

# Discovering Latent Themes in Social Media Messaging: A Machine-in-the-Loop Approach Integrating LLMs

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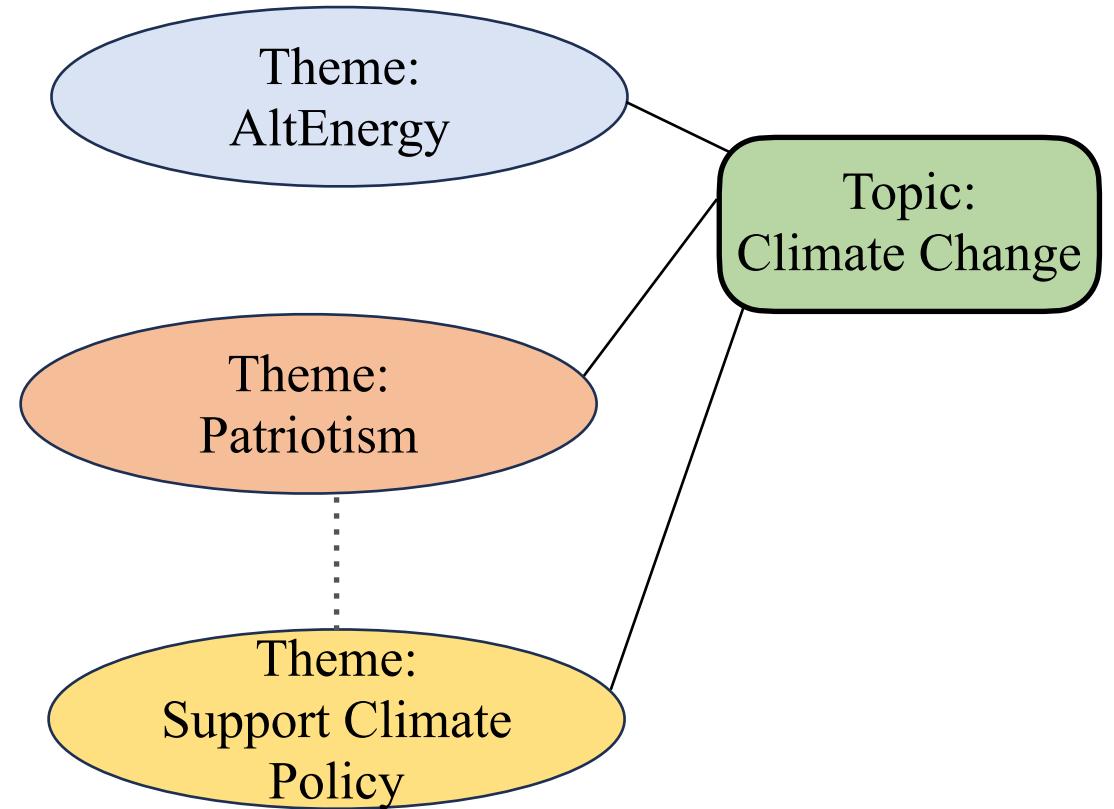
International AAAI Conference on Web and Social Media

June 23-26, 2025, Copenhagen, Denmark



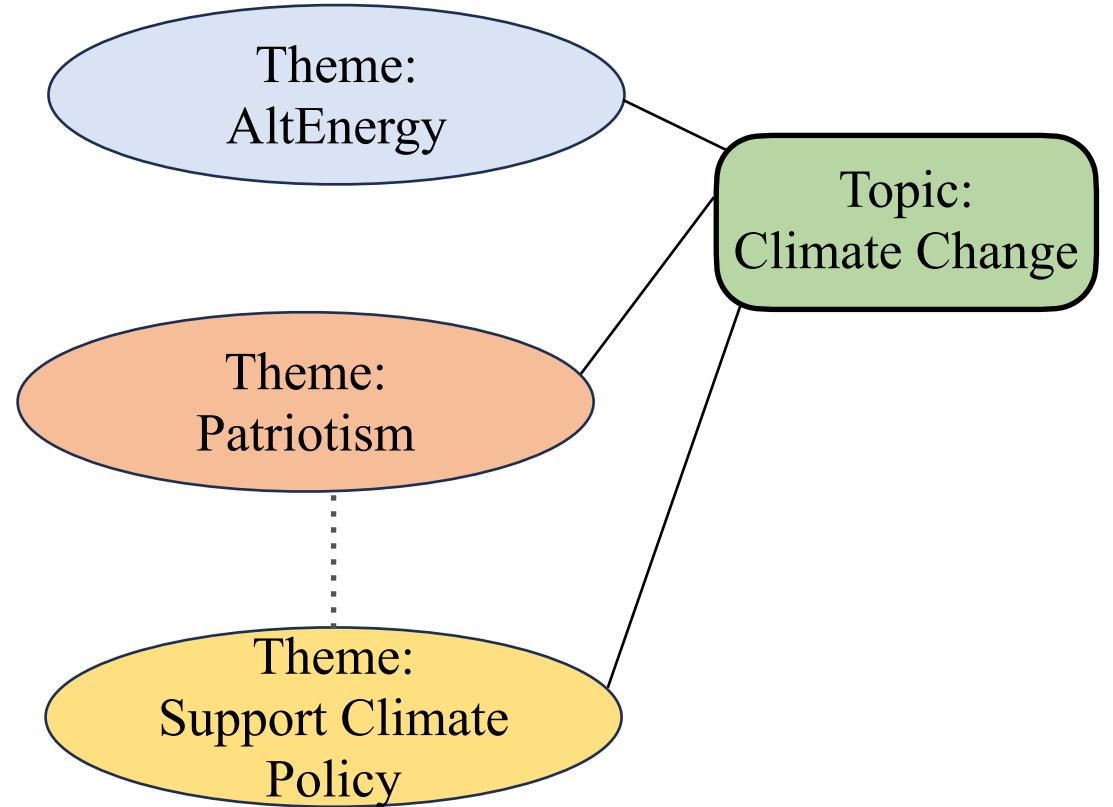
# Unsupervised Text Analysis

- Topic Modeling.
  - Shallow Themes.



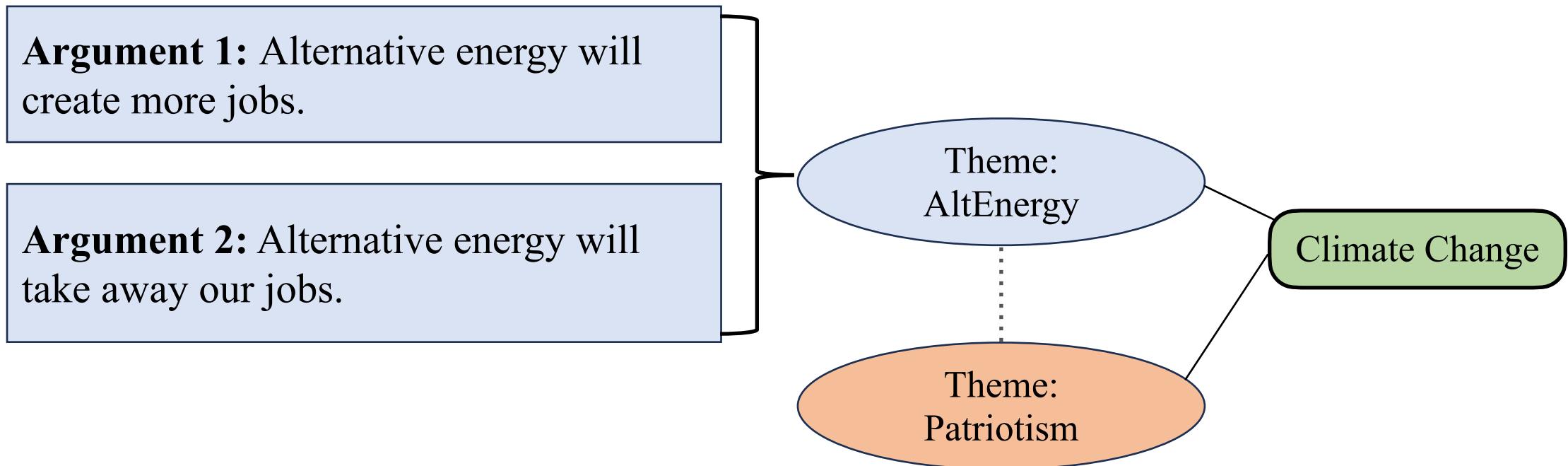
# Theme Discovery - Previous Works

- Topic Modeling.
  - Shallow Themes.
- Manual and qualitative coding (*Hagen et al., 2022; Nguyen et al., 2021; Del Valle et al., 2020*).



