lead to systematic errors in judgment and impact decision-making capabilities.

These cognitive biases, such as confirmation and anchoring bias, extend beyond the personal sphere, influencing the decisions of organizations and governments as well. These biases affect public opinion and the decisions of policymakers, who face challenges in garnering public and political support for eco-friendly practices such as waste reduction, energy conservation, and sustainable transportation (Li & Li, 2023). However, the main obstacle often lies in gathering public opinion and political support.

To address these challenges, our advanced simulator, BRAINS2 (Behavioral Response Analysis and Integrated Network Simulator for Sustainability), implements the Strategic Engineering approach, combining Modeling and Simulation, Data Analytics, and Artificial Intelligence. The simulation Architecture relies on a Stochastic Simulation driven by Intelligent Agents (IA) in order to reproduce the different groups of the population (Bruzzone et al., 2018a). The simulator acknowledges the powerful role of communication in shaping cognitive actions and responses, particularly in the context of propaganda or targeted informational campaigns. BRAINS2 models human behavior and captures cognitive responses to urban and industrial development projects (Bruzzone et al., 2018b). By simulating public sentiment and propaganda from various stakeholders across different media channels, the simulator recreates realistic scenarios and evaluates the impact of media campaigns on public opinion and key decision-makers.

Generative AI, particularly Large Language Models (LLMs), plays a crucial role in this process. These models generate authentic communication content, analyzing and synthesizing responses, and updating population parameters based on sentiment analysis. By simulating various scenarios, BRAINS2 provides valuable insights into how different communication strategies influence public opinion, either fostering support or inciting opposition to sustainability initiatives. A crucial feature of BRAINS2 is its ability to scrape data from various sources to gather demographic information about populations from different regions. This includes data on age, religion, politics, level of education, and economic status. By training Large Language Models (LLMs) on extensive datasets reflecting these diverse characteristics, our generative AI recreate realistic perceptions of people with different backgrounds. Individuals are linked in a social network based on their region, family ties, and use of different technologies (social media, broadcasting, press, etc.).

We model the spread of information and the delay in the spread of deepfakes based on these characteristics. This includes considering the use of different communication channels, the level of education (as people with higher knowledge are more likely to engage in fact-checking), and cognitive biases.

Understanding and managing public perception through effective communication is vital for the successful implementation of green infrastructure and smart city projects. Modeling & Simulation and Strategic Engineering approach offers a powerful tool to support decision-makers in navigating this complex system, ensuring that sustainability initiatives are not only technically sound but also publicly endorsed.

2. State of the art

The urgent need for sustainable energy projects is underscored by the escalating impacts of climate change (McCulloch et al., 2024). According to the International Renewable Energy Agency (IRENA), achieving the 1.5°C climate target necessitates comprehensive transitions in renewables-based electrification, energy efficiency, and direct uses of renewables across various sectors, including transport, industry, and buildings. This transition is crucial to strengthening energy security, mitigating fossil fuel price volatility, and making energy more affordable and sustainable. Despite advancements, the energy transition remains off-track, and further delays will only compound future challenges and investment needs (IRENA, 2023).

The International Energy Agency (IEA) also highlights that renewable energy, particularly solar PV and wind, is set to play a dominant role in future energy capacity additions. However, significant investments in infrastructure, such as expanded grids and storage solutions, are essential to integrate these renewables effectively and maximize their impact on reducing fossil fuel use (IEA, 2023).

Researchers are focusing on producing more studies to assess the feasibility of such projects, evaluating economic viability, infrastructure requirements, and crucially, public acceptance (Shen et al., 2010; Bouhal et al., 2018; Mahmudul et al., 2022). Effective communication is vital in garnering public support and facilitating the implementation of sustainable projects. Public sentiment and social dynamics significantly influence the success of sustainability initiatives (Afroze & Khan, 2017; Ahuja & Priyadarshini, 2015). Research shows that social media and traditional media play crucial roles in shaping public opinion. Social media, in particular, offers a diverse emotional spectrum, while newspapers often convey more negative sentiments. Understanding these dynamics helps in crafting communication strategies that raise public support for sustainability initiatives.

