SWST – International Society of Wood Science and Technology

BIOPRODUCTS BUSINESS

Bioenergy Discourse: A Comparison Across Media and Technologies

Rawie Elnur[1] and Hamish van der Ven[2]*

Abstract

This study compares the discourse surrounding bioenergy with carbon capture and storage (BECCS) and sustainable aviation fuel (SAF) across two media: social media and academic literature. Through an automated content analysis of Twitter/X posts (n = 11,314) and peer-reviewed articles (n = 140), we identified significant differences in the prevalence of techno-optimism, techno-skepticism, and engagement with critical issues related to socio-environmental impacts and technological uncertainty for these bioproducts. The findings reveal that social media content is generally more optimistic and less critical of these technologies compared to the academic literature, with a notable lack of discussion on the potential social and environmental consequences. Furthermore, our analysis highlights a greater polarization of views in relation to BECCS, with both techno-optimism and techno-skepticism being more prominent across both media. The study emphasizes the importance of effective science communication, balanced evaluations of risks and benefits, and closer collaboration between academia and businesses to foster a more informed and nuanced discourse on disruptive technologies in the bioeconomy. Our findings also emphasize the need for scholars and businesses operating in the biomaterials and bioproducts industry to adopt a critical approach to media literacy.

Keywords: Bioenergy, sustainable aviation fuels, bioenergy with carbon capture and storage, social media, Twitter/X.

1. Introduction

Efforts to create energy without fossil fuels have emerged as central pillars of humanity's effort to mitigate climate change impacts (Hanssen et al., 2020). Bioenergy production is one of the most promising means of producing energy for applications where wind, solar, and other renewable sources are not viable. Bioenergy involves the creation of energy from organic materials (biomass) that have a lower carbon footprint and can be regenerated more quickly than fossil fuels. Amongst the different forms of bioenergy, two have emerged as potentially critical for addressing greenhouse gas emissions from energy production and transportation: bioenergy with carbon capture and storage (BECCS) and sustainable aviation fuel (SAF).

BECCS is a mode of energy production that involves, first, converting biomass (such as wood chips or agricultural residues) into energy through combustion, gasification, or anaerobic digestion. During bioenergy production, carbon dioxide (CO_2) emissions are captured and then transported and stored underground in geological formations where they are permanently sequestered. BECCS has been called a negative emissions technology (NET) insofar as it involves the active removal of CO_2 from the atmo-

1 Department of Wood Science, Faculty of Forestry, University of British Columbia. 2900 - 2424 Main Mall, Vancouver, BC Canada V6T 1Z4. Email: relnur17@mail.ubc.ca; Ph. +1-604-822-4142.

2 Department of Wood Science, Faculty of Forestry, University of British Columbia. 4644 - 2424 Main Mall, Vancouver, BC Canada V6T 1Z4. Email: hamish.vanderven@ubc.ca

* Corresponding author

Acknowledgements: This research was funded by the Social Sciences and Humanities Research Council of Canada (430-2021-00261).

sphere. NETs are critical to limiting global average temperature increase to no more than 1.5 degrees Celsius by the end of the century, as stipulated under the Paris Climate Agreement.

SAF encompasses biofuels made from biomass like agricultural residues or other renewable feedstocks (Sacchi et al., 2023). SAF is considered a "drop-in" fuel insofar as it can be blended with conventional jet fuel without requiring modifications to aircraft. SAF helps mitigate CO_2 emissions from aviation through the absorption of CO_2 by biomass during its growth phase, which offsets emissions produced when the fuel is burned. By some estimates, the use of SAF could reduce the life cycle emissions of jet fuel by 25% in comparison to fossil fuel (Gonzalez-Garay et al., 2022). Addressing emissions from aviation is critical, given that the sector accounts for 2.5% of global carbon emissions (Friedlingstein et al., 2019).

Both BECCS and SAF can be usefully conceptualized as disruptive biotechnologies insofar as they are intended to disrupt well-established businesses, products, or services, principally, the fossil fuel sector (Taeihagh et al., 2021). Similar to other disruptive technologies (e.g., generative artificial intelligence, cryptocurrencies, autonomous vehicles, etc.), BECCS and SAF offer both advantages and disadvantages. Both offer the prospect of reducing carbon emissions from emissions-intensive sectors of the economy while making better use of waste products. However, both also come with enormous risks related to cost, scalability, and implications for land use change to supply adequate biomass (Uludere Aragon et al., 2023; Zhao et al., 2024).

While many technological barriers remain, the primary barriers to broader utilization of BECCS and SAF are political. Both BECCS and SAF depend upon the creation of favourable market conditions by governments and international organizations. Both technologies require large outlays of new capital to build infrastructure like carbon capture facilities and refineries. Both technologies are also less cost-efficient than conventional fossil fuels, thus market instruments like subsidies and carbon pricing are critically important to increasing uptake. Lastly, both technologies are also accompanied by considerable amounts of regulatory uncertainty about underground storage or international production standards (Stenström et al., 2024).

At the core of all of these challenges are issues of public perception (Bellamy et al., 2019). Public preferences form the bedrock upon which policymakers can provide support and incentivization needed to upscale these technologies (Gössling & Lyle, 2021). Absent widespread public agreement that BECCS and SAF are safe and sustainable, decision-makers lack the foundation of political legitimacy necessary to incentivize their development and deployment (McCormick, 2010).

Increasingly, public perceptions of bioenergy and other disruptive technologies are shaped by dominant discourses on social media (Løkke et al., 2021). Platforms like Twitter/X serve as media through which industry boosters, skeptics, scientists, and the lay public exchange ideas about the risks and benefits associated with SAF and BECCS. For example, environmental groups have taken to Twitter/X to call for the UK government to scrap plans to pay billions in subsidies to a Drax power plant burning wood pellets in North Yorkshire (Ambrose, 2024). For its part, Drax has responded on social media by touting its role in decarbonizing the UK's heavy industry. Thus, it is vitally important to understand which ideas are shared on social media and how social media content aligns with the prevailing expert consensus on the advantages and disadvantages of these technologies.

To this end, this study explores public perceptions of BECCS and SAF in comparative context. Our objectives were to, first, understand how BECCS and SAF are discussed on social media in comparison to the academic literature, and second, gauge the variation in levels of optimism and skepticism across technologies and media. We addressed these objectives through an automated content analysis applied to a novel dataset of historical Twitter/X posts (n = 11,314) and peer-reviewed academic articles (n = 140) related to BECCS and SAF.

We begin by identifying two opposing narratives on bioenergy – techno-optimism and techno-skepticism – and explaining how they are applied to BECCS and SAF. Next, we address key differences between social media and academic literature in discussing bioenergy. Following this, we explain our data and methods before diving into our results and explaining how they relate to extant literature. We conclude by discussing the implications of our findings for scholars and bioenergy businesses.

