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Twitter conversations reveal issue salience of aviation in the broader context of climate change

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ABSTRACT

Growing concern about the climate crisis comes with increased scrutiny of flying as an emission-intensive activity. This study conceptualises a modern communication system and draws on social media data to examine pre-COVID-19 (September to December 2019) public conversations about aviation and climate change. The analysis of >326,000 Twitter posts reveals that issue salience can be considerable at times, especially during key events such as United Nation climate summits and for users from countries such as Portugal, Puerto Rico, Qatar, France and Spain. Topic modelling identified five key frames: economy and industry, public opinion, fairness and conflict, consequences and responsibility. The fairness and conflict frame recorded the largest number of tweets, and was noteworthy for its negative sentiment. It also had the highest retweet rate and the densest network in terms of average users per community. The responsibility frame was interesting for its positive sentiment, and perhaps the opportunity for aviation stakeholders to contribute proactively to the conversations by sharing climate action success stories. Given the importance of public opinion (voters and consumers), and the link between media activity and policy decisions, the ongoing monitoring of issue salience, frames and peer groups related to flying and climate change seems beneficial.

1. Introduction

The current halt to global aviation due to the COVID-19 crisis follows a period of increased public awareness of the contribution of aviation to anthropogenic greenhouse gas emissions. The flightshame movement (Becken et al., 2021; Gössling et al., 2020) and calls for reducing air travel by groups such as Extinction Rebellion are manifestations of wider public concerns about climate change (Pew Research Centre, 2019). Aviation emissions have contributed 3.5% to man-made climate change to date (Lee et al., 2020), and are recognised as hard-to-abate in the urgent need to reduce emissions (UNEP, 2020). Flying can be a major source of emissions in an individual's carbon budget (Peeters et al., 2019). Earlier research has examined people's willingness to address air travel emissions by travelling less often or less far (Higham et al., 2016), or offsetting emissions to mitigate one's climate impact (Becken and MacKey, 2017).

Air travel emissions are both a personal matter and a political topic. The example of the London Heathrow Airport extension (Carrington, 2020) illustrates the conflict between those who see air mobility as a key vehicle for economic prosperity, improved connectivity, and government revenue (Forsyth, 2006; International Air Transport Association [IATA], 2019), versus those who consider it an insufficiently regulated (UNEP, 2020) and inequitable source of emissions (Gössling and Humpe, 2020). More recently, personal concerns have become visible at a societal level as people openly express shame about flying (BBC News, 2019; Gössling et al., 2019), including politicians who advocate for accelerated climate action (Relman, 2019). Social media have intensified conversations about the climate impacts of flying (Becken et al., 2021). This is epitomised in the Swedish Instagram account Aningslösa Influencers (Ai, standing for Clueless Influencers), which gained traction late 2018 to expose social media influencers who were seen to act irresponsibly by excessive flying (Larsson, 2019).

The dynamic topic of aviation emissions is discussed across different channels and communities, and exchanges reflect the salience of an issue, but also shape it in a complex and iterative way. The concept of issue salience seeks to describe or understand why certain topics

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constitute an important "focus of thinking for some citizens while being ignored by others at the same time" (Miller et al., 2016, p. 125). The issue salience of climate change has been studied in the context of news stories (Moernaut et al., 2019), public concern (Crawley et al., 2020), and its relevance to policy action (Bromley-Trujillo and Poe, 2020). However, research on the salience of 'aviation emissions' in social media communications is lacking, despite an increasing trend of using big data analytics in aviation studies (Chung et al., 2020). Much of the aviation-related research using data mining of online content (including social media) to date has focused on various aspects of customer satisfaction (Sezgen et al., 2019) and service quality (Barakat et al., 2021), with topics such as climate change having been overlooked. Social media data offer potential to understand customer and stakeholder opinions on the socio-political problem of carbon emissions and mitigation initiatives, and importantly, provide a channel to engage with people in a two-way manner (Punel and Ermagun, 2018).

This research builds on previous work on issue salience in social media (e.g. Eberl et al., 2020; Larsson, 2019; Spartz et al., 2017). As one of the more popular global social media platforms, Twitter provides an opportunity to 'listen in' on public conversations related to climate change (Becken et al., 2021; Jang and Hart, 2015; Liu and Zhao, 2017). People share and collect information on Twitter to voice their own views and to engage in ideological debate (Ciszek, 2016). Understanding Twitter as one element of the modern communication system, where all actors (including those related to aviation) are senders and recipients of messages, we propose that it is important to understand: 1) how salient the issue of aviation is within broader Twitter conversations on the climate change topic (across time and space); 2) what particular frames emerge regarding views on aviation and climate change, and 3) whether the use of polarised language (sentiment) or 'tagging' peers to increase issue salience differ across frames.

2. Literature review

In response to the accelerating climate crisis, media coverage of relevant scientific studies has increased substantially (Boykoff and Pearman, 2019). This corpus of media stories also addresses aviation, for example considerable attention was given to the United Nations Emissions Gap report that pointed to the challenge of aviation emissions (27% growth in the five years leading up to the COVID-19 crisis) and insufficient policy frameworks to address these effectively (UNEP, 2020). Media attention (Beyers et al., 2018) is an indicator that a topic is relevant to people, or is considered newsworthy by editors. Limited media research has been undertaken in the context of aviation and climate change, although Peeters et al. (2016) reviewed print media cycles to examine the public discourse associated with new technological solutions to reduce aircraft emissions. With the popularity of social media, the way public opinion forms and manifests is becoming increasingly complex.

2.1. A modern communication system

Information shared by mainstream media is intertwined with social media activity in that traditional news channels use online platforms to link back to their stories (Yaqub et al., 2017), but also in that other users draw on news articles in their posting activity. The top part of Fig. 1 illustrates the blurred lines between traditional and social media, and exchanges amongst individual and organisational actors. Social media represent an influential channel both seeding and shaping discussions on – often political – issues (Roxburgh et al., 2019). Whilst providing an egalitarian communication structure, many social media conversations are "mediated by opinion leaders, knowledgeable, media-savvy individuals who could influence the opinions of people in their circle of friends and relatives" (Kirilenko and Stepchenkova, 2014, p. 180). The role of social media in aviation studies remains underresearched (Becken et al., 2021; Chung et al., 2020; Punel and Ermagon, 2018; Vo et al., 2019).

Public communication by individuals, political actors and traditional media influences what other people know and how they feel about a particular issue (Park et al., 2015). The process involves agenda setting and frame building around salient topics (McLennan et al., 2015) that people engage with both cognitively and behaviourally (Miller et al., 2016). As illustrated in Fig. 1, 'people' relates to those who develop frames as well as those who receive them (Scheufele and Tweksbury, 2007). Frames are to be understood as selectively depicting particular aspects of 'reality' (Moernaut et al., 2019). The effects of a frame are moderated by the channel (Spartz et al., 2017) and the context of recipients' environment, culture and politics. Personal experiences of