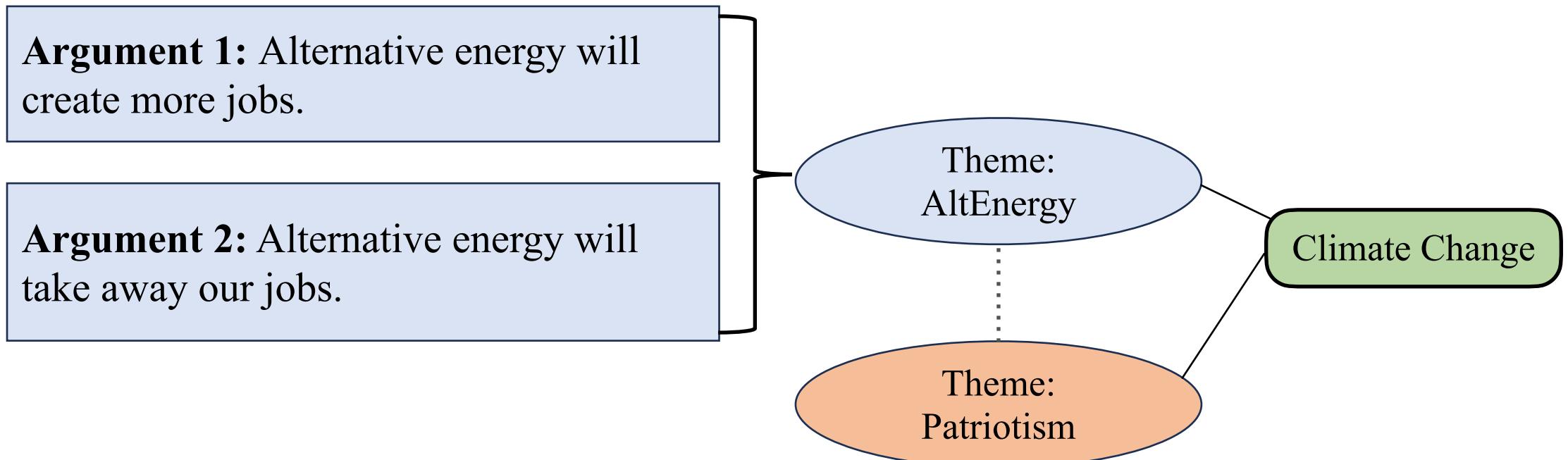
# Theme Discovery - Previous Works

- Predefined set of labels, themes, and arguments (*Islam et al., 2023; Islam & Goldwasser, 2022*).
  - Fixed and established based on existing topics or theoretical frameworks, such as Moral Foundations Theory (MFT) (*Haidt and Graham 2007*).
  - Often fails to capture the nuances of messaging choices.



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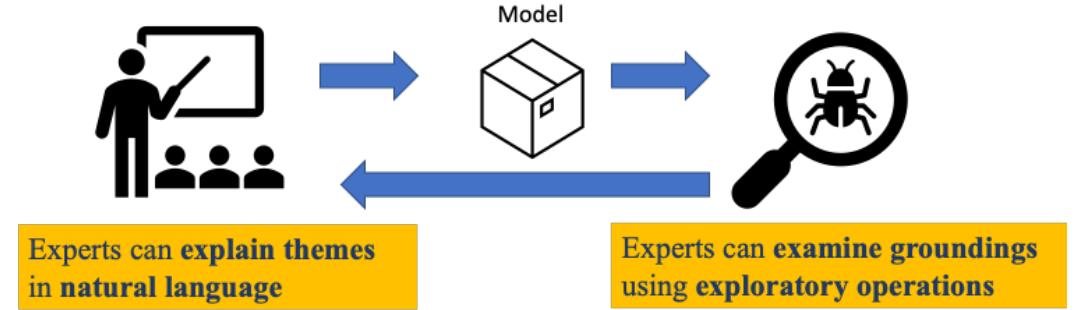
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- Latent Theme Discovery (*Pacheco et al., 2023; Pacheco et al., 2022b;a*).

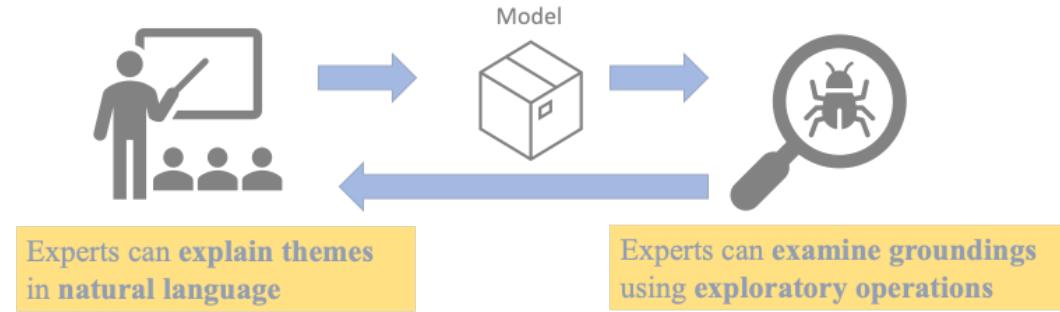
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- Human-in-loop (*Pacheco et al. 2022b;a*).
  - Costly scalability.
  - Time consuming.

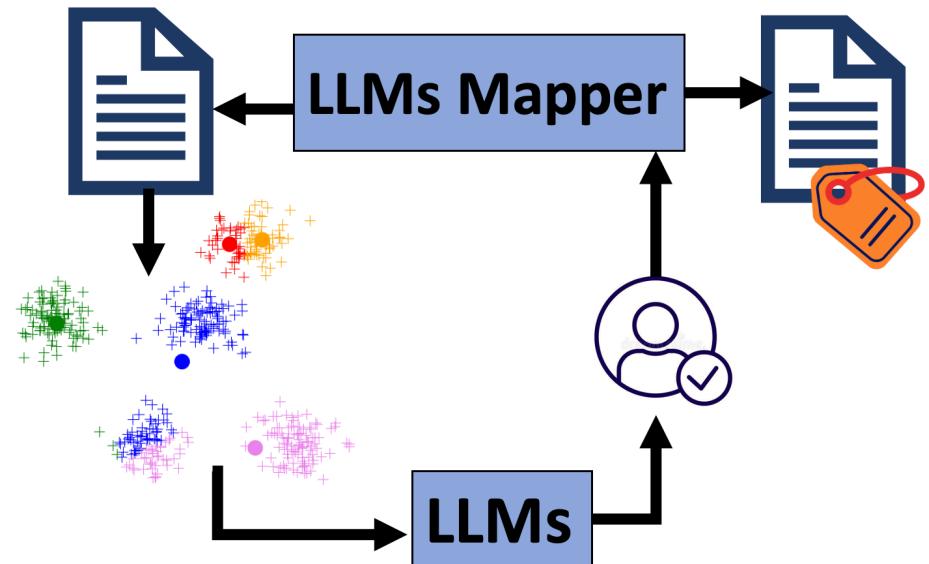


# *Machine-in-the-Loop* Approach

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  - Time consuming.



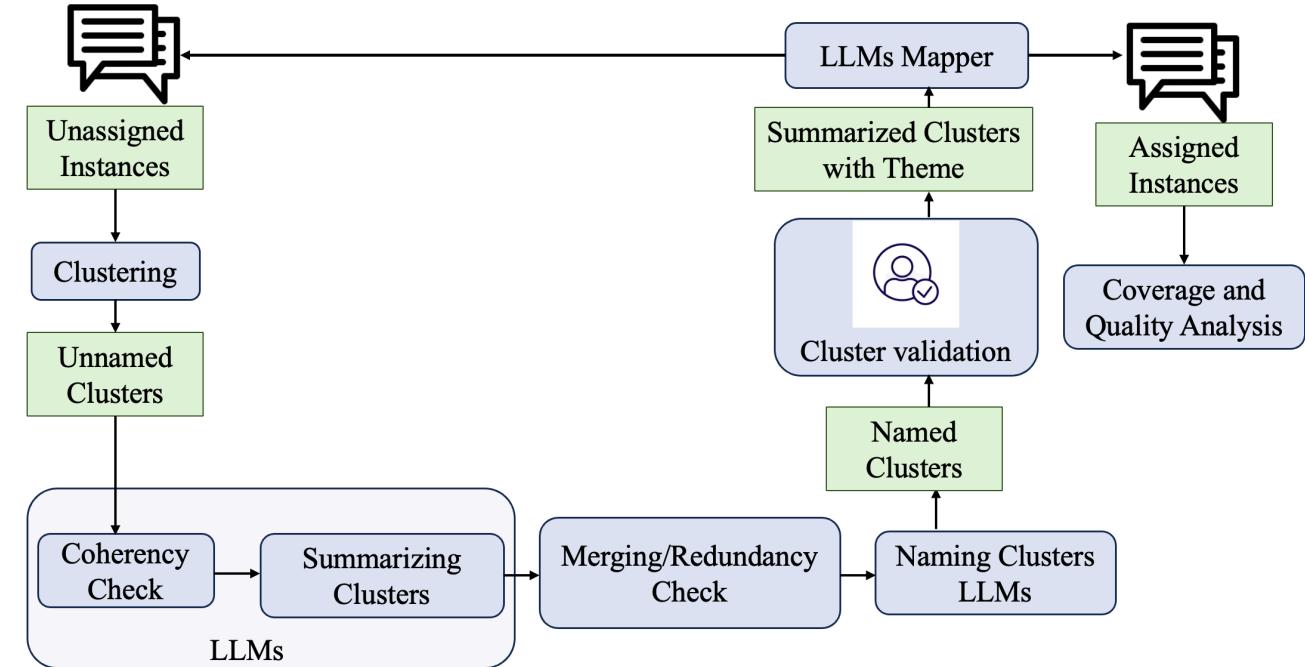
- **Machine-in-the-Loop: LLMs-in-the-Loop.**
  - LLMs possess **extensive domain insights**.
  - **Reasoning** capabilities.
  - **Accelerate** the process of refinement.



