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What is the importance of climate research? An innovative web-based approach to assess the influence and reach of climate research programs

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ABSTRACT

Many parts of the world are increasingly experiencing the effects of climate change, making climate adaptation of rural livelihoods crucial to secure social and economic resilience. While the past two decades have witnessed a significant evolution in climate adaptation policy, evaluating the impact of climate science on policy has remained a challenge. This study employs the Digital Methods epistemology to explore the dynamics of agriculture-focused climate science and changes in attitude towards Climate Smart Agriculture (CSA) and climate change, using the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) as a case study. By considering online networks and narratives as evidence of "offline" influence, it effectively repurposes publicly available data from digital sources such as social media and websites by employing text mining and social network analysis to assess the influence and reach of the program among stakeholder at various levels. Results show that CCAFS has supported increased public awareness of CSA; that it actively engages with key actors within a network of stakeholders with more than 60 thousand members; that it has positively shifted the debate on climate adaptation among strategic partners through increased message alignment and space in the policy agenda; and that the program's reach is potentially amplified to 5.8 M users on Twitter.

1. Introduction

Several parts of the world increasingly experience the effects of climate change through more frequent extreme weather events, higher average temperatures and increased variability. Agricultural systems are particularly sensitive to these effects due to their dependence on stable, long-term climatic conditions that impact productive capacity, quality and yields (Cradock-Henry et al., 2020). Consequently, climate adaptation of rural environments is crucial to secure social and economic resilience. As defined in current literature, climate adaptation involves both public and private actors adjusting practices, processes, capital and infrastructure in response to actual or expected climate shocks (Cradock-Henry et al., 2020; Henstra, 2016). In agriculture, that encompasses the various strategies adopted by farmers, sectors, industries and regions to minimize risk and reduce exposure (Cradock-Henry et al., 2020).

The past two decades have witnessed a significant evolution in climate adaptation policy (Henstra, 2016; Keskitalo and Preston, 2019; Olazabal et al., 2019; Runhaar et al., 2018). As the debate around the theme has shifted from initial awareness raising to actual program implementation, research-for-development organizations have greatly contributed to this policy development process through research, supporting risk assessment, priority setting and planning, as well as engaging stakeholders (Runhaar et al., 2018). Yet, translating climate science into actionable policy has encountered many challenges. The literature surrounding the climate science-policy interface reveals a high

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degree of complexity, as climate policymaking and climate governance are confronted with how climate change and its effects are embedded in complex and dynamic socio-ecological systems (Berkes et al., 2003; Mahon et al., 2008). Other obstacles revolve around divergences between scientific knowledge production and policy cycles (Javeline and Shufeldt, 2014; Ranchod and Vas, 2019; Van Der Sluijs, 2005, 2008). It is evident, however, that despite the stumbling blocks that remain before climate scientists and their goal of impacting policy and governance in truly far-reaching ways, the literature offers innovative and transformative ways to strengthen and facilitate the role of climate science in shaping the policy process. This includes efforts to enhance accessibility to scientific knowledge through communication and translation of research to the relevant audiences, to engage with institutions more effectively through boundary-spanning actors and processes, or to develop transdisciplinary research and knowledge co-production to reach and engage with all potential end-users in a collective process (Rapley et al., 2014; Howarth et al., 2020; Bednarek et al., 2018).

Another key endeavor in this regard would be the codification of shared goals and approaches to evaluating the impact of practices of knowledge co-production and boundary spanning, efforts which have hitherto remained largely anecdotal or derived primarily from other sectors (Cvitanovic et al., 2015; Posner and Cvitanovic, 2019). Leith et al. (2018) helpfully describe knowledge production activities as an iceberg, of which the visible tip constitutes outputs such as publications, reports, and other formal knowledge dissemination products. However, the most important impacts of climate science on policy frequently exist below the surface, representing activities where knowledge, viewpoints and ideas are wrestled with and challenged. Dinesh et al. (2018) argue that effective science policy engagement requires approximately one third of efforts dedicated each to evidence generation, outreach, and engagement.

Hence, assessing the effects of climate science on policy has also proven to be a challenging endeavor. What exactly constitutes evaluation, impact, and success differs across sectors and disciplines: understandings of impact, for instance, range from specific technical interpretations to general descriptions of change (Hearn and Buffardi, 2016). For some, impact means real-life changes in the world, either through increased ecosystem health (Posner et al., 2016), or social transformation (Hansson and Polk, 2018; Lebel and McLean, 2018), while others, take a more holistic perspective. Edwards and Meagher (2020), for example, defend the notion of enduring network connectivity and changes in culture and attitude towards a particular issue or phenomenon, whilst Cvitanovic et al. (2018) consider impacts occurring at different levels: on policy and practice, on organizations, and on individuals.

The latter conceptualizations allow for a closer monitoring of some of the more implicit, 'soft' forms of influence climate science has on policymaking, such as improved knowledge exchanges between stakeholders involved in the policy process (Lemos et al., 2012; Bednarek et al., 2018); increased trust between scientists and policymakers (Lacey et al., 2018); more diverse and stronger social networks (Cvitanovic et al., 2017); and enhanced capacity of policymakers and their institutions (Turnhout et al., 2013).

The literature is, therefore, cognizant of both the limitations of traditional metrics for evaluating the impact of scientific output, as well as the need to develop and deploy innovative methods to monitor and measure alternative proxies for the more intangible influence of climate science. The relatively recent emergence of digital research methodologies (Rogers, 2013) offers an important alternative for exactly that. Considering the pervasiveness of the internet across societies and the increasing hybridization of online and offline dimensions in social relations (Lazer et al., 2009; Fuchs et al., 2010; Song, 2010, Wellman and Haythornthwaite, 2002), web-native techniques represent functional tools for research into cultural and social processes.

In particular, the Digital Methods approach enables exploring indicators beyond standard academic outputs (Kousha and Thelwall, 2015) to complement traditional impact assessments. As data-driven techniques, digital methods often rely on big data, which not only refers to the ability to collect and analyze very large data sets through computational means, but also to "a computational turn in thought and research" (Boyd and Crawford, 2012:665). Benefits of big data research include availability at a larger scale, novel variables, low cost, and real-time data collection (Giannone et al., 2008; di Bella et al., 2018; Einav and Levin, 2014). While important challenges in the use of big data should be acknowledged, such as the heterogeneity of data and problems of privacy and transparency (Boyd and Crawford, 2012; di Bella et al., 2018; Kitchin, 2014), nevertheless, a significant advantage of Digital Methods is the repurposing of digital artifacts (Kallinikos et al., 2013) to examine new questions.