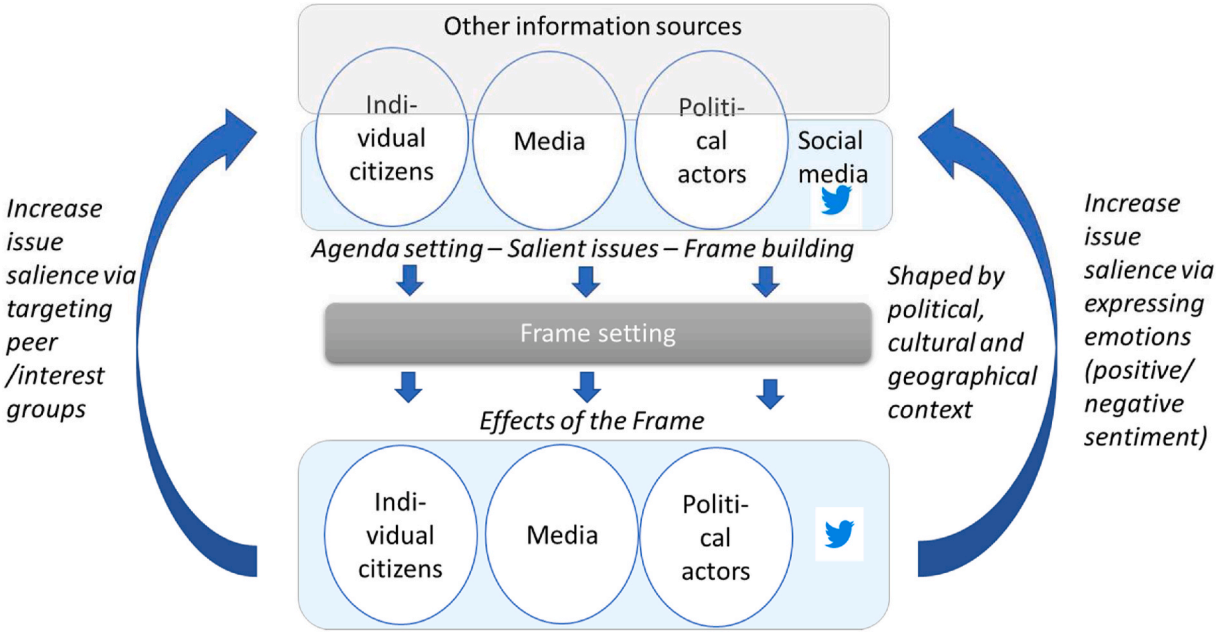


Fig. 1. Conceptual framework of a complex communication system where individuals, media and political actors interact to set frames that in turn shape what communicators consider relevant to include in their information sharing behaviour (Source: authors building on literature summarised in the text).

unusual weather events, for example, have a discernible impact on people's perceptions of climate risk (Sisco et al., 2017). When such events are covered by the media, public opinion is further influenced, manifesting in peak levels of social media activity (Kirilenko and Stepchenkova, 2014).

Different frames resonate with different interest groups (Scheufele and Tweksbury, 2007), for example based on political affiliation (Jang and Hart, 2015). Earlier research on climate change coverage in Dutch and French newspapers, that built on five generic frames proposed by Semetko and Valkenburg (2000), identified common frames related to 'consequences' and 'responsibility', but less so 'morality'. The conflict and human-interest frames appeared in articles involving climate skeptics. One of the most comprehensive analyses of frames is by Card et al. (2015), who used the "Media Frames Corpus" on over 20,000 news articles to derive 15 common media frames. Of these, the economic, fairness and equality, public opinion, and quality of life frames could be particularly relevant for the issue of air travel and climate change. Identifying frames used in the aviation emission context helps decision-makers understand how different members of the public make sense of and construct their 'reality' around this challenging issue (Larsson, 2019) and how to engage with them (Punel and Ermagun, 2018).

2.2. Increasing issue salience

People feel different emotions when confronted with different frames (Eberl et al., 2020), as these either confirm or collide with existing templates that individuals identify with. In the context of flying, and using qualitative methods, Larrson (2019) identified the specific frames of 'shaming' and 'lifestyle changes'. Social media users express their 'voice' (Sezgen et al., 2019) when leaving comments, placing emoticons (or 'like' buttons) or reposting material (Yaqub et al., 2017), and big data analytics are capable of detecting these across large data sets. Research found that the sentiment of a message (i.e. positive or negative) has an impact on how users engage emotionally (Eberl et al., 2020) (Fig. 1, right). Furthermore, Spartz et al. (2017) established that the 'number of views' displayed under climate change YouTube videos influenced how important viewers thought the issue was. Companies can proactively influence sentiment. Vo et al. (2019) found that airlines with a strong Corporate Social Responsibility (CSR) record receive more positive world-of-mouth on Twitter compared with less engaged businesses. Another way to increase issue salience is to connect to peer groups, for example by using hashtags or tagging prominent personalities (Becken et al., 2021) (Fig. 1, left). Peer groups in social media networks have become increasingly important to mobilise like-minded people for politically motivated movements (Park et al., 2015) or to expose 'others' (e.g. flightshame, Larsson, 2019). This is significant if shifting discourse affects social norms and acceptability of flying (Gössling et al., 2020).

A key question is how to measure salience. Different approaches have been suggested, such as examining the number of mentions of an issue in Facebook posts (Eberl et al., 2020), or the resources spent by an organisation on an issue (Beyers et al., 2018). Some have used citizen surveys to gauge salient issues (Dennison, 2019), either at a personal or collective level (Beyers et al., 2018). Miller et al. (2016) suggest that personal perspectives (e.g., values, self-interest or identity) override national concerns, but in practice it is challenging to separate the two. Especially in the wider cacophony of social media, the analysis presented here is likely to extract a combination of both types of salience. Acknowledging these complexities, this research draws on diverse and unmoderated (Jang and Hart, 2015) Twitter posts to examine the issue salience of aviation within the wider climate change discourse.

3. Method

Twitter offers a rich and relevant data source for analysing public opinion. This research used a public API (Application Programming Interface) to extract posts. Twitter is a global platform reaching 73 million monthly users in the USA, 56 in Japan, 22 in India, 18 in the UK, 17 in Brazil, and 16 million each in Indonesia and Turkey, to name the top countries (Statista, 2021). Even at the length limit of 280 characters per tweet, the space limitation means that Twitter messages tend to lack nuance, which – whilst potentially polarising– enables a relatively more straightforward analysis.

3.1. Scope

The scope of this research is defined by tweets that address aviation and climate change. Data were collected from the 22 September - 31 December 2019. This timeframe covers several major events, starting with the UN Climate Action Summit in New York, natural climate disasters, and youth school strikes. We used the API to extract tweets that discussed climate change using the relevant keywords shown in Table 1. This helped capture a baseline of climate change related tweets, within which aviation-related posts could be identified (N = 326,178) using a small number of explicit keywords that are highly relevant to the topic. In other words, the aviation-related keywords in Table 1 helped filter the stored climate change tweets. The keywords were selected by starting with most obvious ones (e.g. airline, airplane, aircraft, aviation), followed by manual examination of a sample of extracted posts to find additional keywords, for example 'flying' and 'jets'. These were added to extract the final set of tweets. Due to the choice of keywords, English posts were extracted, although a small number of tweets contain a combination of English and non-English words.

3.2. Processing of data and analysis

All data was stored for processing in a MongoDB database located at the big data cluster at Griffith University, Australia.

3.2.1. Temporal and spatial analysis

Tweets were downloaded alongside their date of posting. To assess 'relative salience' (Beyers et al., 2018), we normalised the 326,178 aviation tweets by all climate change tweets to derive a measure of percentage of aviation tweets per day. Further, to capture the geographic context of aviation-climate discussions, information on the origin of Twitter users was collected. A python code was developed to identify a user's country of origin, whereby the location specified by the user was used as a reasonable proxy for their country of residence. As a reference, a library was applied to identify the country name (www.geonames.org; see Kirilenko and Stepchenkova, 2014). Several issues inhibited accurate mapping, including that not all users provided a location, some place names could be mapped to multiple countries, and some locations only specified a region (e.g. Europe or EU). Out of the 18 milion climate related tweets, we were able to map 56%, and out of the aviation-specific posts we mapped 51%.

3.2.2. Frames analysis

The identification of frames is usually undertaken through content

Table 1
Database for 'climate change' and 'aviation-related' posts.