# Sketch of *Machine-in-the-Loop* Approach

## 3 steps Process:

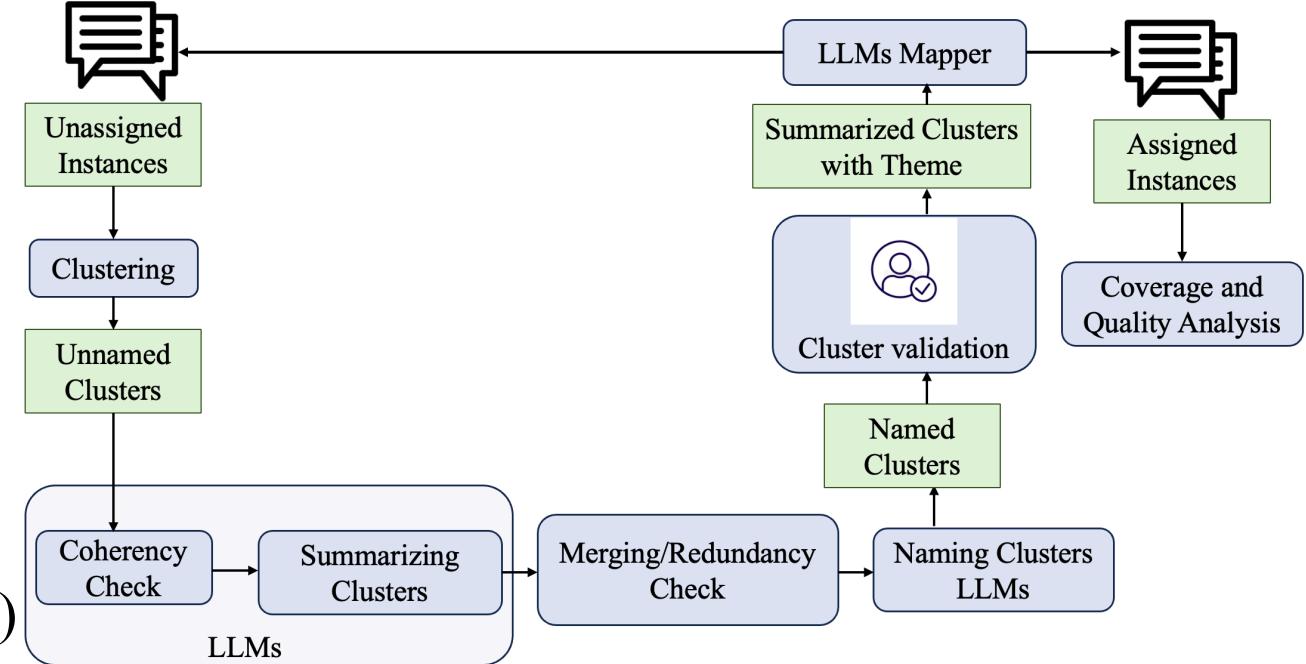
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    - (a) Clustering.
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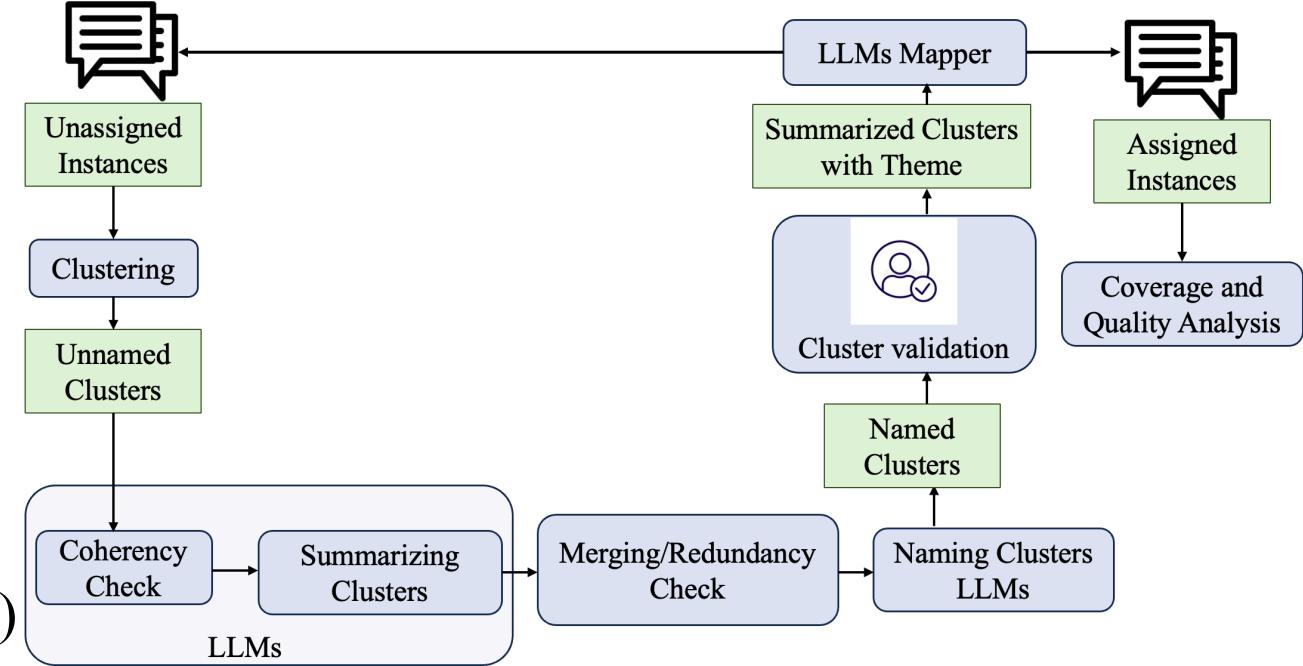
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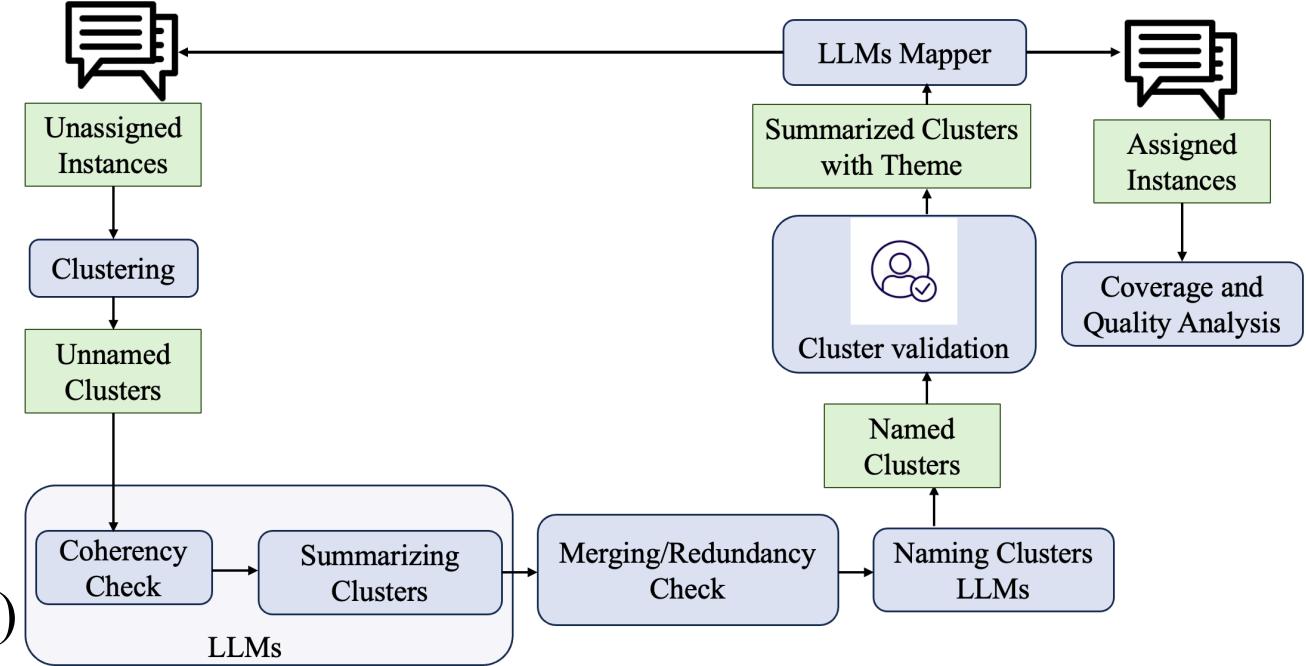
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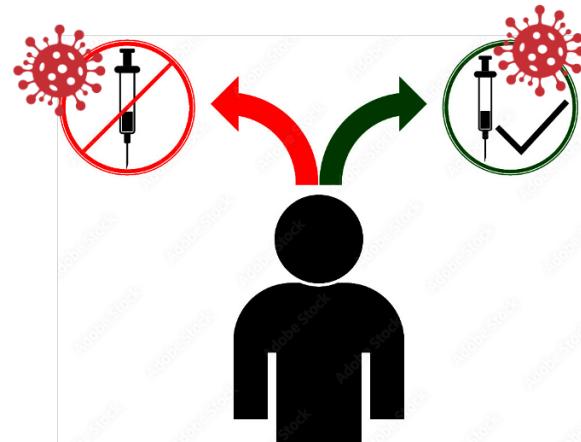
# Case Studies

- Climate campaigns.
  - **21k ads** (*Islam et al. 2023*), January 2021 to January 2022.
  - **Stance** (e.g., *pro-energy, clean-energy*) and **seed theme** (e.g., *support climate policy*).