Hence, this study relies on the foundations of Digital Methods to explore the salience of agriculture-focused climate science among policymakers at various levels, by considering online dynamics and narratives as evidence of "offline" influence. We use the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) as a case study. CCAFS aimed to "marshal the science and expertise of CGIAR and partners to catalyze positive change towards climate-smart agriculture (CSA), food systems and landscapes, and position CGIAR and partners' climate science to play a major role in bringing to scale practices, technologies and institutions that enable agriculture to meet triple goals of food security, adaptation and mitigation" (CCAFS, 2016).

Taking CCAFS as a major contributor to agricultural adaptation research, this study sought to understand the program's influence in engaging its stakeholders to address climate change. Through a data-driven, mixed methods approach that applied machine learning techniques primarily focused data mining, network analysis and text mining of an unstructured mass of data generated on the web, this study investigates three research questions: 1) Has CCAFS contributed to awareness of Climate Smart Agriculture? 2) How central was CCAFS in its network of strategic partners? 3) How did the program influence stakeholders on climate adaptation?

As program delivery was highly focused on strategic partnerships, the influence among direct stakeholders was explored through the analysis of web activity by project partners. CCAFS' place within its network of strategic partners was established through social media analysis, whereas the extent of program influence was measured through a text correlation between project-specific taxonomies and content disseminated by partners on social media and on their websites.

The rest of the paper is organized as follows: section two describes the methodology and techniques employed, section three presents the results, section four discusses the implications of our research for climate science engagement with policy, and section five briefly concludes with some forward-looking remarks.

2. Data and methods

Framed within the Digital Methods epistemology and considering web and social media activities as proxies for wider public discourse and engagement (Lotan et al., 2011; Pearce et al., 2019; Resce and Maynard, 2018; Rogers and Marres, 2000; Schäfer, 2012; Niekler and Wencker, 2019, among many others), this research leverages on publicly available digital artifacts (Kallinikos et al., 2013) as comprehensive data sources. Specifically, our empirical framework includes the following techniques:

2.1. Query analysis

An initial indication of general interest regarding CCAFS' core proposition was considered through an analysis of search engine queries provided by Google Trends.[6] As internet search engine data have increasingly been exploited as measures of aggregate issue salience (Choi and Varian, 2012), data collection with Google Trends has enabled the study of many different phenomena, such as the occurrence of influenza-like diseases (Carneiro and Mylonakis, 2009, Fantazzini, 2020), or public and media interest in the environment and biodiversity (McCallum and Bury, 2014; Chevallier et al., 2019). Hence, considering Google Trends as an effective measure of public engagement with concepts and ideas, changes to Google query searches for the key approach in CCAFS' activities were assessed: the Google Trends dashboard[7] was queried for the worldwide search interest in the term "climate smart agriculture", within the timeframe of January 2004-August 2020.

2.2. Social media and website mapping

While social networking platforms are often discussed in general terms, they are not a homogeneous entity. In fact, social media contains many different "platform cultures" arising from a combination of technical affordances and user behaviors. In particular, Twitter has been described as a digital forum, and regarding climate change activity online, it is considered an important source of climate change information-exchanges and dialogue (Pearce et al., 2019). Considering 325 CCAFS project partners identified in internal monitoring systems for projects launched between 2017 and 2019, we identified that 78% had a Twitter profile. As Twitter's affordances enable analyses of both relationships and discourse, the microblogging platform was selected for the construction of a social media dataset.

A custom script was developed in Python language to extract all publicly available tweets from 2010 to 2020 from the Twitter accounts of 232 unique project partners. For every tweet, the following data was extracted: account name, timestamp, text, #hashtags, @mentions, number of Retweets, number of Favorites and tweet URL. The resulting database contained 888,174 tweets for 231 accounts, in the period between 2010–01–12 to 2020–06–29. The list of accounts is in Supplementary Materials.

In addition to institutional dialogue on social media, the analysis aimed to uncover the adoption of CCAFS priorities on local/national policy agendas beyond reported policy instruments. Considering the websites of government partners as spaces where policies are reported for public transparency and accountability (Lee-Geiller and Lee, 2019), and as we required time-sensitive texts to present policy shifts over time, the news or updates pages were selected as they contain publication dates. Of the 54 websites identified, 35 were considered for analysis, comprising mostly national-level bodies such as ministries of agriculture, environment, and natural resources from 21 countries. The 19 discarded were either abandoned, without relevant news (just technical communications) or without publication dates. Custom scripts were developed in Python language to extract the news/update items, producing a dataset with more than 21 thousand items. Data extracted included partner name, publication date, text, and permalink to item from each news/update item. The complete list of government partners whose news pages were scraped is shown in Supplementary Materials.

2.3. Network analysis

Due to characteristics of the knowledge exchange and knowledge co-production processes of science and policy of climate, a common rubric through which the climate science-policy interface is analyzed within the literature is network analysis (Ranchod and Vas, 2019; Wagner et al., 2021). Using the data collected from Twitter, we assess CCAFS' place within its network of strategic partners by analyzing the relationship between accounts mentioned in tweets. This approach enables the visualization of relational data organized as matrices, where entities are the nodes – in this case, @mentions within the tweets– and their relations are the lines connecting pairs of nodes. This means accounts are connected if they are mentioned by another. The strength (or weight) of this connection is based on the times mentioned by the same account, which captures both the extensive and the intensive margins of connections – that is, not just the presence of a connection, but also the strength of the connection as a measure of significance.

A matrix containing the accounts scraped and the accounts mentioned by them in the corpus of tweets was constructed. The open-source software Gephi (Bastian et al., 2009) was used to import the matrix and construct the network graph. The force-directed algorithm "Force Atlas 2″ was applied to show the spatialization of nodes by mapping the proximity and the authority of categories in relation to each other (Jacomy et al., 2014). This means that linked nodes are drawn closer while unrelated nodes are pushed farther apart, thus allowing for a visual interpretation of the dynamics between actors in the network. A modularity algorithm developed by Blondel et al. (2008) was then applied to identify community structures, or "groups" – as represented by nodes that are more densely connected together than to the rest of the network, and which were colored accordingly.

2.4. Text mining

By recognizing online narratives as evidence of "offline" program influence, content analysis enables the identification of patterns and changes in political agendas over time and across geographies (Brandt, 2019). Within digitally based content analysis approaches, text Mining is broadly defined as an Artificial Intelligence (AI) technique that uses Natural Language Processing (NLP) to transform unstructured text of documents/databases such as web pages, newspaper articles, e-mails, press, posts/comments on social media, in structured and normalized data (Resce and Maynard, 2018). Words, the carriers of meaning, are identified and transformed into a processable data structure. As a way to enable the repurposing of existing, unstructured data, and to efficiently extract meaningful information from large datasets, "the combination of interpretative appraisal and statistical techniques has the potential to generate novel insights, ultimately contributing to evidence-based policy-making" (Niekler and Wencker, 2019:3).