Scope	Keywords (at least one in a post)	Time frame	N Tweets
Climate change	Climate change, climatechange, carbon, CO_2	22 September - 31 December 2019	18,059,299
Aviation-related (subset of the above)	airplane, airplanes, aircraft, airline, airport, aviation, flight, flights, flying, fly, plane, planes, travel, jet, jets	22 September - 31 December 2019	326,178, of which 54,291 posts were original (not retweeted)

analysis or manual annotation of text or images (e.g. Larssen, 2019). However, when it comes to large volumes of data, traditional methods are not practical. Therefore, an automated multi-step method to recognise frames via computer-based topic modelling was developed (Fig. 2). Only original tweets, that is posts that did not start with 'RT' for retweet, were included (N = 54,291 aviation-related posts). The first step involved data cleaning. Hyperlinks, account names, English stop words and those shorter than three characters were removed from a post. Additionally, all words other than nouns, adjectives, and adverbs were removed, as it has been shown that these are not indicative of frames (Burscher et al., 2015), and similar words were merged (e.g. good and better) (so-called lemmatization, Bird, 2006). Finally, we removed words that appeared in less than 10% or more than 20% of all texts, because their very low or high frequency does not differentiate between topics (see also Rehurek and Sojka, 2010). For the pre-processing, we relied on purpose-built Python code and natural language toolkit *nltk* (Bird, 2006).

Second, it was important to determine topics in tweets so that these could be clustered meaningfully and assigned to frames. The pre-processed tweets were segmented into tokens (words after stemming, e.g. "fly[ing]"). Each token was assigned the number of times it occurs in the post (TF), weighted by the Inverse Document Frequency (IDF) of posts in the data set containing the word. To train the model for topic modelling, we built upon the Python framework *gensin* (Rehurek and Sojka, 2010). Then, the Latent Dirichlet Allocation (LDA) was used to extract features in posts. Based on the trained model we performed testing, whereby as a starting point we selected 15 possible topics with each topic described by ten most common tokens. To ensure the model is not trapped in local minima we ran 50 passes. The list of ten tokens for the 15 topics and associated weights is shown in the Appendix (Table 4). Based on the Gaussian-like distribution of the number of posts allocated to an individual topic, it appears that the modelling was not trapped in local minima (Appendix, Fig. 8).

Once the LDA model had helped to select 15 topics, we looped every post to calculate post vectors, and assigned each post to the most relevant topic. To reduce the 15 topics into more manageable clusters that suitably capture perspectives on the issue of aviation emissions, we utilized the widely accepted *Elbow method* (Thorndike, 1953). To implement the *Elbow* method, we created a Python code which clustered the 15 topics and calculated corresponding errors. The optimal number of clusters is when the graph between the number of clusters and the corresponding error value has an elbow. In our case, the elbow is at 5 clusters (Appendix, Fig. 9). Topics were clustered calculating the *Jaccard* distance between topics using *MinHash*. The final step involved a comparison of each cluster (and its topics and tokens) with generic media frames from the literature (Card et al., 2015; Dirikx and Gelders, 2010; Semetko and Valkenburg, 2000). A suitable name was given to each cluster to describe the frame.

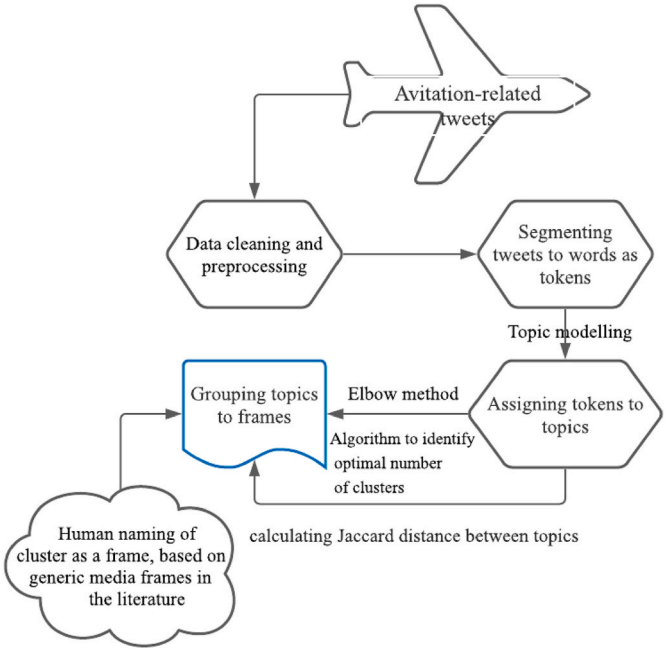


Fig. 2. Process of assigning tweets to frames.

3.2.3. Sentiment analysis

During the above-mentioned looping process, we also calculated sentiment polarity (see Vo et al., 2019) for each original tweet (N = 54,291). To perform sentiment calculation, the lexicon- and rule-based based polarity calculation method VADER (Valence Aware Dictionary and Sentiment Reasoner) was applied (Hutto, 2014; Alaei et al., 2019), which is specifically suited for short text such as tweets and provides more nuanced results than other algorithms (Boghe, 2020). We opted for a lexicon-based model to avoid costly annotation. To ensure higher accuracy in sentiment calculation, we extended existing lexicon with domain specific terms and also adjusted weights. Recent work by Barakat et al. (2021) shows that training the algorithm with aviation-specific data would likely improve performance.

3.2.4. Network analysis

On Twitter, people can tag and retweet other users, and these interaction among users (or nodes) represent a network. Examining the characteristics of a network can help understand information flows, and who is seen as influential in a network community. To this end, a directed network relevant to aviation-climate change discussions on Twitter was generated using Gephi (2020). The connections of users in the network were measured by degree centrality (Zhang, 2017), whereby the more connections one user has the more likely it is that this particular actor has influence over the topic (Casanueva et al., 2016). More specifically, in-degree centrality represents the number of times a user is retweeted or mentioned (using @). For example, in a network with node A and node B, and A directing a post to B, both of them have a degree centrality of one, but node A has one out-degree while node B has one in-degree. High in-degree centrality users are considered to have prestige and importance (Riddell et al., 2017). The distance among nodes was calculated to examine how closely users are connected in the different frames using two parameters: Network Diameter (ND) and Average Path Length (APL). The ND is the maximum distance between any pair of nodes in the network, and users are more engaged in the frame if the diameter of the frame network is smaller. The APL measures the communication efficiency for a network, with a lower value APL indicating that the network is relatively more efficient (Cherven, 2015). Furthermore, based on the interactions of the nodes, a network can be divided into different communities. These communities can be visualised by colour, and the dominant user for each community is evident through the node size.

3.3. Limitations

There are limitations to using Twitter data, including its inherent population bias. However, since this research specifically focuses on the actor group of Twitter users and what is important to them, this bias is not consequential for the findings. It becomes more problematic when extrapolating to the wider population, especially given that Twitter uptake differs by country. Since our focus is on the relative salience of aviation posts within the wider Twitter climate change discussion, these limitations do not affect the research findings. The assessment of whether particular events triggered higher Twitter activity does not represent a causal analysis, but relies on most popular keywords identified for selected dates.

Another limitation is that this research selected English language

keywords for filtering tweets, meaning that other languages are not represented (see Barakat et al. (2021), who also analysed tweets in Arabic). Whilst English is the single most prevalent language used in tweets (34%, Statista, 2013), our research is biased towards countries where English is the main language, disadvantaging input from countries where English tweets make up only a share of posts (e.g. Poblete et al., 2011). The focus on English posts is of less concern for the analysis of relative salience, but it affects the frame analysis. Given that climate change is a global problem and many discussions (and stories, e.g. released by the United Nations) are in English, the analysis still has validity. Future research should verify whether the same frames emerge in other languages. It is important to note that posts only reveal information that a particular account holder wishes to be seen in public (Kirilenko and Stepchenkova, 2014), and this often includes a pseudo instead of an identifiable identity; hence privacy is assured.

