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Vulnerable voices: using topic modeling to analyze newspaper coverage of climate change in 26 non-Annex I countries (2010–2020)

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Vulnerable voices: using topic modeling to analyze newspaper
coverage of climate change in 26 non-Annex I countries
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E-mail: mcallisterl@denison.edu**Keywords:** climate change, global warming, newspaper coverage, topic modeling, non-Annex I countries, panel data econometrics, multidimensional scalingSupplementary material for this article is available [online](#)

Abstract

News media influence how climate change is represented, understood, and discussed in the public sphere. To date, media and climate change research has primarily focused on Annex I countries, or treated non-Annex I countries as a homogenous bloc, despite the global nature of climate change and its geographically uneven impacts. This study uses a mixed-method approach, combining machine learning (topic modeling), econometrics, and qualitative analyses, to investigate newspaper coverage of climate change in 26 non-Annex I countries. We compiled a dataset of 95 216 news articles (dated between 2010 and 2020 from 50 sources) in 26 lower-middle and upper-middle income non-Annex I countries. In line with previous research results, we find that most common topics represented are international governance of climate change, the economics of energy transitions, and the impacts of climate change. Advancing current research understanding, we also demonstrate heterogeneity in coverage between non-Annex I countries and discover that a country's vulnerability to climate change is positively associated with the diversity of topics (based on an article-level entropy index) portrayed by its domestic news media outlets.

1. Introduction

Human-induced climate change severely threatens ecosystems (IPCC 2022) and human communities (Watts *et al* 2021). Media coverage critically influences how information reaches people, and how communities respond to climate impacts. In this study, we examine two key research questions: (1) what are the dominant themes of media coverage in lower-middle and upper-middle income non-Annex I countries? And (2) how do differences in the vulnerability of non-Annex I countries to climate change shape relevant news media coverage? The term 'non-Annex I' countries is derived from the text of the Kyoto

Protocol where 35 countries from Europe and North America agreed on targets and timetables for emissions reductions; while these countries were listed in 'Annex I' of the treaty, other countries were referred to as 'non-Annex I' parties (Glantz 2003).

Focusing on climate media coverage in non-Annex I countries is crucial for two key reasons. First and foremost is the *relative* lack of scholarly attention to these countries. For example, in a systematic cross-national literature review, Comfort and Park (2018) found that nearly three-quarters of their articles examined media and climate coverage in the United States (US) and wealthy European Union (EU) nations. This is likely due to Annex-I countries'

historical and ongoing role in emitting greenhouse gases (IPCC 2022, Friedrich *et al* 2023) and reliable scholarly access to data archives (Boykoff *et al* 2023). Scholars have thus repeatedly called for more research on climate change media coverage in non-Annex I countries (e.g. Schäfer and Schlichting 2014, Ghosh and Boykoff 2019, Boykoff *et al* 2021).

Second, scholars often group and study non-Annex I countries as a homogenous bloc. For example, *cross-national* comparative research often compares Western and non-Western countries (e.g. Painter and Ashe 2012, Schmidt *et al* 2013, Broadbent *et al* 2016, Engesser and Brüggemann 2016, Brüggemann and Engesser 2017, Gurwitt *et al* 2017, Vu *et al* 2019, Painter *et al* 2020, Schäfer and Painter 2020, Hase *et al* 2021, Ejaz *et al* 2022). This work has undoubtedly led to several insights. For example, recent studies by Vu *et al* (2019) and Hase *et al* (2021) showcase differences in media frames between wealthier and poorer countries (e.g. as a matter of politics and science vs. impacts on humans and their daily lives respectively). Other studies, such as Ejaz *et al* (2022), have also demonstrated areas of increasing global consensus such as public attitudes toward climate change. Yet, such comparative research also has limitations. It does not necessarily account for the *heterogeneity among non-Annex I countries* in journalistic cultures and context (Finlay 2012, Ajaero and Anorue 2018, Hase *et al* 2021). The unique social, economic, and political conditions of countries complicate the interpretation of findings (Olausson and Berglez 2014) due to ‘the often missing “functional equivalence” of measurements’ between countries (Wirth and Kolb cited in Schmidt *et al* 2013, p 1234).

Our paper addresses these dual challenges by comparing an expansive set of *economically similar* non-Annex I print media over 11 years (2010–2020). We systematically build a dataset that focuses on highly vulnerable countries (Schäfer and Schlichting 2014)—indicated by their ‘susceptibility to harm...exposure, sensitivity, and adaptive capacity’ (Ford *et al* 2018, p 194). Our data sample consists of 95 216 articles from 50 news sources in 26 non-Annex I countries: Bangladesh, Botswana, China, Egypt, Ghana, India, Indonesia, Jordan, Kenya, Lebanon, Malaysia, Namibia, Nepal, Nigeria, Pakistan, Philippines, South Africa, Sri Lanka, Tanzania, Thailand, Tunisia, Ukraine, Uzbekistan, Vietnam, Zambia, and Zimbabwe (see supplementary materials, table S1). We selected these countries as they are among the most vulnerable to climate change (Chen *et al* 2015). By focusing on examining *differences within a group of highly vulnerable, non-Annex I countries* we build upon and extend insights from existing single-country studies in areas such as Bangladesh (Miah *et al* 2011), Botswana (Faimau

et al 2023), China (Yang 2010), India (Billett 2010, Boykoff 2010, Ghosh and Boykoff 2019, Das 2020, Keller *et al* 2020, Painter *et al* 2020), Nepal (Khatri *et al* 2016), Nigeria (Ukonu *et al* 2012, Batta *et al* 2013, Uzochukwu *et al* 2014), Pakistan (Ejaz *et al* 2023), and the Philippines (Naguimbing-Manlulu 2021). We use a combination of machine learning (topic models), panel econometric analyses, and qualitative reading of source documents in our analyses.

