Supporting the Measurement of Sustainable Development Goals in Africa: Geospatial Sentiment Data Analysis

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Abstract:

In 2015, the United Nations (UN) launched an ambitious set of 17 Sustainable Development Goals (SDGs) to end poverty, protect the planet, and ensure prosperity for all as part of the 2030 Agenda for Sustainable Development. Achieving these far-reaching goals requires effective tracking of progress across 169 targets and over 230 indicators. Furthermore, adopted in 2015, Africa Agenda 2063 is a strategic framework developed by the African Union (AU) to optimize the use of the continent's resources for sustainable and inclusive growth. It aims to deliver on key aspirations shared by African nations including a high standard of living, well-educated citizens, good governance, strong cultural identity, and Africa's strong voice in global affairs. Built around 20 goals and seven priority areas, Agenda 2063 provides a shared vision and roadmap for socioeconomic transformation in Africa over the next 50 years. However, numerous countries in Africa face considerable challenges in collecting, timely, granular, high-quality data to adequately monitor SDG metrics. Traditional data sources like surveys and administrative records often have gaps, especially at subnational levels. As a result, national statistics offices, particularly in Africa, lack the data needed to properly inform SDG-related policies and interventions.

Keywords: Sustainable development , Africa , Target tracking , Soft sensors , Geospatial analysis

In 2015, the United Nations (UN) launched an ambitious set of 17 Sustainable Development Goals (SDGs) to end poverty, protect the planet, and ensure prosperity for all as part of the 2030 Agenda for Sustainable Development. Achieving these far-reaching goals requires effective tracking of progress across 169 targets and over 230 indicators. Furthermore, adopted in 2015, Africa Agenda 2063 is a strategic framework developed by the African Union (AU) to optimize the use of the continent's resources for sustainable and inclusive growth. It aims to deliver on key aspirations shared by African nations including a high standard of living, well-educated citizens, good governance, strong cultural identity, and Africa's strong voice in global affairs. Built around 20 goals and seven priority areas, Agenda 2063 provides a shared vision and roadmap for socioeconomic transformation in Africa over the next 50 years. However, numerous countries in Africa face considerable challenges in collecting, timely, granular, high-quality data to adequately monitor SDG metrics. Traditional data sources like surveys and

administrative records often have gaps, especially at subnational levels. As a result, national statistics offices, particularly in Africa, lack the data needed to properly inform SDG-related policies and interventions.

In this study, an innovative approach known as geospatial sentiment data analysis (GSDA) is introduced and implemented. While GSDA itself is not a novel concept, its application in the context of analyzing progress toward the SDGs is a new development. GSDA combines natural language processing (NLP) and spatial analysis (SA) to track and assess progress toward several key SDGs. In this article, the focus is on the following SDGs: SDG 1 (no poverty); SDG 2 (zero hunger); SDG 4 (quality education); SDG 5 (gender equality); SDG 9 (industry, innovation, and infrastructure); SDG 13 (climate action); SDG 14 (life below water); SDG 15 (life on land), and SDG 17 (partnerships for the goals). In Africa, achieving these SDGs is particularly challenging due to constraints related to data availability, human development, and technology. Applying this approach to public social media data can help gauge grassroots feedback on SDG topics and capture previously hidden perspectives. Hence, integrating such innovative supplementary data smartly where traditional sources fall short can enrich SDG monitoring capacities in Africa. Progress varies widely across the continent and among different countries. Some countries have made significant strides in certain areas, while others face more substantial challenges. However, the SDGs considered in this paper are currently lagging behind in Africa with respect to the UN 2030 Agenda. By combinining the introduced technique (GSDA) with traditional methods such as surveys and official statistics, one can enhance SDG monitoring and response in Africa. Key benefits include understanding geospatial sentiment on SDGs, identifying issues needing intervention, benchmarking specific locations, and guiding survey design to complete secondary data. With thoughtful application, GSDA and new data sources can offset limitations in resources and expertise to improve SDG tracking. Overall, emerging digital innovations such as the introduced technique create new possibilities for developing countries to actively pursue development aims.

It should be noted that because only 65% of posts containing content relevant to the considered SDGs were linked to keywords, only 19 African countries were identified and incorporated into the final analysis. These countries are as follows: Algeria, Benin, Cameroon, Cote d'Ivoire, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Mali, Morocco, Nigeria, Senegal, South Africa, Tanzania, Togo, Uganda, Zambia, and Zimbabwe. The total number of X users in these 19 countries is approximately 57.8 million. This number represents a portion of the population with internet access in these countries. The combined internet penetration rate of these countries is approximately 35%. In this context, the 57.8 million X users represent about 16% of the internet user population in these countries. This suggests that under this scenario, a larger proportion of the internet-using population in these countries is active on X (Twitter), although the majority still does not use the platform. It also emphasizes the varying levels of digital access and social media engagement across the African continent. The 16% of the internet-using population in these African countries that uses X can provide valuable insights for identifying and supporting the monitoring of SDGs through sentiment and geospatial analysis. Geotagged posts can help identify where conversations about specific SDGs are happening, allowing for a spatial understanding of engagement and concerns.

This article explores two existing use cases, namely the "Data for African Development" project and the "African Regional Data Cube" project. The main contribution of this study is to examine early case studies where GSDA techniques have been applied to track SDG progress in African countries. It assesses the benefits and limitations of this approach to complement conventional indicator measurement, especially for national statistics offices with

resource constraints. The article also provides recommendations on how GSDA can be thoughtfully adopted as part of robust national SDG monitoring frameworks. With careful implementation, the proposed technique promises to support better SDG progress tracking in data-scarce developing regions in Africa. Furthermore, by mapping these posts, the map offers a visual representation of social media engagement with SDGs in Africa. The data included in this analysis is influenced by the nature of social media usage and may require further triangulation with other sources such as surveys and national statistics to draw more accurate conclusions.

Literature Review

Geospatial data is one of the most promising data sources that can be applied for monitoring progress in achieving the SDGs. The role of big data in analyzing SDG indicators is discussed by MacFeely [1]. A review of methods for translating SDG interconnected goals into a policy action has been given by Breuer et al. [2]. A study by Allen et al. [3] presented a novel integrated method to prioritize SDG targets through study cases from 22 countries in the Arab region. Avtar et al. [4] provided a systematic review of the scientific literature concerning the use of geospatial data for achieving the SDGs. Furthermore, the authors emphasized the range of SDG indicators that can be monitored using geospatial data and how to improve the monitoring techniques with advanced sensors and big data. At global and regional levels, the Sustainable Development Solutions Network (SDSN) used statistical data from the World Bank database to assess SDG baselines for 149 countries with reference to the SDG index and dashboards as discussed by Sachs et al. [5]. Researchers from South Africa used the statistical database of the World Bank and the UN Food and Agriculture Organization (FAO) to assess the agricultural sustainability in Southern Africa (Nhemachena et al. [6]). Chen et al. [7] tackled the adoption of appropriate indicators at a local level, availability and acquisition of reliable data sets, spatiotemporal analysis with a geographical perspective, interaction between SDGs, and cross-sector coordination. Oluboyede and Odeyemi [8] discussed the importance of geospatial data to support decision-making for SDGs in Africa. Geospatial data sets are becoming more available for use in different applications and new emerging services in most African countries. However, despite this, data access, sharing, integration, and management is a big challenge as stated by Mwange et al. [9] and [10], Nhamo [11], and Siebritz and Fourie [12]. Similarly, another concern is the absence of systematic monitoring and access to social, economic, and environmental data sets. From the literature, it is evident that a gap exists in terms of merging geospatial data with sentiment analysis, specifically in Africa. To provide an overall picture regarding the distance from achieving the 2030 SDGs, a holistic framework should be realized by a comprehensive measurement and with an integrated utilization of geospatial and sentiment analyses.