To assess the extent to which climate adaptation research and knowledge developed through CCAFS projects are represented in the institutional communications of CCAFS partners, text mining was employed to establish a similarity measure between the program's lexicon and messaging from partners on the two aforementioned sources: social media and websites. Our aim is to determine how CCAFS has informed the debate on climate adaptation among stakeholders, and how they in turn in turn amplify the program's mission to a broader audience through social media dialogue and policy agendas.

The first step in the analysis was the development of a custom taxonomy for CCAFS projects that identifies key terminology from which to map text from partner sources against. For this, machine learning algorithms were applied to carry out unsupervised text mining of selected project outputs available from the program's internal monitoring platform for 105 projects launched between 2017 and 2019. For each project, text from three report items was considered: Project summaries (105), descriptions of project Activities (463 in total), and contribution narratives from project Outcomes (253 in total). Text was extracted and aggregated from the three sources, for all projects. Then, the corpus of analysis was prepared using functions from the R package "tm" (Feinerer and Hornik, 2018; Feinerer et al., 2008): punctuation, stop words (i.e. in English, words like "the", "is", "of", etc), and numbers were removed from the corpus. The words were then converted to lowercase and stemmed. Lastly, a Term Document Matrix was produced, with projects by column (105) and stemmed words by row (4201 unique terms). The

[6] https://medium.com/google-news-lab/what-is-google-trends-data-and-what-does-it-mean-b48f07342ee8

[7] https://trends.google.com

Term Document Matrix indicates the number of times each word appears in each project. It is the starting point of text mining, as it transforms unstructured text into numbers.

A central question in text mining is how to quantify what a document is about. One measure of a word's importance is its term frequency (tf), which counts a word's occurrence in a document. Another approach is to look at a term's inverse document frequency (idf), which decreases the weight of commonly used words and increases the weight of words that do not appear frequently in a collection of documents. The two can be combined to calculate a term's tf-idf (the two quantities multiplied together), which measures the frequency of a term adjusted for how rarely it is used (Silge and Robinson, 2017). Formally:

$$\text{idf}(\text{term}) = \ln\left(\frac{n_{\text{documents}}}{n_{\text{documents containing } term}}\right) \tag{1}$$

The statistic tf-idf is widely used to measure how important a word is to a document in a collection of documents (Silge and Robinson, 2017). In our case, the tf-idf combines frequency, i.e. how many times a word is associated to a project, and the inverse of ubiquity, i.e. how exclusive the association is between a word and a project (Hidalgo and Hausmann, 2008, 2009). To this regard, it is worth stressing that more ubiquitous words are more likely to have less informative power than exclusive words.

For the project level taxonomy, the three different reporting sources used in the analysis were aggregated to produce a single term rank, per project. This produced a vector of words with an associated vector of weights (importance = tf-idf) for each of the 105 projects, which constitutes the project-level taxonomy, where each project has its own set of significant terms.

Based on these project-level taxonomies, the analysis that follows detected the presence of terminology associated to CCAFS activities among program partners (through social media) and policy makers (through government partner websites).[8] To measure the influence of CCAFS, we assessed the change in content over time, based on the start dates of the projects that partners were involved in, and in relation to the taxonomies of the particular projects they were involved in. In essence, we compared the text of tweets and website news updates before and after partner involvement with CCAFS.

The similarity between the CCAFS project taxonomy and the text identified in Twitter and governments websites is estimated by a text correlation (*TC*). Formally, for a generic project *P* and a generic tweet or website news *i*, the text correlation can be expressed as:

$$TC_{iP} = \left[\frac{(TF\_IDF_P \in Words_i)}{\sum TF\_IDF_P}\right] \tag{2}$$

Where TF_IDF_P is the term-frequency-inverse-document-frequency (from Eq. 1) of all the words used the documents connected to the project *P*, and $Words_i$ is a bag with all the words used in the tweet (or news) *i*. TC_{iP} is included in the [0:1] interval by construction, and it measures to what extent the text in the tweet (or news) reflects a particular CCAFS project taxonomy. The higher TC_{iP} the higher the similarity between CCAFS project taxonomy and the partner's communications.

3. Results

The core of CCAFS's Theory of Change was the creation of an enabling policy environment to facilitate large-scale Climate Smart Agriculture (CSA) adoption by connecting research and policy engagement. This was expected to be achieved by working with strategic partners in four action points: building field-based evidence, strengthening institutions and services, coordinating climate and agricultural policies, and driving investment to reach scale (CCAFS, 2016:13). Hence, the program engaged with hundreds of different institutions through more than 140 projects implemented in over 60 countries since its inception in 2011. Indicators for monitoring progress included the number of policies, legal instruments, and investments that were informed by CCAFS research. These were reported by the country or regional offices as part of periodic monitoring processes, which either directly supported policy formulation or engaged with local partners in such processes. According to these indicators, between 2017 and 2019, CCAFS projects produced 96 policy outcomes, 70% of which are policy or strategy outputs.

However, this metric may not have captured the full extent of CCAFS influence, as it did not consider the processes that result in policy or investment decisions, and in which 'soft power' plays an important role in shaping perceptions and gaining visibility of CSA as an attractive and viable approach to climate adaptation. Moreover, Rose (2014) emphasizes how the impact of climate science on policymaking is not linear: more evidence does not necessarily result in better policy, and as such, an evidence-informed mindset must be adopted. The following sections present the results of our analyses.

3.1. Has CCAFS contributed to awareness of Climate Smart Agriculture?

The term Climate-Smart Agriculture (CSA) was originally coined by the Food and Agriculture Organization (FAO) and officially presented and at the Hague Conference on Agriculture, Food Security and Climate Change in 2010, through the paper "Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation".[9] CCAFS embraced the concept as its core approach to climate adaptation in agriculture and was considered a reference in diffusing practices and technologies in this regard.

To depict general interest in CSA, the global trend for Google queries for "climate smart agriculture", by month, is presented in Fig. 1. The first search dates to August 2010, in line with the timing of the aforementioned conference. From February 2011, when CCAFS was launched, the term has been searched on Google every month, with a continuing increase. Markedly, several peaks are observed in moments when CCAFS was engaged in high-level advocacy moments, such as the program's participation in the UN Climate Summit in 2014, and *Climate Week NYC* in September 2019. These participations included panels, workshops and seminars that discussed the program's strategies and outcomes in relation to its CSA solutions. Hence, while CCAFS did not originate the approach, increased interest since the program's launch indicate its continued activities supported raising the profile and establishing the relevance of climate-smart agriculture.