Focusing exclusively on vulnerable countries also allows us to systematically examine the *interrelated* nature of economic, social, and environmental challenges caused by climate change (Gasper *et al* 2011). The worst impacts of climate change are experienced unevenly, with populations in more vulnerable countries facing numerous inequalities (Thomas *et al* 2019, IPCC 2022, Ngcamu 2023). As the intensity and frequency of extreme climate and weather events increase, the co-occurrence of climate impacts on vulnerable populations also rises (AghaKouchak *et al* 2020, Ebi *et al* 2021, IPCC 2022). Extreme weather, water and food shortages, and disruption in critical services, among other climate impacts, can increase the risk for marginalized populations (Cuartas *et al* 2023). However, what remains empirically unexamined is whether and how the media in vulnerable countries portrays the interrelatedness of such issues. We posit that, *ceteris paribus*, the news media from more vulnerable countries should report several types of climate impacts and consequences. Moreover, if the interrelated nature of climate change impacts is accurately reflected in the media, a focal news article in a comparatively more vulnerable country should also span (i.e. discuss) more topics vis-à-vis focusing its attention on a single topic (see methods for article ‘topic diversity’ computation). Formally, we test the following hypothesis at the *news article level*:

Hypothesis 1: *There will be a positive association between country-level climate change vulnerability and the diversity of climate topics covered in relevant news media articles.*

2. Methods

2.1. Sample selection and data collection

We selected lower- and upper-middle-income countries using World Bank (2022) income classification data, as they have traditionally lacked significant resources to address climate change. We did not select low-income countries due to limited data access throughout the study period (Okoliko and de Wit 2020). Using the Factiva and LexisNexis databases, and following prior studies (McAllister *et al* 2021), we searched for the terms ‘climate change’ or ‘global warming’ in 50 unique print news sources

across 26 non-Annex I countries from 01 January 2010 to 31 December 2020. To select the 50 newsprint sources, we drew from the Media and Climate Change Observatory (MeCCO) ‘World Table’ (Boykoff *et al* 2023) and the Reuters Institute Digital News Report 2022 (Newman *et al* 2022). MeCCO has been cited extensively in the literature (e.g. Brüggemann and Engesser 2017, Kristiansen *et al* 2021, O’Neill 2020, Schäfer and Painter 2020, Thackeray *et al* 2020, Hase *et al* 2021). From these lists, we sampled the highest circulating sources that also included access to the entire print article. We focused on English-language media, which have been viewed as international drivers of public discourse and agenda-setting (Sonwalkar 2002, Khatri *et al* 2016). Using English-language print sources also enabled us to manually and qualitatively cross-check the findings (see topic modeling section below). Figure S1 and table S1 of the supplementary materials provide more details on our sample.

2.2. Topic modeling

We used Latent Dirichlet Allocation (LDA) to uncover the major themes in our dataset. LDA is a probabilistic modeling technique for discovering the ‘latent’ topics in a large and unstructured collection of documents (Blei *et al* 2003, Griffiths and Steyvers 2004, Blei 2012), such as news articles, journals, blogs, and annual reports, among others. LDA assumes that a document is generated in a process that includes hidden distributions (e.g. the topic structures). Specifically, there are two distributions to be inferred. The first is the word distribution within a topic; the second is each document’s topic distribution. The algorithm treats each word in a document (i.e. a news article in our study) as created through two generative probabilistic steps: (1) a topic is chosen among the set of topics with a priori distribution, and (2) a word is chosen from the selected topic, which is a distribution over a set of words. The topic distribution for each news article and the distribution of the words are estimated based on the set of documents. We manually read the top 100 articles (based on model-assigned topic probabilities) from each topic to verify the model’s veracity and cross-validate the topic labels. More details on the models implementation and tuning metrics are in the supplementary materials (see methods S1, table S2, and figure S2).

2.3. Multivariate regression analyses

After identifying the main topics, we examined the relationship between a country’s vulnerability to climate change and the diversity of topics discussed by its media. We joined our data to annual measures of a country’s vulnerability to climate change from the Notre Dame Global Adaptation Initiative (e.g. Chen