Critical SDGS in Africa

According to the 2022 Africa SDGs report, Africa is making slow progress in the following SDGs: SDG 1 (no poverty), SDG 2 (zero hunger), SDG 4 (quality education), SDG 5 (gender equality), SDG 9 (industry, innovation, and infrastructure), SDG 13 (climate action), SDG 14 (life below water), SDG 15 (life on land), and SDG 17 (partnerships for the goals). Achieving these SDGs is particularly challenging due to constraints related to data availability, human development, and technology. The underlying factors for each SDG are discussed as follows.

SDG 1: No poverty

Monitoring progress toward SDG 1 in Africa presents several challenges, particularly from a data perspective. Accurate and timely data on poverty levels, income distribution, and access to basic services are essential for effective policy-making and targeted interventions. However, numerous African countries face limitations in data collection and analysis capabilities, including insufficient resources, incomplete data sets, and a lack of standardized methodologies. Additionally, other challenges in monitoring this SDG include political instability, which can affect the reliability of data and the implementation of poverty reduction strategies, and economic constraints that limit the ability of governments to invest in data infrastructure and social programs. Despite progress, sub-Saharan Africa remains the region with the highest prevalence of poverty, with over 40% of the population living on less than U.S. $ 1.90 a day, the international poverty line. Also, the region is home to more than half of the world's extremely poor population, with an estimated 389 million people living in extreme poverty.

SDG 2: Zero Hunger

Monitoring progress toward SDG 2 in Africa faces several challenges, particularly related to data availability and reliability. Accurate and up-to-date data on food security, agricultural productivity, and nutrition are crucial for assessing progress and identifying areas in need of intervention. Additionally, the impacts of climate change, conflicts, and economic instability further complicate the monitoring of this SDG, as they can rapidly alter food security conditions and agricultural productivity. Addressing these challenges requires investments in data infrastructure, the adoption of innovative data collection methods, and strengthened cooperation between governments, international organizations, and local communities. Approximately 20% of the population in Africa is undernourished, with significant variations across regions, including North Africa where the rate is lower compared to sub-Saharan Africa. Also, 55% of the population in Africa experiences moderate to severe food insecurity, with challenges in both rural and urban areas in ensuring access to sufficient and nutritious food.

SDG 4: Quality Education

Despite some progress, Africa still faces major challenges in providing inclusive, quality education to all children. While school enrolment has improved considerably, about 288 million school-age children remain out of school, particularly in conflict-affected regions. The report highlights the need for increased funding to strengthen education infrastructure, especially at the preprimary and primary levels. Overall, Africa has made slow advances in ensuring access to quality education for every child, and greater financial commitment is required to bridge enrolment gaps, improve facilities, support educators, and leverage technology—areas essential for meeting education goals on the continent. In Africa, over 98 million children of primary and lower secondary school age are out of school, representing one of the highest out-of-school rates globally. Also, the adult literacy rate in sub-Saharan Africa remains low, with only about 65% of adults aged 15 and above being able to read and write, significantly below the global average of 86%.

SDG 5: Gender Equality

The report reveals Africa's slow advancement toward gender inclusivity and calls for stronger enforcement of laws protecting women and girls from discrimination, domestic violence, child

marriage, and genital mutilation. For example, though women make up a major part of Africa's workforce, only 29.8% of managerial roles were held by women in 2022, excluding North Africa—a small increase from 29.3% in 2015. Overall, progress on women's rights and gender equality across Africa has been modest. The report advocates for tighter implementation of legal frameworks as critical to safeguard women and girls from various abuses. It also points to the need for greater female representation in leadership roles across sectors, as women remain underrepresented despite their significant contributions to local economies. Africa has one of the highest rates of child marriage globally, with over 30% of girls in sub-Saharan Africa married before the age of 18, significantly affecting their health, education, and opportunities for economic empowerment.

SDG 9: Industry, Innovation, and Infrastructure

Monitoring progress toward SDG 9 presents its own set of challenges, particularly in terms of data availability and comprehensive measurement progress. Reliable data on industrial development, technological innovation, and infrastructure quality and accessibility are essential for evaluating advancements and identifying areas for improvement. The importance of SDG 9 in Africa cannot be overstated, as it is closely linked to economic growth, job creation, and sustainable development. A well-developed industrial sector, coupled with technological innovation and robust infrastructure, can drive economic diversification, enhance productivity, and improve access to markets and services. Africa's progress in developing resilient infrastructure has been slow, with only 34% of the population having access to electricity in sub-Saharan Africa, compared to a global average of 87%. Investment in research and development (R&D) is limited, with most African countries spending less than 1% of their GDP on R&D, hindering the advancement of innovation and technological capabilities.

SDG 13: Climate Action

Monitoring progress toward SDG 13 is challenging due to several factors, particularly related to data availability and the complex nature of climate change impacts. Accurate and timely data on greenhouse gas emissions, climate-related hazards, and adaptation and mitigation efforts are crucial for assessing progress and informing policy decisions. The importance of SDG 13 in Africa is significant, as the continent is particularly vulnerable to the impacts of climate change, including extreme weather events, rising temperatures, and changing precipitation patterns. These impacts threaten food security, water availability, public health, and overall development progress. Addressing the challenges in monitoring SDG 13 requires strengthening meteorological and environmental monitoring networks, enhancing data collection and analysis capabilities, and fostering collaboration among governments, international organizations, research institutions, and local communities. Africa is one of the continent's most vulnerable to climate change, with an estimated 600 million people projected to be exposed to increased water stress by 2025 due to climate-related events. Also, the economic cost of climate change in Africa is projected to be between 2% and 4% of GDP by 2040, severely impacting development and poverty reduction efforts.

SDG 14: Life Below Water

Pollution from human activities persists as a major threat to marine ecosystems in Africa. The report underscores the need to strengthen governance capacities to better enforce laws and regulations around the sustainable use of ocean resources. Marine life is an essential source of livelihood for many African nations, particularly small island developing states that depend

heavily on the oceans. Unless pollutants both organic and chemical are curtailed through rigorous protections and sustainable practices, the health of intricate underwater systems and communities across the continent remains endangered. Bolstering institutional abilities to uphold critical environmental rules and policies can help safeguard Africa's vulnerable marine environments. Over 50% of coral reefs in the Western Indian Ocean, which borders the eastern coast of Africa, are at risk of collapse due to overfishing, pollution, and climate change-included coral bleaching. Also, African coastal cities generate approximately 17 million tons of waste annually, with a significant portion ending up in the oceans, leading to severe marine pollution and threatening marine biodiversity and livelihoods dependent on marine resources.