4. Results

4.1. Issue salience of the aviation-climate change issue

The average daily volume of climate change tweets is 209,195. The data show considerable variation, between about 100,000 and 800,000 tweets per day, indicating that aviation and climate change is not constantly a highly talked about topic, but rather conversations spike in response to particular events or viral tweets. The peak in climate change tweets overall, for example, was observed one day after the United Nations Climate Action Summit in New York on 23rd of September (Fig. 3). Variability was also high across the total number of 326,178 aviation-related posts (including original and retweeted). For example, whilst the average daily number of aviation-related posts was 3254 (contributing 1.8% to climate change posts), the volume went up to 64,602 on the 2nd and 15,787 on the 3rd of December. The December days associate with the UNFCCC Climate Change conference in Madrid, and the highest share of aviation-related tweets (23.4% of climate posts). Closer examination reveals that the peak is largely caused by retweets of a single post that denounced rich people using personal jets for pleasure whilst others were being asked to change their behaviour. Whilst such retweet behaviour might not indicate richness of the conversation, it does reflect that the original post resonated with a large number of people who increased issue salience by rebroadcasting it. A smaller peak of aviation-related tweets was observed early November when Greta Thunberg asked for help to sail to Europe.

The largest number of climate-related tweets came from the USA with 4.6 million posts (25.4% of mapped posts), and the UK were second (17.3%), Australia third (9.8%), Canada fourth (8.5%), and India fifth (3.4%). Since these numbers are biased towards English-speaking countries, it is more interesting to consider the aviation-specific conversations, and more specifically the relative share of aviation posts within all climate change tweets (Fig. 4). This provides a better measure of salience of the climate-aviation nexus in different countries. The highest percentages of aviation tweets were found in Bahrein (4.2%) and Nicaragua (4.0%), but both countries recorded only small volumes of aviation posts (50 and 30, respectively). Other countries with higher Twitter activity and high aviation salience were Puerto Rico and Portugal (3.1%, respectively), Qatar (2.8%), Spain (2.7%), France (2.6%), and Malaysia and Romania (2.5%, respectively). Countries with lower shares were the United Kingdom at 1.9%, the USA at 1.8%, and Australia with only 0.7%, indicating that aviation is a less salient topic in the online climate debates.

4.2. Frame analysis

The second research objective was to identify frames, which is a useful way of capturing different, and potentially opposed, views of the publics towards aviation and climate change. Based on the tokens and topics, we distinguish five frames (topic clusters). Table 2 presents the

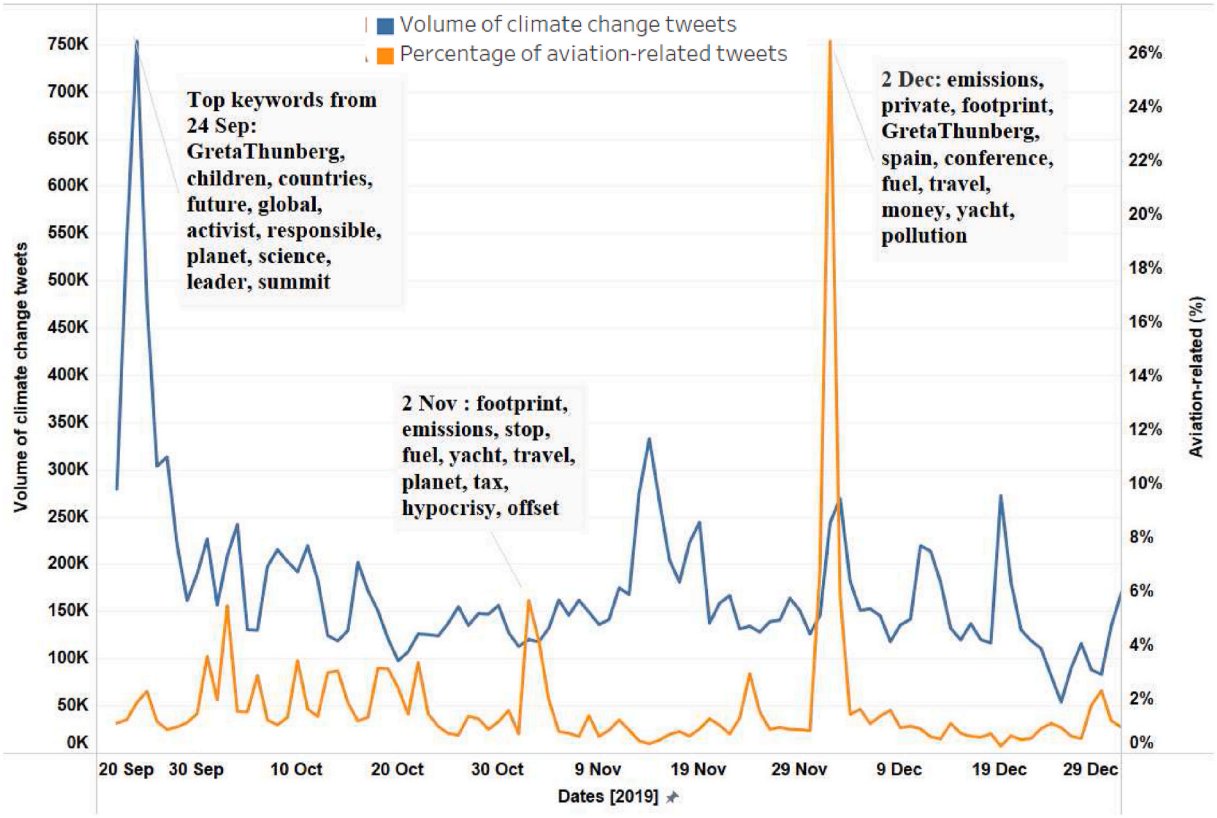


Fig. 3. Climate change tweets and percentage of aviation-related tweets.

