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Tweeting climate change: analyzing actor diversity and influence in climate-change discourse post-Paris agreement

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Abstract
The Paris Agreement represents the notable characteristics of global environmental governance, namely multi-actor and multi-level governance. Despite these changes, limited empirical studies have investigated the actors in global environmental governance who participate in political discourse on climate change. To comprehend whether or not the Paris Agreement's actors represent the transformation of global environmental governance, we adopted a big-data approach to analyze Twitter's climate-change discourse. The classification of actors provided an understanding of the diversity of the actors involved in providing public information. We also calculated the closeness centrality and identified the changes in the actors' influence, comparing the changes in the 5 years since the Agreement was adopted. The results showed an increased diversity of actor types. Non-state actors are not homogeneous in their changes, and Intergovernmental Organizations exhibited an increased influence. The findings indicated that the actors participating in the climate-change discourse post-Paris Agreement partially reflect the changes in global environmental governance.

Keywords Actor diversity · Big data · Global environmental governance · Paris agreement · Political discourse · Twitter

1 Introduction

Global environmental governance (GEG) is considered one of the most dynamic areas in global politics due to the vast emergence of its institutions and actors [1]. To provide effective solutions for transboundary environmental problems, GEG requires involvement outside of state-driven actors, such as national governments and international organizations [2]. Therefore, GEG has been evolving into multi-actor, multi-level governance. Multi-actor governance is the understanding that meaningful actors in environmental politics expand into private, non-profit, and civil society [3]. Multi-level governance provides an understanding of how the participation of varied actors works [4]. Thus, GEG is perceived as diverse in its participating actors and governing dynamics.

In this context, the Paris Agreement was adopted in the 21st session of the Conference of the Parties (COP 21). It is a considerable milestone that has overcome the limited success of the Kyoto Protocol. The major game-changer has been stepping away from "Kyoto-style top-down regulation" and adopting a bottom-up approach to managing greenhouse gas emissions [5]. Another important characteristic of the Paris Agreement is its extended scope. The Kyoto Protocol imposed commitments to emission-reduction targets, mainly on Annex 1 countries, whereas the Paris Agreement involves all parties, including both developed and developing countries [5]. Moreover, more than 8,000 non-state observers, such as business and industry, environment, and trade union nongovernmental organizations (NGOs), participated in the summit,

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and companies committed to participating in the reduction process [6–8]. These characteristics have contributed to the Paris Agreement becoming more inclusive of the non-state actors in GEG. As a result, the Paris Agreement reflects GEG's multi-actor and multi-level characteristics.

These changes in GEG and international climate cooperation acknowledge non-state actors as meaningful in GEG. Previous studies have analyzed this transformation from diverse angles, ranging from comparing non-state actors with state-driven actors, identifying their relationships, and determining non-state actors' roles within GEG [9–16]. They have also demonstrated collaboration and contestation between non-state and state-driven actors as well as amongst non-state actors [15, 16]. Moreover, Allan and Hadden [13] analyzed how NGOs' reframing resulted in important outcomes in the global governance of climate change and in the Paris Agreement.

In this context, political discourse by diverse actors is particularly important for the success of the Paris Agreement as it relies on civil society and its understanding of climate change. The Paris Agreement emphasizes public awareness and the importance of providing adequate public information. Its Article 12 articulates the importance of climate-change education, training, public awareness, public participation, and public access to information [17]. Furthermore, the public is an important actor that impacts the Agreement's review system and various actors' compliance [5, 18].

Despite the importance of public awareness, the understanding of who and what influences the public in new media environments such as Twitter is limited [19–21]. Twitter is becoming an increasingly important arena for public discourse on climate change [20, 22]. It is an independent public sphere that provides ultimate access to and distribution of information [23]. Dellmuth and Shyrokykh [22] argued that Twitter discussion could influence climate governance through norm diffusion, opinion leadership, and public opinion formation. Particularly, actors in GEG include various stakeholders, and their motivations and objectives are diverse; thus, the public information provided by diverse actors cannot be homogenous. In this light, identifying the actors and their influence is an important starting point to understand public awareness about climate change and its implications on GEG and the effectiveness of the Paris Agreements. Previous literature has insufficiently analyzed climate-change discourse on Twitter, focusing on particular non-state actors, with only a few studies comparing different actors such as scientists, journalists, politicians, citizens, civil society, and international organizations [20, 24].

This study examines the question of who provides public information about climate change on Twitter and how changes in providers 5 years after the adoption of the Paris Agreement represent the changes in GEG. By analyzing public-information providers and their composition in the representative social networking service (SNS), Twitter (now X), with a big-data approach, this study obtains empirical evidence about whether the information providers are diverse, how actors' influence differs, and whether differences exist within non-state actors. The empirical results provide insight into the Paris Agreement's efforts toward better public awareness and whether this effort aligns with the transformation in GEG.

2 Literature review

GEG is based on acknowledging that traditional hierarchical governing structures and measures of government steering have limitations. As environmental problems are complex, interdependent, negotiational, and require a process of learning, they necessitate a more dynamic structure to solve them [25]. In this respect, GEG is a recent understanding of environmental politics that political structures and relevant actors involved in solving environmental problems transgress national borders [2]. Through incorporating a bottom-up perspective, the GEG scheme is unique in moving away from the traditional top-down approach of environmental politics [26]. The finding recognizes that the traditional actors in GEG, such as intergovernmental organizations (IGOs) and governments, are not the only meaningful participants, and non-state actors are also identified as important contributors. The previous literature has emphasized the roles of non-state actors as essential for successful cooperation, knowledge co-production, trust building, and learning [26]. These insights highlight the value of collaboration among various actors at all levels.