# Case Studies

- Climate campaigns.
  - 21k ads (*Islam et al. 2023*), January 2021 to January 2022.
  - Stance (e.g., *pro-energy, clean-energy*) and seed theme (e.g., *support climate policy*).
- COVID-19 vaccine campaigns.
  - 9k ads (*Islam and Goldwasser 2022*), December 2020 to January 2022.
  - Moral foundation (e.g., *care/harm*) (*Haidt and Graham, 2007*) and seed theme (e.g., *vaccine equity*).



# Results: Coverage

- SBERT embedding for theme assignment for each ad.

CASE STUDY	METHOD	NUM. THEMES	THR < 0.6	NUM. COVERED ADS			
				THR < 0.5	THR < 0.4	THR < 0.3	
Climate	Pre-existing	13	14652	9725	3731	558	
	+After Iter1	20	18702	14583	8646	2944	
	<b>+After Iter2</b>	<b>25</b>	<b>18988</b>	<b>15052</b>	<b>9079</b>	<b>3180</b>	
COVID-19	Pre-existing	15	7889	6426	3480	771	
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# Results: Coverage

- SBERT embedding for theme assignment for each ad.
- **Better coverage after two iterations of *machine-in-the-loop* approach.**

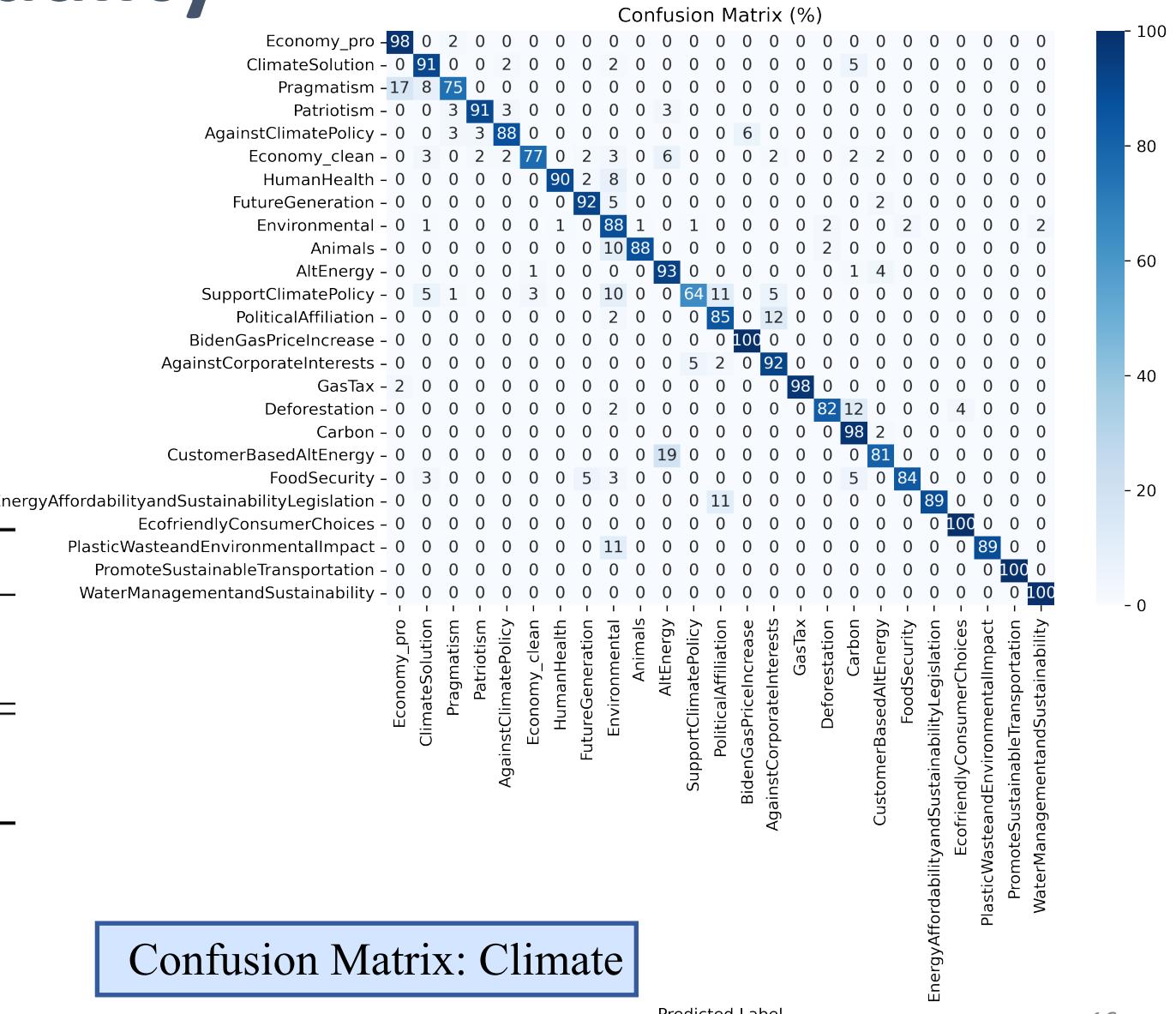
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# Results: Mapping Quality

- Ground truth:
  - 1072 climate ads.
  - 565 COVID-19 ads.
- Mapping Quality w.r.t Human Judgements.

Case Study	Method	Acc. (%)	F1 (%)
Climate	SBERT Assign.	84.05	79.32
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COVID-19	SBERT Assign.	41.42	44.83
	LLMs Mapper	<b>85.49</b>	<b>81.74</b>

True Label



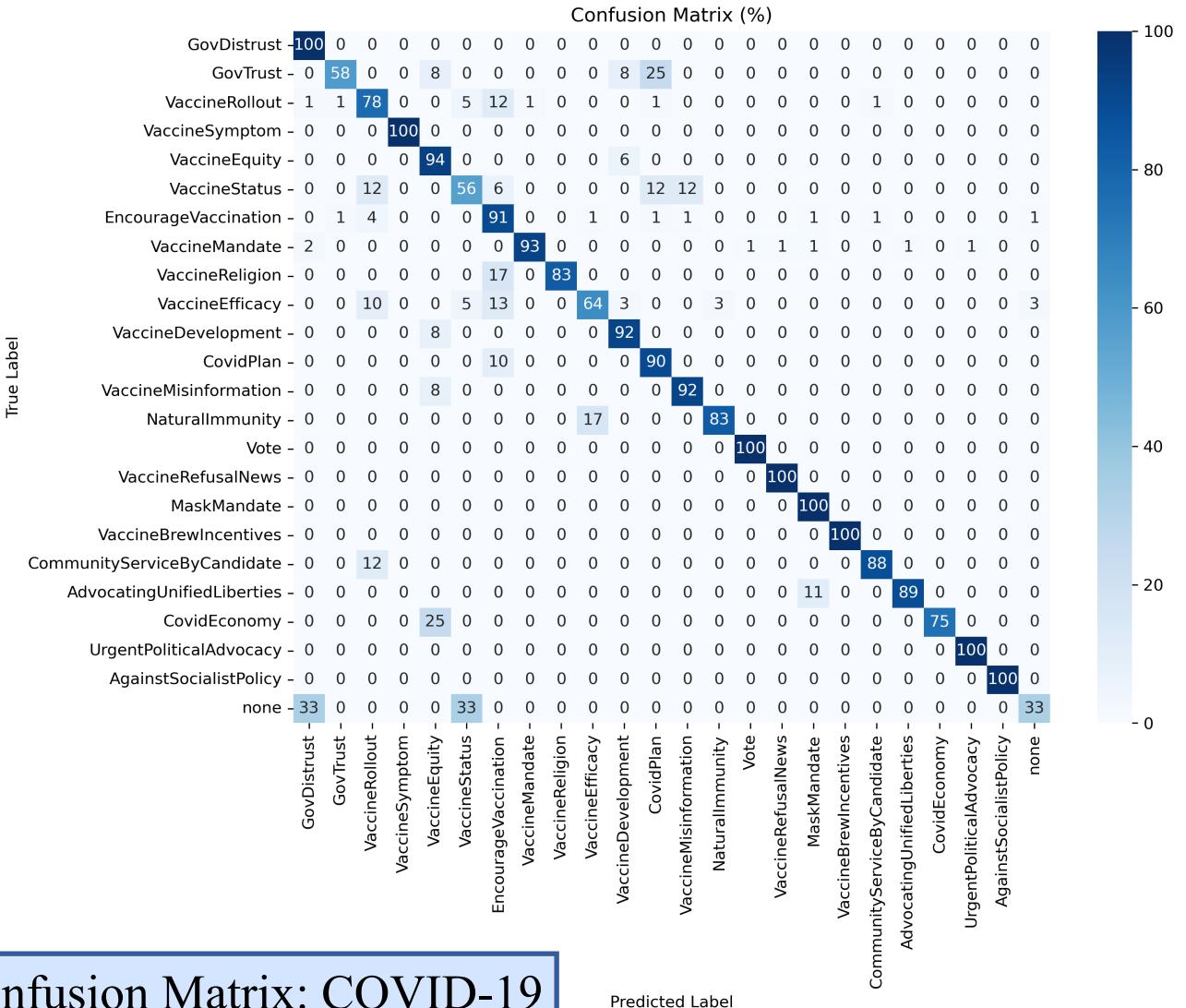
Confusion Matrix: Climate

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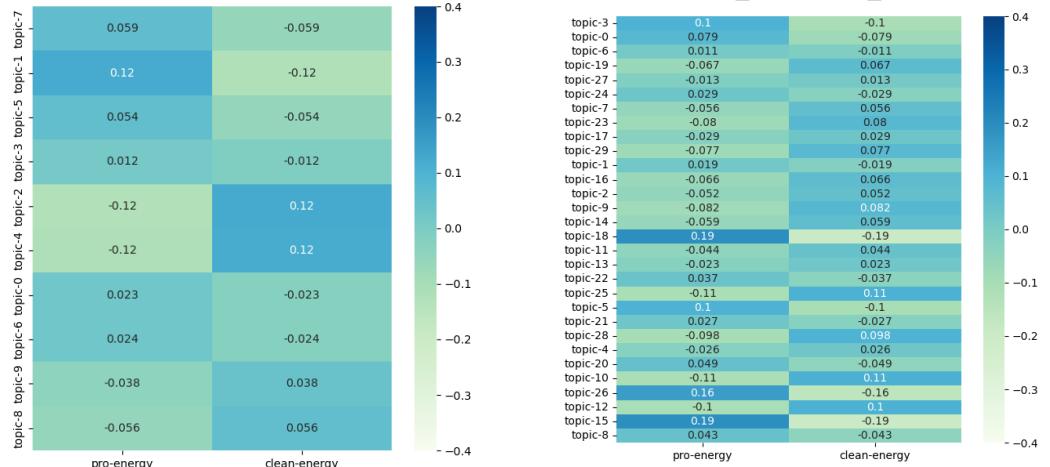
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Confusion Matrix: COVID-19