Modeling and simulation are powerful tools for understanding and predicting social behaviors and interactions in the complex systems (Bruzzone et al, 2011; Bruzzone et al., 2014b). Advances in computational modeling, such as the use of virtual reality systems and sophisticated 3D graphics engines like Unity, have enabled researchers to create immersive environments to study human behavior on a large scale. The Unity Experiment Framework (UXF) is one example of a comprehensive suite tailored to the needs of behavioral scientists, facilitating the exploration of social links and their impact on sustainability initiatives (Brookes et al., 2020).

The integration of large language models (LLMs) in human behavior modeling represents a significant advancement in creating effective communication strategies for sustainability projects (Qi, 2024). LLMs generate realistic communication content, analyze responses, and perform sentiment analysis to update population parameters dynamically.

Recent surveys have highlighted a significant shift in information consumption preferences, with a growing number of people favoring social networks such as Twitter, Facebook, Instagram, and LinkedIn over traditional media like TV and newspapers. This trend is concerning as trust in social media platforms is anticipated to increase, despite the presence of misinformation and bot accounts. For instance, in 2018, it was reported that there were approximately 48 million fake or bot accounts on Twitter and 270 million on Facebook, underscoring the potential impact of misinformation on political communication and societal discourse.

According to a Pew Research Center study, about half of U.S. adults reported getting news from social media sites often or sometimes, with Facebook being the most dominant platform for news consumption. Other platforms like YouTube, Twitter, and Instagram also serve as regular news sources for significant portions of their users. The data shows that social media plays a crucial role in how information is disseminated and consumed, with diverse demographics engaging differently across various platforms.

Moreover, reports from GlobalWebIndex (GWI) have shown that media habits are continuously evolving, with a noticeable decline in trust across traditional news sources and an increasing reliance on digital platforms. This shift in media consumption is driven by changing consumer priorities and the increasing prevalence of mobile and internet usage.

The influence of media and the spread of information are increasingly significant, particularly when considering the pervasive impact of cognitive biases on how individuals perceive and respond to information. The human brain is susceptible to over 200 cognitive biases due to the complexities of thought and decision-making (Turel & Serenko, 2020; Aarøe & Petersen, 2020).

These cognitive biases underscore the complexity of human information processing and decision-making, highlighting their profound implications for media consumption, public opinion formation, and societal discourse.

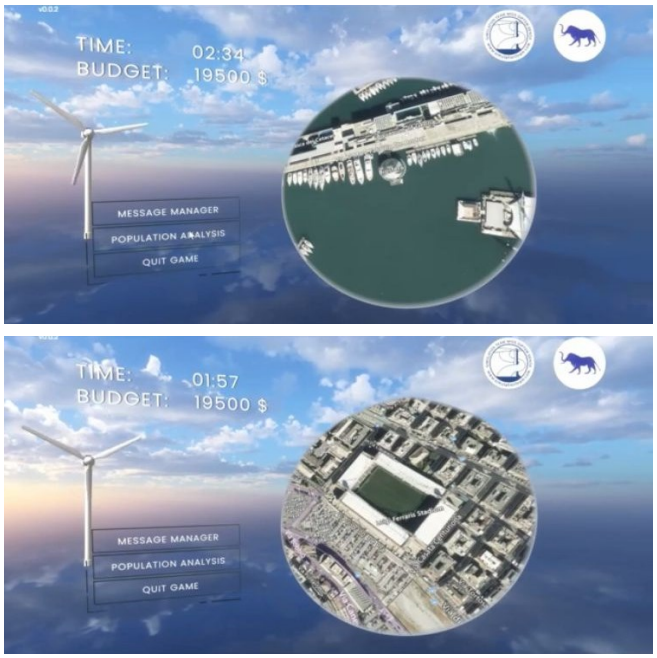

Fig.1 BRAINS Graphic User Interfaces

These findings underscore the critical role of social media in shaping public opinion and highlight the importance of addressing the challenges associated with misinformation and the proliferation of bot accounts to ensure the integrity of the information being consumed by the public.