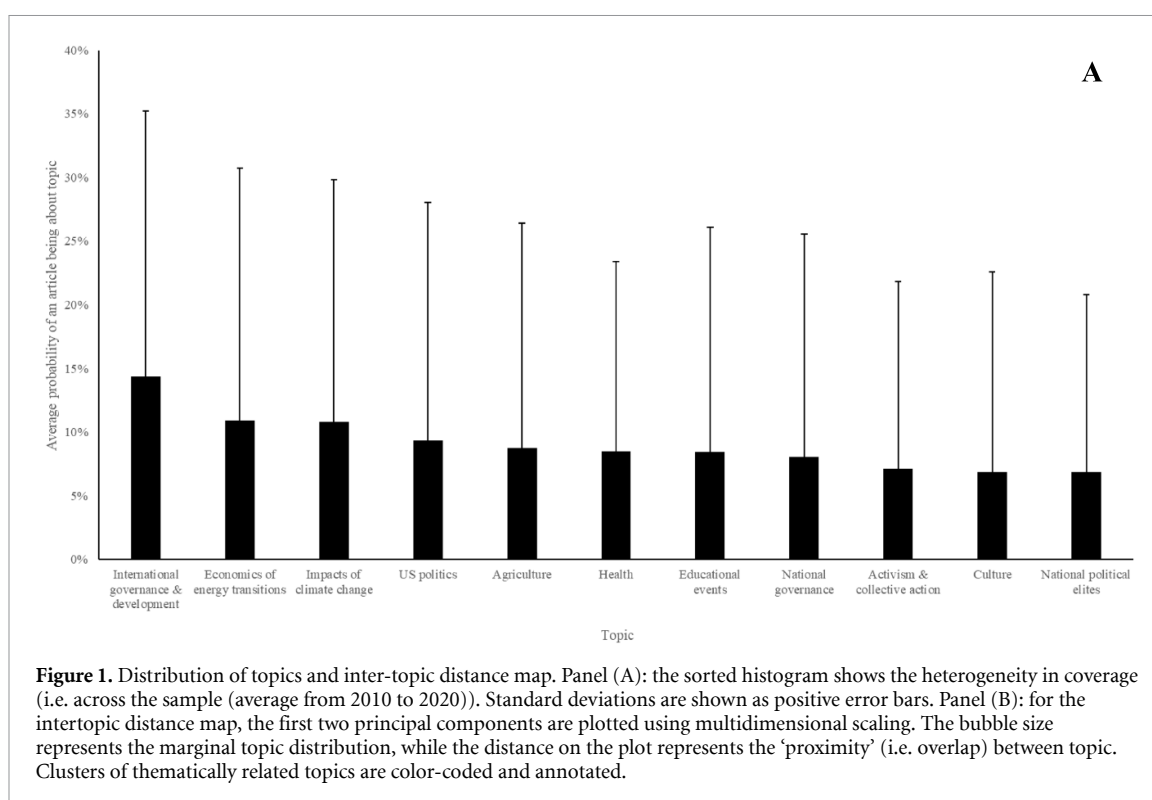
et al 2015, Kling *et al* 2021). To measure our outcome variable (i.e. the diversity of topics discussed by a focal news article), we computed a Shannon entropy index ($H = -\sum_{i=1}^{i=11} p_i * (\ln p_i)$) and a reverse coded Herfindahl–Hirschmann concentration measure ($HHI = -\sum_{i=1}^{i=11} p_i^2$), where p represents the probability that a given news article belongs to a topic, and i is one of the 11 topics in our LDA model (also see articles S1–S2 in the supplementary materials). We then executed multivariate regression analyses using (1) ordinary least squares estimates at the news article level and (2) a fixed effects specification with an unbalanced panel, organized by newspaper source and the month that an article was published as the time identifier (132 time periods, i.e. 11 years \times 12 months). We also included controls at both the news article (word count, sentiment, average sentence length, and % of unique words) and country (readiness to adapt to climate change (Chen *et al* 2015), population, gross domestic product (GDP) per capita, and human development index (HDI)) levels. Standard errors were clustered at the news source level.

3. Results

3.1. Major topics covered by the media in non-Annex I countries

Figure 1 (panel (A)) shows the average probability (as a percentage) of the occurrence of a topic in a news article. The three most commonly occurring topics are international governance & development (14.45%), the economics of energy transitions (10.86%), and the impacts of climate change (10.70%). These three topics account for over one-third (36%) of the sample topic distribution. The overall distribution is relatively uniform, albeit with a high level of variability as shown by the error bars. Exemplar excerpts in the supplementary materials (see table S3) qualitatively illustrate these topics.

Figure 1 (panel (B)) shows an intertopic distance map, with two distinct clusters. The first ‘socioeconomic’ cluster (in green) focuses on energy economics, agriculture, and activism & collective action. The second ‘sociopolitical’ cluster (in blue) focuses on international governance & development, national governance, and education-related events about climate change. Discussions about climate science (impacts of climate change) co-occur more often with socioeconomic vis-à-vis sociopolitical topics. Four topics are spatially isolated (national political elites, culture, US politics, and health) indicative of their more peripheral and/or discrete (vis-à-vis interconnected with other topics) media coverage.