SDG 15: Life On Land

The report reveals extensive and ongoing loss of forest cover, biodiversity, and land degradation across Africa due to deforestation for agriculture and grazing as well as climate change impacts. An estimated 46% of Africa's land and 65% of its population are affected by degradation, costing $ 9.3 billion annually. To scale up sustainable management of forests, biodiversity, and lands for a green, resilient recovery, the report emphasizes the critical need for more public–private partnerships to mobilize and direct funding efforts. With high rates of degradation linked to farming, grazing, and climate change continuously impacting vital ecosystems and communities, building collaborative financing models is key to reversing these unsustainable practices and environmental declines. Africa is home to some of the world's most endangered species, with over 20% of its mammal species classified as threatened with extinction due to habitat loss, poaching, and illegal wildlife trade.

SDG 17: Partnerships for the Goals

According to the report, Africa has seen slow, uneven progress in mobilizing domestic resources and attracting foreign direct investments compared to other world regions. Managing debt burdens remains a persistent struggle for African governments, as debt servicing eats into already limited capital. In 2020 alone, Africa incurred U.S. $ 89 billion in losses from illicit financial flows. Overall, the continent continues to lag on benchmarks of revenue generation and foreign investment inflows while debt obligations and illicit flows siphon away critical capital. These financing gaps and setbacks hamper development efforts and must be addressed through fiscal reforms, anti-corruption measures, and policies to curb the external drainage of resources. Tackling these systemic economic challenges is key for Africa to boost sustainable self-financing abilities. Despite the target of 0.7% of gross national income (GNI) set for developed countries, official development assistance (ODS) to Africa remains below this target, with numerous countries receiving less than 0.3% of their GNI in aid, hindering efforts to build partnerships for sustainable development.

Projects in Africa

Geospatial techniques generate location-specific, integrated, and real-time monitoring insights for data-driven and participatory SDG planning, implementation, and tracking. Interactive maps, dashboards, and visualizations engage diverse stakeholders in SDG monitoring transparently. Despite challenges around data, capacity, and coordination in Africa, numerous projects and initiatives are already in place to use geospatial data in monitoring SDGs in various African countries.

The first use case is the Data for African Development project that was launched in 2017 by the Center for International Earth Science Information Network (CIESIN) at Columbia University. It aims to harness data innovation, ML, and technology to help African governments better track progress on the SDGs. The project focuses on two initial pilot countries, Ghana and Senegal, with plans to expand to other African nations over time. It combines satellite data, ML algorithms, and cloud computing to generate real-time insights on SDG indicators at national and subnational levels. The project represents an innovative collaborative model for how data science and artificial intelligence (AI) can support evidence-based policymaking in Africa amid data constraints. However, it faces sustainability challenges along with the need to strengthen institutional coordination, retain trained staff, and improve access to quality foundational data sets over time.

The second use case is the African Regional Data Cube project that was initiated in 2019 through collaboration between the Committee on Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO). It aims to establish an operational Regional Data Cube platform that provides analysis-ready satellite data at scale across the African continent. The data cube integrates satellite imagery from sources like Landsat and Sentinel to enable time-series analysis. It builds on the existing Data Cube technology and Open Data Cube initiative, offering a geospatial database and analytics framework. This project supports several SDG indicators related to poverty, food security, sustainable resource management, and more by providing open access to analysis-ready geospatial data. This helps overcome the lack of high-quality foundational data for monitoring and planning. Pilot countries include Sierra Leone, Ghana, Kenya, and Tanzania, with plans to expand coverage across Africa over time. However, it faces challenges around institutional coordination, sustainability, capacity building, infrastructure, and data policies. Overall, the Regional Data Cube aims to transform the availability of geospatial data to boost SDG monitoring capabilities in Africa.

Geospatial Analysis

Geospatial Analysis plays a pivotal role in supporting the measurement of SDGs in Africa. By leveraging spatial data and advanced analytical techniques, geospatial analysis enables the accurate mapping and monitoring of various indicators related to the SDGs. For instance, it can be used to assess land-use changes, agricultural productivity, and urbanization patterns, which are crucial for goals related to zero hunger, sustainable cities, and climate action. Furthermore, geospatial analysis facilitates the identification of vulnerable regions and populations, enabling targeted interventions and resource allocation. In the context of Africa, where data availability and quality often pose challenges, geospatial analysis offers a powerful tool to overcome these limitations and provide insights that are essential for informed decision-making and progress tracking toward the SDGs.

Sentiment Analysis

Sentiment Analysis is a trending technique to get insights from any written text and is used to classify text into various categories, for example, having positive, negative, or neutral sentiments. Sentiment Analysis techniques are being increasingly applied in Africa to monitor public attitudes and discourse related to key SDGs to focus on areas such as health, education, gender equality, and clean water sanitation. This involves using NLP and ML to classify social media data like posts or text as expressing positive, negative, or neutral sentiments toward SDG-related topics. Geo-tagging of social media posts further allows sentiment insights to be mapped to reveal spatial patterns and hotspots at subnational levels. Although limited social

media penetration and nonrepresentative samples pose challenges, real-time sentiment tracking provides more granular, subjective perspectives to complement traditional objective development statistics for SDG monitoring. While still an emerging application in the African context, targeted sentiment analysis experiments have focused on gauging public perceptions on issues like vaccination drives in Nigeria or education quality across districts in Ghana. However, caution is required in interpreting results due to linguistic complexities and data biases. Validation through ground-truthing and combining social media sentiment signals with other data sources can lead to balanced perspectives on SDG progress.

Geospatial Sentiment Data Analysis

In this study, an innovative approach known as GSDA is introduced and implemented. While GSDA itself is not a novel concept, its application in the context of analyzing progress toward the SDGs is a new development. GSDA combines NLP and SA to track and assess progress toward several key SDGs. This approach focuses on analyzing the posts geospatially and then performing GSDA based on the location of the events versus the geospatial postdistribution for that particular event. This approach is an emerging technique with meaningful potential to complement traditional indicator metrics for SDG monitoring in Africa. By extracting subjective insights from geotagged social media content, public attitudes, and grassroots opinions on development issues can be mapped and tracked in near real-time. With thoughtful implementation, GSDA can become a useful addition to the SDG measurement toolkit—providing granular, people-centric insights on progress at national and local levels across Africa. The study method includes an interdisciplinary approach in data science, regression analysis, geospatial statistics, and ML for content classification. GSDA combined two advanced fields of study: geospatial analysis and sentiment analysis, both of which have gained significant traction in recent years due to advancements in technology and data availability.

Also, this approach is advantageous in resource-limited settings as follows.

1. Cost-effectiveness: Open data is usually free and this reduces the cost barriers associated with data collection, allowing for the implementation of advanced data analysis techniques without the need for expensive proprietary data sets.

2. Community engagement and transparency: Using open data extracted from social media can foster greater community engagement and transparency. Since the data is publicly available, it allows for more stakeholders (including the general public) to engage with and understand the issues being addressed. This can be particularly important for initiatives related to SDGs, where community involvement is key.

3. Informed decision-making: GSDA can provide insights into public opinion and attitudes across different regions, which is valuable for policy-making and prioritizing resources. In resource-limited settings, it is crucial to allocate resources efficiently, and data-driven insights can guide where and how to invest efforts most effectively.

4. Overcoming data scarcity: In many resource-limited environments, reliable and comprehensive data are scarce. Open data sources can partly mitigate this challenge, providing a basis for analysis and planning in the absence of extensive local data collection resources.

5. Capacity building: Engaging with open data can help build local capacity in data analysis and interpretation. It provides an opportunity for local analysts, policymakers, and academics to work with real-world data, developing skills that are crucial in the modern data-driven world.