# Qualitative Analysis: Climate

- Correlation heatmap between identified **themes** and **stances** expressed in the ads (i.e., pro-energy or clean-energy).
- Stronger correlations with stances than the derived LDA and BERTopic topics.**



Baseline: 10 LDA Topics

Baseline: 30 LDA Topics

Baseline: 15 BERTopic Topics



Pro-Energy → ‘BidenGasPriceIncrease’ & ‘GasTax’



Clean-Energy → ‘Environmental’ & ‘AltEnergy’

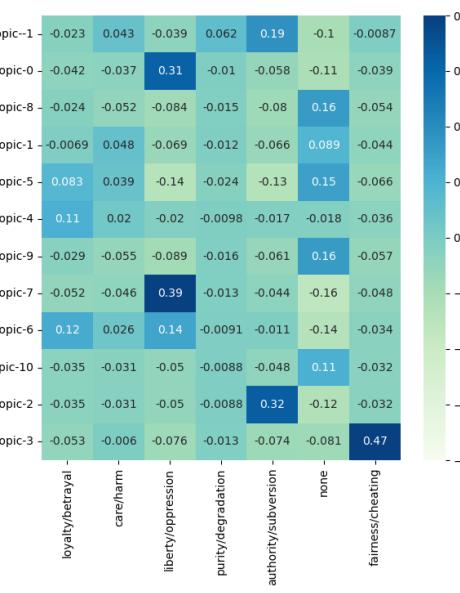
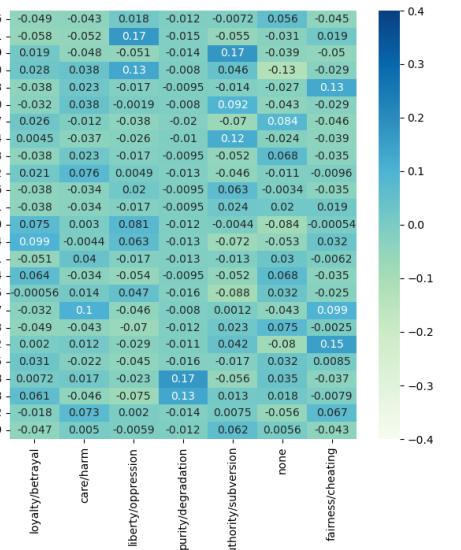
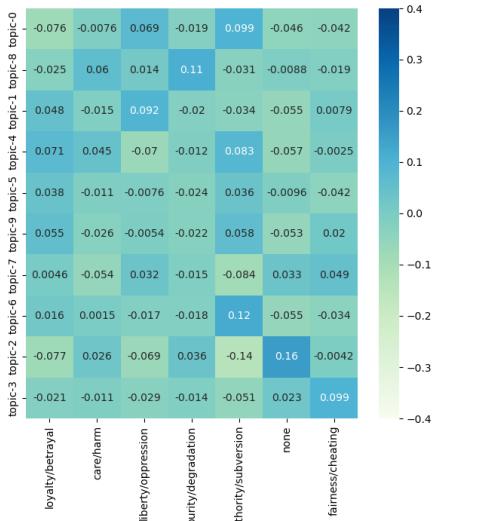
This heatmap shows correlations between various climate-related stances. The columns are labeled 'Carbon', 'SupportClimatePolicy', 'PoliticalAffiliation', 'FoodSecurity', 'EcofriendlyConsumerChoices', 'AgainstCorporateInterests', 'BidenGasPriceIncrease', 'Deforestation', 'Pragmatism', 'PlasticWasteandEnvironmentalImpact', 'ClimateSolution', 'WaterManagementandSustainability', 'Environmental', 'EnergyAffordabilityandSustainabilityLegislation', 'PromoteSustainableTransportation', 'AgainstClimatePolicy', 'FutureGeneration', 'AltEnergy', 'Animals', 'Economy\_clean', 'Economy\_pro', 'CustomerBasedAltEnergy', 'HumanHealth', 'Patriotism', 'GasTax', 'pro-energy', and 'clean-energy'. The 'pro-energy' and 'clean-energy' columns are highlighted with a red border. The color scale ranges from -0.4 (dark red) to 0.4 (dark green).

stance	Carbon	SupportClimatePolicy	PoliticalAffiliation	FoodSecurity	EcofriendlyConsumerChoices	AgainstCorporateInterests	BidenGasPriceIncrease	Deforestation	Pragmatism	PlasticWasteandEnvironmentalImpact	ClimateSolution	WaterManagementandSustainability	Environmental	EnergyAffordabilityandSustainabilityLegislation	PromoteSustainableTransportation	AgainstClimatePolicy	FutureGeneration	AltEnergy	Animals	Economy_clean	Economy_pro	CustomerBasedAltEnergy	HumanHealth	Patriotism	GasTax	pro-energy	clean-energy
stance	-0.13	-0.13	0.13	0.13	0.11	0.11	0.14	-0.13	0.17	-0.054	0.27	-0.06	-0.16	-0.054	-0.063	0.29	-0.12	0.12	-0.12	0.14	0.41	-0.15	-0.11	0.3	-0.37	0.4	

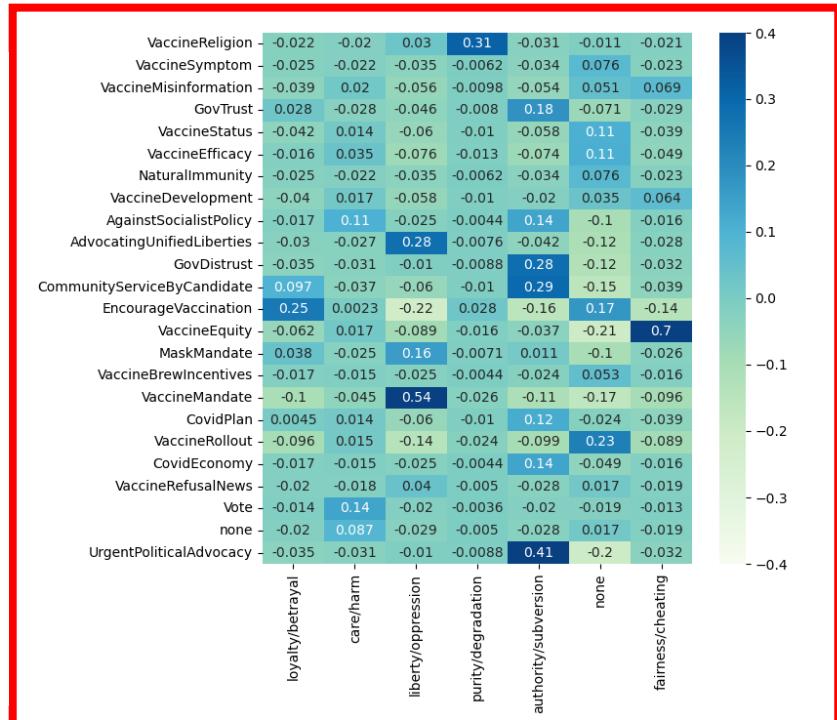
Ours: After 2nd round of iteration

# Qualitative Analysis: COVID-19

- Correlation heatmap between identified **themes** and **moral foundation** expressed in the ads (i.e., liberty/oppression, fairness/cheating).
- Stronger correlations with moral foundations than** the derived LDA and BERTopic topics.



Fairness/Cheating → ‘vaccine equity’  
 Liberty/Oppression → ‘vaccine mandate’ & ‘advocating unified liberties’



Baseline: 10 LDA Topics

Baseline: 25 LDA Topics

Baseline: 15 BERTopic Topics

Ours: After 2nd round of iteration

# Demographic Targeting

- How Themes Differ based on **Gender**.
- Extract ads **targeted exclusively** at *males* and *females*.

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Theme: GasTax



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Theme: FutureGeneration



# Demographic Targeting

- How Themes Differ based on **Red** vs. **Blue** States.
  - ▶ **North Dakota (ND)** vs. **Vermont (VT)**
- Different emphasis placed on the *entity* ‘Community’.