2. Theoretical background

2.1 The tension between techno-optimism and skepticism related to BECCS and SAF

The discourse surrounding BECCS and SAF in the academic literature and on various social media platforms has become a battleground for contrasting viewpoints. At the heart of this discourse is a fundamental debate between techno-optimists and techno-skeptics. This is a debate that harkens back to the Industrial Revolution in late 18th century Europe, but has resurfaced in recent years as advances in artificial intelligence, gene editing, and autonomous vehicles have prompted renewed public discourse about the role of technology in human society. In academia, techno-optimism and skepticism have emerged as useful concepts for illustrating the tension between different perspectives on technology and sustainable development (Buchanan, 2024). Techno-optimists champion BECCS and SAF as beacons of hope, lauding their potential to not only curb carbon emissions but also usher in a new era of sustainable energy production. They envision a future where BECCS can achieve negative emissions, while SAF revolutionizes the aviation industry, providing a viable alternative to fossil fuels (Asayama & Ishii, 2017; Azar, 2011; Fuss et al., 2014; Jaschke & Biermann, 2022). Both technologies are viewed by optimists as having the potential to decouple economic growth from environmental impacts, thereby skirting thorny debates about flying less or reducing energy consumption (King, 2021).

Conversely, techno-skeptics approach BECCS and SAF with a discerning eye, raising concerns about the feasibility, scalability, and unintended social and environmental consequences of these technologies. Techno-skeptics can be usefully divided into those with technological concerns and those with broader social or environmental concerns. For SAF, technological uncertainties are focused on the scale and pace of infrastructure development, including retrofitting existing facilities and building new ones (Chiaramonti, 2019). For BECCS, technological concerns centre around how securely CO_2 can be stored underground, the potential for leaks, and the long-term monitoring of storage sites (Anderson & Peters, 2016; Low & Schaefer, 2020).

In terms of broader social and environmental concerns, both technologies have the potential to be major contributors to food insecurity insofar as they require harvesting biomass from arable land (Calvin et al., 2021; Hasegawa et al., 2020; Smith et al., 2013). The large-scale cultivation of bioenergy crops for both technologies could compete with food production and leave marginalized individuals dependent on expensive and unreliable food imports. There are concerns that the increased attractiveness of certain bioenergy crops could drive down local food production, significantly increase food prices, lead to the eviction of poor people from their lands, and even destroy rainforests and other sensitive ecosystems to make way for bioenergy plantations (Arevalo et al., 2014; Gamborg et al., 2012; Kline et al., 2017).

Both technologies also face scrutiny for contributing to land-use change, particularly in the Global South, where the majority of biomass is projected to be harvested (Jaschke & Biermann, 2022). Despite the potential for bioenergy feedstocks coming from sustainable sources like industrial residues and waste products, increased use of forest products or land use change for bioenergy might indirectly intensify the demand for natural forests and drive higher harvest rates globally (Popp et al., 2014). As one author notes: "the global land areas needed for the deployment of BECCS by 2100 have been estimated to range from 380 to 700 Mha. The upper bounds correspond to three times the world's harvested land for cereal production, twice the current water use for agriculture and 20 times the current US annual fertilizer use" (Jones & Albanito, 2020).

A key aim of this study is to advance understanding about how the debate between techno-optimists and techno-skeptics plays out across different media and technologies and what implications this discourse holds for the future of bioenergy writ large. To this end, we utilize the extant literature on techno-optimism and skepticism to code content across social media and academic literature.

2.2 Differences between social media and academic content

Social media and academic publishing are both media through which research on BECCs and SAF is shared with the wider public. However, as modes of scientific communication, they are vastly different. Academic journal articles, books, and other scholarly publications are targeted at an audience that is both smaller and better informed on the topic than the lay public (Shapin, 2005). The textual format for such content is longer and allows greater room for nuance and substantiating evidence. The lag time in scientific publishing often means that academic content is behind the pace of discourse on emergent technologies (Dong et al., 2006). By contrast, social media reaches a broader and more diverse audience, encompassing both experts and non-experts. The format of social media content is shorter (especially on Twitter/X) and allows for a diversity of communication formats, including audio, video, and imagery (Zeng et al., 2021). The lag time on social media is virtually nonexistent and content often skews towards immediate reactions to topical phenomena (Park & Rim, 2020). Taken together, the differences in the mode of scientific communication mean that we might expect to see different types of content related to BECCs and SAF on social media versus in academia.

However, the differences in media extend beyond just format. There are also marked cultural, sociological, and political differences that separate social media from academic publishing. First, the criteria for what information is widely seen differ in meaningful ways. Academic content is more likely to be read when it upholds the highest standards of scientific rigour and makes well-substantiated claims on knowledge. Content is primarily disseminated by its authors. Conversely, social media algorithms promote content that creates feelings of anger or contention (Berger & Milkman, 2012; Cinelli et al., 2021). Often, this content is shared or re-posted without the original author's knowledge or consent. These differences create incentives for different types of content in each medium.

Second, the two media differ in their incorporation of concepts and debates associated with environmental justice. Past research has found that some academic literatures, particularly those focused on emerging technologies, take a piecemeal approach to incorporating environmental justice issues (Clark & Miles, 2021). By comparison, social media platforms, and Twitter/X in particular, have been linked to increased discourse about environmental justice issues related to energy and climate change (Capoano et al., 2024; Fang et al., 2023). Thus, we may expect to observe some variation in the nature and amount of content related to environmental justice issues.

Third, there are significant differences in who produces content across both media and the extent to which powerful interest groups can monopolize content production. Social media content (and Twitter/X in particular) tends to be dominated by a handful of very prolific users (Hughes, 2019). Moreover, since the business model of the most widely used social media platforms depends on advertising sales, content produced or promoted by businesses tends to be algorithmically favoured. By contrast, there is less evidence to suggest that corporate interests dominate the production of academic content in the same way. While well-resourced researchers are certainly more prolific, they are not necessarily more widely read or cited.

The differences between these two media inform our analysis of the data. Broadly, we seek to reify, refute, or add nuance to existing conceptions about how social media differs from academic publishing.

3. Methods

3.1 Data

We drew data from two sources: SAF- and BECCS-related posts on Twitter/X and relevant academic literature. We focused on Twitter/X in lieu of other social media platforms for two reasons. First, Twitter/X is the most commonly used platform focused on news and current events (Robertson, 2023). Thus, we expected it to be the most active network in terms of discourse about bioenergy. Second, Twitter/X is a public, text-based platform as opposed to more private, visual platforms like Instagram and TikTok, where user videos and images are often unavailable to researchers. Practically, this makes Twitter/X more conducive to content analysis. To obtain Twitter/X data, we used a third-party scraping service named Tweetbinder. We chose a 10-year time period for analysis to allow for enough variation in content and volume of tweets related to the topic.

The search parameters for the Twitter/X scraping process consisted of the following guidelines:

1. Tweets must include a combination of “BECCS” and “carbon” OR tweets must include “sustainable aviation fuel.”
2. Tweets must exclude $CCS and $SAF. This was done to avoid financial market-related tweets and unrelated ticker names.

Table 1. Twitter/X data collection

Search terms	Total tweets (n)	Original contribs. (n)	Likes of most-liked tweet (n)	Earliest tweet	Tweets per user	Most active poster (stakeholder category)	Top hashtag
((BECCS) AND (CARBON)) OR (Bioenergy carbon capture and storage)	5,657	2,462	2,517	03/07/2012	2.3	@Draxgroup (industry) @biofuelwatch (NGO) @Peters_Glen (academic) @empathiser (activist) @ddwg (industry)	#BECCS
Sustainable aviation fuels (SAF)	30,192	11,641	3,517	02/17/2012	2.59	@biofuelsmag (industry media) @BiofuelsCent (industry media) @poandpo (media) @BiomassMagazine (industry media) @50skyshades (industry media)	#AVIATION

3. The chosen date range for tweets must fall between 12/31/2011 and 12/31/2022.
4. Only original tweets are included (no retweets). We did so to minimize the amount of bot activity skewing our data, since bots are known to retweet content with little audience but other bots (Han et al., 2022).
5. Only tweets in English are included.