Methodology

To obtain publicly available X data, the public application programming interface (API) stream provided by X was accessed and leveraged for downloading public posts located in Africa in 2022. To retrieve highly relevant posts from the public API, keywords are strategically chosen to be broad and inclusive. Overall, GSDA of posts to monitor SDGs in Africa is a complex process that involves several steps, from data collection and preprocessing to sentiment analysis and statistical validation. Data collection and analysis were conducted in Python, ArcGIS, and R. A detailed explanation of the process is outlined as follows:

- *Data collection:*
    - *Keyword selection:* For each of the identified SDGs, a set of relevant keywords and phrases is selected to filter posts related to that specific SDG. For example, for SDG 1, keywords might include "poverty," "income inequality," and "economic growth." In implementing this technique in the linguistically diverse continent of Africa, the key languages used on X in the target countries are identified. The selected keywords and phrases related to each SDG are translated into languages to capture relevant posts across different linguistic groups. Language detection packages in Python such as lingua-py and langid-py are used to filter and organize posts by language, allowing for targeted sentiment analysis. The implemented process is dynamic, with continuous monitoring and adaptation of the keyword list to reflect changes in language usage and emerging trends on the X platform.
    - *Geospatial filtering:* Posts are filtered based on their geolocation data to focus on those originating from Africa. As part of this process, cities with higher internet penetration and larger population sizes are prioritized, as these areas are likely to generate a higher volume of posts and are often more representative of public sentiment. Furthermore, cities where SDGs are of particular concern, such as those facing significant challenges related to poverty, health, education, or environmental sustainability, are selected to ensure that the analysis focuses on regions where interventions are most needed. By targeting these cities, one can gather more relevant and impactful data, which can provide valuable insights into the progress and challenges related to SDGs in urban areas with significant online engagement and where the goals are most pressing.
- *Preprocessing:* Posts are cleaned by removing URLs, hashtags, mentions, and nonalphabetic characters. Posts are also converted to lowercase for consistency. Stop words are removed, and posts are tokenized into individual words.
- *Sentiment analysis:* Each tweet is analyzed for sentiment using NLP techniques. Sentiments are labeled as positive, negative, or neutral depending on what sentiment they possess. This task is completed by training a custom model on a labeled data set. For example: tweet 1: "New job training center opens to fight poverty in our community!" This tweet is labeled as positive. Tweet 2: "10% of the world lives on less than U.S. $ 1.90 a day. Time for change." This tweet is labeled as neutral. Tweet 3: "Natural disaster worsens poverty crisis. Urgent aid needed." This tweet is labeled as negative. Tweet 1 is labeled as positive because the tweet highlights a proactive step

(opening of a job training center) aimed at combating poverty, which is a positive development for the community. Tweet 2 is labeled as neutral because the tweet simply presents a fact about the state of poverty without expressing a clear positive or negative emotion. The call for change is a general statement that does not convey a specific emotional tone. Tweet 3 is negative because the tweet communicates a worsening situation (natural disaster exacerbating poverty) and conveys a sense of urgency and need for assistance, highlighting a negative development in the fight against poverty. Sentiments are aggregated at the country level by averaging the sentiment scores of all posts from a particular country related to a specific SDG.

- *Optimal number of posts:* To ensure statistical significance, a sample size calculation is performed to determine the optimal number of posts needed for each country and SDG. This can be based on the desired confidence level and margin of error. The calculation considers the variability in sentiment scores and the total number of posts available for each SDG in each country. In some regions, X users may not accurately reflect the demographics of the most affected populations, leading to potential biases in the analysis. This disparity in representation is a crucial factor to consider, as it may result in an incomplete or skewed understanding of public sentiment and priorities regarding the SDGs. Efforts to address this challenge might include incorporating additional data sources or applying weighting methods to account for demographic differences in social media usage.
- *Data validation:* The semi-supervised sequence learning model (SSLM) based on recurrent neural networks is used for data validation. This model is trained on a small set of labeled posts for sentiment classification and then fine-tuned using a larger set of unlabeled posts to improve its generalization ability. This model is useful for data validation and improving accuracy in sentiment analysis in several ways. First, it leverages abundant unlabeled data to enhance language understanding and context, leading to better performance. Second, techniques like pseudo-labeling refine the model's decision boundaries, improving sentiment classification accuracy. Lastly, this model helps validate the quality of labeled data sets by comparing model predictions on unlabeled data with a small set of manually labeled validation data.
- *Missing data:* In cases where posts for a specific country or SDG are insufficient, imputation techniques are used to estimate missing values based on available data from similar countries or SDGs. Alternatively, countries or SDGs with insufficient data can be excluded from the analysis to maintain the integrity of the results.
- *Geospatial visualization:* The series of maps (Figure 2) presented shows the geographic distribution of posts linked to various SDGs in Africa. Each map uses bubble sizes and colors to represent the number of posts, with larger and more intensely colored bubbles indicating a higher number of posts. Presenting the geographic distribution of posts linked to various SDGs in Africa is useful for several reasons. It provides a clear visual representation of online discourse related to each SDG across different regions, helping to identify areas with high levels of engagement or concern. By comparing maps for different SDGs, stakeholders can identify trends and patterns in public interest or awareness, which can inform the prioritization in regions with significant online engagement. Furthermore, monitoring changes in the distribution of posts over time can provide insights into the evolving public engagement with different SDGs, aiding in the assessment of awareness campaigns or policy interventions.

Table 1 Keywords linked to each SDG

Table 1 provides the word clouds to represent the key focus areas for each SDG. These visual representations highlight the most frequent and significant themes associated with each goal,

emphasizing the variety and complexity of challenges within each domain. These world clouds serve as an illustrative summary of the African community's shared ambitions and the diverse strategies required to achieve these goals. These are extracted from the posts on social media and are used for the GSDA methodology targeting Africa. This shows that there is an active and multifaceted discussion around these SDGs. The prevalence of these terms on social media suggests that there is a significant public interest and engagement with sustainability topics. It also reflects the African community's perspective on the urgency of these issues and the collective desire to seek solutions and drive change through dialog, advocacy, and action.