3.2. Geographic differences in media coverage among non-Annex I countries

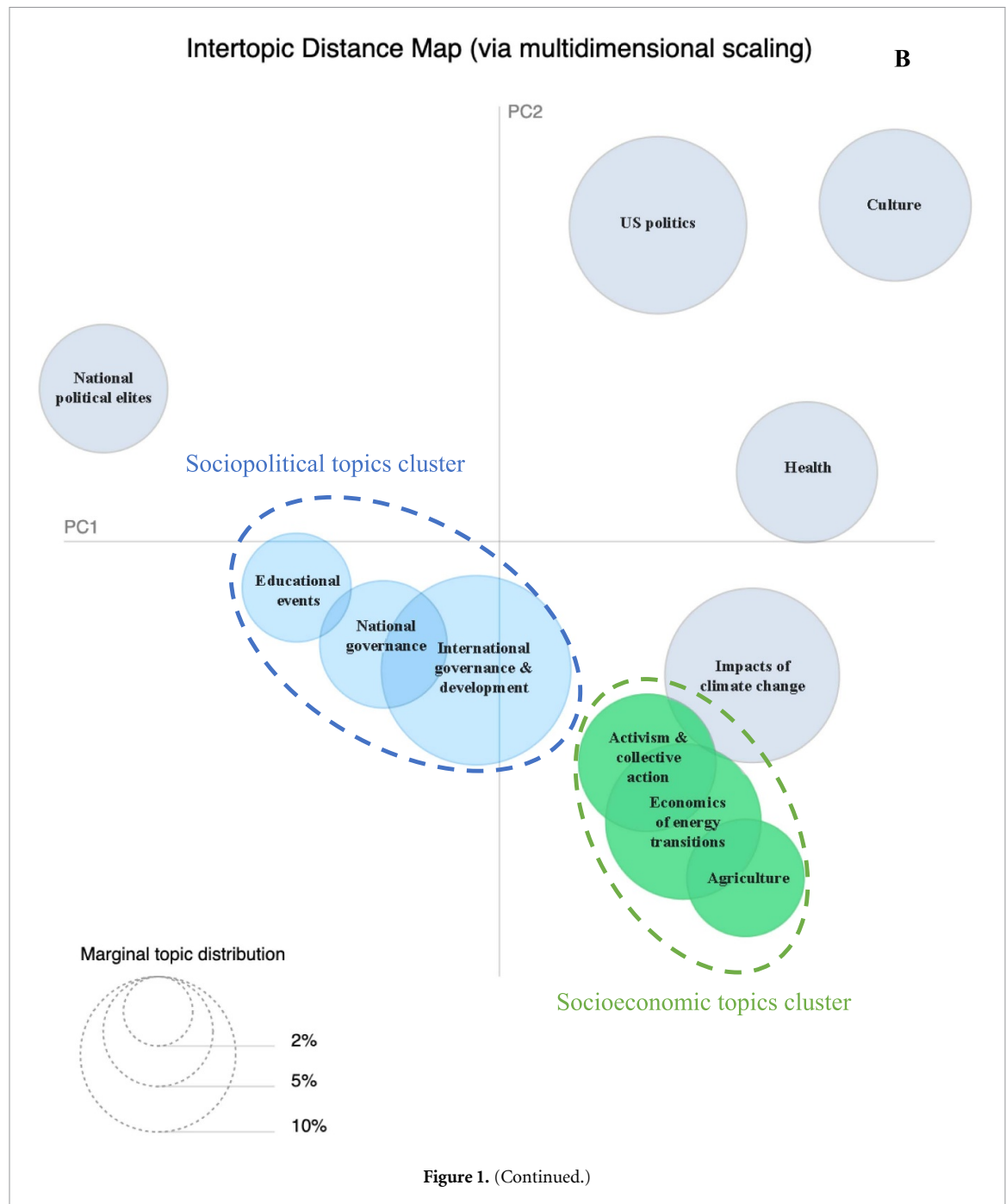
Countries in table 1 are organized by five geographic regions, using World Bank definitions. Topics in table 1 are organized from left to right (same order as figure 1), and the three most prevalent topics are highlighted in grey. One-way ANOVA tests at both the country and region level showed that mean differences were statistically significant. We observed that the media in Sub-Saharan Africa pays a significantly higher level of attention to agriculture relative to other regions. The media coverage in South Asia, which has the most vulnerable countries in our sample (standardized average = 0.83; last column of table 1), also has a relatively unique focus. It emphasizes the impacts of climate change, educational events, and national political elites (likely due to the comparatively low focus in India on international governance).

The inter-topic distance map in figure 2 uses the country-level topic averages in table 1. We observe that the coverage in South Asia and East Asia is more homogenous relative to the middle East or Sub-Saharan Africa (i.e. the South Asian and East Asian countries form smaller clusters). Interestingly, coverage in South Asia is more similar to that in Sub-Saharan Africa, relative to that in East Asia & Pacific. Note that the eight most vulnerable countries in our sample were Bangladesh, Pakistan, Kenya, Tanzania, Zimbabwe, India, Nepal, and Nigeria (all in the highest quartile of the ND-gain global index,

>75% relative to the rest of the world). We observe that they cluster together (shown in red), indicative of an association between media coverage and country climate change vulnerability. We also note that South Africa and Vietnam appear as 'outliers' (i.e. distant from other countries in their region). This is consistent with their disproportionately high focus on topics such as energy economics and collective action respectively (see table 1).

3.3. Relationship between climate change vulnerability and topic diversity

The average vulnerability for each country (see last column of table 1) is positively moderately correlated with the diversity of topics in an article ($r = 0.44$). In table 2, we examined this correlation more systematically through multivariate regressions. Model 1 and Model 2, use the entire data sample ($N = 95\,216$). A 1 standard deviation increase in country climate change vulnerability is associated with ~ 0.25 standard deviation increase in the topic diversity of the average news article in that country ($\beta_{\text{model 1}} = 0.27, p = 0.01$; $\beta_{\text{model 2}} = 0.23, p = 0.01$). In Models 3 and 4, we repeated the analyses after collapsing (averaging) the data and creating an unbalanced panel ($N = 5155$) at the news source-observation month level. Again, we find a positive and statistically significant relationship ($\beta_{\text{model 3}} = 0.31, p = 0.01$; $\beta_{\text{model 4}} = 0.20, p = 0.06$) between a country's climate change vulnerability and the diversity of topics discussed by its media. We carried out several sensitivity analyses (e.g. removing



the bottom 15 sources which had less than 500 articles, excluding India, restricting data from India to one or two sources, excluding ‘outlier countries’ such as Ukraine, Uzbekistan, and South Africa, omitting highly correlated (with country vulnerability) control variables such as GDP per capita and/or HDI, using a 1 year time lag in the models) and found robust results. We thus find a positive association between country-level climate change vulnerability and the diversity of climate topics covered in relevant news articles (see article S1 and article S2 in the supplementary materials for illustrative examples).