3.2. How central is CCAFS in its network of strategic partners?

A social network analysis explored the dynamics between accounts mentioned in the Twitter corpus from CCAFS project partners and located the program within its network of stakeholders. The technique leverages on one of Twitter's key affordances, the ability to notify or engage in direct dialogue with other users through the @mention. A "mentions network" comprises directed links that indicate a user has referred to another in a tweet (Williams et al., 2015).

The complete mentions network derived from the corpus was very large, containing 63,000 accounts mentioned through 100,000 connections. In order to understand the key actors within this network, and

[8] As a first step in data processing, the languages of the tweets were identified with R package 'textcat' (Feinerer et al., 2013). English and Spanish were the most frequent languages, representing 59% and 14% of the tweets, respectively. Likewise, the languages were detected in the government websites database, with Spanish as the prevalent language in the corpus. Then, as the project taxonomies were developed in English, all non-English text was translated with the Google Translate API in order to identify the textual similarity.

[9] http://www.fao.org/3/i1881e/i1881e00.htm

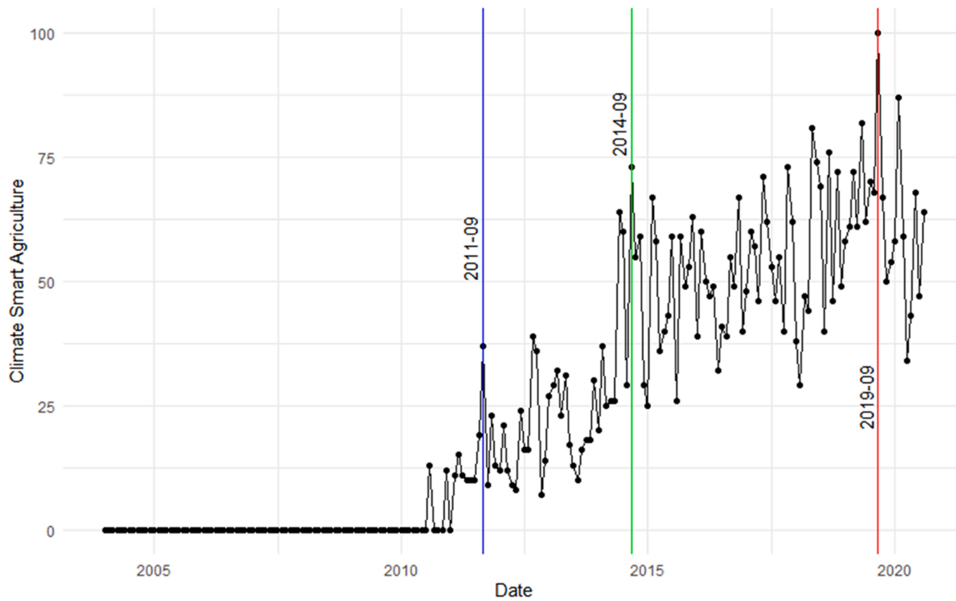

Fig. 1. Monthly queries for "Climate Smart Agriculture".

to deal with imbalances in the level of activity, the analysis considered only accounts that had at least 10 connections, either by mentioning other accounts of receiving mentions (i.e. degree distribution). This criterion reduced the number of nodes to 901, with 15,626 thousand connections between them. This focused network was also denser, with nodes connected on average to 17 other nodes.

Fig. 2 shows the resulting visualization. The sizes of the labels correspond to their in-degree of connectivity, that is, the sum of in-links (when a user is mentioned by other users). This in-degree centrality highlights the institutional actors most referenced in the Twitter conversations of CCAFS project partners. The two largest nodes are the UN and the World Bank, meaning that were mentioned by the greatest number of other accounts in the network. According to this metric, the CCAFS account (@CGIARclimate) and the general CGIAR accounts (@CGIAR) are within the top 30 mentions.

The spatialization of the nodes places them closer to those they are more directly or indirectly related to. The colors pertain to the communities identified by the modularity algorithm, which measures the level of interaction between nodes and groups them into clusters according to how much they associate with each other. The Louvain method (Blondel et al., 2008) algorithmically determines user communities by identifying each group of users who interact more frequently with each other than they do with others. Hence, each community represents groups of users who are frequently connected within the same

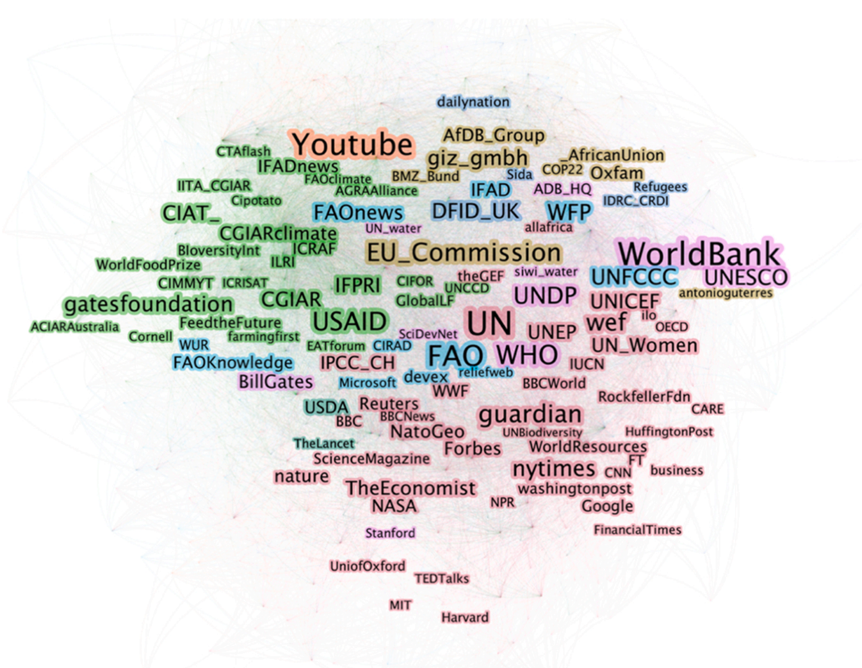

Fig. 2. Force directed network of mentions from CCAFS partner Twitter accounts, filtered for nodes with at least 10 connections (degree distribution). Node and label sizes partitioned by In-Degree Centrality, colors according to modularity class. Labels include only accounts mentioned more than 30 times (Nodes = 901 accounts, edges = 15,626).

tweet, indicating the dynamics of interactions in the network (Marcelo and Marcelo, 2021). However, a measure of modularity establishes the level of homogeneity within groups; in this case, a modularity score of 0.314 (on a scale from −1 to +1) suggests that while certain groups tend to interact more with each other, nodes still interact beyond their clusters and with other nodes in the network.