Data was gathered on Feb. 1 2024. This search strategy yielded n = 5,657 tweets related to BECCS and n = 30,192 tweets related to SAF. To ensure parity between BECCS and SAF, we randomly selected 5,657 tweets from the SAF search results for inclusion in our analysis. Descriptives are presented in Table 1.

We gathered academic literature related to BECCS or SAF through a search on the Web of Science Core Collection database. Web of Science was utilized for its coverage of high-quality peer-reviewed academic literature. To maintain a fair comparison between platforms, the search terms used for Twitter/X and Web of Science were identical, with the same specified date range, between 12/31/2011 and 12/31/2022. Academic journals were then sorted by top citations, and the top 70 articles were downloaded as PDFs. Citation counts were specifically considered as they could serve as a reliable indicator of a publication's influence and relevance within the academic community. A Python script was then used to convert the PDFs into a homogenous digital format (i.e., text files) which made the articles easily readable for the automated content analysis. Descriptives are presented in Table 2.

Table 2. Web of Science data collection

Search terms:	Sorted by:	Number of documents
Bioenergy carbon capture and storage	Highest number of citations	70
Sustainable aviation fuels	Highest number of citations	70

3.2 Analysis

The analysis of historical Twitter/X data and academic articles was made using automated content analysis calibrated on an assessment framework used to identify discourse related to techno-optimism and techno-skepticism (and sub-variables) in social media posts about BECCS and SAF. The content analysis was implemented with CtrlFindr, a natural language processing and content analysis toolkit written in Python (Scartozzi, 2024). First, the text was preprocessed and cleaned. Next, we created a taxonomy using an inductive and deductive approach. Drawing on relevant literature, we created a list of 20 variables related to different components of techno-optimist/techno-skeptic arguments about BECCs and SAF. The variables and proxies chosen ranged from the socioeconomic and environmental implications of technology adoption, to techno-economic feasibilities, to a range of equity and justice considerations, to strings of regions and communities associated with technology development and feedstock sourcing. Finally, relevant content was identified and sorted into variables using CtrlFindr's rule-based algorithms, which run on this predefined taxonomy using a list of search strings compiled by the researchers.

The content analysis evaluated each sentence individually to determine if a document or tweet contained one of the 20 predefined variables or the 73 proxy variables in the assessment framework. Each variable and proxy was associated with a unique search string. For instance, sentences in an academic journal or a tweet mentioning land-use changes (variable 2) could include a search string falling under proxies such as: (2.1) deforestation; (2.2) soil degradation; (2.3) land-use change; or (2.4) land-use implications. A full list of the variables, proxies, and search strings used in the content analysis is available upon reasonable request from the corresponding author.

The search strings for each proxy were developed using two methods. First, GPT-4 aided in generating lowercase words or n-grams relevant to each variable. We consistently used a prompt for all search strings in the taxonomy, with the only modification being replacing the variable in question with another one. An example of the GPT-4 prompt is as follows: "I am developing a taxonomy for a natural language processing (NLP) content analysis algorithm. The taxonomy is about emerging technologies in the bioenergy space. More specifically, the content analysis investigates the implications of using biofuels in sustainable aviation and the application of bioenergy to carbon capture and storage. Make an exhaustive list of lowercase words or n-grams that can be used by my algorithm to find words related to <variable>."

Second, we employed a corpus analysis toolkit called AntConc to analyze the corpus of tweets and documents related to BECCS and SAF. AntConc facilitated the identification of word clusters and n-grams highly associated with the search strings in my taxonomy. Additionally, it helped us include co-occurrences in our taxonomy of words commonly found in clusters with the search strings we provided.

The presence of a proxy was evaluated by searching for specific constructs, namely the presence of particular words or co-occurring words. Through this approach, the content analysis generated a codebook indicating the extent to which documents engaged with 20 variables: (1) biofuels; (2) land-use changes; (3) conflict; (4) policy and regulation; (5) equity and justice; (6) environmental impacts; (7) technology development; (8) economic costs; (9) feedstock availability; (10) techno-skepticism; (11) techno-optimism; (12) regional impacts of biofuel production; (13) food vs. fuel debate; (14) technological uncertainty; (15) climate change; (16) technology development discussed in relation to social, economic, political, or environmental impacts; (17) heat and power generation; (18) social implications; (19) civil society activism opposing biofuels; (20) corporations engaged in biofuel production. Given that both the data and the code used to run the analysis are open source, the method aims to be fully replicable (Scartozzi, 2024).

We then compared the prevalence of different variables between media and technologies. Prevalence was measured as the percentage of tweets/academic documents that contained a variable or its proxies. We used this comparison of variable prevalence to draw distinctions between BECCS and SAF within and across social media and academic literature.

4. Results

4.1 Social media differs markedly from academic content across both technologies

Both technologies demonstrated a marked disjuncture between social media and academic content (see Figures 1-4). For BECCS, the potential for climate change mitigation was one of the only variables equally present across both datasets. Most other topics barely overlapped. For example, equity and justice concerns were discussed in 66% of BECCS-related academic literature, whereas those considerations were only echoed in a mere 1% of tweets (n = 49). Of those tweets, energy access accounted for 40, while indigenous rights, disproportionate impacts, and environmental justice were discussed in the remaining 9 tweets.

A similar pattern distinguished social media and academic content related to SAF. The food vs. fuel debate (variable 13) appeared in a mere 0.2% (14) of 5657 tweets, whereas the same variable appeared in nearly 50% of SAF-related academic literature. Another stark contrast is the discussion of technology development in relation to social, economic, political, and environmental impacts (variable 16). This topic was present in 54% of SAF-related academic literature, compared to only 0.19% (11) tweets.