The increased participation of non-state actors leads to the active involvement of multi-actors and the complex decision-making structure of multi-level governance [4, 18]. Since the 1980s, the participation of various actors has increased in size and variety [4], with GEG demonstrating characteristics of multi-actor governance with the increased role of non-state actors [27]. Actors involved in GEG include governments, IGOs, NGOs, transnational corporations, civil society, and individuals [3]. The role of non-state actors has expanded to areas such as promoting public awareness [14].

In line with the involvement of various actors, GEG presents the complex decision-making structure of multi-level governance [18]. Multi-level governance is a political structure and process that transgresses the borders of administrative jurisdictions [28]. It recognizes how regional, national, and international policy processes are interconnected [4]. As the political process of multi-level governance involves various levels of governing, it is characterized by the redistribution of power and authority [29]. The major redistributions of power are three: "(1) devolution of power from central to local governments; (2) increased sharing of power between the state and civil society; and (3) reduction of state sovereignty through joining of international coordination mechanisms" [29, 30]. These changes have occurred with increasing fragmentation and complexity—both vertically and horizontally—within the governing system [2]. Measures such as promoting public awareness have also revealed the participation of various levels of governing [31].

The Paris Agreement reflects these characteristics of GEG [5]. The Agreement's universal adaptation and broadened participation imply an expanded understanding of who should be involved in GEG regarding climate-change actions. Expanding the scope of actors shows an official acceptance that climate change cannot be managed with the involvement of a particular actor. Further, the alterations in governing structure from top-down to bottom-up reflect a new distribution of power and transition's effectiveness in solving this issue. These points are also recognized in the Paris Agreement's official statement, which states "the importance of the engagements of all levels of government, and various actors" [17].

A relevant activity these actors engage in is political discourse on the Paris Agreement [20, 32]. Political discourse refers to a decision-making process that influences public beliefs, public attitudes, and the legitimization of policies [18, 33]. It is particularly important because the Paris Agreement relies on Nationally Determined Contribution (NDC) set by each government to reduce greenhouse gas emissions [5]. This shift in governance structure has increased the scope of voices that need to participate in political discourse and yet requires careful coordination amongst them. Additionally, changes in the media environment, such as the emergence of Twitter, have transformed political communication surrounding climate change. The new media environment offers new opportunities for diverse stakeholders, such as equal opportunities in agenda-setting and reduced distance between the public and policymakers [34]. This provides new opportunities for diverse stakeholders in GEG to provide different framings and functions as gatekeepers of information, thereby changing the dynamic of climate change political communication and transforming the context and understanding of the issue [35]. Naturally, political communication by diverse stakeholders is active on Twitter, with users ranging from politicians such as Joe Biden to IGOs such as the United Nations [36]. Moreover, hashtags are used by non-profit organizations and governments alike to promote campaigns, raise funds, and provide information [37, 38].

Despite these changes in GEG and the media environment, studies on who participates in framing the issue of climate change on Twitter are limited [39]. In general, acknowledgment and scholarly interest in the involvement of non-state actors on the governing process has been growing, resulting in empirical studies on non-state actors in the global climate-change governance [9–16]. This has also led to the creation of theoretical concepts such as orchestration, which proposes that environmental governance still involves a focal point while including multiple actors [40–42].

However, interest in this change in perspective, as represented in the Paris Agreement, and in the participation of various non-state actors in GEG in political discourse on platforms such as Twitter has been lacking [22]. Considering the emphasis in previous literature on the role of non-state actors in knowledge co-production and the wider interest in the political communication conducted by notable non-state actors such as NGOs and corporations, we could expect an increase in diversity among stakeholders participating in political communication on Twitter [26, 39]. In this regard, the first hypothesis is as follows: *Hypothesis 1: Diversity among GEG actors providing public information on Twitter will increase after the adoption of the Paris Agreement.*

The relationships between various actors participating in climate-change discourse on Twitter have also received little attention. A substantial part of the previous literature on stakeholder framing has focused on NGO or economic sectors and their contents [39]. The role of non-state actors in promoting public awareness has attracted scholarly interest [43], with some studies even comparing their influence with that of other political actors [44, 45]. Hopke et al. [20] compared visual tweets during COP 21, examining various stakeholders; however, their selection was based on contextual knowledge. Studies on political communication among various stakeholders participating in climate communication are also limited, with few exceptions focusing on network and content analysis among scientists, journalists, politicians, citizens, civil society, and international organizations [20, 46, 47]. Moreover, the understanding of the difference in influence between non-state actors and other actors within the context of the Paris Agreement is lacking. Given the increased involvement of non-state actors in GEG after the Paris Agreement, this study proposes the second hypothesis: *Hypothesis 2: Non-state actors' influence in providing public information on Twitter increases compared to the influence of state-driven actors after the adoption of the Paris Agreement.*

Considering the heterogeneous roles of non-state actors within GEG, research on diverse actor types and their relationships requires further understanding [14, 42]. The perceived roles of non-state actors are distinctly different, and they have different objectives [14]. For example, NGOs are emphasized as advocating for stopping climate change, whereas corporations advocate their own interests [48, 49]. In particular, oil companies' lobbying activities affect national and subnational policies [50–52]. However, research on who, amongst non-state actors, influences climate-change discourse on Twitter is lacking. In view of these points, we assume that variations in influence and intention exist in providing public information within the non-state actors. In this regard, the last hypothesis is as follows: *Hypothesis 3: The influence of non-state actors in providing public information related to climate change on Twitter is heterogeneous.*