Results

Only 65% of all posts were geotagged which contained the latitude/longitude information. To geocode the posts, the location from the user profile is accessed and converted to their respective coordinates using the Google Places API for the purpose of GSDA. It should be noted that because only 65% of posts containing content relevant to the considered SDGs were linked to keywords, only 19 African countries were identified and incorporated into the final analysis. These countries collectively comprise approximately 70% of Africa's population. These countries are as follows: Algeria, Benin, Cameroon, Cote d'Ivoire, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Mali, Morocco, Nigeria, Senegal, South Africa, Tanzania, Togo, Uganda, Zambia, and Zimbabwe. From the list, eight countries (Nigeria, Ethiopia, Egypt, Tanzania, South Africa, Kenya, Uganda, and Algeria) are among the top 10 most populous countries in Africa. Muhammad et al. [14] introduced a sentiment analysis benchmark and discussed the number of X users in Africa. Estimating the number of X users can be challenging due to varying levels of internet penetration and social media usage. From the aforementioned article and other resources available, here are some rough estimates: 1) Algeria (2 million); 2) Benin (700,000); 3) Cameroon (1 million); 4) Cote d'Ivoire (800,000); 5) Egypt (7 million); 6) Ethiopia (3 million); 7) Ghana (2.5 million); 8) Kenya (6 million); 9) Madagascar (500,000); 10) Mali (550,000); 11) Morocco (3.5 million); 12) Nigeria (12.5 million); 13) Senegal (800,000); 14) South Africa (13.5 million); 15) Tanzania (700,000); 16) Togo (500,000); 17) Uganda (850,000); 18) Zambia (700,000); and 19) Zimbabwe (650,000). Therefore, by adding up these numbers, the total number of X users in these 19 countries is approximately 57.8 million. This number represents a portion of the population with internet access in these countries. The combined internet penetration rate of these countries is approximately 35%. In this context, the 57.8 million X users represent about 16% of the internet user population in these countries. This suggests that under this scenario, a larger proportion of the internet-using population in these countries is active on X, although the majority still does not use the platform. It also emphasizes the varying levels of digital access and social media engagement across the African continent. The 16% of the internet-using population in these African countries that uses X can provide valuable insights for identifying and supporting the monitoring of SDGs through sentiment and geospatial analysis. Geotagged posts can help identify where conversations about specific SDGs are happening, allowing for a spatial understanding of engagement and concerns. Insights derived from X analysis can complement traditional data sources, providing a more nuanced and real-time understanding of the challenges and opportunities related to SDGs, thereby informing policy and decision-making. It is important to note that there might be a demographic skew in terms of the socioeconomic status of X users in these countries. This status can influence their perspectives, experiences, and engagement with various issues addressed by the SDGs. Hence, it is important to complement X data with other data sources, including surveys, interviews, and official statistics, to ensure a more comprehensive and inclusive understanding of the progress and challenges related to SDGs. Also, this article could assist in targeting outreach and engagement

efforts to encourage more diverse groups to participate in conversations about SDGs on social media platforms.

Figure 1 presents the number of posts per country related to various SDGs. It reveals that discussions on SDGs vary significantly by country and by the specific goal in question. For instance, Egypt, Nigeria, and South Africa are prominent for posts concerning SDGs 1 and 4, suggesting a high level of public engagement with these issues in these nations. On the other hand, there is a noticeable concentration of posts related to SDG 5 in Kenya, illustrating a strong societal focus on gender issues. The visual data for SDGs 14 and 15 indicates that these environmental concerns have comparatively less discussion across the board, with a few exceptions like Nigeria and South Africa showing higher tweet volumes. Posts concerning SDG 9 and SDG 13 are relatively sparse in countries like Algeria and Tunisia, possibly reflecting a lower public discourse on these topics. Conversely, there is a substantial amount of tweeting about SDG 17 in Nigeria, pointing to strong advocacy for collaborative efforts in achieving the SDGs. Overall, this visual suggests that while there is engagement with SDG-related issues on X across these African countries, the focus of the conversations can vary greatly, likely reflecting the diverse priorities and challenges faced by each country.

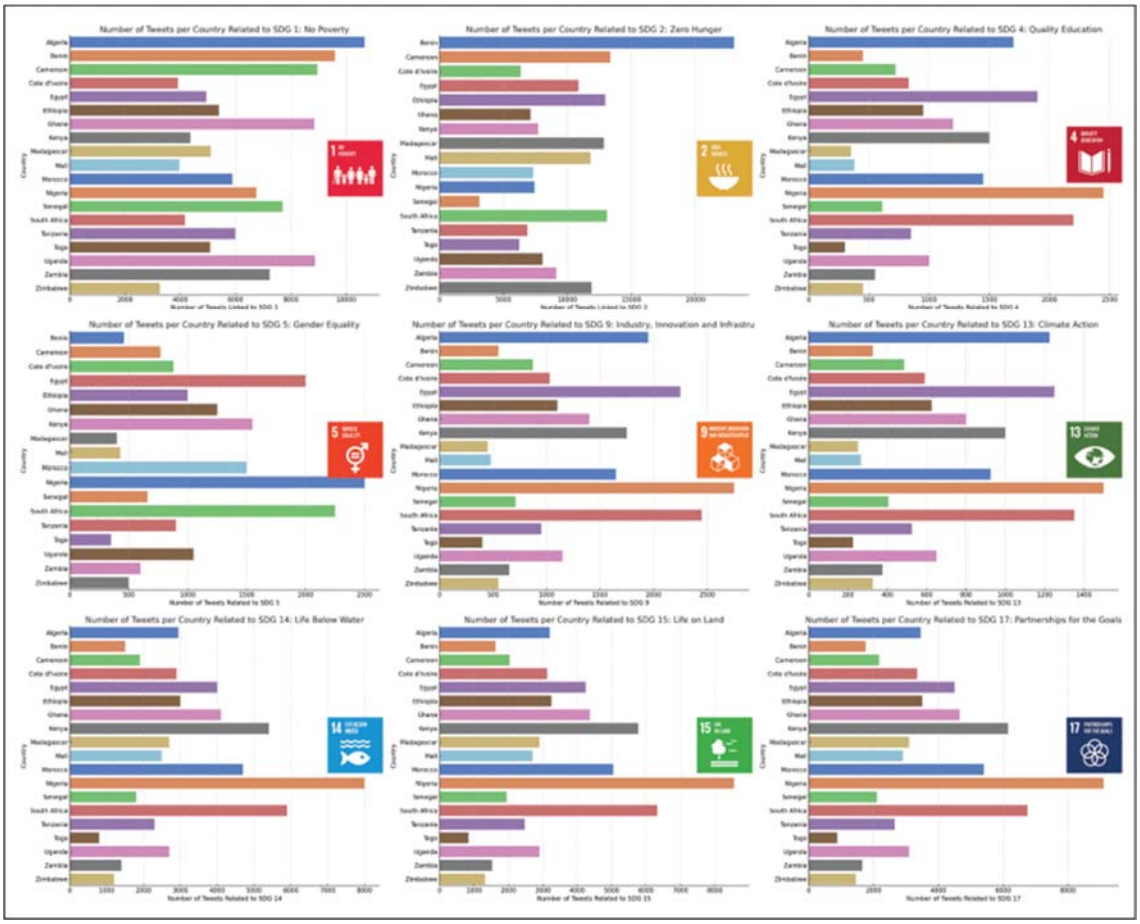

Figure 1. Number of posts per country and per SDG.

Figure 2 reveals specific regions in Africa where discussions related to each SDG are more prevalent. Areas with larger and darker markers indicate higher volumes of posts, suggesting a higher level of public engagement or concern about poverty issues in these locations. The

variance in tweet volumes across different countries and regions can indicate the varying levels of SDG awareness, affected populations, or active advocacy and campaigns. This visual provides a multifaceted view of public engagement. A comparative analysis might reveal disparities in the volume of conversation about different SDGs, suggesting regions where hunger is more of a focal point than poverty, or vice versa. This can inform policy and aid focus, as NGOs and governments can use these insights to direct awareness campaigns and resources to areas where public discourse is most active. When examining the correlation between graphs, areas with high engagement across multiple SDGs may signal interconnected challenges, emphasizing the need for comprehensive strategies. This data is actionable, offering stakeholders empirical foundations for targeted interventions and resource allocation. Lastly, the varying levels of activity could indicate the effectiveness of awareness and advocacy efforts, whereas lower activity regions might benefit from increased campaigns to boost SDG engagement.