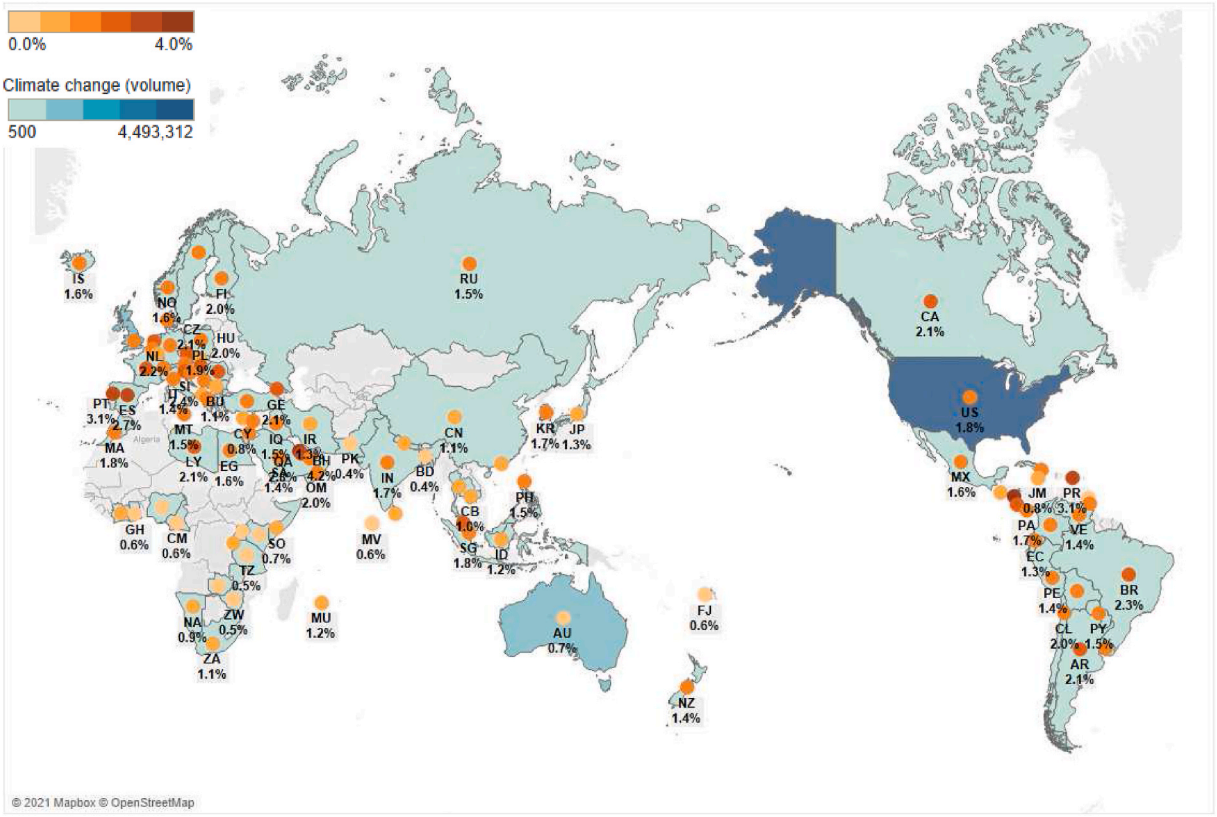


Fig. 4. Geographic origins of Twitter posts on climate change (by number) and the subset of aviation posts (as %).

Table 2
Frames identified in the Twitter corpus of aviation-related climate change posts.

Frame name	Description	Topics clustered to this frame (Table 4)	Key tokens/words
1. Economic and industry	Builds on 'economic consequences' (Semetko and Valkenburg, 2000) and 'capacity and resources frames' (Card et al., 2015)	1, 2, 3	Airport, industry, conscience, expansion, fuel, target
2. Public opinion	Relates to attitudes and opinions of the general public (Card et al., 2015)	4, 5, 6	Plane, protest, arrest, shame, quite, flight, flying, tourism
3. Fairness and conflict	Relates to 'conflict' frame in Semetko and Valkenburg (2000), highlighting opposing views and behaviours, including those of elites (see 'fairness and equality' frame by Card et al., 2015)	7, 8, 9	Private, footprint, plane, boat, sail, people, world, crew
4. Consequences	Highlights how climate change will affect people (Dirikx and Gelders, 2010)	10, 11, 12	Weather, average, affect, atmospheric, cause, bushfires, stream, ice, warm
5. Responsibility	'Responsibility' frame in Semetko and Valkenburg (2000), referring to who can do what to address issue	13, 14, 15	Flight, offset, reduce, electric, neutral, train, net, credit

frames, a description, and selected key words that were identified in the machine-based algorithm.

Posts were probabilistically assigned to frames and the frame with the highest probability was selected. For example, the following offsetting post was identified as an economic frame, although the algorithm also detected some relation to the responsibility frame: "*How the aviation industry's carbon offsetting scheme will work. According to ICAO data, airlines will spend between $5.3 billion and $23.9 billion of CO2 reductions elsewhere depending on the future price of units in the carbon market*". The most prevalent frame relates to fairness and conflict (Fig. 5), although the responsibility frame became most common in mid-November 2019. The fairness frame peaked again in early December, with the following sample post illustrating a key concern: "*Did ever notice that ALL these climate change experts, ppl in Hollywood, politicians & lobbyists live in huge houses, fly all over the world, tell US how to live but it doesn't apply to them*?" The notion of flightshame was evident in posts that formed part of the public opinion frame. For example, a post from the 7th of October read "*Flying shame: Greta Thunberg gave up flights to fight climate change Should you - Vox* ".

4.3. Increasing issue salience

Social media users deploy a range of tools to increase the salience of their message. Two known approaches include the use of emotional language, and the other one involves connecting to like-minded people in a network. Sentiment analysis helps quantify the negative or positive sentiment of a post. Calculating a score for each post reveals two main insights. First, that sentiment is not constant but fluctuates depending on the dominant conversation (Fig. 3 above). Second, the five different frames display different levels of positivity or negativity (Fig. 6). The responsibility frame trends as the most positive one, which is maybe not surprising as it contains aspirations of addressing aviation-related climate impacts. In contrast, the fairness-related frame appears the most consistently negative, likely because people are sensitive to conflict and evidence of inequality. The remaining three frames are more volatile in their sentiment. For example, the consequences and impact frame

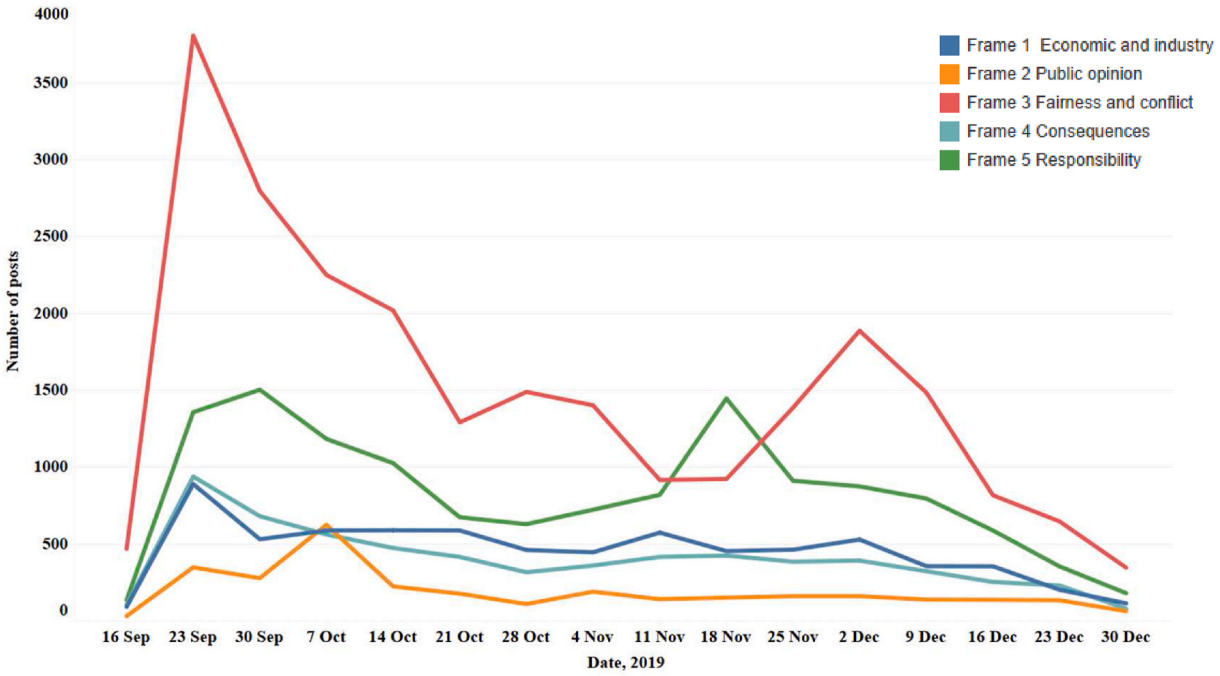


Fig. 5. The average number of posts per week for the five frames.