Empirical methods so far have had difficulty grasping public information disseminated by the various actors in GEG. The reasons for this lack of understanding of the diverse actors providing public information about climate change are two. First, diverse actors utilize different methods when providing public information and promoting public awareness [53, 54]. Second, until recently, abundant public information was provided through the media [55]. Therefore, it is particularly hard to establish an analyzable database. Fortunately, the recent advancement of the World Wide Web has provided various actors with opportunities to utilize more flexible and direct measures, such as social media. Social media is unique compared to previous social discourse arenas as the public can actively participate in and be more directly influenced by the information provided through the platform [56]. Moreover, an online community enables the comparison of various actors and the public information they provide [57]. These changes facilitate the empirical analysis of the different actors participating in climate-change discourse.

3 Data and methodology

This study investigated Twitter data to analyze the characteristics of the public-information providers of GEG and their diversity. Twitter is one of the most popular microblogging platforms, and its ability to make the larger community connect has attracted various researchers [58, 59]. In particular, the networks formed by sharing text, commenting, and retweeting on Twitter operate to spread events and news, making Twitter function as both a social discourse platform and news media channel [60, 61]. Despite the limitation of Twitter data concerning distributive power and inclusivity, many studies have utilized the platform to analyze political discourse [44, 62].

This study crawled tweets and various tweet-related data using the Twitter API for Academic Research, which is a service that provides researchers access to the full archive of tweets published on Twitter.[1] The data were collected in 2022 using the Request library and Python. Tweets that included "climate change" or "climatechange" were collected to analyze the broad and inclusive discussion about climate change. Tweets containing "climate change" have become more prevalent in public discussion compared to keywords such as "global warming," making it a suitable keyword for identifying tweets related to the general climate-change discourse in the context of GEG [63]. We also selected tweets written in English as most formal organizations use English, which is the most commonly used language on Twitter, for general public communication [64]. This study only includes mentions and replies, excluding retweets or quotes to focus on direct interactions and identify actors actively participating in climate-change discourse. The relationships formed by mention and reply activity are more direct interactions, initiating a link between two indirect accounts [65].

Regarding research periods, we considered the timeline of the Paris Agreement. Specific events sparked political discourse and increased tweets related to climate change [66, 67]; accordingly, we selected two periods in 5 years intervals after the adoption of the Paris Agreement to compare the changes in the GEG actors participating in public information and providing dynamic. The first period (period 1) was from November 2015 to November 2016. The Paris Agreement was adopted by 196 parties at COP 21 on November 30, 2015 and entered into force on November 4, 2016. Previous studies have also analyzed the periods following the Paris Agreement to study information dissemination [32]. The second period (period 2) was from November 2020 to November 2021, when each country submitting their NDC initiated the implementation of the Agreement [68]. We crawled 4,503,998 tweets during period 1 and 5,932,052 tweets during period 2.

Based on the relations of mentions and replies between accounts, we were able to draw a directed network of the accounts actively involved in climate-change discourse during the two periods of the Paris Agreement. The nodes of the directed network reflect the accounts, and the edges reflect mention and reply tweets. We calculated closeness

[1] Academic Research access was granted to scholars who could demonstrate their association with an academic research project and clearly state the research purpose and data use.

centrality using this created network to identify the major public-information providers in the network. Closeness centrality allows to understand how close a certain node is to every other node; the higher the closeness centrality of the node, the closer the node is to most of the other nodes. Thus, nodes with a higher closeness centrality enable the node to affect the discourse more easily. As a result, nodes with a high closeness centrality are more likely to be the effective information providers within the network. This study identified 1000 information providers of each period based on closeness centrality, following the closeness centrality calculation based on Beauchamp's [69] by NetworkX package as seen in Eq. (1).

$$\mathcal{C}(u) = \frac{n-1}{\sum_{v=1}^{n-1} d(v,u)} \tag{1}$$

where u represents the node, and $d(v, u)$ is the shortest path distance between v and u. Thus, the closeness centrality of a node u is the average shortest path distance to u over all n-1 reachable nodes. The NetworkX package for Python computes closeness centrality for each connected component separately. Moreover, centrality is scaled according to the components' size.

After identifying the essential information providers of the network, we investigated their roles in GEG. Table 1 shows the tweet data used in this study. Using these data, we developed an automated classification program to classify the accounts into the various actor types participating in the climate-change discourse of GEG. This self-developed Python code incorporates Wikipedia data to classify information-providing accounts into actor types within GEG. Specifically, first, we preprocessed the name and description by deleting emojis. Then we used the name, username, or uniform resource locator (URL) of the Twitter accounts and searched those parameters on Wikipedia. This process was performed automatically by requesting Wikipedia search results through MediaWiki API, which is a service that provides access to Wiki features and performs certain wiki-actions such as authentication, page operation, and search. The search results crawled through API provided the description and information included on a certain actor's Wikipedia page. When multiple pages on Wikipedia had the same title but refer to different entities, we redirected the search pages using information from the description, username, and URL to crawl accurate data. As a result, the test batch of 1000 Twitter accounts scored over 90% accuracy in classification when compared to the manual classification.

Along with the state-driven actors in GEG, such as IGOs and Government organizations, non-state actors are also important actors as GEG develops. Theoretically, the increased involvement of non-state actors characterizes GEG. Therefore, we classified various non-state actors into four types to show the various characteristics and objectives of non-state actors in GEG. Those accounts that did not fall into any of the categories were classified as unidentified and excluded from further analysis. The number of unidentifiable accounts is 165 and 139 in periods 1 and 2, respectively. Table 2 presents the actor types in this study.