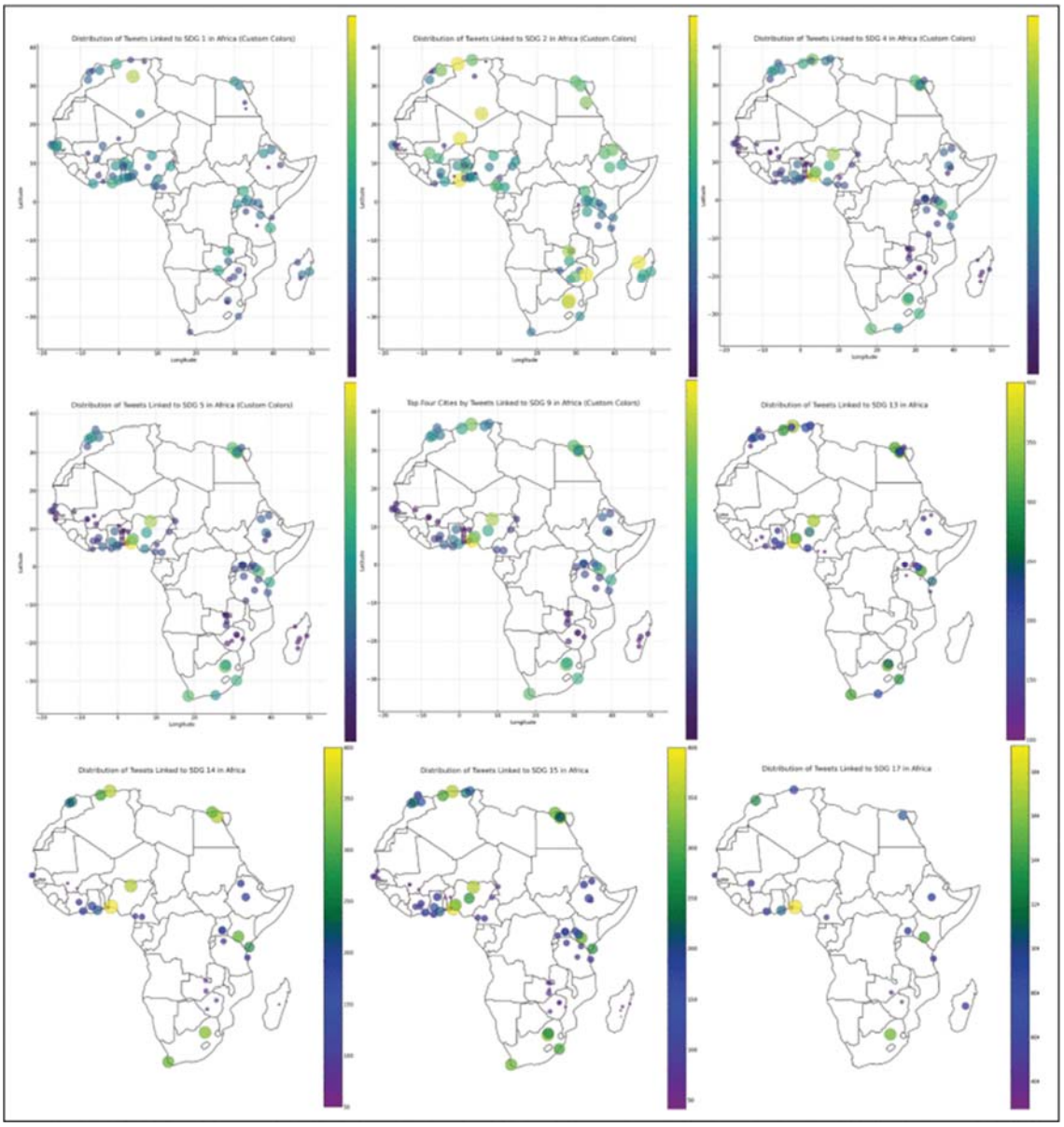

Figure 2. Geospatial distribution of posts linked to various SDGs.

In summary, while the maps provide a visual representation of X's engagement with SDGs in Africa, they should not be taken as definitive indicators of the actual conditions on the ground or the importance of each SDG in different regions. The data is influenced by the nature of X usage and may require further triangulation with other sources to draw more accurate conclusions.

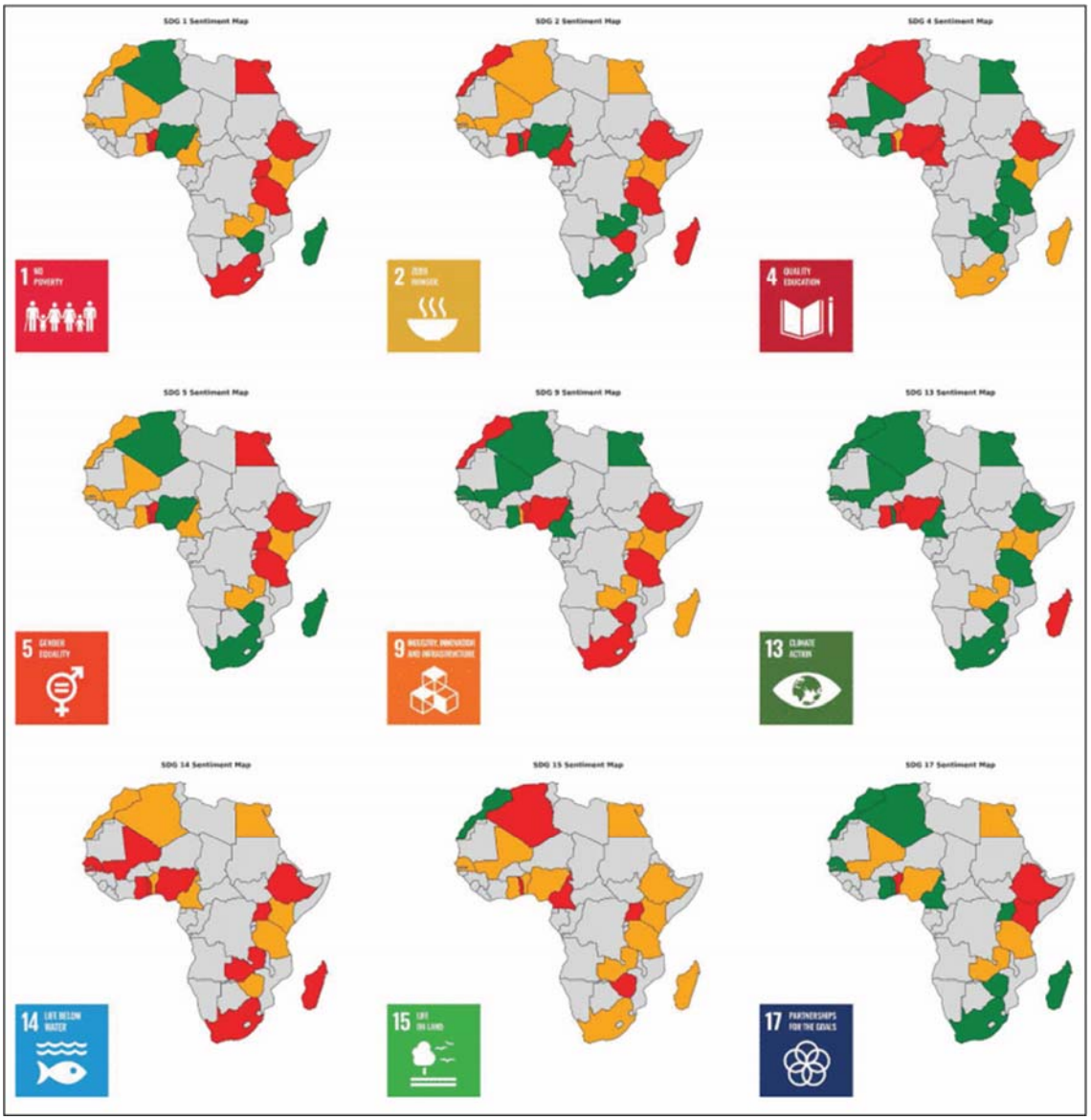

Figure 3. Sentiment distribution of posts linked to various SDGs.