We also carried out a supplemental analysis (see supplementary materials, table S4) where we regressed country vulnerability on the probability of

occurrence of each topic as separate dependent variables (instead of computing a single entropy measure). A country’s climate change vulnerability is significantly negatively associated with a focus on international governance ($\beta = -0.43$, $p = 0.01$), and US politics ($\beta = -0.49$, $p = 0.03$). It is significantly positively associated with coverage of national governance ($\beta = 1.5$, $p = 0.004$) and national elites ($\beta = 0.62$, $p = 0.04$). Thus, we find tentative evidence that an increase in a country’s vulnerability to climate change is associated with a shift in media coverage towards domestic (or internal) issues vis-a-vis external matters. We provide exemplar articles to illustrate this pattern (see supplementary materials articles S3–S6).

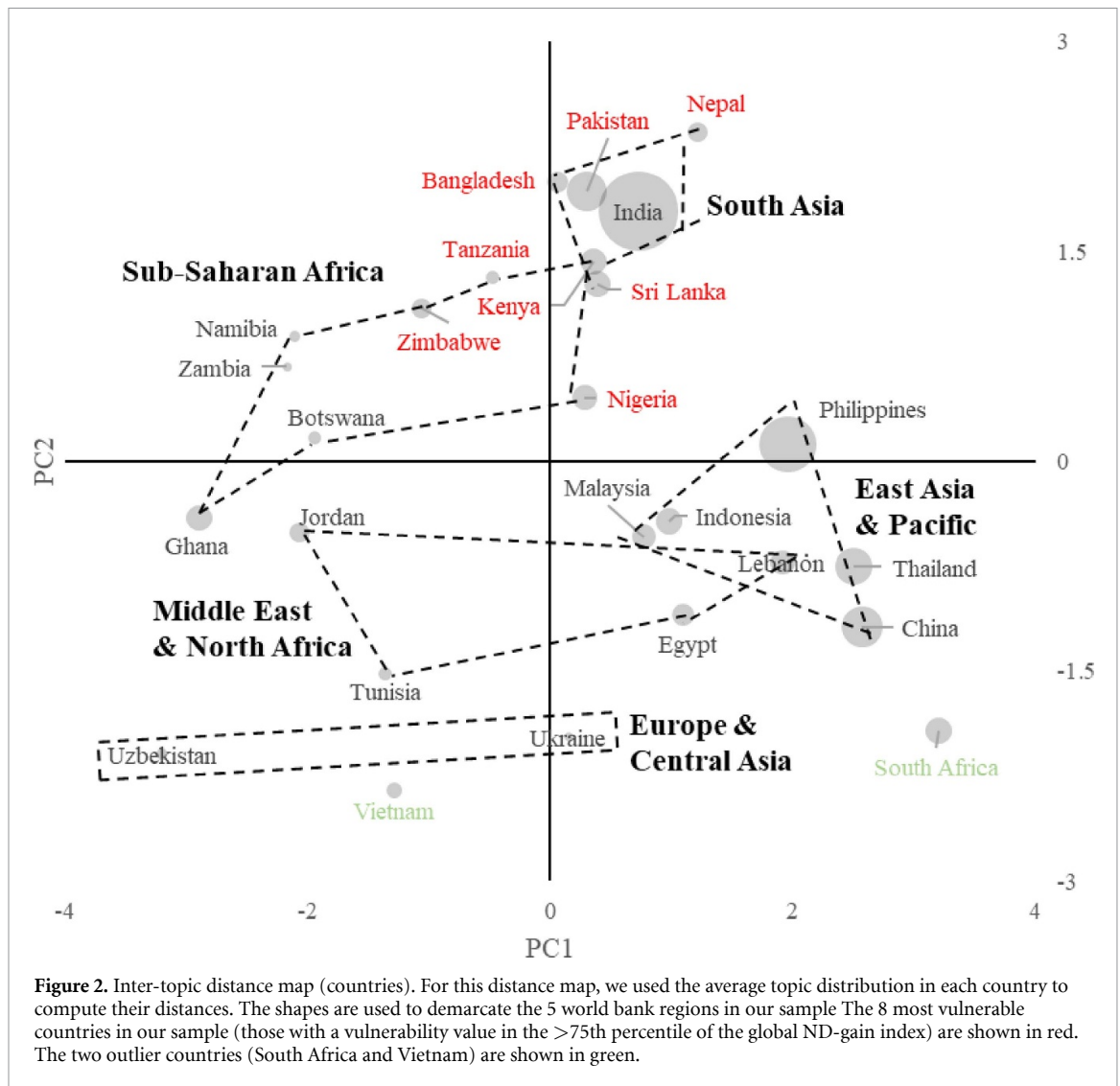
Table 1. Geographic variability in topic coverage. Averages were computed using the probabilistic topic distribution for each news article. Mean comparisons are provided by country and region as grouping units. One-way ANOVA tests were conducted to calculate F statistics, and show significant group mean differences. The three highest values for each row (i.e., the top three most common themes) are highlighted in grey. The average vulnerability for each country is provided in the last column.