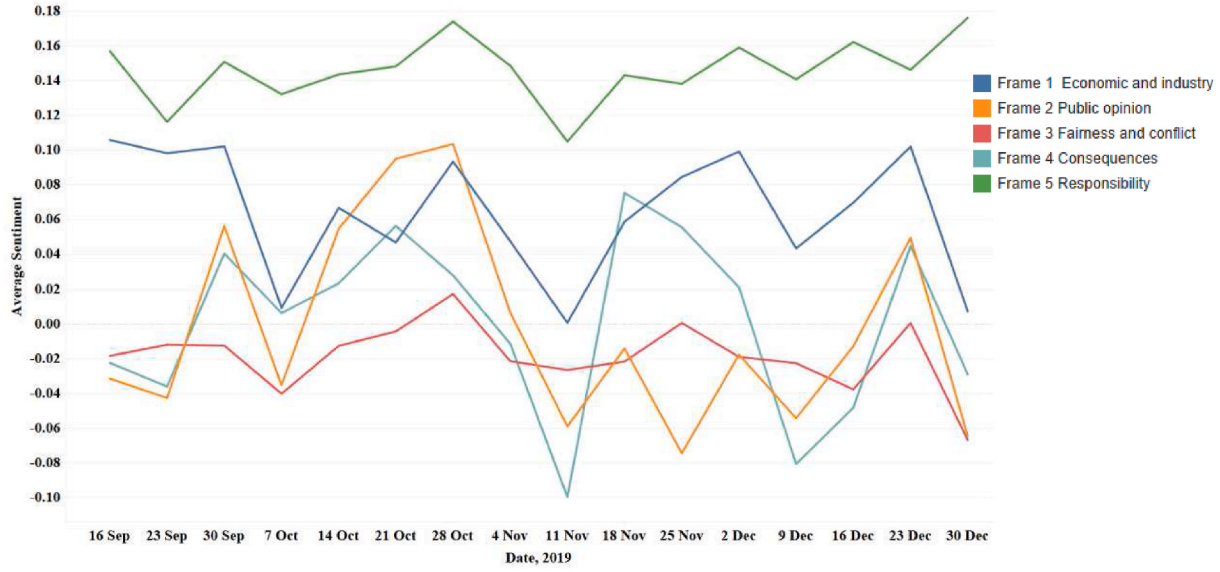


Fig. 6. Average sentiment per week of different frames. Average scores across the study period are: Frame 1 (0.0647), Frame 2 (−0.0282), Frame 3 (−0.0166), Frame 4 (0.0082) and Frame 5 (0.1375).

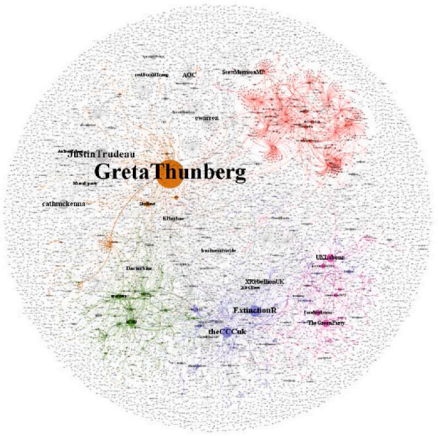
shows the most negative average sentiment across the timeline in the middle of November. An example reads: "*Unfortunately it is too late. We are to suffer a cataclysm, even if we all stopped driving and flying tomorrow. #ClimateChange #ExtinctionRebellion*". Another negative post commented on unusual weather conditions in Europe: "*SEVERE -30C (−22F) SNOWSTORMS TO STRIKE PARTS OF EUROPE. This is 'Climate Change' - just not as you might know it. The lower-latitudes are refreezing in line with historically low solar activity, as a wavy jet stream diverts Arctic air unusually-far south*".

The dataset revealed considerable extent of rebroadcasting, with a proportion of retweets of 81.2%. Analysis of whether polarised sentiment led to higher retweet rates was inconclusive, partly because of a skewed distribution towards posts with only very small number of retweets. The fairness and conflict frame made the highest overall contribution to the corpus of Twitter posts in the sample (44.4%), although when focusing on original posts this reduced to (38.2%). This means that Twitter conversations that address aspects of fairness related to aviation and climate change are particularly likely to be reposts of other people's views (Table 3). In contrast, the economic and industry and the responsibility frame represented more diverse and original conversations, which can be seen in their relatively higher shares of original posts.

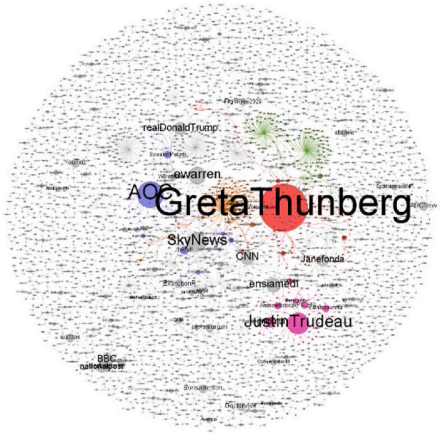
In addition to re-tweets, users tag other people to establish a connection either because they feel the topic is of interest to this user or because they want to tap into that person's (potentially large) network of followers. The networks shown in Fig. 7 represent individual users,

Table 3
Retweets and original posts in the Twitter sample.

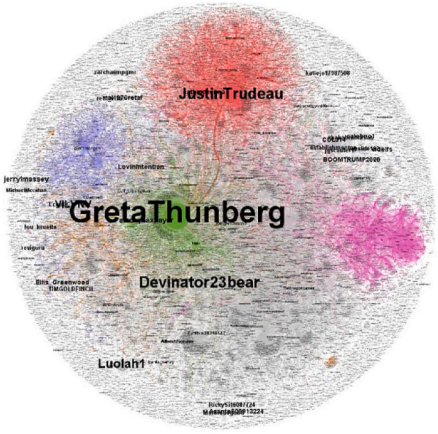
Frame	Number of posts	Percentage of posts in sample (%)	Number of original posts	Percentage of original posts	Relative change (%)
1. Economic and industry	7302	13.45	1831	16.84	25.22
2. Public opinion	3134	5.77	657	6.04	4.69
3. Fairness and conflict	24,111	44.41	4153	38.20	−13.99
4. Conse-quences	6427	11.84	1328	12.21	3.18
5. Respon-sibility	13,317	24.53	2903	26.70	8.86
Total	54,291		10,872		



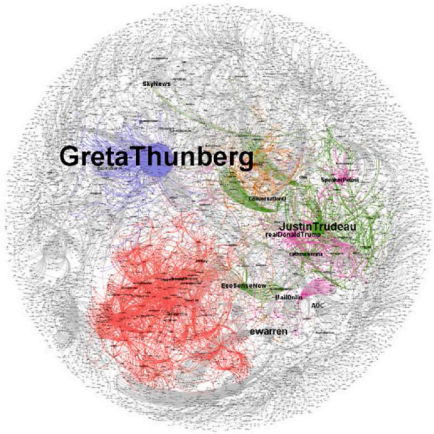
6a) Economy and industry (ND: 14, APL:4.21)



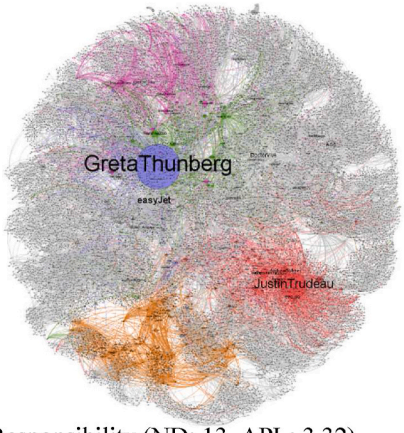
6b) Public opinion (ND: 3, APL: 1.12)



6c) Fairness and conflict (ND: 13, APL: 3.32)



6d) Consequences (ND: 12, APL: 3.35)



6e) Responsibility (ND: 13, APL: 3.32)

Fig. 7. In-degree centrality networks for the five frames.

whereby the size of the nodes corresponds to their in-degree centrality. All frames link to Greta Thunberg as a leading climate activist. When users often tag or re-tweet each other, they will be recognised as the same community (Gephi, 2009). The networks for each frame visualise the top five communities in different colours. Network Diameter (ND) and APL are also shown. Each frame has different numbers of users and communities, but the public opinion frame demonstrated the highest connection and efficient communication amongst users. It also shows a traditional media outlet (Sky News) as one of the most influential nodes, highlighting the interwovenness of different communication channels. The consequences frame has closer connections between users, compared with the fairness and conflict frame, noting that this is the largest frame in terms of volume and number of communities. Responsibility has a similar structure to the fairness frame, and displays the second largest number of communities. Economic and industry is the least connected frame. It is the second smallest – and as such perhaps less influential than the other frames.