Figure 3 presents the sentiment maps for various SDGs across Africa and illustrates the diverse public sentiment toward these goals in different countries. Countries colored green show positive sentiment, suggesting a favorable or hopeful view of progress toward the associated SDG, while those in red indicate negative sentiment, potentially reflecting dissatisfaction or concern regarding the challenges in achieving the goals. Notably, SDG 2 and SDG 13 demonstrate a mix of sentiments, signifying varied perceptions of these issues across the continent. Some countries show consistently positive sentiment across multiple SDGs, possibly indicating overall optimism about sustainable development. Conversely, negative sentiments

across several SDGs in other countries could highlight areas where intensified efforts and new strategies are needed to address underlying issues and improve public perception and reality of these critical goals. The negative perception could be due to a variety of factors such as: 1) lack of awareness or understanding; 2) perceived irrelevance; 3) dissatisfaction with efforts or outcomes; 4) cultural or contextual factors; 5) economic or political constraints; and 6) prioritization of other issues. The orange color on the sentiment maps indicates a neutral or mixed public sentiment toward the respective SDGs in the depicted African countries. This suggests that the population may have a balanced view of progress or may hold both positive and negative perceptions simultaneously. The presence of neutral sentiment can also signal a need for increased awareness and more information to shape a more distinctly positive or negative public opinion on the SDGs. Also, the orange color signals to policymakers and organizations that these are areas potentially open to influence or change, with no strong existing biases, making them prime targets for educational campaigns and policy initiatives.

This visualization, as part of open and publicly available data on social media, serves as a critical tool for the evaluation and implementation of SDGs, particularly in resource-limited settings like Africa. First, it helps to identify which SDGs are already resonating with the public and which are not, allowing for a targeted approach to resource allocation. By understanding public perception across different countries, policymakers and organizations can focus on advocating for and implementing the SDGs that require more attention and support. This strategic approach ensures that the limited resources are not spread too thinly across all goals but are directed toward those with either poor perception, indicating a need for increased awareness and action, or toward goals with positive perception to maintain and build momentum. Second, the fact that this data is open and accessible on social media means it can be used to foster greater public engagement and accountability. By involving the public in the conversation about SDGs and their progress, there is an opportunity to increase awareness and educate people on the importance of these goals, potentially shifting neutral or negative perceptions to positive ones. Moreover, public data allows for crowd-sourced solutions and ideas, which can be particularly valuable when dealing with limited resources. Citizens and local organizations can contribute to SDG efforts in their communities, leveraging local knowledge and innovative approaches that may not be apparent to external observers. This collaborative approach not only optimizes the use of available resources, but also ensures that the initiatives are tailored to the specific needs and contexts of the communities they are intended to serve.

Recommendations

Implementing the Novel Approach (Gsda) To Measure Sdgs In Africa Is Innovative and Impactful. Here Are Use Cases For Sdgs 1, 2, 4, 5, 9, 13, 14, 15, and 17.

1. *SDG 1:* To Leverage Gsda For Sdg 1, Collect and Map Geotagged Social Media Sentiment On Poverty and Integrate It with Socioeconomic Data For Comprehensive Insights. Establishing A Real-Time Monitoring Tool For Dynamic Response and Public Platforms For Engagement and Crowd-Sourced Feedback Is Essential. Engaging with Local Communities For Contextual Understanding and Community-Driven Solutions Also Plays A Role. Furthermore, Another Way Is By Fostering Collaboration with Tech Firms and Academics To Refine Analysis and Develop Predictive Models, While Enhancing Local Data Literacy For Effective Use of Sentiment Data In Combating Poverty.

2. *SDG 2:* For Sdg 2, Gsda Could Involve Collecting Social Media Data To Map Public Sentiment On Food Security. This Data Should Be Combined with Agricultural Productivity Metrics and Food Distribution Logistics. Real-Time Sentiment Tracking Can Highlight Areas of Immediate Concern, Guiding Targeted Interventions. Engaging Communities Via Digital Platforms Can Harness Local Insights and Foster Participatory Approaches To Food Security. Collaborative Efforts with Agricultural Technology Companies Can Innovate Data-Driven Farming Solutions.

3. *SDG 4:* Gsda Can Be Used To Identify Areas Where Negative Sentiments About Education Quality and Access Are Most Prevalent. This Can Involve Analyzing Social Media Posts, Surveys, and Forums In Different Regions To Assess Public Opinion On Educational Matters. Mapping these Sentiments Geographically Can Help Pinpoint Regions That Require Urgent Educational Reforms Or Resources. Platforms For Community Engagement Would Allow For Direct Feedback From Students and Educators, Ensuring That Interventions Are Relevant and Effective. Collaborations with Educational Technology Innovators Can Foster New Learning Solutions, While Training For Educators and Policymakers In Data Utilization Can Promote Informed Strategies To Achieve Inclusive Education.

4. *SDG 5:* Gsda Can Be Used To Analyze Changes In Public Sentiment Before and After the Implementation of Gender-Focused Initiatives To Measure their Impact and Effectiveness Across Different Regions. Real-Time Sentiment Tracking Would Help Identify Regions Requiring Urgent Attention To Gender Issues, While Interactive Platforms Could Engage Communities, Especially Women, In Dialog and Action. Collaborations with Gender-Focused Ngos Can Develop Tailored Solutions, and Capacity-Building Initiatives Can Empower Local Stakeholders To Use Data Effectively In Promoting Gender Equality.

5. *SDG 9*: For Sdg 9, Gsda Could Involve Mapping Social Media Data Related To Infrastructure Development, Industrial Growth, and Technological Advancements. By Correlating This Sentiment with Data On Infrastructure Quality, Industrial Output, and Innovation Indicators, Regions In Need of Development Or Areas Ripe For Innovation Can Be Identified. Real-Time Monitoring of Sentiment Could Help Track Public Perception of Infrastructure Projects and Industrial Policies, Guiding Improvements and Investments. Digital Platforms Could Engage Communities and Businesses In Discussions About Infrastructure Needs and Innovative Solutions.

6. *SDG 13*: For Sdg 13, Gsda Could Involve Mapping Social Media Data Related To Climate Change Awareness, Adaptation Measures, and Renewable Energy Initiatives. By Correlating This Sentiment with Data On Climate Vulnerability, Carbon Emissions, and Renewable Energy Adoption, Regions Requiring Urgent Climate Action Or Areas Leading In Sustainability Efforts Can Be Identified. Collaborations with Environmental Organizations and the Renewable Energy Sector Could Foster Innovative Solutions To Climate Challenges, While Capacity-Building Initiatives Could Empower Local Stakeholders To Use Data For Climate Advocacy and Informed Decision-Making In Support of Sdg 13.