3. Conceptual Model

The model of our proposed solution, BRAINS2, integrates several key components to simulate public perception and behavioral responses to sustainability initiatives. The system leverages a combination of Agent-Based Modeling (ABM), stochastic processes, data analytics, and advanced AI technologies such as Large Language Models (LLMs) to predict and analyze public opinion. This hybrid approach allows for the dynamic modeling of complex interactions between different societal groups, communication channels, and cognitive biases, which influence public perceptions and decision-making processes. The conceptual model of BRAINS2 consists of five core components: Agent Modeling, Cognitive Bias Representation, Communication Channels, Information Diffusion, and Sentiment Analysis and Feedback Loop. Each component is designed to work in conjunction with others, enabling the accurate simulation of various scenarios involving sustainability communication strategies.

Fig.2 BRAINS Message generator and evaluator

The foundation of BRAINS2 lies in its ability to simulate human behavior using Intelligent Agents (IAs). These agents represent diverse population segments based on demographic, socio-economic, and psychological attributes such as age, education, political affiliations, religious beliefs, and technological access. Agents are designed to mimic the behavior and decision-making processes of real individuals by incorporating rules that reflect both rational and biased cognitive responses.

These agents operate within a social network, with interactions governed by relationships and connections influenced by several parameters, like social ties, personal interests, social media use, and media consumption patterns. The inclusion of varying levels of trust, influence, and interaction frequency among agents ensures that the model captures the nuances of information propagation in a realistic manner.

Agents' behavior is influenced not only by external stimuli, such as media messages and policy announcements, but also by their cognitive biases, personal values, and group dynamics. This multi-dimensional agent model provides the necessary structure to replicate the complexities of human behavior when facing sustainability issues.

Cognitive biases play a critical role in shaping how individuals and groups perceive sustainability initiatives. BRAINS2 explicitly incorporates biases like confirmation bias and bandwagon effect which systematically affect how agents interpret information, make decisions, and update their beliefs.

- **Confirmation Bias**: Agents tend to seek out information that aligns with their pre-existing beliefs and dismiss contrary evidence. This is particularly important in polarized environments where sustainability initiatives may be perceived differently depending on the political or ideological background of the agents.
- **Bandwagon effect**: Agents tend to seek out information which are viral and have more consensus of a large part of the population.

By modelling these biases, BRAINS2 accounts for the psychological tendencies that often hinder rational decision-making and affect the success of sustainability campaigns.

A vital element of this model is its ability to simulate communication across various media channels. The model integrates traditional media (e.g., television, radio, print) and digital media (e.g., social media platforms, blogs). Each communication channel is characterized by its reach, credibility, and influence on specific population segments.

For example, agents characterized by a younger age may be more influenced by social media campaigns, while older agents might be more reliant on television broadcasts or newspapers. Moreover, the model captures the varying credibility assigned to each channel by different demographic groups. Misinformation, fake news, and deepfake videos are incorporated into the simulation to assess how these elements impact public perception, especially when disseminated through social networks.

The inclusion of diverse communication channels ensures that the model simulates the full spectrum of information dissemination patterns that influence public opinion on sustainability.

The diffusion of information follows a network-based approach, where agents are connected based on social ties, shared interests, and media consumption patterns. Information spreads through these networks via cascades, where an initial set of agents receives a message, processes it (influenced by cognitive biases), and then passes it on to their connections.

This diffusion process is further nuanced by incorporating delays and decay in message transmission. The decay factor captures the likelihood that information may lose relevance or impact over time, while repetition or reinforcement through multiple channels boosts message retention.

BRAINS2 also models the emergence of echo chambers, where agents only receive information from like-minded sources, reinforcing their pre-existing beliefs and making it harder for opposing views to penetrate these groups.

A key innovation in BRAINS2 is the integration of real-time sentiment analysis using LLMs to assess how agents react to various messages. These models process the content disseminated through communication channels, identifying emotional responses, tone, and shifts in public opinion over time.

Agents' sentiment toward sustainability initiatives is updated based on the information they consume, leading to either growing support or increased opposition. This feedback loop allows for continuous adjustment of the communication strategy, ensuring decision-makers are able to tailor their messages to target groups effectively. For example, if sentiment analysis reveals rising skepticism in a particular

demographic, campaign messages are adjusted to address specific concerns or counteract misinformation.