While 13 communities were detected, two of them are the most clearly visible and account for more than half of the network: the pink cluster on the bottom (33%) and the green cluster at the top (20.75%). The first cluster comprises the UN and some of its agencies such as UNICEF, UN Women and UNEP, as well as news media and scientific publication outlets (The Guardian, New York Times, Nature, Science, etc.). The latter contains the CCAFS account (@CGIARclimate), the CGIAR's central accounts and many of its research centers, as well as key program funders USAID and the Bill & Melinda Gates Foundation (@gatesfoundation). The third community is light blue and is not grouped together; rather, it is distributed among other communities across the graph. It represents 13% of nodes and includes the UN's food security agencies (World Food Program - WFP, Food and Agriculture Organization – FAO and the International Fund for Agricultural Development – IFAD) and the United Nations Framework Convention on Climate Change (UNFCCC).

In-degree centrality presents the frequency with which actors were mentioned in Twitter conversations, signalling the institutions that capture the most attention in this network. However, to assess information exchange flows, a measure of betweenness centrality was applied to the same network to assess information exchange flows. This metric determines how often a node sits between two other nodes, that is, how much it serves as a bridge in the network. According to literature that has examined interactions between organizations and the public on Twitter, profiles with high betweenness centrality can be considered "social mediators" and "information brokers", playing an important role in connecting actors that do not interact directly (Hansen et al., 2011) and influencing information flow across groups. Results presented in Fig. 3 show that CCAFS (@CGIARclimate) is the third largest node in the network, thus holding a prominent brokerage role among its program partners.

3.3. How has CCAFS influenced stakeholders on climate adaptation?

Results of the text mining analysis show that CCAFS has positively influenced its partners towards increased sensitivity for agricultural adaptation. A first approximation of some key topics covered by CCAFS partners is through the analysis of hashtags present in the corpus of tweets. Hashtags (#) are a typical affordance of Twitter, with topics and issues frequently denoted by specific hashtags (Resce and Maynard, 2018) that are utilised by platform users to reference a particular topic or event, enabling them to locate and contribute to related discussion (Williams et al., 2015). Fig. 4 shows word clouds (Fellows et al., 2018) for the hashtags used by all partners, one year before and one year after the project start dates. All identified hashtags are included, with sizes corresponding to their absolute frequencies in the corpus. Visibly, while #climatechange and #agriculture were already among the top hashtags used before CCAFS interventions, Table 1 shows a 57% increase in the presence of #foodsecurity, which is a central element of the program's agenda.

A similar shift is visible in the frequency of words present in the news pages of government partners. The word clouds in Fig. 5 illustrate the frequency of stemmed words in the corpus of government news, one year prior and one year after their respective project start dates. The stem word for agriculture (agricultur*) gained significant prominence in the second image.

However, although word clouds are a very visual representation of term distribution, they reflect absolute frequencies that are influenced by the level of activity of particular accounts on Twitter, or of government partners on their websites. Also, it is not possible to attribute the changes to CCAFS, as hashtags or terms by themselves lack the necessary context to assess how the program may have played a role in narrative shifts.

To tackle these limitations and exclude external associations, we move from general term frequency to contextual text correlation. The more in-depth text correlation analysis established the similarity between CCAFS project taxonomies and text from partners' Twitter corpus and government news pages corpus. In this analysis, biased data is tackled by measuring the entire text in the corpora against the taxonomies, over a period of time, thus keeping potential influence deriving from the level of activity constant throughout the period of analysis. More importantly, the text from partners' online activities were not measured against climate adaptation buzzwords, but rather, assessed in relation to distinct project-level vocabularies. This means that each partner's Twitter communication was compared only to the specific narrative of the projects they were involved in.

Between 2017 and 2019, CCAFS implemented 57 projects, from which Twitter data is available for at least one partner for 52 of them. These projects launched in seven different start dates. For each partner, a text correlation was estimated between their web content and the taxonomies (see Eq. 2) for their respective projects by measuring the presence of significant words in the corpus of tweets and website items. By construction, the text correlation is included in the interval [0:1] and gives a measure of how similar partner content is to the taxonomy of CCAFS projects.

Fig. 6 presents the text correlation between CCAFS project taxonomies and the corpus of tweets for all partners of projects that started between 2017 and 2019 (left) and news pages of government partners (right). The x-axis represents months – the analysis considered 12 months prior and 12 months after for all seven start dates. The line in the middle represents these projects' start dates. In both instances, there is a consistent increase over time, after the project start dates, suggesting a positive correlation between the narrative of CCAFS projects and that of project partners.

To provide an empirical measure to the text correlation over time, and to test whether the correlations after the projects start are significant, linear regressions were performed. Results in Table 2 show that the text correlation between project taxonomies and the Twitter content disseminated by project partners increases by about 5% after the projects begin, and that this increase is statistically significant ($p < 0.05$), confirming the hypothesis that CCAFS has significantly influenced the narrative of its partners around issues of climate change, adaptation, agriculture and food security. Considering the sum of followers of the partner accounts analyzed, the program's reach is potentially amplified to 5.8 million users on the platform.

The linear regression for the government websites (Table 3) shows that the text correlation increases about 10% after the project start dates, and that the increase is statistically significant ($p < 0.01$). Recognizing government websites as a primary source of information regarding public policy, the growth in content related to their respective project taxonomies on news and updates pages indicates heightened sensitivity to climate issues, especially in relation to agricultural adaptation. In addition to the policies reported in the program's monitoring systems, the text correlation also suggests that CCAFS is influencing broader government agendas in beneficiary countries.

4. Discussion

As discussed, assessing the impact of research programs has traditionally focused on measuring scientific output through peer-reviewed publications, bibliometrics, and securing research funding (Lavery et al., 2021). Web sources like social media, blogs, or social bookmarking platforms have also enabled the development of innovative metrics to gauge scientific impact and influence (Fang et al., 2020), with an increasing number of scholars indicating that altmetrics captures diverse forms of scholarship impact that differ from traditional