7. *SDG 14:* Gsda Can Be Used To Track Sentiments In Coastal Communities Regarding Marine Conservation Efforts, Pollution, and Sustainable Fishing Practices. This Can Inform Policymakers and Conservationists About Areas of Resistance Or Support,

Helping them Tailor their Approaches. Mapping Sentiments Against Coastal Development Data and Marine Biodiversity Records Could Pinpoint Critical Areas For Conservation Efforts. Real-Time Sentiment Tracking Could Signal Emerging Marine Issues Or Shifts In Public Awareness, Guiding Responsive Marine Policy and Education Campaigns. Digital Engagement Platforms Could Foster Community Reporting On Marine Pollution Or Illegal Activities, Enhancing Stewardship.

8. *SDG 15*: Gsda Can Be Used To Evaluate How Public Sentiment Toward Wildlife Conservation and Antipoaching Measures Changes Over Time, Particularly In and Around Protected Areas. This Can Be Crucial For Adjusting Strategies and Community Engagement Efforts. By Correlating This Sentiment with Data On Land-Use Changes, Wildlife Populations, and Deforestation Rates, Hotspots For Targeted Conservation Action Can Be Identified. Real-Time Monitoring of Sentiment Could Help Track the Effectiveness of Policies and Public Awareness Campaigns. Community Engagement Platforms Could Empower Local Voices and Gather Indigenous Knowledge For Ecosystem Management.

9. *SDG 17*: For Sdg 17, Which Aims To Strengthen the Means of Implementation and Revitalize the Global Partnership For Sustainable Development, Gsda In Africa Could Focus On Mapping Social Media Data Related To International Cooperation, Funding For Development Projects, and Technology Transfer. By Integrating This Data with Information On Development Aid Distribution, Trade Agreements, and Technology Access, Areas Lacking Sufficient Support Or Collaboration Can Be Identified. Real-Time Sentiment Tracking Could Provide Insights Into the Effectiveness of Partnerships and Highlight Areas For Improvement. Digital Platforms Could Facilitate Cross-Sectoral and Cross-Border Dialogs, Fostering Stronger Partnerships. Collaborations with International Organizations, Private Sector Entities, and Academic Institutions Could Enhance Resource Mobilization and Knowledge Sharing.

In All these Use Cases, It Is Important To Ensure That the Data Used For Sentiment Analysis Is Representative, Ethically Sourced, and Respects Privacy. Also, Considering Cultural Nuances and Language Diversity In Sentiment Analysis Is Crucial For the Accurate Interpretation of Results. This Can Be Useful For Policymakers and International Organizations As It Highlights Where To Concentrate Efforts To Improve Understanding and Support For the Sdgs. In Many of these Regions, X Users Tend To Be Younger and often Come From Families with Higher Incomes. As A Result, they May Not Necessarily Represent the Populations Most Affected By the Issues Related To the Sdgs. This Discrepancy Can Lead To A Misalignment Between the Sentiments Expressed On Social Media and the Actual Priorities and Needs of the Broader Population. therefore, It Is Essential To Approach Data Interpretation with Caution and To Complement Social Media Analysis with Other Sources of Information To Ensure That Policy Recommendations Are Inclusive and Effectively Address the Needs of All Segments of Society.

It Is Important To Note That In Regions Where X Users May Not Accurately Reflect the Demographics of the Most Affected Populations, Leading To Potential Biases In the Analysis. This Disparity In Representation Is A Crucial Factor To Consider, As It May Result In An Incomplete Or Skewed Understanding of Public Sentiment and Priorities Regarding the Sdgs. Efforts To Address This Challenge Might Include Incorporating Additional Data Sources Or Applying Weighting Methods To Account For Demographic Differences In Social Media Usage.

It Is Crucial To Emphasize the Importance of Considering Biases In Data Interpretation and Policy Recommendations When Using Social Media Data To Monitor Sdgs. the Potential Disparities In Representation, Particularly In Developing Countries, Can Lead To An Incomplete Understanding of Public Sentiment and Priorities. Policymakers and Researchers Must Acknowledge these Limitations and Take them Into Account When Interpreting the Data and Formulating Policy Recommendations. Addressing these Biases Is Essential To Ensure That the Insights Derived From Social Media Analytics Are Accurate and Representative of the Broader Population, Leading To More Informed and Effective Policy Decisions. Also, the Following Factors Need To Be Taken Into Consideration While Implementing Gsda: 1) the Volume of Posts Might Not Necessarily Equate To the Severity of the Issue But Rather the Level of Discussion Or Awareness On Social Media; 2) Socioeconomic Factors, Such As Internet Access, Literacy Rates, and the Popularity of X In Each Region, Would Significantly Impact the Implementation of Gsda; and 3) Posts In Different Languages May Not Have Been Equally Captured If the Data Collection Was Biased Toward Certain Languages.

In Conclusion, This Case Study Demonstrates the Potential For Gsda To Strengthen Monitoring of Sdgs Achievements In Africa. By Harnessing Data Science and Ml To Extract Insights From Satellite Imagery, Social Chatter, and Other Geospatial Sources, Sentiment Analysis Can Fill Critical Gaps Left By official Statistics. It Provides A More Real-Time, Localized Perspective On Where Further Progress Is Required Across Different Sdgs. However, the Realization of This Potential Will Require Investing In Data Science Capacity On the Continent and Addressing Ethical Challenges Around Data Representativeness and Transparency. If these Issues Are Navigated Carefully and Inclusively, Gsda Can Become A Powerful Tool For Guiding Data-Driven Development Policy and Driving Progress On the Sdgs In Africa. Also, This Approach Is Advantageous In Resource-Limited Settings.

- Cost-Effectiveness: Open Data Is Usually Free and This Reduces the Cost Barriers Associated with Data Collection, Allowing For the Implementation of Advanced Data Analysis Techniques without the Need For Expensive Proprietary Data Sets.
- Community Engagement and Transparency: Using Open Data Extracted From Social Media Can Foster Greater Community Engagement and Transparency. Since the Data Is Publicly Available, It Allows For More Stakeholders (Including the General Public) To Engage with and Understand the Issues Being Addressed. This Can Be Particularly Important For Initiatives Related To Sdgs, Where Community Involvement Is Key.
- Informed Decision-Making: Gsda Can Provide Insights Into Public Opinion and Attitudes Across Different Regions, Which Is Valuable For Policy-Making and Prioritizing Resources. In Resource-Limited Settings, It Is Crucial To Allocate Resources Efficiently, and Data-Driven Insights Can Guide Where and How To Invest Efforts Most Effectively.
- Overcoming Data Scarcity: In Many Resource-Limited Environments, Reliable and Comprehensive Data Are Scarce. Open Data Sources Can Partly Mitigate This Challenge, Providing A Basis For Analysis and Planning In the Absence of Extensive Local Data Collection Resources.
- Capacity Building: Engaging with Open Data Can Help Build Local Capacity In Data Analysis and Interpretation. It Provides An Opportunity For Local Analysts, Policymakers, and Academics To Work with Real-World Data, Developing Skills That Are Crucial In the Modern Data-Driven World.

It Is Important To Note That Access To X Is Biased Through Socio-Economic Factors Like Age, Economic Status, Language, and Sex (Equal Access To the Platform From Diverse Backgrounds).

More Work Is Still Needed To Refine Techniques and Scale Up Responsibly, However, the Possibilities Are Certainly Worth Exploring Further Through Academic–Government Partnerships.

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