Country	N	Economics of			Impacts of climate change	US politics	Agriculture	Health of marginalized populations	Educational events	National governance	Activism & collective action	Culture	National political elites	Vulnerability (z-score)
		International governance	energy transitions											
East Asia & Pacific														
China	7088	21.90%	14.50%	11.10%	18.50%	3.30%	6.90%	2.00%	1.20%	6.30%	13.10%	1.10%	1.59	
Indonesia	3057	23.20%	15.40%	10.60%	8.90%	6.30%	9.60%	2.30%	7.90%	8.60%	6.10%	1.10%	-0.37	
Malaysia	2413	16.80%	17.10%	8.10%	7.80%	5.40%	12.30%	4.60%	6.50%	12.70%	5.30%	3.60%	-2.12	
Philippines	13 459	13.80%	10.00%	12.10%	10.20%	6.40%	6.00%	3.70%	19.60%	9.70%	8.10%	0.30%	-0.01	
Thailand	5886	13.30%	16.70%	10.60%	17.00%	6.30%	9.10%	2.30%	5.40%	8.70%	9.60%	1.10%	-0.70	
Vietnam	1166	22.20%	11.70%	7.00%	3.30%	9.60%	1.60%	4.00%	3.70%	30.70%	3.20%	3.00%	0.07	
Weighted average		16.80%	13.20%	11.00%	12.70%	5.80%	7.40%	3.00%	10.50%	9.60%	8.90%	1.00%	-0.66	
Europe & Central Asia														
Ukraine	345	18.00%	24.40%	6.90%	11.50%	3.00%	0.80%	1.30%	2.40%	2.70%	0.60%	28.50%	-2.13	
Uzbekistan	524	52.90%	13.70%	5.40%	2.70%	7.30%	3.00%	6.40%	1.20%	4.70%	1.30%	1.40%	-2.15	
Weighted average		39.00%	17.90%	6.00%	6.20%	5.60%	2.10%	4.40%	1.70%	3.90%	1.00%	12.20%	-2.14	
Middle East & North Africa														
Egypt	2185	23.70%	19.80%	12.40%	11.80%	6.70%	6.10%	3.50%	2.30%	6.10%	5.70%	1.90%	-0.94	
Jordan	1637	26.60%	11.90%	6.80%	5.70%	16.70%	4.20%	13.80%	3.00%	5.60%	2.90%	2.80%	-1.89	
Lebanon	2528	17.90%	15.40%	11.40%	19.70%	5.00%	8.20%	4.20%	2.70%	6.80%	5.90%	2.90%	-1.28	
Tunisia	748	34.90%	14.10%	8.40%	8.60%	6.60%	2.70%	9.20%	3.60%	6.40%	2.10%	3.30%	-1.88	
Weighted average		23.50%	15.80%	10.30%	12.80%	8.40%	6.00%	6.70%	2.80%	6.30%	4.70%	2.60%	-1.38	
South Asia														
Bangladesh	1831	16.80%	8.30%	11.10%	7.20%	9.80%	12.70%	4.70%	1.50%	3.40%	1.80%	22.80%	1.62	
India	26 224	5.80%	5.90%	11.70%	5.90%	7.90%	8.40%	16.50%	12.00%	5.70%	6.90%	13.40%	0.78	
Nepal	1646	20.50%	6.10%	16.90%	3.50%	6.80%	11.90%	5.10%	1.90%	4.50%	8.00%	14.80%	0.62	
Pakistan	6466	12.00%	6.80%	10.20%	7.50%	12.00%	11.70%	5.40%	5.50%	5.70%	3.50%	19.70%	1.17	
Sri Lanka	2892	17.80%	10.10%	9.40%	6.90%	7.60%	15.20%	3.50%	1.50%	8.40%	4.20%	15.40%	0.14	
Weighted average		8.90%	6.40%	11.50%	6.20%	8.60%	9.80%	12.60%	9.20%	5.80%	5.90%	15.10%	0.83	

(Continued.)

Table 1. (Continued.)

Country	N	Economics of		Impacts of climate change	Health of		Activism &		National political elites	Vulnerability (z-score)			
		International governance	energy transitions		US politics	Agriculture	marginalized populations	Educational events			National governance	collective action	Culture
Sub-Saharan Africa													
Botswana	702	30.70%	9.20%	6.30%	5.70%	19.10%	8.30%	7.80%	2.40%	4.70%	3.80%	2.10%	−0.85
Ghana	2777	21.70%	11.70%	6.60%	3.80%	11.30%	4.10%	29.90%	3.40%	5.30%	1.00%	1.20%	−0.15
Kenya	2840	13.90%	9.90%	8.90%	12.40%	24.70%	13.00%	3.20%	2.80%	4.00%	6.30%	0.90%	1.02
Namibia	480	30.30%	7.10%	8.90%	4.20%	24.80%	7.30%	6.90%	1.40%	4.10%	3.40%	1.50%	0.13
Nigeria	2710	17.20%	11.60%	9.90%	14.60%	13.00%	10.10%	9.20%	4.20%	5.30%	2.80%	2.20%	0.56
South Africa	2901	9.30%	30.10%	8.40%	13.10%	4.70%	10.80%	1.80%	1.40%	5.20%	14.30%	1.00%	−1.60
Tanzania	739	20.10%	9.50%	7.90%	10.90%	22.30%	13.40%	4.70%	2.50%	2.90%	4.10%	1.80%	0.87
Zambia	392	33.20%	9.00%	7.40%	4.40%	21.30%	9.90%	5.60%	2.80%	3.40%	1.70%	1.20%	0.49
Zimbabwe	1580	22.60%	10.40%	9.90%	7.30%	27.00%	9.10%	3.20%	1.80%	4.20%	3.00%	1.50%	0.86
Weighted average		18.00%	14.30%	8.40%	10.00%	16.10%	9.60%	9.40%	2.70%	4.70%	5.50%	1.40%	0.07
One-way ANOVA tests													
F _{25,95 190 (by country)}		542.54	291.99	34.68	244.9	332.75	129.26	690.02	534.91	205.81	158.2	1363.4	
F _{4,95 212 (by region)}		225.12	622.13	452.6	1446	1659.75	887.59	85.37	924.46	7360.68	777.6	264.44	