By continuously updating the simulation with real-time feedback from sentiment analysis, BRAINS2 enables the testing of different communication strategies to determine the most effective methods for gaining public support or mitigating opposition.

At the heart of BRAINS2 is a stochastic simulation engine that allows for the exploration of various scenarios. The stochastic nature of the model ensures that each run may yield different outcomes, depending on random variations in how information spreads, how agents interact, and the influence of external factors like political events or economic conditions.

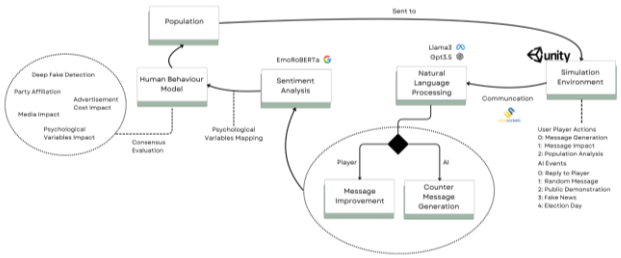

Fig.3 BRAINS Architecture

Scenario analysis allows stakeholders to experiment with different strategies, such as launching targeted social media campaigns or focusing on community-based engagement, to observe their potential effects on public sentiment. This helps decision-makers identify the most effective communication strategies for achieving broad-based support for sustainability initiatives.

4. Conclusions

The urgent need to address climate change and environmental degradation demands innovative solutions in urban planning and sustainable development. The transition toward renewable energy, green infrastructure, and smart cities is critical to mitigating these challenges. However, the success of these initiatives is not solely determined by their technical feasibility or economic viability but also by the perceptions and acceptance of the public. This work has emphasized the importance of understanding and managing public opinion as a central factor in the implementation of sustainability projects.

BRAINS2, our Behavioral Response Analysis and Integrated Network Simulator for Sustainability, represents a significant leap forward in addressing this challenge. By combining Agent-Based Modeling (ABM), data analytics, and cutting-edge AI technologies such as Large Language Models (LLMs), BRAINS2 provides a robust platform for simulating public sentiment and responses to various communication strategies. Through realistic representations of demographic groups and their cognitive biases, BRAINS2 offers decision-makers critical insights into how public perceptions is influenced by media campaigns, social networks, and other forms of communication.

Key to this system's success is its ability to simulate complex interactions between societal groups, media channels, and cognitive biases that shape how sustainability initiatives are received. The simulator's modeling of information diffusion and public sentiment, combined with real-time feedback from sentiment analysis, provides a dynamic tool for continuously refining communication strategies. By accounting for factors such as confirmation bias, bandwagon effect, and the spread of misinformation or deepfakes, BRAINS2 equips decision-makers with the foresight to anticipate public responses and adjust their strategies accordingly.

Importantly, the system's stochastic simulation engine allows for the exploration of numerous scenarios, enabling stakeholders to experiment with different approaches to public engagement. Whether it's launching targeted social media campaigns, focusing on traditional media outlets, or addressing specific demographic concerns, BRAINS2 provides a comprehensive environment to test and refine communication strategies that foster public support for sustainability initiatives.

In light of these advancements, the implications of BRAINS2 extend beyond the scope of sustainability alone. The system's architecture, grounded in strategic engineering and modeling & simulation, offers potential applications in a wide range of domains, from public health campaigns to political communication. By integrating real-time data scraping, demographic analysis, and behavioral modeling, BRAINS2 bridges the gap between technical implementation and societal acceptance, ultimately increasing the likelihood of success for any large-scale initiative requiring public endorsement.

In conclusion, achieving widespread support for sustainability initiatives requires more than sound technological solutions—it necessitates a deep understanding of public perception and cognitive behaviors. BRAINS2 demonstrates the power of combining advanced AI with agent-based simulation to anticipate public responses, craft more effective communication strategies, and drive the necessary social change for a sustainable future. By leveraging these insights, decision-makers are better positioned to navigate the complexities of public opinion, ensuring that sustainability projects are not only implemented but also embraced by the communities they aim to serve.

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