We analyzed the classified accounts by examining changes in their characteristics and influence within the Twitter discourse between periods 1 and 2. The characteristics of each actor were accessed by comparing how accounts change between two periods. We identified accounts than were present in both periods as well as those that appeared only in period 1 or period 2, providing insight into the continuity of influence from period 1 to period 2. To facilitate comparison of changes in account proportions amongst different actors with varying account volumes, we normalized the data as shown in Eq. (2).

Table 1 Tweet data and description used in this study Source: Twitter [70]

Tweet data	Description
Name	The profile name of the Twitter account as defined in the profile
Username	The Twitter screen name by which the user identifies themselves
Description	The text of the accounts' profile description if the user provides one. Usually presenting the account owners' biography
URL	Additional information specified to describe the account's profile, if provided. Presenting relevant website about the account
Verified[a]	Twitter-certified accounts are those accounts acknowledged by Twitter to be authentic or of public interest

[a]Verified data was collected to assess user authenticity and classify similar accounts. However, unverified accounts were not deliberately excluded from the analysis. While accounts advocating climate change denial may not be verified by Twitter, they still play a significant role in the climate-change discourse on this platform, so they were included in the study

Table 2 GEG Actor classification

Actor type		Description	Example account[a]
Intergovernmental organization (IGO)		Accounts that represent organizations dealing with issues across national borders or organizations that are task-specific to international problems	United Nations, IPCC, World Meteorological Organization
Government organization		Accounts that represent government agencies that are a part of a state government's administrative branch	The White House, NASA, NOAA
Non-state actor	Non-profit Organization	Accounts that represent organizations categorized as 503(c), charity, nonprofit, not-for-profit, or State-owned enterprise	World Economic Forum, WWF UK, Climate Central
	For-profit Organization	Accounts that represent organizations with the goal of making money	YouTube, ExxonMobil, Mashable
	Media Organization	Accounts that represent organizations producing newspapers, journals, magazines, broadcasting, radio, online news, or a publication website	The Guardian, The New York Times, CNN
	Individual	Accounts that represent a person regardless of their public or personal social status	POTUS, Joe Biden, Leonardo DiCaprio
Unidentified		Unidentifiable account using Twitter data alone	–

[a]The full names corresponding to the abbreviated account names are as follows: Cable News Network (CNN), Intergovernmental Panel on Climate Change (IPCC), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), President of the United States (POTUS), and World Wide Fund for Nature United Kingdom (WWF UK)

$$N^a(p,t) = \frac{X^a_{pt}}{\sum_{p,t} X^a_{pt}} \quad (2)$$

where a represents actor type, p represents period, and t represents account type, X^a_{pt} refers to the volume of t account in period p for actor type a. The normalized value for each actor type is calculated by dividing the volume of accounts of a specific period and account type by the sum of the account volumes across both periods. Moreover, we analyzed the influence of each actor by examining changes in their volume and rank between periods 1 and 2. The volume for each actor in each period corresponds to the total number of accounts classified under that actor type within given period. The rank for each actor in each period is determined by the mean ranking of accounts based on the Top 1000 and Top 100 closeness centrality ranks.

We performed this study in line with the principles of the Declaration of Helsinki. We collected Twitter data that are voluntarily revealed and open to the public and analyzed them in an aggregated form using big data analysis. In this regard, the Ethics Committee of Ewha Womans University waived the requirement for informed consent and granted approval (No. ewha-202208–0002-01).

4 Results and discussion

The overall characteristics of the climate-change discourse network are presented in Table 3. The number of tweets, nodes, and edges increase from period 1 to period 2 of the Paris Agreement, and this percentage increase is higher in the nodes and edges compared to the number of tweets. This tendency shows the increased complexity of the climate-change discourse network, which reflects an increase in user interaction in climate-change discourse.

Figure 1 presents the comparative account volume between period 1 and period 2. Normalization of the account number was done by dividing by the sum of the account numbers of periods 1 and 2. The darker section of the bar represents the account volume included in both periods. The IGO results show that the tweet accounts included only in period 1 are 16.55%, and those included in both periods are 22.3%; thus, more than half of the IGO accounts in period 1 are still included in the top 1000 accounts in period 2. The IGO accounts included only in period 2 are 38.85%, which suggests that almost two-thirds of accounts in the period 2 are newly included accounts.

Regarding the Government and Non-profit actor type results, accounts included only in period 1 are 25.71% and 25.98%, respectively, and accounts included in both periods are 20% and 22.55%, respectively. This indicates that almost half of the accounts in period 1 are consistently included in the top 1000 accounts after 5 years. Interestingly, Government and Non-profit accounts included only in period 2 are larger in volume, with Government accounts comprising 34.29% and Non-profit accounts comprising 28.92%. This implies that most of the accounts in period 2 are newly included.

On the contrary, the results of For-profit and Media accounts show that most accounts included only in period 1, with For-profit accounts as 29.03% and Media accounts as 36.64%, are not included in period 2. The accounts included in both periods are 22.58% and 21.99%, respectively, while accounts included only in period 2 are 25.81% and 19.39%, respectively. This indicates that only about half of the accounts are newly included after 5 years, which is the smallest proportion compared with other actors. Last, Individual accounts comprise 33.78% of accounts included only in period 1 and 40.65% of accounts included only in period 2, which means that many new accounts are included during 5 years. Moreover, accounts included in both periods are only 12.79%, whereas other actor types of accounts included in both periods range from 20% to 22.58%. This shows that Individual accounts had the biggest change during the two periods.