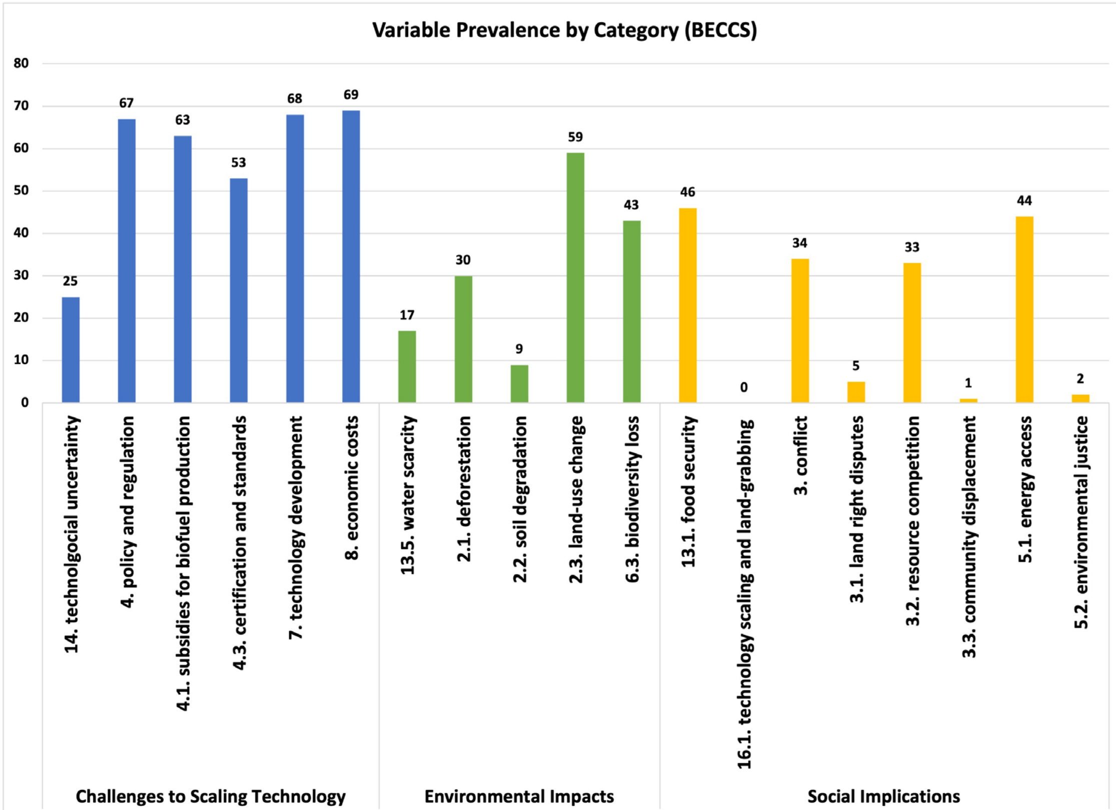

Figure 1. Academic content related to BECCS by variable

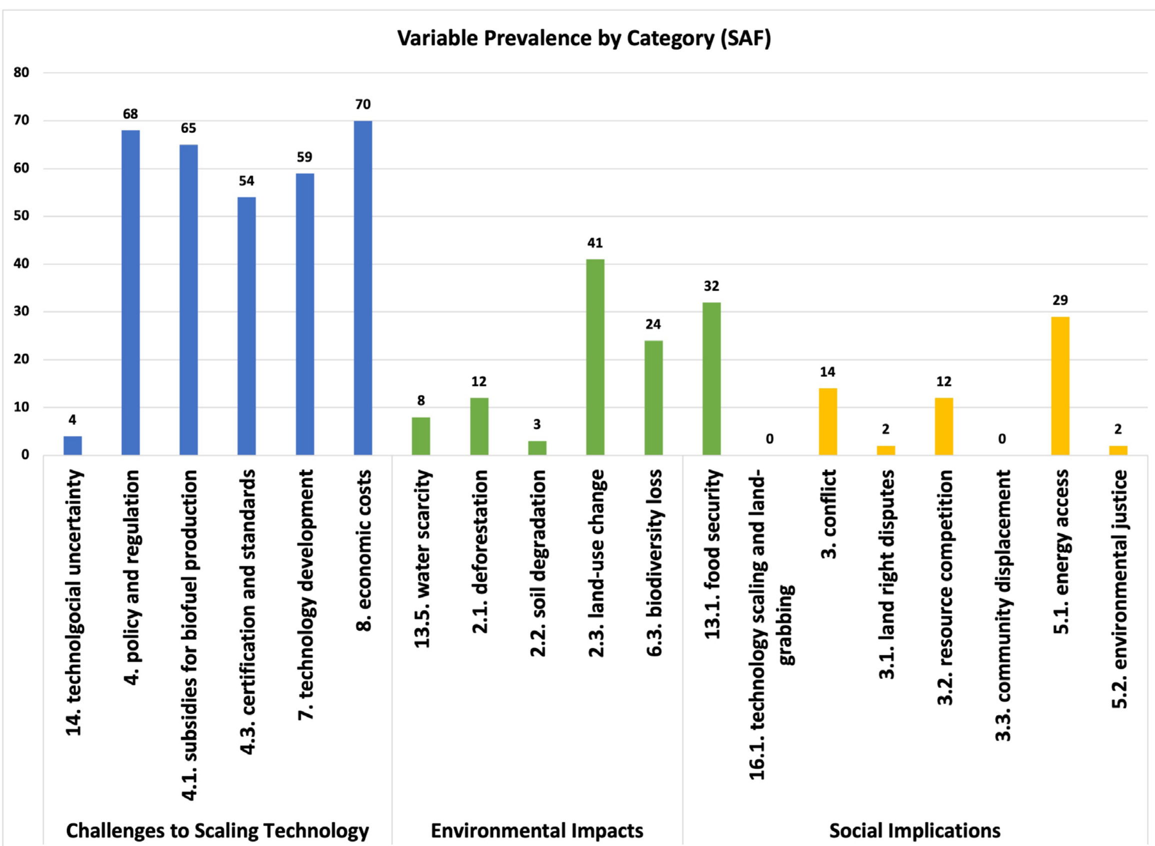

Figure 2. Academic content related to SAF by variable.

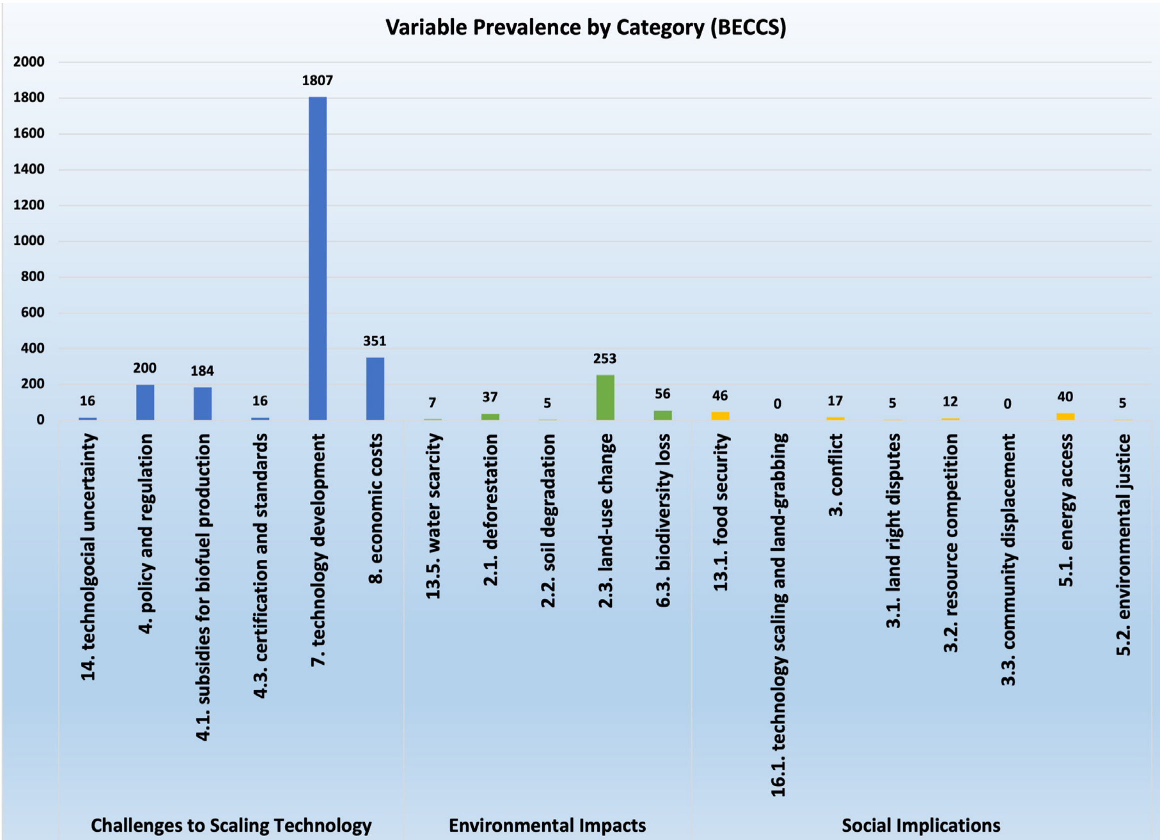

Figure 3. Social media content related to BECCS by variable.