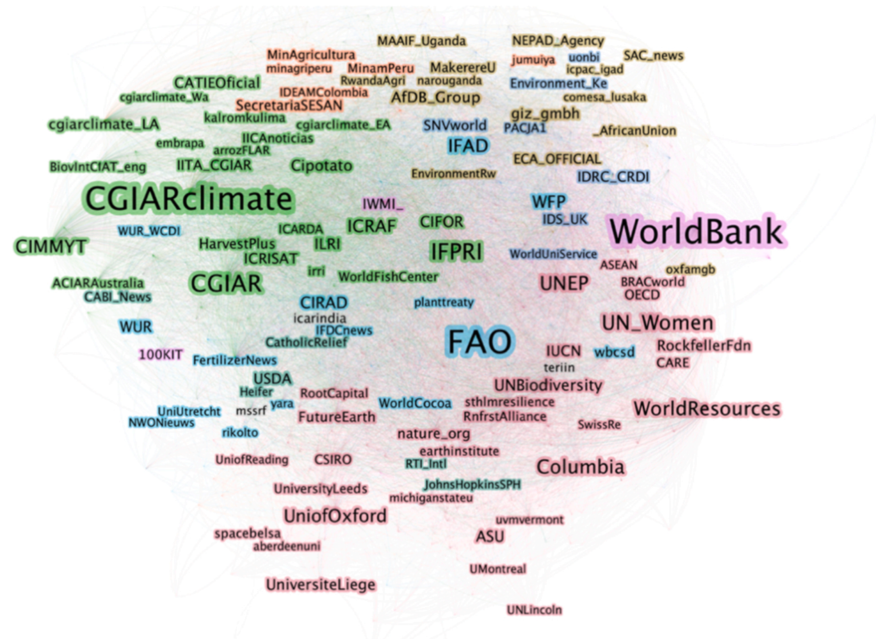

Fig. 3. Force directed network of mentions from CCAFS partner Twitter accounts, filtered for nodes with at least 10 connections (degree distribution). Node and label sizes partitioned by Betweenness Centrality, colors according to modularity class. Labels include only those mentioned more than 30 times (Nodes = 901 accounts, edges = 15,626).

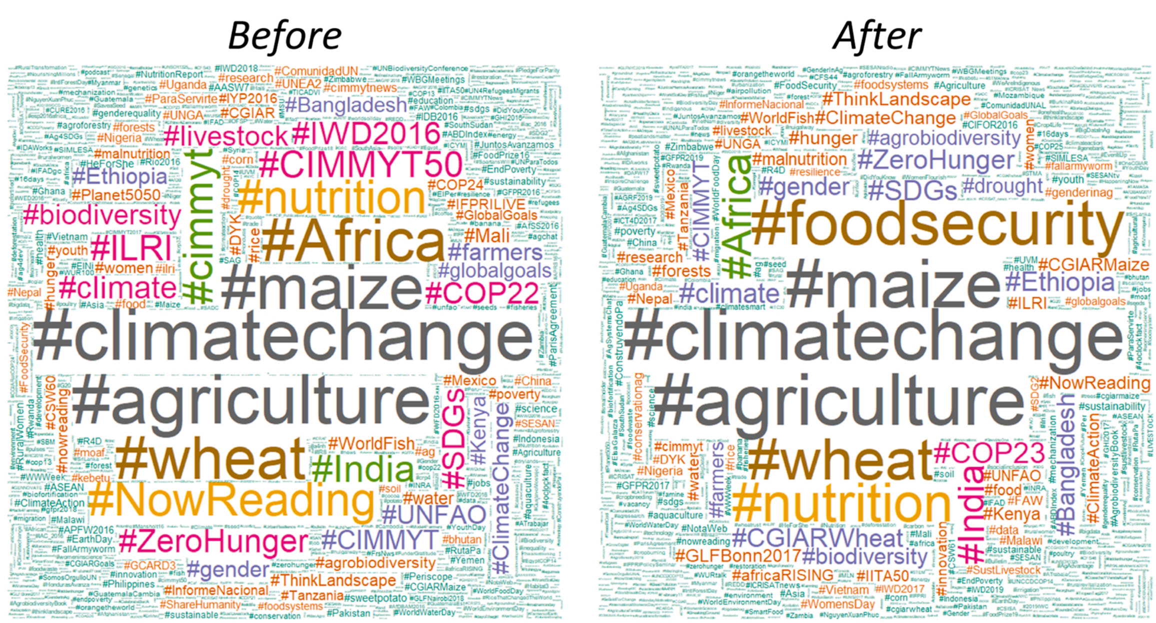

Fig. 4. Word Clouds of hashtags for all partners, before and after project start dates.

Table 1
Frequency change for top hashtags used by CCAFS partners before involvement in projects.

Hashtag	Before	After	Difference (%)
#climatechange	6104	7178	17.6
#agriculture	5834	7154	22.6
#maize	5347	6699	25.3
#Africa	5017	3967	-20.9
#wheat	4994	5751	15.2
#foodsecurity	4004	6268	56.5
#nutrition	3910	5301	35.6

bibliometrics (Eysenbach, 2011; Zahedi et al., 2014; Fujimoto et al., 2017).

However, both traditional and novel metrics tend to focus on the significance of research within the scientific community and fail to unpack reach beyond networks of researchers and research institutions (Lavery et al., 2021). Establishing approaches to evaluate the extended impact of science is important for both scientists and policymakers: it enables effective strategic reviews of program outcomes and makes research accountable to short- and medium-term outcomes (Bednarek et al., 2016); it can lead to more effective practice through learning what works in what contexts (Cvitanovic and Hobday, 2018; Henrick et al., 2017; Pitt et al., 2018), and it can help justify investments in boundary

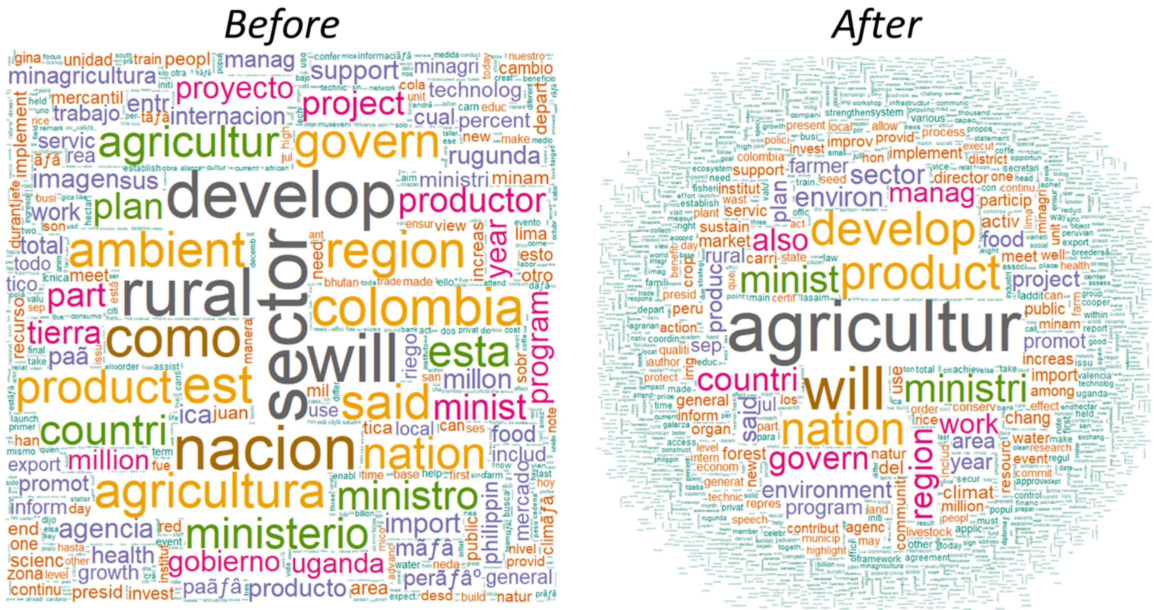

Fig. 5. Word clouds for news pages of all government partners in projects launched between 2017 and 2019.