Figure 2 and Table 4 present the volume of each actor type and percentage change of each actor's volume between two periods. Among the state-driven actors, the volume of IGO accounts increases significantly from 54 to 85, with a

Table 3 Characteristics of climate-change discourse network

	Period 1 (Nov. 2015–Nov. 2016)	Period 2 (Nov. 2020–Nov. 2021)	Percentage increase
Number of tweets	4,503,998	5,932,052	31.7%
Number of nodes	1,026,177	2,074,222	102.1%
Number of edges	1,880,743	7,400,536	293.5%

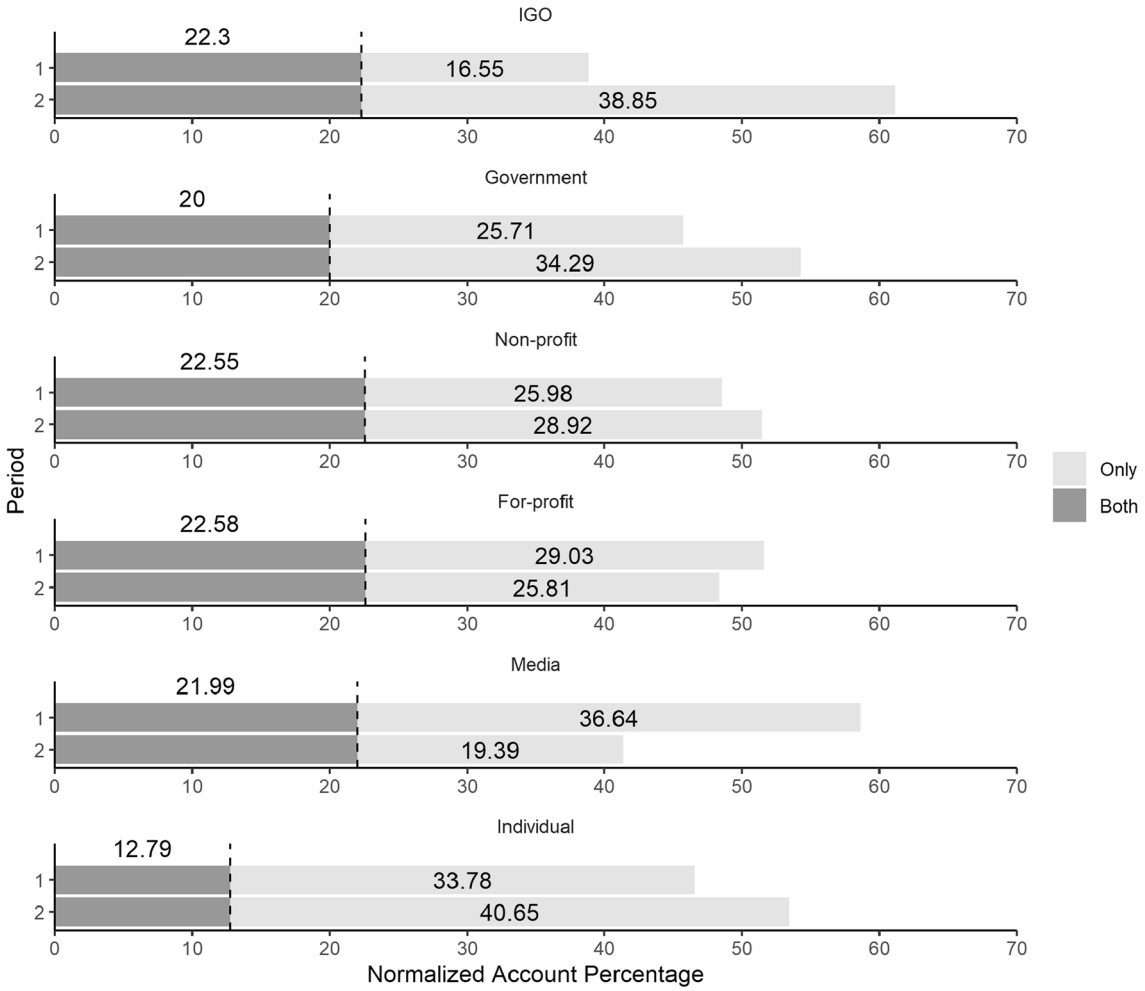


Fig. 1 Account comparison. "Only" refers to accounts included in each respective period; "Both" refers to accounts included in both periods. Numbers are rounded to two decimal places

percentage change of 57.4%. The volume of the Government actor type is similar, increasing from 32 to 38 and showing only an 18.75% change. This indicates that IGOs' power to provide information increases throughout the period based on their volume, while the Government's power remains similar. Considering previous studies that have emphasized IGO's effort to orchestrate GEG [71, 72], we find the increase in the influence of IGOs compared to that of the Government interesting. The combined volume of all state-driven actors—IGOs and Government—is 86 in period 1 and 123 in period 2. Interestingly, this is low compared to the combined volume of all non-state actors, which is 749 in period 1 and 738 in period 2. This suggests that non-state actors show a bigger influence in providing information in Twitter climate-change discourse.