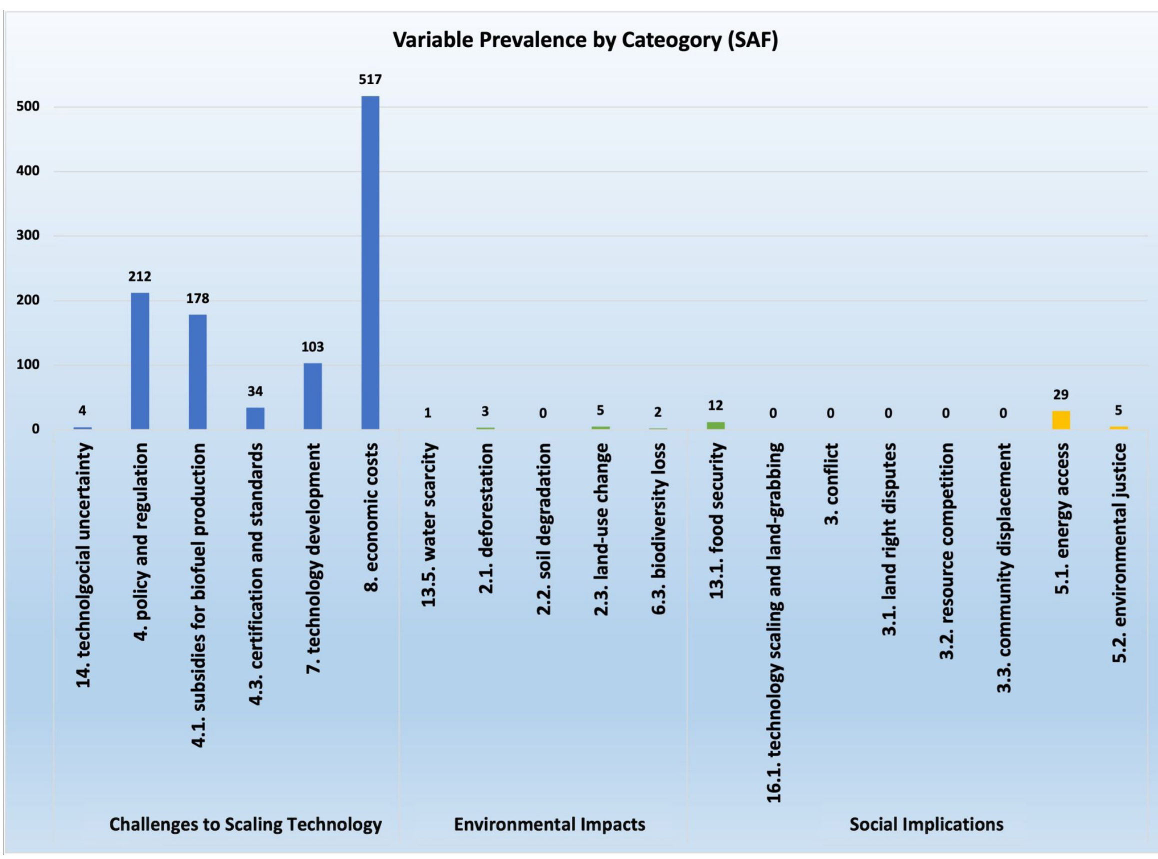

Figure 4. Social media content related to SAF by variable.

The paucity of mentions about the food vs. fuel debate on Twitter/X stands in stark contrast to its abundance in academic documents related to BECCS and SAF, with BECCS documents engaging with the issue in 72% of documents, and SAF literature discussing it in 48% of documents. This suggests a shared concern among scholars over the potential trade-offs between using biomass for energy production and its implications for food security. Regarding land-use changes (variable 2), both BECCS and SAF-related literature devoted considerable attention to this topic. In BECCS documents, land-use changes were discussed in 85% of documents, with deforestation and broader land-use implications accounting for 46% and 72% of documents, respectively. Literature related to SAF similarly addressed land-use changes in 64% of documents, with deforestation mentioned in 17% of documents and broader land-use implications in 34% of documents.

Another notable similarity found between social media corpora was the conspicuous absence of technological uncertainty discussions for each technology. Only 4 tweets discussed technological uncertainty for SAF and only 16 mentioned the variable in BECCS-related tweets. Given the prominence of retrofitting challenges discussed in academic literature surrounding SAF and the long-term storage and monitoring challenges associated with BECCS, it is interesting to note the absence of these topics on Twitter/X.

One potential source of the disparity in topical focus pertains to who is involved in bioenergy discourse on Twitter/X in comparison to academia. As Table 1 illustrates, 4/5 of the most active Twitter/X posters on SAF were industry media with strong financial ties to the industry; 2/5 of the most active posters on BECCS were industry sources. The remainder was a mix of NGOs, individual activists, and academics. The increased presence of industry voices on social media may, in part, explain the paucity of techno-skepticism on Twitter/X. It may equally explain some of the variation in skepticism between BECCS and SAF discussed in the next section.

Taken together, the results illustrate the dearth of techno-skeptic content on Twitter/X and the extent to which social media is largely decoupled from the academic literature in terms of discourse. The prominent critiques of both technologies that are extensively covered in academic articles are scarcely present in social media content.

4.2 BECCS content is both more optimistic and skeptical, across media

A notable difference between the academic literatures on BECCs and SAF was the relative presence of techno-skepticism (variable 10) in BECCS and its comparative lack of representation in the SAF literature. Variable 10 occurred in 39% of the documents on BECCs and only 10% of documents on SAF. Similarly, techno-optimism (variable 11) appeared in 86% of BECCS-related documents, whereas SAF-related documents only mentioned it in 54% of documents. However, the disparity widens significantly when considering the frequency of the variable (how many times it was mentioned as a whole across a corpus). Techno-optimism was mentioned 1143 times across BECCS-related academic documents, over 10 times more frequently than the 108 times it appeared in SAF-related academic documents. This potentially indicates a much greater degree of optimism for the outcomes and benefits of technological developments within the BECCS research community.