4. Discussion

Scholars have called for climate communication strategies that fit the unique context and ‘localized climate impacts’ (Ejaz and Najam 2023) of individual nations as well as nations outside Annex I countries (Vu *et al* 2019, Nguyen *et al* 2020), given the significant variance in predictors of the broader public’s risk perception and awareness of climate change (Lee *et al* 2015, Hase *et al* 2021). Despite facing the worst impacts of our changing climate, non-Annex I countries are largely under-represented in the climate change and media literature (Schäfer and Schlichting 2014, Painter and Schäfer 2018, Bohr 2020). Our cross-national study addresses a significant research gap by focusing on the differences between economically similar, highly vulnerable non-Annex I nations.

4.1. Dominant themes and regional differences in media coverage in non-Annex I countries

Our study supports and extends findings of recent analyses of media reporting on climate change. For

example, Hase *et al* (2021) found that Global South media coverage focuses on the societal dimension of climate change, including increased reporting on economics, climate politics, and human impacts. Vu *et al* (2019) found that poorer countries report more on ‘international relations and the natural aspects of climate change’ (p 7). Using a much larger sample of countries from non-Annex I countries, we found that the three most discussed themes were *international governance & development, the economics of energy transitions, and the impacts of climate change*. We also find significant cross-regional differences (e.g. between South Asia, sub-Saharan Africa, and East Asia). The importance of international politics and the impacts of climate change, such as sea level rise and flooding, are thus highlighted across all studies. These findings are also consistent with the fact that many non-Annex I countries often depend upon resources from Annex I countries to mitigate and adapt to the consequences of climate change (IPCC 2022).

Interestingly, both our study and Vu *et al* (2019)’s findings do slightly differ from those of Hase *et al*

Table 2. Multivariate regressions between country vulnerability and the diversity of topics covered by the news media. Topic diversity is measured using the Shannon entropy measure (Models 1 and 3) and a reverse-coded Herfindahl–Hirschmann concentration index (Models 2 and 4). Models 1 and 2 use the complete article-level data set, while Models 3 and 4 used an unbalanced panel created at the newspaper–month level. Results are robust to using or omitting a one-year time lag between the dependent and independent variables in all models.

	Model: ordinary least squares		Model: fixed effects panel regression	
	DV: entropy (1)	DV: HHI (reversed) (2)	DV: entropy (3)	DV: HHI (reversed) (4)
Country-level variables				
Country vulnerability to climate change (z-scored)	0.275** [0.006](0.097)	0.233** [0.010](0.087)	0.312* [0.013](0.121)	0.201+ [0.063](0.105)
Country readiness to adapt to climate change (z-scored)	−0.024 [0.116](0.015)	−0.034* [0.024](0.014)	−0.038+ [0.076](0.021)	−0.040+ [0.064](0.021)
Population (10's of millions)	−0.008+ [0.095](0.005)	−0.006 [0.285](0.006)	−0.017** [0.008](0.006)	−0.014* [0.047](0.007)
GDP per capita (logged)	0.603* [0.017](0.243)	0.578** [0.008](0.209)	0.707* [0.015](0.280)	0.542* [0.031](0.244)
Human development index	0.587 [0.553](0.982)	−0.143 [0.909](1.243)	1.194 [0.298](1.136)	0.358 [0.808](1.462)
Article-level variables				
Word count (logged)	1.099*** [0.000](0.106)	0.967*** [0.000](0.103)	0.952*** [0.000](0.165)	0.896*** [0.000](0.193)
Sentiment	0.001 [0.659](0.002)	−0.005** [0.005](0.002)	−0.001 [0.770](0.003)	−0.006+ [0.074](0.003)
Average sentence length	0.004 [0.118](0.002)	0.005 [0.143](0.004)	0.009*** [0.000](0.002)	0.007* [0.049](0.003)
Vocabulary uniqueness (# of unique words/total words)	3.099*** [0.000](0.472)	2.334*** [0.000](0.457)	2.338*** [0.000](0.458)	1.919*** [0.000](0.495)
Time dummies (month and year)	Yes	Yes	Yes	Yes
Newspaper source dummies	Yes	Yes	Yes (fixed effects)	Yes (fixed effects)
Constant	−6.543*** [0.000](1.280)	−5.324*** [0.000](1.387)	−6.652*** [0.000](1.503)	−5.167*** [0.000](1.311)
Number of newspaper sources	50	50	50	50
Observations	95 216	95 216	5155	5155
r^2	0.064	0.052	0.078	0.063

Standard errors in parentheses. P -values in square brackets. Results robust to including or excluding temporal lags.

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

(2021), who *did not* find an increase in extreme weather events in their analysis. One potential reason for these differences could be the vastly different sample sizes; both Vu *et al* (2019) and our study ($N = 26$ non-Annex I countries) have a significantly larger sample size than Hase *et al* (2021), which only examined four countries from the Global South. The studies also used marginally different topic labels. For example, Hase *et al* (2021) categorize rising sea levels and flooding as ‘Impacts on humans’, but distinguish these from extreme weather events. Lastly, both our study and Hase *et al* (2021) highlight the importance

and interconnectedness of economic issues in more vulnerable countries, unlike Vu *et al* (2019). More generally, the comparison of our findings with Vu *et al* (2019) and Hase *et al* (2021) reinforce the importance of studying the *intersections* between different themes. Our study highlights how non-Annex I countries are taking a comprehensive approach to climate change media coverage, interweaving topics such as international governance, economic transitions away from fossil fuels to cleaner energy sources, and impacts (e.g. flooding, extreme weather events) of climatic changes (see figure 1, panel B). This finding also aligns with

scholarly calls to explore systemic institutional solutions to alleviate climate related challenges (Kalyango *et al* 2017, Nassanga *et al* 2017, Chattopadhyay 2019).