5. Discussion

5.1. Aviation and climate change issue salience varies across time and borders

Social media analysis based on Twitter posts in late 2019 revealed variable interest in aviation as a topic within wider climate change discussions. With an average daily volume of 4838 extracted posts, English language aviation-related tweets represent a relatively small subset of posts, compared with other topics of interest such as the 2016 Presidential election in America, where tweets about Clinton and Trump were in the order of 55,000 and 75,000 per day, respectively (Yaqub et al., 2017). This present study was not influenced by the COVID-19 crisis, as media coverage of the virus only began in January 2020. As a result, the findings present a baseline of pre-pandemic social media activity on discussions related to aviation and the climate crisis. Given the socio-economic importance of air travel (Forsyth, 2006), understanding public communication is valuable – especially since it can influence actual climate policy decisions (Boykoff and Pearman, 2019). This research presents a machine-driven approach that is suitable for large datasets.

Aviation-related tweets represent a small but occasionally substantial subset of climate change posts that peaks in response to particular events (Kirilenko and Stepchenkova, 2014; Sisco et al., 2017). The UNFCCC Climate Change summit in Madrid in December 2020, for example, sparked high activity in the context of hypocricy and inequality of access to air travel (Becken et al., 2021). Whilst the research method favoured English language posts, the geographic analysis did show that the issue of aviation and climate change is of interest globally. When looking at relative issue salience, there was above-average interest in countries such as Portugal and Puerto Rico, and to a lesser extent in the UK and Scandinavia. However, the USA, Australia and Japan revealed notably lower relative issue salience. It would be useful to complement this present work with an analysis of mainstream media, as well as in non-English social media activity (including platforms such as Weibo, Liu & Zhao, 2017). The methodology developed here for mapping relative issue salience and detecting frames within large datasets could be easily extended, and this would provide a deeper insight into perspectives of citizens from non-English countries.

The machine-based topic modelling approach helped to identify five key frames, namely economy and industry, public opinion, fairness and conflict, consequences and responsibility. The existence of different frames highlights the diverse – and sometimes polarised (Jang and Hart, 2015) – landscape of the Twitter communication network. Understanding the relative volume and dynamics of these frames is helpful to decision-makers involved in aviation. For example, the dominance of the fairness and conflict frame should be of concern to policy makers who consider different policy options to reduce emissions effectively and legitimately. The responsibility frame is pertinent to industry leaders and confirms the importance of (genuine and proactive) engagement in CSR activities to weather various crises (Vo et al., 2019). However, the analysis also revealed some overlap across frames, for example questions around conscience were apparent in the economy and industry frame, but might also resonate with the responsibility frame. It is here where the automated process of deriving clusters via tokens and topics might fall short and could be strengthened by manual annotation. The word conscience, for example, could indicate the lack thereof or its existence, leading to a potentially directly opposed content of the message. Future research could test the frames (e.g. through expert interviews), including their conceptual relationships, and use those findings to improve the algorithm. Frames could also be tested against commercial customer segments, for example those derived from online reviews (Sezgen et al., 2019).

5.2. Sentiment of frames differs

Sentiment analysis, as illustrated in this research, assists further in differentiating frames. The negative sentiment associated with the public opinion and fairness and conflict frames should be of concern, even though this finding is perhaps not surprising given that public opinion was strongly associated with flightshame, which in itself had been linked to questions around travelling elites and meaningless climate promises (Becken et al., 2020). The vast inequalities associated with aviation emissions have been unearthed by Gössling and Humpe (2020) who found that 1% of global population are responsible for 50% of commercial aviation emissions. Frequent flyer taxes and more aggressive demand management then seem to be policies that might resonate with the public; and are required from a climate action point of view (UNEP, 2020). These might not appeal to airlines, especially when business models rely heavily on higher yielding premium classes.

In contrast, the economic frame was associated with positive sentiment, perhaps because people connect flying with positive emotions, and because posts that discussed industry action (e.g. targets) are welcome. Again, domain-specific human annotation or deep learning (Barakat et al., 2021) would likely improve accuracy of sentiment algorithms (Boghe, 2020), for example the word 'alternative' (e.g. alternative aviation fuels, Soria Baledón and Kosoy, 2018) is positive in the context of carbon emissions; but is currently not recognised as such in the VADER algorithm. Understanding polarity is important as this could affect issue salience (Firdaus et al., 2018). In this research, it was difficult to discern whether highly polarised tweets received more attention (see framework of Fig. 1), but one avenue for future work would be to develop an experiment to specifically test the impact of different word choices and associated sentiment in the wider communication network. Another avenue of research would be to explore what aviation stakeholders could do to increase the positive connotations of particular frames, for example through climate actions or targeted communication.

5.3. The identified frames display different networks structures and behaviours

Retweet rates were high at 81% of posts, compared with rates of 70% and below mentioned in the literature (Chen et al., 2020). This finding highlights that – as in traditional media where similar messages keep being reinforced (Becken, 2014) – the conversation can be disproportionally shaped by a small number of tweets (and account holders) (Firdaus et al., 2018). For example, the single most retweeted post with close to 56,000 re-posts reads: "*yeah billionaires taking personal jets everywhere just to go for DINNER and we nobodies gotta think thrice asking for plastic bags to carry groceries cause it increases the carbon [*rude word*] footprint*". This example then raises questions whether the post was retweeted because it did strike a chord with social media users, or whether it is the post itself that shapes opinions - or sets the agenda – on

the climate-aviation nexus (see Fig. 1 of users as sender and audience, Scheufele and Tweksbury, 2007). In the communication system's ability to rebroadcast so efficiently lies a major danger. Different to (more closed) traditional systems that are subject to a code of ethics of journalism, the social media system is democratically open to all information and users (including most political leaders, Statista, 2021). This is concerning because research has demonstrated that false information spreads both farther and faster on Twitter than the truth (Vosoughi et al., 2018).

The analysis of the retweet/tag network on aviation-related climate change posts visualises the decentralised structure of users associated with the five different frames. As in other research, Twitter networks are quite dispersed, but can be characterised by a small number of influential nodes (Park et al., 2015). Often these sub-sets or communities are not connected, but within themselves display a marked core-periphery structure (Bastos et al., 2018). The small and poorly connected network of the economic and industry frame deserves more attention as it might indicate that aviation stakeholders are not well represented in the communication system. Instead, Greta Thunberg appeared as the most influential node across all frames. This is not surprising, given the central role the young Swedish climate activist plays in the anti-flying movement (Becken et al., 2020). Mkono et al. (2020) established that the majority Facebook user posts in response to stories by BBC, CNN, and Sky News expressed negative views towards Thunberg, although about one third indicated attitudes of admiration and inspiration. Future research could further investigate the nodes identified across the five frames and determine the nature of the Twitter account (e.g. individual, organisation or political actor). More detailed content analysis would reveal potential 'hidden agendas', broader context (e.g. beyond the aviation climate discussion) and role in the modern communication system.

6. Conclusion

At times of critical discourse moments (Becken, 2014), it might be the combination of a new idea (e.g. not flying), and the ability to 'go viral' that contributes to tipping points that turn societal beliefs or catalyse revolutionary movements (Park et al., 2015). The time leading up to the COVID-19 crisis might have presented such a critical moment (e.g. Gössling et al., 2019), although it is now likely that public opinion will also be shaped by airline recovery and renewed positioning of the aviation-climate discussion. Government support packages that fail to account for 'green recovery', for example, are being criticised (UNEP, 2020), and calls for low-carbon aviation (Becken and Carmignani, 2020) might converge with grassroot drivers requesting greater sustainability. Thus, the long-term challenge for airlines to effectively address global climate change continues, and analyses of issue salience such as this are useful for all stakeholders involved in the industry. This paper makes an important contribution in that it provides a methodology, as well as an important baseline to monitor different ways how the public frame the climate-aviation nexus.