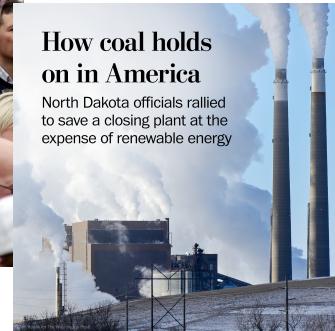
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Theme: Economy



THE U.S. OIL AND  
NATURAL GAS  
INDUSTRY SUPPORTS  
NEARLY **11 MILLION**  
JOBS



Claim: Oil & gas supports jobs and  
**community** growth.

NORTH DAKOTA

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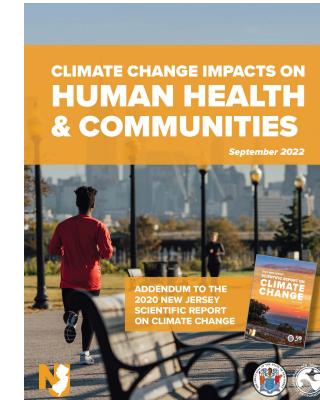
- Different emphasis placed on the *entity* ‘Community’.

Theme: HumanHealth

Theme: Economy



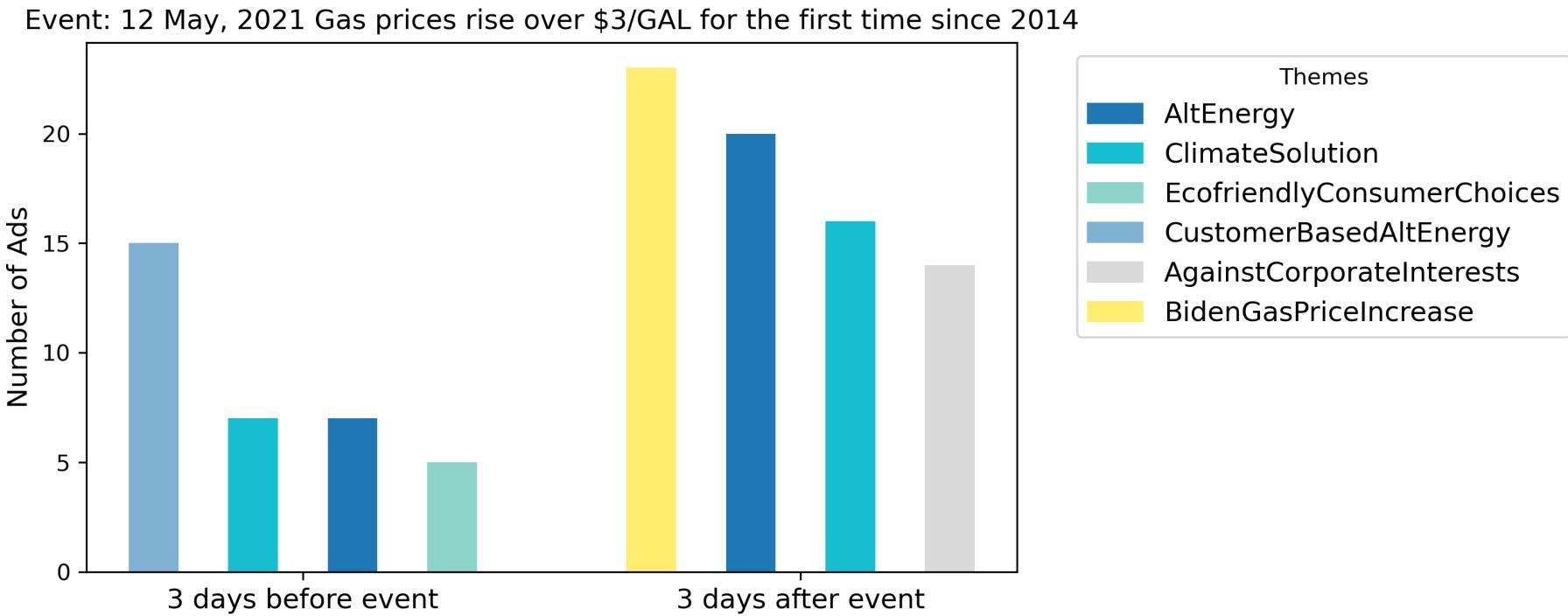
Claim: Oil & gas supports jobs and community growth.



Claim: Climate change impacts health, family & community.

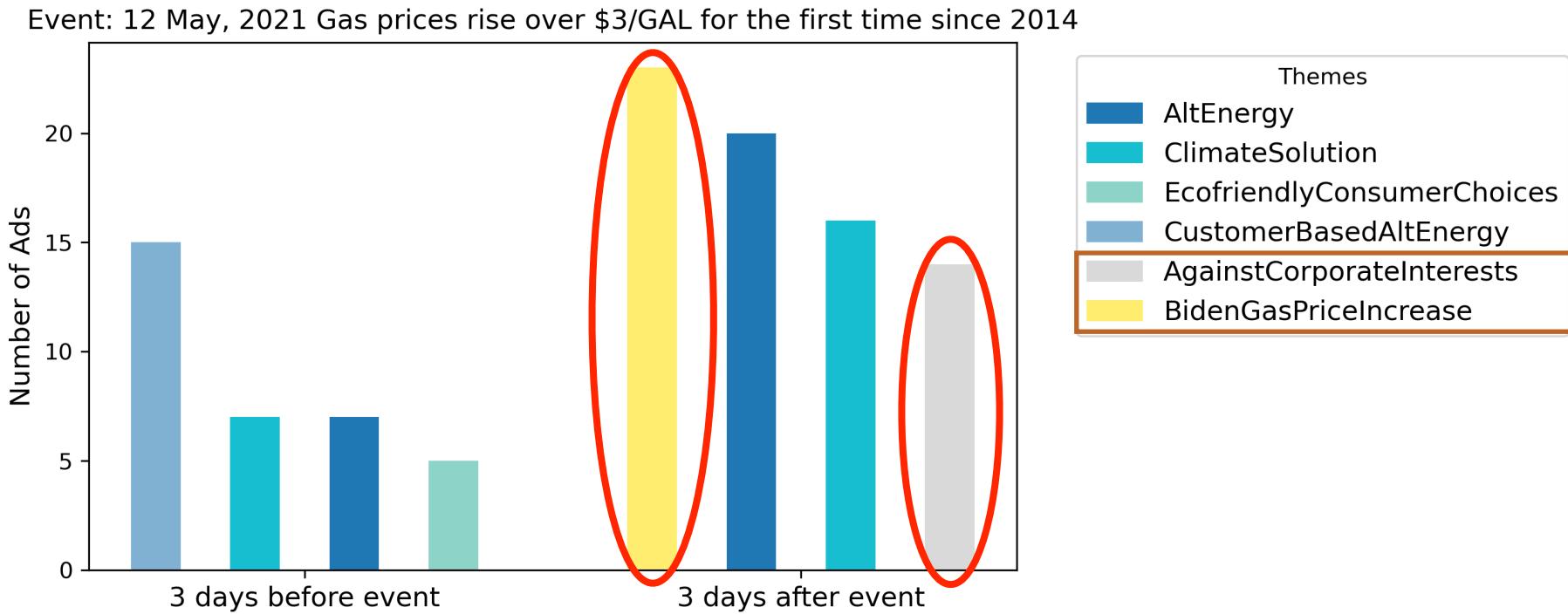
# Theme Shifts Triggered by Key Events

- Event1: **Gas Price Increase**, Date: **May 12, 2021**.
- Theme Freq.: AltEnergy, ClimateSolution **increased**.



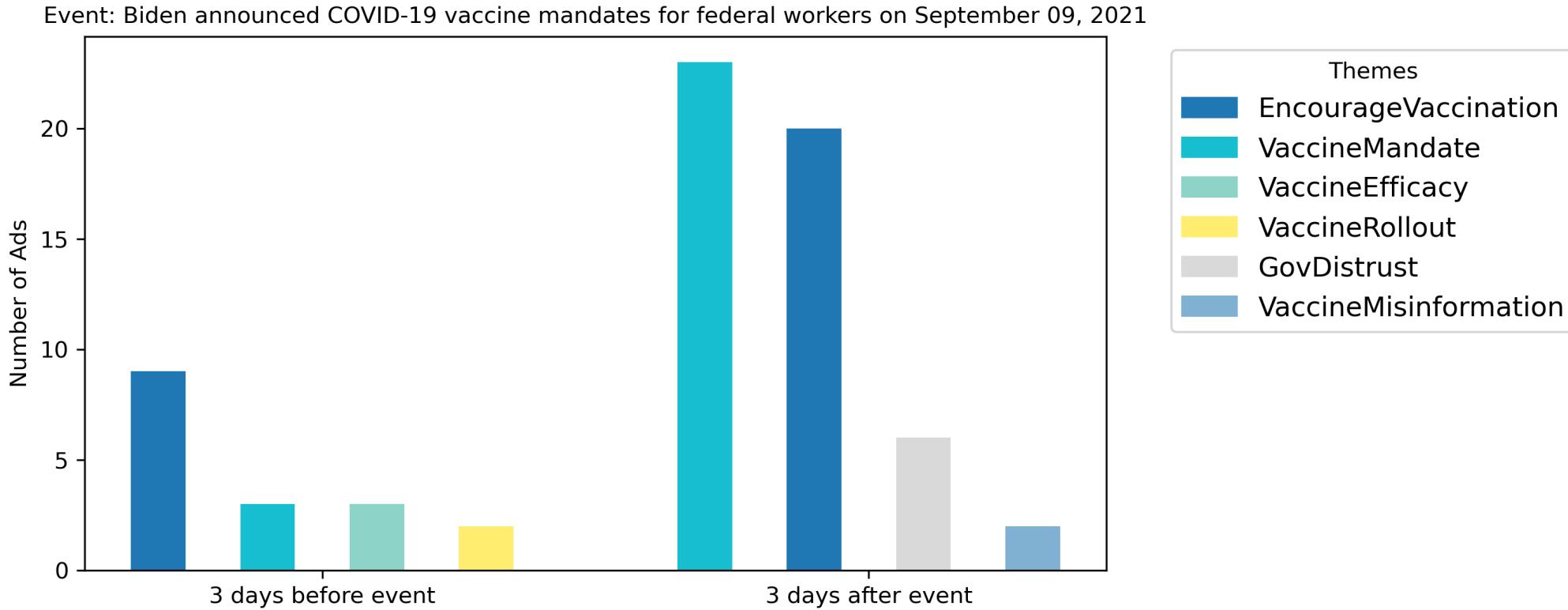
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- Event1: **Gas Price Increase**, Date: May 12, 2021.
- Theme Freq.: AltEnergy, ClimateSolution **increased**.
- New Themes: **AgainstCorporateInterests, BidenGasPriceIncrease**.