A similar pattern existed in social media content related to BECCS and SAF. On Twitter/X, there was more optimism about BECCS as a technology than SAF. In total, techno-optimism (variable 11) appeared in 108 SAF-related tweets, compared to 885 BECCS-related tweets. This discrepancy suggests a greater degree of confidence regarding the outcomes of technological developments within the BECCS community when compared to SAF. Similarly, the examination of techno-skepticism (variable 10) revealed a notable contrast. Sustainable aviation fuel tweets rarely discussed techno-skepticism, with only 1 mention, in comparison to the prevalence of the variable in 14 BECCS-related tweets. This, in addition to similar patterns with respect to land use change and technology development in relation to social, economic, political, or environmental impacts, suggests that both optimism and skepticism co-exist in greater frequency within the discourse on BECCS.

5. Discussion

This study has a number of implications for scholarship on BECCS and SAF, social media as a mode of scientific communication, and discourse about disruptive biotechnologies more generally. In brief, our findings echo previous literature in finding discourse on social media dominated by a relatively small number of prolific users. However, contra existing research, we also found that Twitter/X does not necessarily amplify negative or controversial posts and contains a surprising sparsity of discourse on environmental justice issues related to BECCS and SAF. We also add nuance to past scholarship by illustrating significant variation in how different technologies are communicated across media. We elaborate on these and other points in the subsections below.

5.1 Lack of contention about bioenergy on social media

Many scholars have suggested that social media creates more polarization and that social media algorithms promote content that creates feelings of anger more than nuanced debate (Berger & Milkman, 2012; Cinelli et al., 2021). Our findings generally contradict the past findings that social media exacerbates polarization or promotes anger-based content. Despite the high prevalence in the academic literature of contentious techno-skeptic topics such as resource conflict, land-use change, and biodiversity loss, these topics were scarcely discussed in SAF and BECCS-related tweets. Across both technologies, there was more techno-optimism than techno-skepticism in social media discourse. These findings align with past research, which has found that Twitter/X discourse can be dominated by a relatively small number of prolific users (Hughes, 2019). In this case, it would appear that the bioenergy industry and its supporters have been far more prolific content creators on social media than their critics. The findings illustrate that Twitter/X is far from an equal public square; rather, some interests are better positioned to monopolize the discourse (Labonte & Rowlands, 2021).

5.2 Dearth of environmental justice content related to the Global South across media

Past research has found that academic literature often marginalizes environmental justice issues, whereas social media is a fertile domain for environmental justice discourse (Clark & Miles, 2021; Fang et al., 2023). Our findings suggest that neither medium comprehensively represents the environmental justice issues associated with BECCS and SAF. Both academic literature and social media frequently contained references to the “Global South,” a region that stands to be disproportionately affected by the need to produce biomass to scale-up BECCS and SAF. Paradoxically, mentions of the Global South were not accompanied by discourse on the issues that disproportionately affect it, namely, land grabbing, food insecurity, land rights disputes, agricultural land conversion, deforestation, water consumption, pollution, and impacts on indigenous, rural, and marginalized communities. The Global South was mentioned, but the issues that affect it were not. Apart from food security, which appeared in 66% of BECCS academic literature and 45% of SAF academic literature, the remaining variables appeared in less than 20% of academic documents, with some, such as land grabbing in indigenous communities, appearing in none. The figures were even lower for social media. The fact that the discourse about the Global South omitted most environmental justice issues suggests a striking lack of skepticism about the socio-environmental impacts of BECCS and SAF that transcends media and technologies.

5.3 Discourse is mediated by technology and not just medium

There is a tendency in the literature to treat bioenergy technologies as fundamentally similar. After all, both face challenges with respect to technological uncertainty (Uludere Aragon et al., 2023; Zhao et al., 2024). Both also confront socio-environmental challenges with respect to sourcing biomass (Azar, 2011; Løkke et al., 2021). However, our findings illustrate that these concerns are mediated by the nature of the technology, as well as the medium of discourse. On the whole, BECCS discourse was characterized by more techno-optimism, potentially due to the centrality of the integrated assessment model (IAM) research community on both social media and in academia. At the same time, BECCS discourse also contained significantly more skepticism across media. Variables related to tech skepticism appeared in 39% of the academic documents on BECCs and only 10% of documents on SAF. The disparity in the discourse between technologies suggests that other variables, beyond the medium of communication, play an important role in shaping discourse. While understanding the cause of this variation is beyond the scope of this research, one possibility is that BECCS is at a different stage of technological and market maturity compared to SAF. Hence, there is more uncertainty and contention about its positive and negative impacts. Whatever the cause for variation, our findings illustrate the need to treat emergent biotechnologies as distinct phenomena, with each one provoking distinct discourses in the academic literature and on social media.

6. Conclusion

Bioenergy has emerged as one of the leading solutions to an escalating climate crisis. Yet, the fate of technologies like BECCS and SAF hinges on public opinion and how these technologies are discussed and portrayed in academic literature and on social media. Optimistically, discourse that foregrounds the promise of negative emissions technologies (BECCS) and highlights the ability to decarbonize the hard-to-abate aviation sector (SAF) could create grounds for greater technology deployment. Governments and investors may be more inclined to build the infrastructure needed to scale up these technologies if they believe they enjoy broad public support. Skeptically, discourse that highlights the serious environmental and social consequences of bioenergy production, including biodiversity loss, threats to food security, and increased deforestation, could sour public opinion and severely restrict the deployment of these technologies. In short, discourse is important for the future of bioenergy.

Our findings highlight a serious disjuncture between academic discourse on bioenergy and social media discourse on the same topic. Briefly, our findings illustrate the degree to which social media can misrepresent key issues about disruptive technologies and privilege certain discourses over others. Whereas academic discourse grapples with the technological uncertainties and socio-environmental challenges that accompany BECCS and SAF, this same techno-skepticism is largely absent on Twitter/X. This is problematic given the larger audience of social media vis-à-vis academic work and the growing influence of social media over policy-makers and investors (Ceron & Negri, 2016; Sul et al., 2017). If key decision-makers are being presented with an overly sanguine perspective on bioenergy – one that ignores major concerns about the technological uncertainties, land-use, and social justice impacts of these technologies – then they risk making misinformed decisions.

From a scholarly perspective, the lack of engagement with critical issues such as equity, justice, and the food vs. fuel debate on social media platforms like Twitter/X highlights the need for more effective science communication strategies. Academics must find ways to bridge the gap between their research findings and public discourse, ensuring that the broader societal implications of these technologies are not overshadowed by techno-optimism.

From a business standpoint, the findings suggest that companies operating in the bioeconomy must be cautious when relying on social media as a barometer for public opinion or as a source of information about these technologies. The disconnect between social media and academic discourse could lead to misguided business decisions if not properly contextualized. Instead, businesses should actively engage with the academic community to gain a more comprehensive understanding of the complex issues surrounding BECCS and SAF.

The prominence of techno-optimism in BECCS-related content across both media indicates a potential opportunity for businesses to capitalize on the positive sentiment surrounding this technology. However, companies must also be prepared to address the concerns raised by techno-skeptics and ensure that their operations prioritize sustainability, social responsibility, and environmental justice.

To navigate these challenges effectively, businesses in the bioeconomy should foster closer collaborations with academia, policymakers, and civil society organizations. By working together to develop evidence-based strategies and communicate the benefits and risks of these technologies to the public, businesses can help create a more informed and balanced discourse around BECCS and SAF.