However, the overall volume of non-state actor accounts decreases, and the ratio of non-state actor accounts changes. The volume of the Non-profit actor type increases from 99 to 105, and that of For-profit actor types decreases from 16 to 15; both show less than 10% change throughout the research periods, respectively. This implies that two actors maintain similar levels of influence according to volume regardless of the period. On the contrary, the volume of the Media and Individual actor types change by −29.44% and 14.77%, respectively; the Media actor type's volume decreases from 248 to 175, whereas the Individual actor type's volume increases from 386 to 443. The decrease of Media actor type volume could be the result of the increased influence of other stakeholders on Twitter. Twitter functions as a unique media environment with less distinction between media performers and audiences [35]; this could result in traditional news media losing its power as gatekeepers [73, 74]. Conversely, the increase of Individual actor type volume and its biggest increase amongst non-state actors suggest that the Individual type may be most effective in sharing information, making

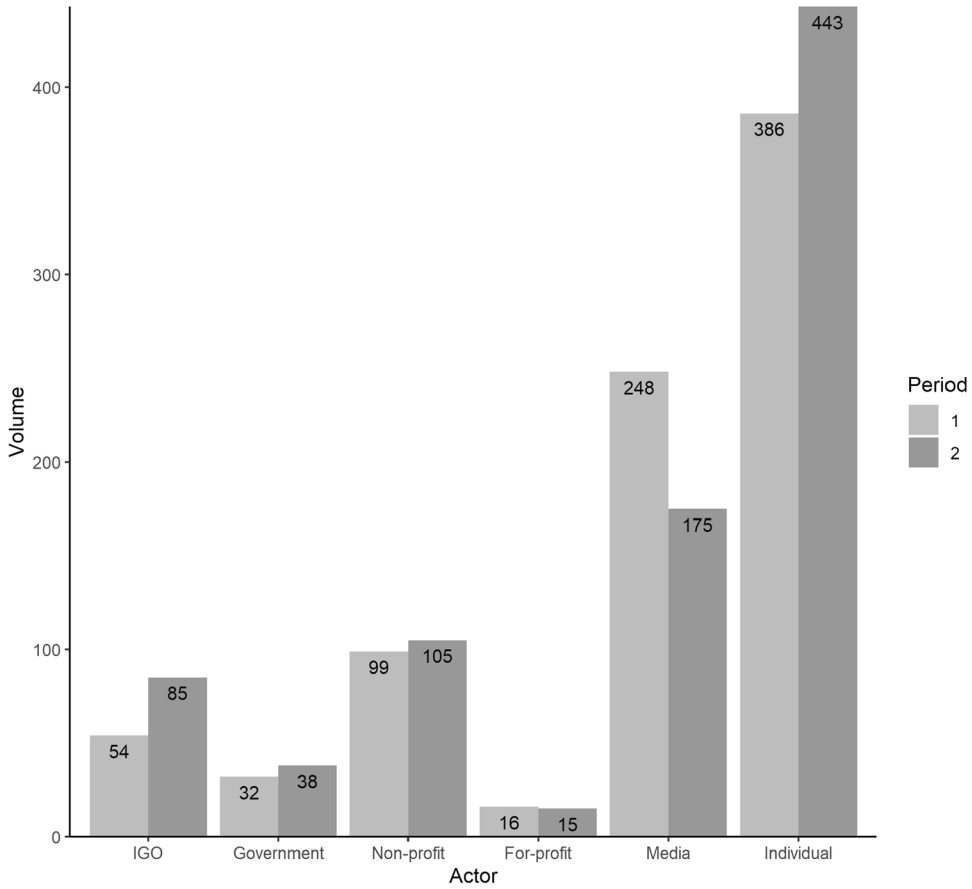


Fig. 2 Volume of actors between two periods

Table 4 Percentage change of actors between two periods[a]

IGO	Government	Non-profit	For-profit	Media	Individual
57.4%	18.75%	6.06%	−6.25%	−29.44%	14.77%

[a]Numbers are rounded to two decimal places

use of personalized aspects of communication within Twitter [75]. To summarize, the Individual actor type is the most dominant non-state actor based on volume in both periods.

Figure 3 and Table 5 show the changes in mean rank among the Top 1000 and Top 100 accounts, providing implications that concern actors' influence in providing information and how this influence changes. The Y-axis of Fig. 3 indicates the ranking of actors from 1 to 6 based on the mean ranking of accounts by each actor type in Table 5. The results of state-driven actors show an opposite trend: the mean ranking of IGO accounts increases, and that of Government accounts decreases in both analyses. According to the results of the Top 1000, IGOs are the highest-ranking actors in both the period 1 and period 2, and the mean ranking increases from 400.89 to 372.95. Based on the analysis of the Top 100, the mean ranking of IGOs increases from 40.4 to 37.8, and IGOs are the highest-ranking actors in period 2, which, regardless of the analysis, implies the increased importance of IGOs. The mean ranking of Government accounts decreases significantly from 26 to 57.2 in the analysis of the Top 100 and from 458.69 to 522.74 in the Top 1000. This is interesting considering that Governments are some of the most powerful actors in GEG and the highest-ranking actors in period 1.