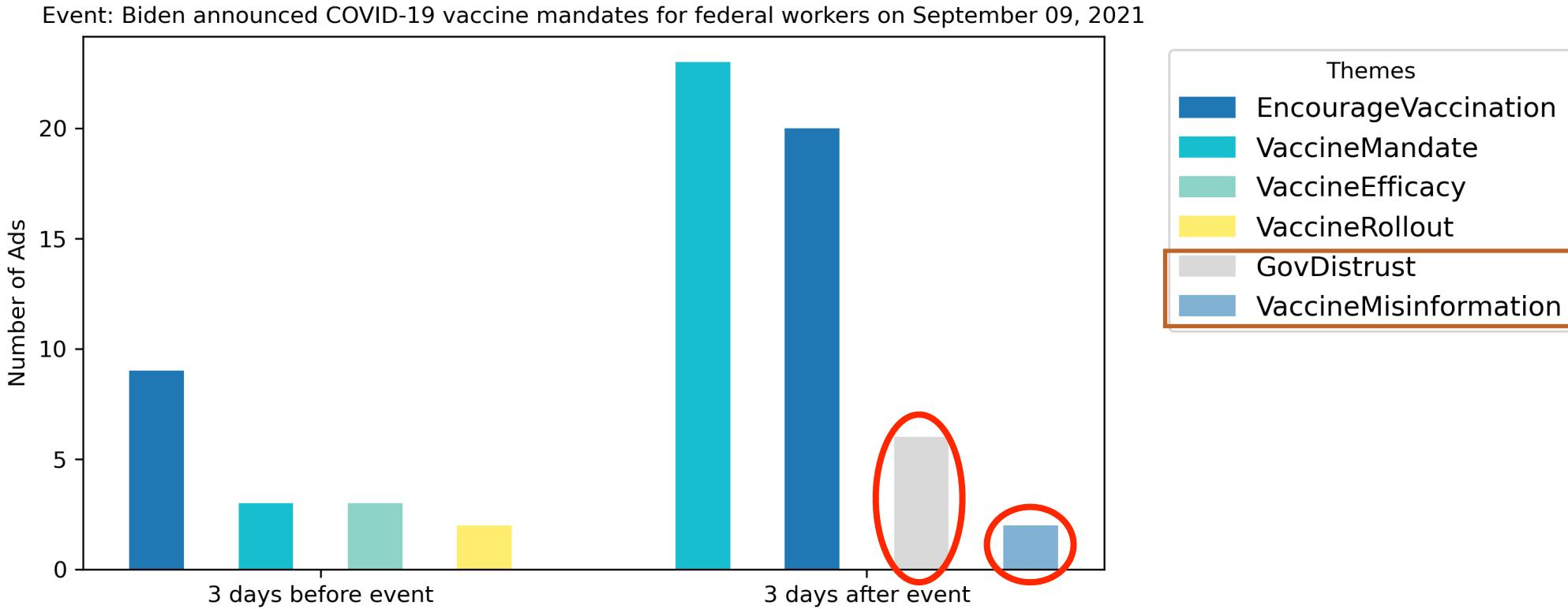
# Theme Shifts Triggered by Key Events

- Event2: **Federal COVID-19 vaccine mandate**, Date: **September 09, 2021**.
- Theme Freq.: VaccineMandate **increased**.



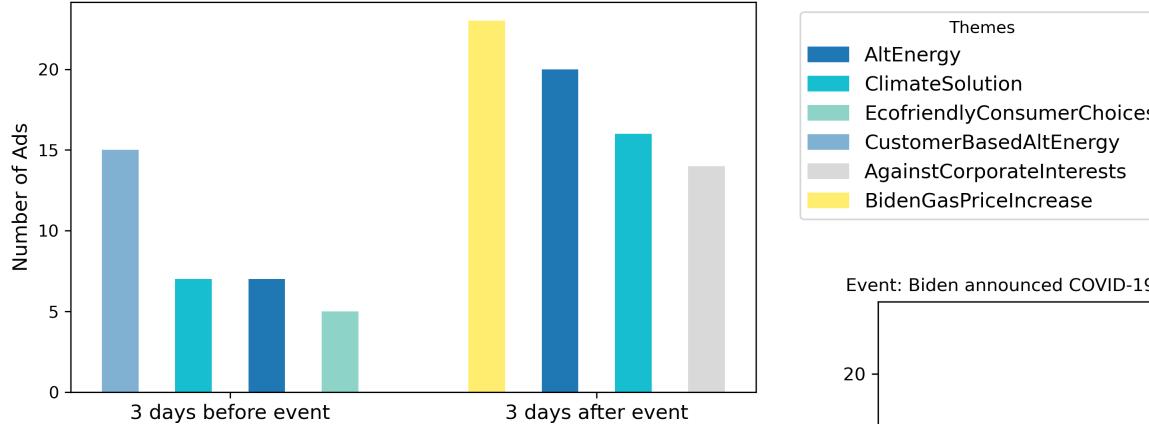
# Theme Shifts Triggered by Key Events

- Event2: **Federal COVID-19 vaccine mandate**, Date: **September 09, 2021**.
- Theme Freq.: VaccineMandate **increased**.
- New Themes: **GovDistrust, VaccineMisinformation**.

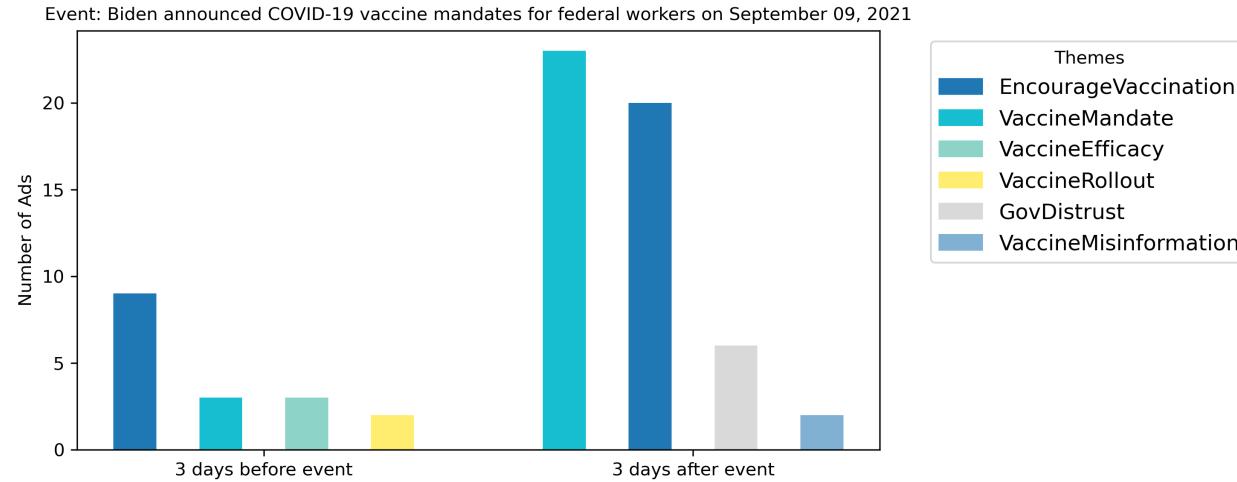


# Theme Shifts Triggered by Key Events

Event: 12 May, 2021 Gas prices rise over \$3/GAL for the first time since 2014



Event: Biden announced COVID-19 vaccine mandates for federal workers on September 09, 2021



## Findings:

- Sponsored content is **highly responsive** to real-world events
- Reflect and potentially **shape public discourse** on pivotal issues.

# References

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Thank  
You!!!

Code and Dataset: <https://github.com/tunazislam/latent-themes-llms/tree/main>  
Slide: <https://tunazislam.github.io/files/LatentThemesLLMsICWSM25.pdf>

Questions



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 [@Tunaz\\_Islam](https://twitter.com/Tunaz_Islam)



# Backup Slides

# Research Questions (RQs)

- **RQ1:** Can LLMs determine if two given texts, without prior knowledge of existing codes, are discussing the same topic?

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- **RQ2:** If provided with a definition of a theme, can LLMs successfully categorize other texts under that specific theme?