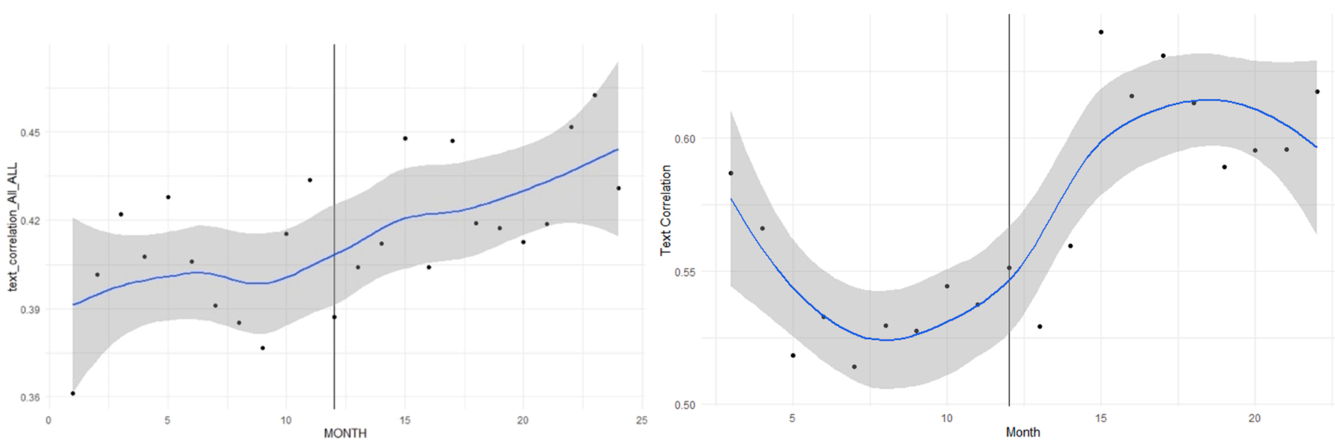

Fig. 6. Overall text correlation between CCAFS taxonomy and tweets of partners (left) and news pages of government partners (right) for all projects started between 2017 and 2019.

Table 2
Regression results for text correlation between CCAFS taxonomy and tweets of partners.[10]

	Estimate	Std. Error	t value	Pr (>|t|)	
(Intercept)	0.403	0.007	59.980	0.000	***
After approval	0.022	0.009	2.377	0.027	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.02226 on 22 degrees of freedom
Multiple R-squared: 0.2044, Adjusted R-squared: 0.1682
F-statistic: 5.651 on 1 and 22 DF, p-value: 0.02657

Table 3
Regression results for text correlation between CCAFS taxonomy and news pages of government partners.[11]

	Estimate	Std. Error	t value	Pr (>|t|)	
(Intercept)	0.540	0.010	53.715	0.000	***
After Approval	0.055	0.014	4.027	0.001	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '**' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.03015 on 18 degrees of freedom
Multiple R-squared: 0.474, Adjusted R-squared: 0.4447
F-statistic: 16.22 on 1 and 18 DF, p-value: 0.0007904

spanning activities by legitimizing boundary spanning and co-production as practices (Bednarek et al., 2018).

This study proposed a framework to measure the broader influence of a research-for-development program through online media representations. While there is no academic consensus about the impact of the digital dimension on social relations, nor about the best ways of measuring it, this study contributes to the critical analytics perspective proposed by Rogers (2018: 450) that "social media are not only a space for the presentation of self and for productive social networking but a site for the mobilization of publics around social issues and causes". We were not interested in finding out how well CCAFS was doing online, but rather, we relied on online sources to uncover the issue networks it belonged to and the positioning it engendered among its stakeholders.

The assumption that online interactions and discourses are representative of information exchange, debate, and opinion formation beyond the virtual space is a central element of our analysis. Internet use is now pervasive, with 63% of the global population accessing the world wide web in 2021.[12] The transformation of information technologies in the digital era have expanded the reach of communications tools to all aspects of social life, in which individuals rely on digital platforms and services for socialising, shopping, accessing information or entertainment, among many other activities. Consequently, institutions have also embraced web spaces and their more horizontal modes of interaction in order to stay connected with their various stakeholders – citizens, consumers, opinion leaders, and other institutions. As such, online and offline dimensions are no longer separate realms, they have become complementary and interchangeable (Rogers, 2013), making online content appropriate sources for our analysis of CCAFS' reach.

Lazer et al. (2009) argue that digital traces from such online activity can be compiled to generate comprehensive pictures of both individual and collective behaviour. A single tweet or blog post may not tell us much, but a corpus of posts collected over time becomes a rich dataset, which can be assessed through social network analysis and content analysis to uncover patterns in issue prevalence and processes of online social influence (Williams et al., 2015). While each platform has its own set of technical affordances and socially constructed norms that shape the types of content, behaviour and interactions among users, Twitter in particular has been used extensively in social research because its conversational structure that links users and topics through mentions and hashtags enables assessing how online debates evolve over time. Jungherr (2015) argues that Twitter has become a legitimate space for both personal and public participation in political discourse, a process that has been facilitated by the willingness of political and institutional actors, as well as the media, to incorporate Twitter into their communication repertoires. In fact, journalists increasingly rely on the platform for public declarations on current events, and posts by celebrities, athletes, brands, politicians, and opinion makers are subject to constant public scrutiny.

Hence, while we cannot exclude the proposition that the social media narratives of institutions may be part of public relations strategies, the fact that certain issues or topics are publicly addressed indicates that taking a position on those particular issues is also strategic. Linking this back to our case study of CCAFS, though we cannot determine what significant actions project partners took with regards to climate adaptation or CSA, we can say that, since their involvement with the program, they are publicly more sensitive to the linkages between climate change and food security, as well as to the technologies and practices disseminated by CCAFS. The positive results from the text correlation analyses indicate the program has shifted the debate on climate adaptation among its strategic stakeholders, as knowledge generated through the program was not only adopted and transmitted by these institutions, but also given increased space. Further, they provide evidence that the program's partners aligned both their strategic communications and official institutional narratives with the key concepts of the CCAFS projects they were involved with, amplifying the program's agriculture-focused approach to climate change across their own networks. These results support other reviews of the program that have found CCAFS is effectively engaging in science-policy interactions at both the global and the local level, positively influencing policies and investments towards climate-smart agriculture and raising climate and agriculture up the policy agenda (CAS Secretariat, 2020).