Conceptualising a modern communication system has helped to highlight the crucial role of social media in co-shaping discourse, opinion, and perhaps political action (Miller et al., 2016). Drawing on Twitter data from the last quarter of 2019, this research revealed that there is at times considerable interest in the issue of aviation and climate change. Whilst salience varies not only across time but also by country, the data revealed that certain types of events may cause viral activity. The example of a cynical post regarding a United Nations climate summit illustrated this. The research revealed five common frames, with the most prominent ones relating to fairness and equality, and taking responsibility. This sends important messages to aviation decision-makers who can proactively demonstrate progress on climate action and shape the conversations to potentially improve sentiment. The fairness frame also had a denser network and most negative polarity. As such, it is likely to be more influential than other frames. In contrast, the responsibility frame with its positive sentiment provides potential to further encourage action across all levels; individuals, industry and politicians – all of whom form part of the Twitter communication system. The other three frames identified in the machine-based approach, displayed various levels of activity and sentiment, and further work would be beneficial to validate frames through manual coding, deep learning and drawing data from other platforms and languages. For a highly disrupted global aviation industry, understanding the public, engaging in climate change and communicating good practice will be important going forward.

CRediT authorship contribution statement

Susanne Becken: Conceptualization, Methodology, Writing – original draft. **Bela Stantic:** Data curation, Software, and, Formal analysis. **Jinyan Chen:** Formal analysis, Investigation, Visualization. **Rod M. Connolly:** Writing – review & editing.

Appendix

Table 4
Topics and their associated key tokens (with weight indicating importance within topic)

Topic	Token1	Token2	Token3	Token4	Token5	Token6	Token7	Token8	Token9	Token10	Count
1	0.016airport	0.013aviation	0.011expansion	0.009fuel	0.008target	0.008emission	0.007tax	0.006flight	0.006amp	0.006plan	3821
2	0.032industry	0.025combine	0.024emit	0.024fashion	0.023ship	0.022international	0.021maritime	0.017flight	0.017the	0.016aviation	2001
3	0.008conscience	0.007fuel	0.006oil	0.006aviation	0.005power	0.005airplane	0.005emission	0.005official	0.005spend	0.005nuclear	1480
4	0.009plane	0.008flight	0.008chemtrails	0.007shame	0.006footprint	0.005seat	0.005species	0.005chemical	0.005inside	0.005coast	1338
5	0.021climb	0.018plane	0.017protest	0.016protester	0.013arrest	0.011flight	0.011did	0.011delay	0.010tonne	0.008catch	1030
6	0.010quit	0.008flight	0.008flying	0.006shame	0.006tourism	0.005part	0.005fart	0.005contributes	0.005tourist	0.005long	766
7	0.007plane	0.006amp	0.006stop	0.006people	0.006car	0.006footprint	0.005private	0.005use	0.005like	0.005go	4334
8	0.017private	0.008plane	0.008people	0.008world	0.007footprint	0.007like	0.007amp	0.007tax	0.006preach	0.006talk	13828
9	0.015footprint	0.012boat	0.010sail	0.010private	0.010crew	0.010plane	0.010thousand	0.009people	0.008stop	0.008she	5949
10	0.010person	0.010average	0.009year	0.009flight	0.009eat	0.008emission	0.008meat	0.008airplane	0.007time	0.007footprint	3767
11	0.016stream	0.007weather	0.007cause	0.007affect	0.007cold	0.007bushfires	0.007ice	0.006warm	0.006global	0.005baby	1750
12	0.011frequent	0.007initiative	0.006flyer		0.006stream	0.006cause	0.005doe	0.005aviation	0.005flight	0.005lead	910

(*continued on next page*)

Table 4 (*continued*)

Topic	Token1	Token2	Token3	Token4	Token5	Token6	Token7	Token8	Token9	Token10	Count
				0.006atmo-spheric							
13	0.012flight	0.009offset	0.008reduce	0.008emission	0.008travel	0.007footprint	0.007train	0.006plane	0.006year	0.006people	5554
14	0.011fuel	0.011aircraft	0.010emission	0.009flight	0.009electric	0.008aviation	0.006travel	0.006plane	0.006operate	0.006reduce	5019
15	0.055offset	0.040easyjet	0.033flight	0.027airline	0.026emission	0.018neutral	0.018domestic	0.015net	0.014credit	0.014zero"	2744

Note: amp is related to "&" and was included as a token as it fitted into the range of frequency and was not removed as extremes by LDA filter.

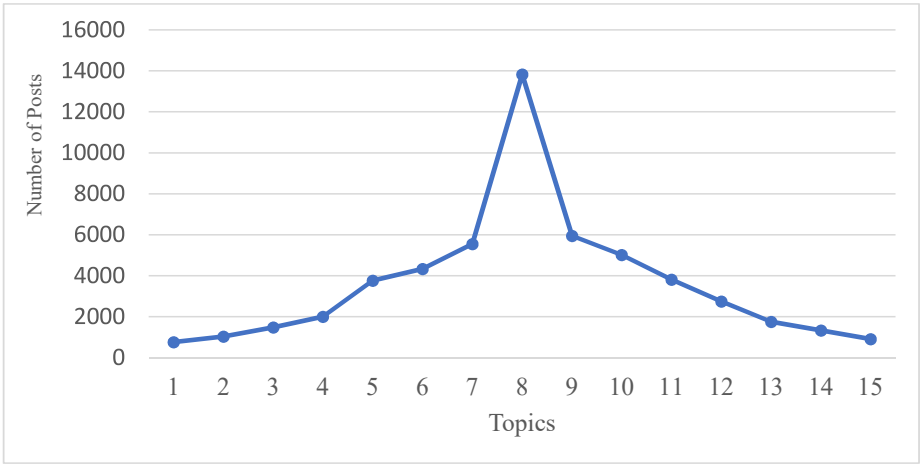


Fig. 8. Number of posts per topic.

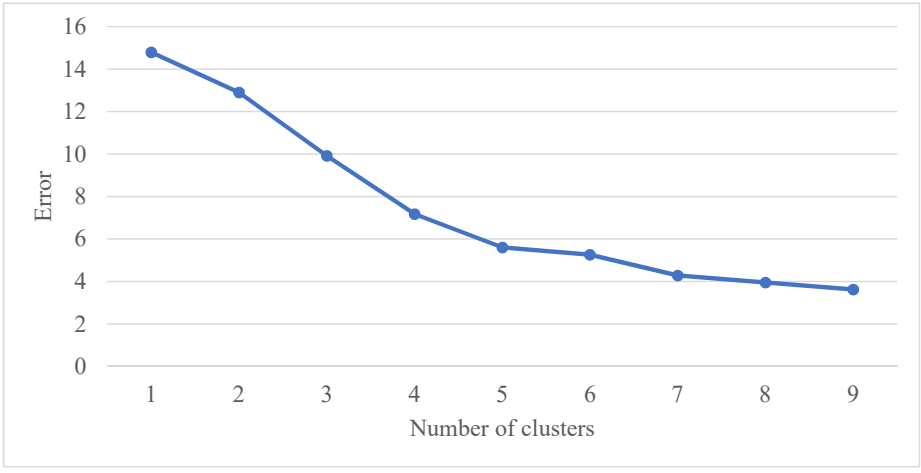


Fig. 9. Identification of the optimal number of clusters (Elbow Method).

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