7. Study limitations and future research

There are a number of limitations to our approach that warrant mentioning. First, the decision to focus on one social media platform, Twitter/X, likely conditions our results. Social media platforms have unique user demographics, norms, and cultures. The unique demographics of Twitter/X users – predominantly affluent, urban, American, and male – likely condition the types of discourse we identify on the platform. Second, there are challenges to attaining search strings in the taxonomy suitable for a content analysis applied to both an academic corpus and a social media corpus. The challenge lies in finding lay terms for more technical words found in academia that would also be commonly used on social media. Thus, we may underrepresent some topics on social media due to an inability to locate a counterpart to a more technical, academic term. Third, there is a possibility of sample bias in our selection of academic literature. We included only the top 70 most-cited articles for both SAF and BECCS, inferring these to be the most read or influential sources of information. However, using citation counts could introduce bias towards which types of articles are included in our dataset, given that institutional affiliation, sex, nationality, and race have all been shown to influence citations (Ray et al., 2024). Hence, there is a risk that our sample excludes important, but under-cited, research on BECCS and SAF.

This paper opens up a number of avenues for future research. First, future research should move beyond cross-sectional analysis and examine changes to discourse over time. One way of doing this would be to use an event analysis to understand how important bioenergy developments (e.g., new regulations or specific controversies) affect the discourse on bioenergy on social media and in academia. Another avenue for further research would be to apply the same research design to different social media platforms. This approach would enable researchers to explore differences in bioenergy discourse across platforms such as Twitter/X, Facebook, Reddit, and Instagram. A better understanding of the variables shaping bioenergy discourse will increase understanding of the critical role of public discourse in shaping the uptake and legitimacy of all forms of bioenergy.

8. References

Ambrose, J. (2024, August 27). Green groups urge Ed Miliband to scrap Drax subsidies. *The Guardian*. https://www.theguardian.com/environment/article/2024/aug/27/subsidies-biomass-wood-burning-drax-power-station-uk

Anderson, K., & Peters, G. (2016). The trouble with negative emissions. *Science*, *354*(6309), 182–183. https://doi.org/10.1126/science.aah4567

Arevalo, J., Ochieng, R., Mola-Yudego, B., & Gritten, D. (2014). Understanding bioenergy conflicts: Case of a jatropha project in Kenya's Tana Delta. *Land Use Policy*, *41*, 138–148. https://doi.org/10.1016/j.landusepol.2014.05.002

Asayama, S., & Ishii, A. (2017). Selling stories of techno-optimism? The role of narratives on discursive construction of carbon capture and storage in the Japanese media. *Energy Research & Social Science*, *31*, 50–59. https://doi.org/10.1016/j.erss.2017.06.010

Azar, C. (2011). Biomass for energy: A dream come true… or a nightmare? *WIREs Climate Change*, *2*(3), 309–323. https://doi.org/10.1002/wcc.109

Bellamy, R., Lezaun, J., & Palmer, J. (2019). Perceptions of bioenergy with carbon capture and storage in different policy scenarios. *Nature Communications*, *10*(1), 743. https://doi.org/10.1038/s41467-019-08592-5

Berger, J., & Milkman, K. L. (2012). What Makes Online Content Viral? *Journal of Marketing Research*, *49*(2), 192–205. https://doi.org/10.1509/jmr.10.0353

Buchanan, M. (2024). Techno-optimism needs a reality check. *Nature Physics*, *20*(2), 176–176. https://doi.org/10.1038/s41567-024-02390-7

Calvin, K., Cowie, A., Berndes, G., Arneth, A., Cherubini, F., Portugal-Pereira, J., Grassi, G., House, J., Johnson, F. X., Popp, A., Rounsevell, M., Slade, R., & Smith, P. (2021). Bioenergy for climate change mitigation: Scale and sustainability. *GCB Bioenergy*, *13*(9), 1346–1371. https://doi.org/10.1111/gcbb.12863

Capoano, E., Balbé, A. D., & Costa, P. R. (2024). Is There a "Green Moral"? How Young People's Moral Attributes Define Engagement with Narratives about Climate Change. *Social Sciences*, *13*(3). Scopus. https://doi.org/10.3390/socsci13030145

Ceron, A., & Negri, F. (2016). The "Social Side" of Public Policy: Monitoring Online Public Opinion and Its Mobilization During the Policy Cycle. *Policy & Internet*, *8*(2), 131–147. https://doi.org/10.1002/poi3.117

Chiaramonti, D. (2019). Sustainable Aviation Fuels: The challenge of decarbonization. In J. Yan, H. X. Yang, H. Li, & X. Chen (Eds.), *Innovative Solutions for Energy Transitions* 158, pp. 1202–1207). Elsevier Science Bv. https://doi.org/10.1016/j.egypro.2019.01.308

Cinelli, M., De Francisci Morales, G., Galeazzi, A., Quattrociocchi, W., & Starnini, M. (2021). The echo chamber effect on social media. *Proceedings of the National Academy of Sciences*, *118*(9), e2023301118. https://doi.org/10.1073/pnas.2023301118

Clark, S. S., & Miles, M. L. (2021). Assessing the Integration of Environmental Justice and Sustainability in Practice: A Review of the Literature. *Sustainability*, *13*(20), Article 20. https://doi.org/10.3390/su132011238

Dong, P., Loh, M., & Mondry, A. (2006). Publication lag in biomedical journals varies due to the periodical's publishing model. *Scientometrics*, *69*(2), 271–286. https://doi.org/10.1007/s11192-006-0148-3

Fang, M., Njangang, H., Padhan, H., Simo, C., & Yan, C. (2023). Social media and energy justice: A global evidence. *Energy Economics*, *125*, 106886. https://doi.org/10.1016/j.eneco.2023.106886

Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Hauck, J., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Bakker, D. C. E., Canadell, J. G., Ciais, P., Jackson, R. B., Anthoni, P., Barbero, L., Bastos, A., Bastrikov, V., Becker, M., … Zaehle, S. (2019). Global Carbon Budget 2019. *Earth System Science Data*, *11*(4), 1783–1838. https://doi.org/10.5194/essd-11-1783-2019

Fuss, S., Canadell, J. G., Peters, G. P., Tavoni, M., Andrew, R. M., Ciais, P., Jackson, R. B., Jones, C. D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M. R., Sharifi, A., Smith, P., & Yamagata, Y. (2014). Betting on negative emissions. *Nature Climate Change*, *4*(10), Article 10. https://doi.org/10.1038/nclimate2392

Gamborg, C., Millar, K., Shortall, O., & Sandøe, P. (2012). Bioenergy and Land Use: Framing the Ethical Debate. *Journal of Agricultural and Environmental Ethics*, *25*(6), 909–925. https://doi.org/10.1007/s10806-011-9351-1

Gonzalez-Garay, A., Heuberger-Austin, C., Fu, X., Klokkenburg, M., Zhang, D., Made, A. van der, & Shah, N. (2022). Unravelling the potential of sustainable aviation fuels to decarbonise the aviation sector. *Energy & Environmental Science*, *15*(8), 3291–3309. https://doi.org/10.1039/D1EE03437E