Non-state actors show different trends according to the actor type. In the Non-profit results, the mean rank of the Non-profit actor type decreases 77 ranks from 432.54 to 509.54 in the analysis of the Top 1000, which shows the largest change among actors. Moreover, this mean rank decreases from 43.09 to 58.92 in the analysis of the Top 100, showing that Non-profits are the lowest-ranking actors in period 2. In period 2, Non-profits take fourth in the analysis of the Top 1000 and are the lowest-ranking actors in the analysis of the Top 100; this implies the decreased importance of higher-ranking Non-profit accounts. In both analyses of the For-profit accounts, the mean ranking increases from 436.81 to 399.47 and from 59.5 to 51 in the Top 1000 and Top 100, respectively. However, in the case of the Media actor type,

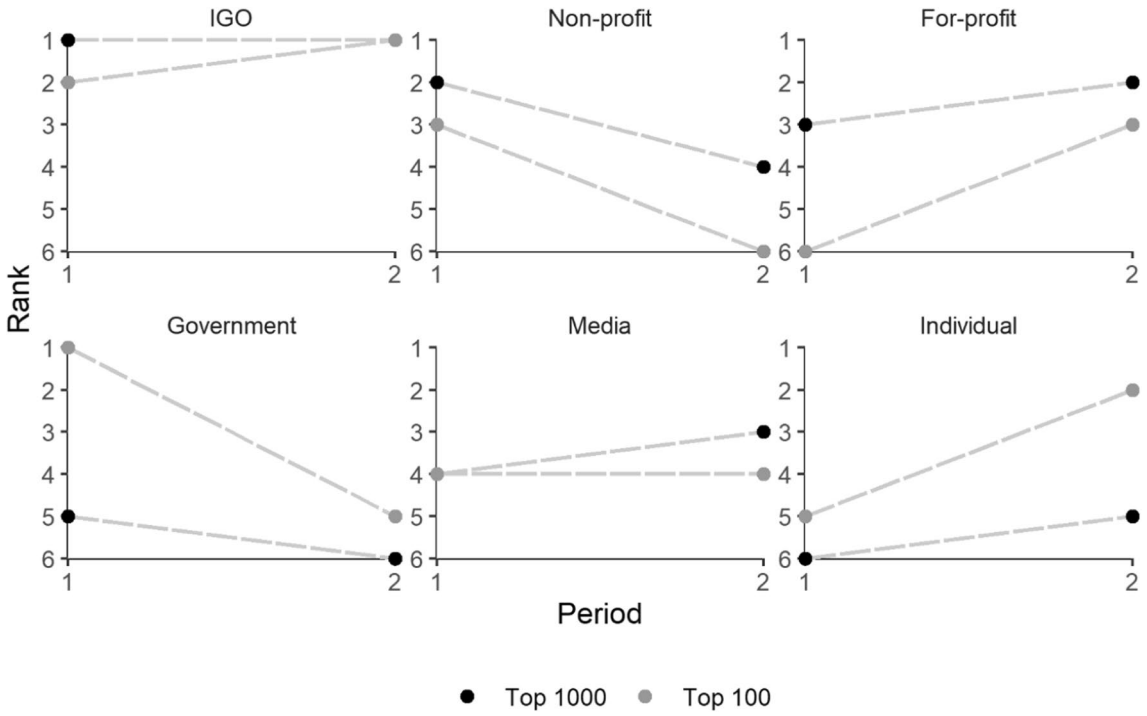


Fig. 3 Actors' rankings in Top 1000 and Top 100 tweet accounts

Table 5 Actors' mean rankings in Top 1000 and Top 100 tweet accounts[a]

		IGO	Government	Non-profit	For-profit	Media	Individual
Top 1000	Period 1	400.89	458.69	432.54	436.81	457.83	530.22
	Period 2	372.95	522.74	509.54	399.47	496.93	519.72
Top 100	Period 1	40.4	26	43.09	59.5	51.58	52.47
	Period 2	37.8	57.2	58.92	51	51.67	48.18

[a]The highest ranking is 1; the lowest ranking is 100 or 1000, as mentioned in the respective rows. Numbers are rounded to two decimal places

the mean ranking decreases in both analyses, from 457.83 to 496.93 and from 51.58 to 51.67. According to the results regarding the Individual actor type in the analysis of the Top 1000 accounts, even though their mean ranking increases from 530.22 to 519.72, it is the lowest in period 1 and second lowest in period 2. In the analysis of the Top 100 accounts, this mean ranking increases from 52.47 to 48.18, making Individuals the second highest-ranking actor type 5 years after the adoption of the Paris Agreement. This indicates the increased importance of higher-ranking Individuals' accounts.

To summarize, climate-change discourse on Twitter presents the characteristics of GEG and changes of the Paris Agreement. The changes shown in the empirical results reflect the multi-actor and multi-level governance enhanced by the Paris Agreement and the subsequent transformation of the political discourse of climate change. Overall, the dominant volume of non-state actors demonstrates the inclusiveness of the Paris Agreement. These findings provide important implications for our study hypotheses, confirming an increase in diversity among actors participating in climate-change discourse on Twitter.

First, the active participation of non-state actors supports the diversification of actors in GEG and climate-change political discourse. The dramatic increase in nodes and edges in Table 3 implies a higher involvement of diverse actors in period 2 compared to period 1. Figure 1 shows the inclusion of new accounts in the Top 1000, which represents a new distribution of power 5 years after the adoption of the Paris Agreement. These results show that all actors—except for Media actors—comprise 50% or more of the new accounts in period 2. Furthermore, from the analysis of the volumes of the actor types in Fig. 2 and Table 4, the dominant actor type is non-state actors in both periods, which implies the active participation of non-state actors in both research periods. Additionally, according to Fig. 2 and Table 4, Media shows the highest negative percentage change according to the volume. The media is a gatekeeper for elite-driven framing [35,

76]. The decrease in its volume suggests a diversification in stakeholders providing information within Twitter regarding climate-change discourse.