The increased salience of CCAFS' project narratives across partner web activities supports the broader upward trend presented through the Google Trends query for Climate Smart Agriculture. Since the program's inception, search interest in the topic, as represented by Google searches, has consistently grown. Particularly, interest spiked in moments when CCAFS was engaged in high visibility advocacy moments.

Altogether, these findings are in line with Wyborn et al.'s (2018) much broader disaggregation of influence that includes conceptual, strategic, instrumental, or capacity- and relationship-based impact. Moreover, as argued by Weiss (1977), research can lead to the infiltration of new ideas, which over time become "common knowledge" and can contribute more to the overall issue at stake than any particular policy decision.

The other major analysis located CCAFS within its network of stakeholders, placing it among key actors in the international development and scientific research communities, while also playing a central role bridging different actors. Network analysis has proved to be a key tool for understanding how the structure and operation of a particular (policy) network impacts the policy formation process (Normann, 2017; Soomai et al., 2013), and how resources may be leveraged for better access and policy outcomes (Beyers and Braun, 2014). Insights emerging from network analysis have driven recommendations regarding the facilitation of contact, collaboration, and relationships as central drivers of using climate science usage in policy, including creating the necessary institutional structures and cultures to foment knowledge flow into policy processes (Oliver et al., 2014).

In studying social media platforms, it has been argued that the network structures that link individuals and institutions engaged in online dialogue can affect how framings and attitudes evolve over time (Williams et al., 2015). The focus of the analysis shifts from individual traits to relational ties between social entities, where "collections of these ties or connections aggregate into emergent patterns or network motifs" (Himelboim et al., 2017:2). Within the Twitter ecosystem, social networks are formed by users and their connections when they mention and reply to one another. These user mentions are used to draw attention, to acknowledge, or to engage in conversation with other users. For institutional-level networks, interorganizational brokerage relations can be formed based on mutual interest between the initiator and the recipient of the mention, as well as representing a mean to strengthen strategic relationships (Fujimoto et al., 2021; Gálvez-Rodríguez et al., 2016).

While it must be noted that this network is based on CCAFS project partners, and hence may be biased towards the program, the objective is indeed to understand CCAFS' interactions with direct and indirect stakeholders identified in social media conversations. The two visualizations demonstrate that CCAFS is engaged in a broad network composed of key players within humanitarian aid, agricultural development, scientific research, civil society, and news media, supporting dissemination and exchanges about climate adaptation knowledge to a diverse range of actors. Furthermore, as the CGIAR's key initiative to address the relationship between climate change and food systems, CCAFS was an important bridge between the research developed by the various CGIAR centers and regional and global level policy institutions. This role in the creation of new and durable network connectivity is a boundary-spanning activity crucial for leveraging scalable change (Edwards and Meagher, 2020).

Our results complement a growing body of research that shows the potential of social network platforms, search engines and other web-based sources in identifying issue networks and measuring public awareness. In this case study, the digital methods perspective was applied to investigate the success of CCAFS in increasing the salience of its climate adaptation science among stakeholders, which can be seen as a crucial step for creating an enabling policy environment. It is important to highlight, however, that while we were able to determine influence in discourse, information flows and actor dynamics on various online spaces, the study is not intended as an impact evaluation of CCAFS programming. As such, a limitation of this study is that, despite reliance on project documentation to develop the analytical framework to map narrative representations, the analysis does not make linkages between activities and outcomes at the project level with changes in discourse or strengthening of network ties.

A further step to this research could include the incorporation of

[11] Quadratic term not significant.
[11] Quadratic term not significant.
[12] https://datareportal.com/reports/digital-2022-global-overview-report

qualitative narrative approaches to illustrate and provide more depth to our quantitative findings (Lavery et al., 2021). As the exchange of knowledge that occurs at the climate science-policy interface is characterized by partnership, interactive dialogue, and co-production, the development of approaches that leverage on non-conventional sources of information to elicit insights that complement traditional monitoring can give a fuller picture of a program's reach.

5. Conclusion

As the science-policy interface is characterized by a non-linear, multi-actor, 'messy' social process of knowledge co-production, traditional evaluation metrics constructed upon linear and one-dimensional understandings of impact fail to capture underlying dynamics and thereby may not detect the subtler forms climate science is affecting surface-level changes in policy. This study applied an innovative approach to assess such 'soft' forms of influence through the analysis of public web sources. By considering online networks and narratives as evidence of influence, it effectively repurposed publicly available digital artifacts to assess the reach of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) among stakeholder at various levels. Taking into account the affordances of the platforms, we assessed the dynamics of information diffusion, interaction and discourse amplification as representations of how the CCAFS is supporting policymaking at various levels of engagement, as opposed to simply examining 'formal' policy outputs or academic impact. Google Trends, network analysis and text mining were employed to assess the centrality and influence of CCAFS in the climate science-policy interface. Influence, in this sense, is therefore understood to include the exchange of concepts and framings, as well as inter-institution relationship building and improving the capacity of stakeholders to articulate and promote climate-smart agricultural practices.

Results show that CCAFS was well-placed to effectively influence the debate on climate adaptation. Its advocacy efforts helped elevate public interest in climate smart agriculture. It is engaged in a broad network of significant actors within humanitarian aid, agricultural development, scientific research, civil society, and news media, supporting dissemination and exchanges about climate adaptation knowledge. Through its partner network of more than 63 thousand accounts, information is exchanged and messages are amplified.

On Twitter, the text correlation between project-specific taxonomies and tweets by CCAFS strategic partners increases about 5% after the project start date, potentially amplifying the program's reach to 5.8 M followers on the platform. Government partners increase dissemination of content related to CCAFS projects with which they are involved in on their news pages by 10% after project start dates. Such results suggest that CCAFS has influenced broader institutional and government agendas.

Importantly, this study also establishes the pertinence of innovative methods to assess relationships and discourses that reflect policy dynamics. The approach adopted in this study points to the possibility of leveraging on data-driven methods and on repurposing publicly available data – such as social media and other online media – to assess interactions and estimate influence. As such, the development of comprehensive evaluation frameworks by climate research programs requires the establishment of indicators that capture influence from a holistic perspective, not only based on formal policy numbers, but also in relation to messaging, visibility, knowledge exchange and engagement.

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Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bia Carneiro and Giuliano Resce were consultants to CCAFS. Peter Läderach, Frans Schapendonk and Grazia Pacillo are employees of Alliance Bioversity International and CIAT, where they are Lead CGIAR Climate Security, Visiting Researcher, and Senior Economist in Climate Change and Food Security, respectively.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2022.03.018.

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