Gössling, S., & Lyle, C. (2021). Transition policies for climatically sustainable aviation. *Transport Reviews*, *41*(5), 643–658. https://doi.org/10.1080/01441647.2021.1938284

Han, N., Huang, H., Wang, J., Shi, B., & Ren, L. (2022). Information Diffusion Model of Social Bots: An Analysis of the Spread of Coverage of China Issues by The New York Times on Twitter. *Complexity*, *2022*(1), 4733305. https://doi.org/10.1155/2022/4733305

Hanssen, S. V., Daioglou, V., Steinmann, Z. J. N., Doelman, J. C., Van Vuuren, D. P., & Huijbregts, M. a. J. (2020). The climate change mitigation potential of bioenergy with carbon capture and storage. *Nature Climate Change*, *10*(11), 1023–1029. https://doi.org/10.1038/s41558-020-0885-y

Hasegawa, T., Sands, R. D., Brunelle, T., Cui, Y., Frank, S., Fujimori, S., & Popp, A. (2020). Food security under high bioenergy demand toward long-term climate goals. *Climatic Change*, *163*(3), 1587–1601. https://doi.org/10.1007/s10584-020-02838-8

Hughes, S. W. and A. (2019, April 24). Sizing Up Twitter Users. *Pew Research Center: Internet, Science & Tech*. https://www.pewresearch.org/internet/2019/04/24/sizing-up-Twitter-users/

Jaschke, G., & Biermann, F. (2022). The policy discourse on negative emissions, land-based technologies, and the Global South. *Global Environmental Change-Human and Policy Dimensions*, *75*, 102550. https://doi.org/10.1016/j.gloenvcha.2022.102550

Jones, M. B., & Albanito, F. (2020). Can biomass supply meet the demands of bioenergy with carbon capture and storage (BECCS)? *Global Change Biology*, *26*(10), 5358–5364. https://doi.org/10.1111/gcb.15296

King, C. W. (2021). *The Economic Superorganism: Beyond the Competing Narratives on Energy, Growth, and Policy.* SpringerLink, Springer International Publishing. https://link.springer.com/book/10.1007/978-3-030-50295-9

Kline, K. L., Msangi, S., Dale, V. H., Woods, J., Souza, G. M., Osseweijer, P., Clancy, J. S., Hilbert, J. A., Johnson, F. X., McDonnell, P. C., & Mugera, H. K. (2017). Reconciling food security and bioenergy: Priorities for action. *GCB Bioenergy*, *9*(3), 557–576. https://doi.org/10.1111/gcbb.12366

Labonte, D., & Rowlands, I. H. (2021). Tweets and transitions: Exploring Twitter-based political discourse regarding energy and electricity in Ontario, Canada. *Energy Research & Social Science*, *72*, 101870. https://doi.org/10.1016/j.erss.2020.101870

Løkke, S., Aramendia, E., & Malskær, J. (2021). A review of public opinion on liquid biofuels in the EU: Current knowledge and future challenges. *Biomass and Bioenergy*, *150*, 106094. https://doi.org/10.1016/j.biombioe.2021.106094

Low, S., & Schaefer, S. (2020). Is bio-energy carbon capture and storage (BECCS) feasible? The contested authority of integrated assessment modeling. *Energy Research & Social Science*, *60*, 101326. https://doi.org/10.1016/j.erss.2019.101326

McCormick, K. (2010). Communicating bioenergy: A growing challenge. *Biofuels, Bioproducts and Biorefining*, *4*(5), 494–502. https://doi.org/10.1002/bbb.243

Park, K., & Rim, H. (2020). “Click First!”: The Effects of Instant Activism Via a Hoax on Social Media. *Social Media + Society*, *6*(2), 2056305120904706. https://doi.org/10.1177/2056305120904706

Popp, J., Lakner, Z., Harangi-Rákos, M., & Fári, M. (2014). The effect of bioenergy expansion: Food, energy, and environment. *Renewable and Sustainable Energy Reviews*, *32*, 559–578. https://doi.org/10.1016/j.rser.2014.01.056

Ray, K. S., Zurn, P., Dworkin, J. D., Bassett, D. S., & Resnik, D. B. (2024). Citation bias, diversity, and ethics. *Accountability in Research*. https://www.tandfonline.com/doi/abs/10.1080/08989621.2022.2111257

Robertson, C. (2023, October 25). *Here’s what our research says about news audiences on Twitter, the platform now known as X*. Reuters Institute for the Study of Journalism. https://reutersinstitute.politics.ox.ac.uk/news/heres-what-our-research-says-about-news-audiences-Twitter-platform-now-known-x

Sacchi, R., Becattini, V., Gabrielli, P., Cox, B., Dirnaichner, A., Bauer, C., & Mazzotti, M. (2023). How to make climate-neutral aviation fly. *Nature Communications*, *14*(1), 3989. https://doi.org/10.1038/s41467-023-39749-y

Scartozzi, C. M. (2024). Conflict sensitive climate finance: Lessons from the Green Climate Fund. *Climate Policy*, *24*(3), 297–313. https://doi.org/10.1080/14693062.2023.2212640

Shapin, S. (2005). Hyperprofessionalism and the Crisis of Readership in the History of Science. *Isis*, *96*(2), 238–243. https://doi.org/10.1086/431535

Smith, P., Haberl, H., Popp, A., Erb, K., Lauk, C., Harper, R., Tubiello, F. N., de Siqueira Pinto, A., Jafari, M., Sohi, S., Masera, O., Böttcher, H., Berndes, G., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E. A., Mbow, C., … Rose, S. (2013). How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology*, *19*(8), 2285–2302. https://doi.org/10.1111/gcb.12160

Stenström, O., Khatiwada, D., Levihn, F., Usher, W., & Rydén, M. (2024). A robust investment decision to deploy bioenergy carbon capture and storage—Exploring the case of Stockholm Exergi. *Frontiers in Energy Research*, *11*. https://doi.org/10.3389/fenrg.2023.1250537

Sul, H. K., Dennis, A. R., & Yuan, L. (Ivy). (2017). Trading on Twitter: Using Social Media Sentiment to Predict Stock Returns. *Decision Sciences*, *48*(3), 454–488. https://doi.org/10.1111/deci.12229

Taeihagh, A., Ramesh, M., & Howlett, M. (2021). Assessing the regulatory challenges of emerging disruptive technologies. *Regulation & Governance*, *15*(4), 1009–1019. https://doi.org/10.1111/rego.12392

Uludere Aragon, N. Z., Parker, N. C., VanLoocke, A., Bagley, J., Wang, M., & Georgescu, M. (2023). Sustainable land use and viability of biojet fuels. *Nature Sustainability*, *6*(2), 158–168. https://doi.org/10.1038/s41893-022-00990-w

Zeng, J., Schäfer, M. S., & Allgaier, J. (2021). Research Perspectives on TikTok & Its Legacy Apps| Reposting "Till Albert Einstein Is TikTok Famous": The Memetic Construction of Science on TikTok. *International Journal of Communication*, *15*(0), Article 0.

Zhao, X., Mignone, B. K., Wise, M. A., & McJeon, H. C. (2024). Trade-offs in land-based carbon removal measures under 1.5 °C and 2 °C futures. *Nature Communications*, *15*(1), 2297. https://doi.org/10.1038/s41467-024-46575-3