# Coherency Checking

1. Here are some key things to know about used motor oil:

- 💧 200 million gallons of oil are dumped into U.S. waterways, sewers, and landfills by people changing their own motor oil.
- \* Used motor oil is considered hazardous waste in California.
- ♻️ Used motor oil is recyclable! Every 1 gallon of used oil recovered can produce 2.5 quarts of re-refined oil.
- 🚗 Oil never wears out—it just gets dirty. Most cars can go more than 5,000 miles between oil changes.

2. Check out more interesting facts about used motor oil and ways to prevent oil pollution at <https://bit.ly/3wFZue1>.

The oil and gas industry in Eddy County is the economic driver for our state. I fully support the oil and gas industry and am proud of the environmental standards these great companies impose on themselves.

3. The EPA will hold three virtual listening sessions to take public input on the Agency's upcoming regulations for the Oil and Natural Gas Industry. What you cannot see at an oil & gas well can hurt you. Local Front Range residents are visiting oil and gas sites to learn how invisible methane gas and other health-harming pollution are threatening their communities.

4. Biodiesel (also known as biofuel) is a gallon-for-gallon substitute for petroleum-based fuels, which have a higher carbon intensity. By 2030, it's estimated that biodiesel will displace 529 million gallons of heating oil!

5. Biodiesel is nontoxic, biodegradable renewable liquid fuel. The biofuel that's blended with heating oil to create Bioheat fuel is generally produced by agricultural byproducts, including used cooking oil, animal fats, inedible corn oil, soybean oil and canola oil. This puts excess oil and fats to good use!

Supports motor oil

Against oil & gas industry

Supports biofuel

# *Coherency Checking: Incoherent Cluster*

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Supports motor oil

LLMs categorize this cluster as **incoherent** cluster.

Against oil & gas industry

Supports biofuel

# *Merging Checking*

**Summary of cluster 1:** #PlantingChallenge aims to plant trees in California to combat climate change, while another initiative promotes the planting of "super trees" with superior carbon storage capabilities. Oxford is considering a Tree Planting and Urban Forestry program to maintain its aging tree canopy, emphasizing the multiple benefits of trees. Criticism is directed at the Obama Presidential Center for cutting down over 300 mature trees, underlining the importance of preserving older trees for carbon storage. Additionally, a service offers to plant trees worldwide for a small monthly fee to help mitigate climate change and replenish forests.

**Summary of cluster 18:** The Tongass National Forest in Alaska, a crucial carbon sink and habitat, is at the center of environmental advocacy efforts. Accusations against Central Maine Power (CMP) suggest misleading claims about renewable energy development, while campaigns emphasize the Tongass's role in storing 44% of carbon absorbed by U.S. national forests and its significance for clean air, water, and climate. Calls to action focus on reinstating the Roadless Rule to protect the forest from logging and development, with the U.S. Forest Service planning to reinforce these protections. This highlights the forest's importance for salmon populations, local communities, and climate resilience, urging public involvement in conservation efforts.

- **Embed the summaries using SBERT.**
- **Compute the cosine similarity between the embedding summaries of cluster pairs.**

# *Merging Checking: Merged*

**Summary of cluster 1:** #PlantingChallenge aims to plant trees in California to combat climate change, while another initiative promotes the planting of "super trees" with superior carbon storage capabilities. Oxford is considering a Tree Planting and Urban Forestry program to maintain its aging tree canopy, emphasizing the multiple benefits of trees. Criticism is directed at the Obama Presidential Center for cutting down over 300 mature trees, underlining the importance of preserving older trees for carbon storage. Additionally, a service offers to plant trees worldwide for a small monthly fee to help mitigate climate change and replenish forests.

**Summary of cluster 18:** The Tongass National Forest in Alaska, a crucial carbon sink and habitat, is at the center of environmental advocacy efforts. Accusations against Central Maine Power (CMP) suggest misleading claims about renewable energy development, while campaigns emphasize the Tongass's role in storing 44% of carbon absorbed by U.S. national forests and its significance for clean air, water, and climate. Calls to action focus on reinstating the Roadless Rule to protect the forest from logging and development, with the U.S. Forest Service planning to reinforce these protections. This highlights the forest's importance for salmon populations, local communities, and climate resilience, urging public involvement in conservation efforts.

**Argument:** Take initiatives to plant new trees and protect existing forests to save our planet.

Clusters are merged  
(cosine similarity  $\geq 0.6$ ).

# Results: Coverage

- Climate
  - Pre-existing themes:
    - ▶ Coverage: 17.5% ads.
  - After Iter1:
    - ▶ Coverage: **40.5%** ads.
  - After Iter2:
    - ▶ Coverage: **42.5%** ads.

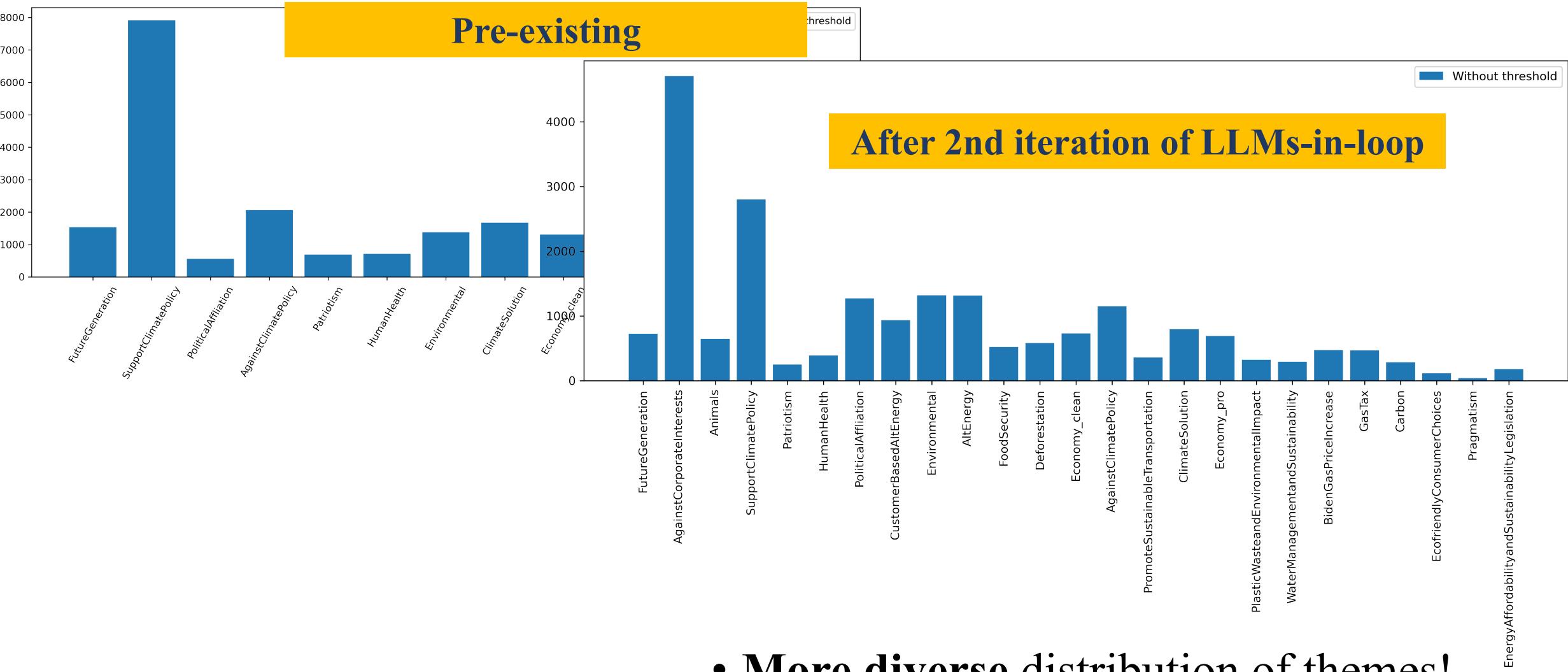
CASE STUDY	METHOD	NUM. THEMES	NUM. COVERED ADS			
			THR < 0.6	THR < 0.5	THR < 0.4	THR < 0.3
Climate	Pre-existing	13	14652	9725	3731	558
	+After Iter1	20	18702	14583	8646	2944
	+After Iter2	<b>25</b>	<b>18988</b>	<b>15052</b>	<b>9079</b>	<b>3180</b>
COVID-19	Pre-existing	15	7889	6426	3480	771
	+After Iter1	20	8852	7627	4737	1302
	+After Iter2	<b>23</b>	<b>9092</b>	<b>7898</b>	<b>5038</b>	<b>1590</b>

# Results: Coverage

- **Climate**
  - Pre-existing themes:
    - ▶ Coverage: 17.5% ads.
  - **After Iter1:**
    - ▶ Coverage: **40.5%** ads.
  - **After Iter2:**
    - ▶ Coverage: **42.5%** ads.
- **COVID-19**
  - Pre-existing themes:
    - ▶ Coverage: 35.08% ads.
  - **After Iter1:**
    - ▶ Coverage: **47.75%** ads.
  - **After Iter2:**
    - ▶ Coverage: **50.79%** ads.

CASE STUDY	METHOD	NUM. THEMES	THR < 0.6	NUM. COVERED ADS			
				THR < 0.5	THR < 0.4	THR < 0.3	
Climate	Pre-existing	13	14652	9725	3731	558	
	+After Iter1	20	18702	14583	8646	2944	
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# Is Machine-in-the-Loop Helpful?



- More diverse distribution of themes!