4.2. Relationship between country climate change vulnerability and diversity of topics covered by the media

We also show that there is a significant positive association between countries' vulnerability to climate change and the diversity of topics discussed in their media coverage (table 2). Many studies discuss the interrelated nature of climate change impacts; our study systematically *quantifies* this phenomenon in non-Annex I countries. Our study thus adds nuance to the literature by highlighting the localized impacts of climate change across the Global South (Ejaz *et al* 2022). We also highlight the need for more partnerships and knowledge transfer between South Asia and Sub-Saharan Africa, as these regions share similar climate coverage and climatic challenges, relative to East Asia & Pacific.

Most importantly, our findings demonstrate that in *the most vulnerable* countries, the media explicitly reports on the complexity and multifaceted nature of climate change. By speaking to the social, economic, scientific, and political aspects of climate change, news coverage in the most vulnerable countries is highly sophisticated. Our findings call out a Western bias and colonial lens by refuting a reoccurring narrative in the climate media literature that journalism in the Global South is less robust due to resource constraints. The Western bias is further reflected by the dearth of scholarship on the media coverage of climate change in less developed countries. For example, Okoliko and de Wit (2020) show that scholarship on media coverage of climate change has only been examined in *nine* African countries. Our study shows that, even while developing countries may have fewer resources or training to inform climate coverage (Ajaero and Anorue 2018), reporting in the most vulnerable countries is highly nuanced and distinctive from common Western conceptualizations of climate change (Olausson and Berglez 2014).

Intuitively, the implications of our findings make sense as we see that as the most vulnerable countries experience the urgency and worst impacts of our changing climate; the co-occurrence of issues and interconnectedness of climate change is forefronted and reflected in media reporting through the diversity of topics covered in its articles. In the most vulnerable countries, climate change information is not siloed, but addressed systemically. This also tracks the objectives of developmental journalism as vulnerable countries work on developmental, intervention, and educational objectives in the context of

lived climate impacts (Kalyango *et al* 2017). This contrasts with global media coverage, which still struggles to make explicit connections between two topics, such as climate change and health (Romanello *et al* 2022). Our findings emphasize the opportunity for the Global North to learn from media coverage of climate change in the Global South where the problem is most acute.

5. Study limitations

First, engagement with print media is declining in many countries (Newman *et al* 2022). That said, audiences for print media remain particularly relevant in the countries in our sample (Schmidt *et al* 2013, Wahyuni 2017, Comfort *et al* 2020, Painter *et al* 2020). Single-country studies have also found that print media content is highly correlated with online versions of newspapers (Dhiman 2022). Moreover, print media is still an influential source of information for local elites and has been found to impact voting choices (Prat and Strömberg 2013). Second, our study only used English language sources. This is problematic because of the vast circulations of vernacular languages across many countries in our sample, such as India (Audit Bureau of Circulations 2023), China (World Association of Newspapers 2023), Malaysia, and Thailand (Newman *et al* 2022). However, we purposefully chose English-only sources because: (1) English language sources are essential for reaching policy-making elites and agenda setting (Sonwalkar 2002), (2) English-language newspapers include articles from many experts and representatives of funding agencies (Khatri *et al* 2016), and (3) we could manually qualitatively verify the topic model findings. Third, we acknowledge that the countries we compare have different media landscapes and political structures, among other unobservable confounding factors. We tried to mitigate such bias by comparing non-Annex I countries with similar economic profiles and using fixed-effects model specifications (see table 2). Fourth, there are notable limitations of topic modeling, such as the inability of the method to understand contextual specifics (Brookes and McEnery 2019). We thus complemented the LDA analysis with a set of qualitative analyses (e.g. Hase *et al* 2021) to reach 'substantive interpretability' (see methods and supplementary materials, table S3).

6. Conclusion

The historic and ongoing scarcity of climate communication research in the Global South has understandably been highlighted as an area of scholarly concern (Wright *et al* 2019, Okoliko and de Wit 2020).

Moreover, treating the Global South as a homogenous bloc is reductionist and limits explanatory power. Our study is the first to categorize the themes used by the media to cover climate change in 50 sources within 26 economically similar non-Annex I countries, and to identify a positive relationship between a country's vulnerability to climate change and the diversity of topics covered by its news media. Our findings help expand heterogeneous understandings of Global South climate change news coverage and advance ongoing investigations into relationships between climate change and discourses in the world's most vulnerable countries. Future research can also use the methodology presented in this paper across other forms of digital media, such as social media. Our study can also serve as an important bridge, helping the media in the Global North learn from their counterparts in non-Annex I countries. As climate threats increase globally, the ability of the media to articulately reflect the overlapping and interrelated nature of climate threats is critical. Ultimately, it is our hope that a more nuanced portrayal of climate change in the global media as a *systemic problem* (Lehtonen et al 2018) can inform and improve the sophistication of local, national, and international mitigation and adaption efforts.

Data availability statement

The data cannot be made publicly available upon publication because they are owned by a third party and the terms of use prevent public distribution. The data that support the findings of this study are available upon reasonable request from the authors.


Conflict of interest

The authors declare no competing interests.

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