The second hypothesis stating that the influence of non-state actors increases compared to that of state-driven actors throughout two periods is partially rejected. According to the analysis of the actor types' volumes (refer to Fig. 2 and Table 4), the volume of IGOs increases significantly, but the proportion of non-state actors decreases slightly throughout the research period; thus, the results reject the second hypothesis. However, the results about the state-driven actors are more complex and partially reject the hypothesis. From the mean rank analyses in Fig. 3 and Table 5, the mean ranking of IGOs is the highest in both analyses of the Top 1000 and Top 100 accounts in period 2. This empirical evidence supports IGOs' meaningful power in GEG, confirming an increase in the volume, variety, and importance of their mean ranking. The increased role of IGOs could imply that public-information providers' governing structure resembles the concept of orchestration rather than a purely bottom-up approach [41]. This could also suggest that new communication measures such as Twitter provide a new discourse arena that provides direct communication between stakeholder and public [34]. However, the mean ranking of Government decreases significantly and remains in the lower ranks in period 2 in both analyses. This is consistent with the theoretical explanation of multi-level governance describing the redistribution of power from the state to an international coordination mechanism [29]. Despite governments' traditional role as important players in climate politics and GEG, their impact as information providers on Twitter has significantly decreased with the empowerment of various actors in the Paris Agreement. As the Paris Agreement expanded governance to include a wider array of actors, thereby diminishing the exclusive control previously held by governments, it is noteworthy that these other actors (e.g., NGO, certain individuals) may be perceived as more trustworthy than governments in discussions about climate-change issues. From this contradictory result regarding IGO and Government accounts, this study reveals the distinct characteristics among the state-driven actors and partially rejects the second hypothesis.

It confirms the third hypothesis about the heterogeneity of non-state actors as their influence is significantly different depending on the actor type in the analyses of the top-ranked accounts (see Fig. 3 and Table 5). According to the volume analysis in Fig. 2 and Table 4, the portion of Media accounts decreases significantly, whereas that of Individual accounts increases. Moreover, the results of the mean ranking in Fig. 3 and Table 5 show that the influence of Non-profit and Media accounts decreases, while that of For-profit and Individual accounts increases. These results provide important implications for a current understanding of political discourse about the Paris Agreement. Previous studies have pointed to non-state actors—especially NGOs—as prominent information-providing actors [14]. Moreover, the previous literature about non-state actors in GEG has mainly focused on NGO strategies and power among various actors [14, 77]. The literature on political communication and framing has also focused on NGO or corporation [39]. However, the empirical results of this study reveal the increased influence of For-profit and Individual accounts and the decreased influence of Non-profit and Media accounts; this suggests that non-state actors other than NGOs require academic interest to develop a comprehensive understanding of these influential public-information providers.

5 Conclusion

This study investigated the characteristics of actors on Twitter to understand their roles and changes as public-information providers during the processes of the Paris Agreement. We applied a big-data approach to empirically analyze various actor types that provide information and their influence. The findings support the characteristics of multi-actor and multi-level governance, which are reinforced by the transformation of the Paris Agreement. A substantial redistribution of power occurred during the research period, which included the decreased influence of Government accounts and the increased influence of IGO and non-state-actor accounts. Additionally, these actors, such as For-profit and Individual accounts, were meaningful in their influence compared to other types of non-state actors.

This study makes three key contributions. First, it empirically analyzes the relationship and power distribution between various actors in GEG participating in climate change political discourse. Through this research, we have empirically found the significant inclusivity represented in the Paris Agreement's agenda through the perspective of multi-actor and multi-level governance. Second, this study empirically proves the limitations of the previous literature and contributes to future research. Prior research about actors participating in climate-change discourse has concentrated on NGOs and corporations; however, these only partially represent the characteristics of political discourse about climate change. Our findings provide evidence regarding what future research should focus on, and the empirical evidence reveals the importance of focusing on the heterogeneity of non-state and state-driven actors participating in climate-change discourse. Last, this study is one of the few to utilize technologically advanced methods to focus on providers of public

information regarding climate change. Using a big-data approach, we analyzed a large volume of tweet data and overcome previous technical limitations.

Despite the important academic and technical implications mentioned above, this study has some limitations. First, it was limited to the actors' influence on their connective characteristics within the tweet network and did not consider the content and influence of the tweets. Additionally, this study's research data were limited to those who used Twitter and wrote in English; thus, the results may reflect the demographics that actively participate and are being influenced by social media. Last, conducting an empirical study on a certain period of the Paris Agreement has its limitations. In particular, as Twitter is prone to showing reactions based on a particular event, there are limitations in its implication for the overall public information providing activity of GEG actors. Future studies will benefit from expanding their interest from NGOs to various non-state actors to have a comprehensive understanding of GEG. Furthermore, expanding the research objects—for example, other SNS platforms such as YouTube or TikTok—and analyzing the content of tweets, including diverse languages, could provide meaningful results.

Author contributions All authors contributed to the study conception and design. All authors wrote and revised the manuscript and approved the final manuscript.

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Data availability The datasets analyzed during the current study are available upon request with the consent of Twitter.

Code availability The codes are available upon request.

Declarations

Ethics approval and consent to participate This study received the IRB exemption by Ewha Womans University IRB. All collected Tweet data used in this study are voluntarily revealed and open to the public. Furthermore, all data are automatically analyzed in an aggregated form during the big analysis process; thus, under no circumstances do we analyze or present individual tweets. In this regard, the IRB waived the requirement for informed consent through the IRB exempt approval process. Approval was granted by the Ethics Committee of Ewha Womans University (No. ewha-202208–0002-01).

Competing interests The authors declare no competing interests.

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