

Heavyweights Registered for a Marathon: Topical & Temporal Structures in “Hard-to-Abate” Firm’s Decarbonization Strategies

Introduction

Because global emissions are driven largely by fossil fuel combustion in industrial processes, climate change mitigation demands fundamental changes in how firms strategize, invest, and operate (Howard-Grenville et al., 2014; Bansal et al., 2025). Policy interventions such as the EU Emission Trading System (EU ETS) seek to accelerate this shift by creating economy-wide decarbonization incentives and accountability for heavy emitters (EC, 2021; Stern & Valero, 2021). This pressure is particularly acute for emission-intensive “hard-to-abate” firms, which account for roughly 20% of EU emissions yet rely on production processes that are difficult to electrify and face limited availability of scalable low-carbon alternatives (IEA, 2023; Bachorz et al., 2025; Edelenbosch et al., 2024). While strategy research has increasingly examined responses in energy transitions where decarbonization pathways are more visible and actionable (e.g., Kim, 2013; Eklund & Kapoor, 2019; Falcke, Zobel & Comello, 2023), hard-to-abate sectors such as building materials, heavy industry, and chemicals remain comparatively overlooked despite their outsized exposure to regulatory pressures and resulting strategic challenges (Fankhauser et al., 2022; Edelenbosch et al., 2024). Accordingly, we need a more granular understanding of how firms in hard-to-abate industries structure their decarbonization strategies (Kapacinskaite 2026; Howard-Grenville et al., 2014; George et al., 2016; Bansal et al., 2025). Capturing the systemic nature of decarbonization in these settings, I define decarbonization strategy as a firm’s overall scope of actions, within and beyond its boundaries, aimed at reducing emissions.

In Europe, this strategic challenge is increasingly shaped by binding climate policy, especially the EU ETS and the broader tightening of decarbonization governance such as the “Fit for 55” package. A binding carbon ‘cap-and-trade’ policy forces firms to pursue near-term emission reductions to manage compliance exposure, while simultaneously preparing for deep strategic transformation aligned with long-term net-zero targets, often under uncertainty about which technological pathways will scale and when (Hansen et al., 2024). These pressures and uncertainties collide with an institutionalized timeline: in line with the Paris Agreement and IPCC pathways, firms are expected to reduce emissions in the near term, halve emissions by around 2030, and reach net-zero by 2050 (IPCC, 2022). This tripartite temporal demand extends firms’ conventional planning horizons and typical investment cycles (Bansal & Slawinski, 2015; Feuls, Hernes & Schultz, 2025). Thus, meeting different and competing temporal demands is a key strategic challenge for firm’s decarbonization efforts that goes beyond measuring emission reduction progress.

Despite the fundamental strategic shift firms in hard-to-abate sectors are subjected to, we still lack systematic understanding of how these firms articulate their strategic focus, and how they distribute strategic commitments across short-, mid-, and long-term horizons. Corporate reports offer a key window into how public firms articulate climate-mitigation strategy for investors and other stakeholders, but due to their unstructured nature they are notoriously difficult to analyze systematically (Zavvalova, Pfarrer, Reger & Shapiro, 2012; Amel-Zadeh & Serafeim, 2018; Coen et al., 2022). Prior research has thus often approximated decarbonization strategies through quantitative measures such as emissions performance, target setting and narrow disclosure-based indicators, frequently drawing on the CDP survey dataset (e.g., Ioannou, Shelley & Serafeim, 2016, Callery & Kim, 2025). While this work has generated important insights into the tension between ambition and action, it leaves open a key strategic question: whether, and in what ways, firms in hard-to-abate industries articulate decarbonization strategies across multiple time horizons. I thus ask:

How do firms in hard-to-abate industries structure, and sequence decarbonization strategies across temporal horizons?

I empirically examine this question by inductively mapping the topical and temporal structure of firm-specific decarbonization strategies as articulated in corporate reports. I draw

on a novel panel corpus of climate-strategy disclosure from 114 public European hard-to-abate firms (2016–2024) governed by the EU ETS. Methodologically, I apply a scalable pipeline that extracts strategy-relevant text, identifies dominant themes through stable topic modeling, and detects temporal cues through dictionary-based analysis to trace how strategic content is allocated across time horizons.

Literature Review

Management and strategy scholarship increasingly treats corporate decarbonization as a strategic response to a complex, uncertain, and interdependent problem that no single firm can address alone, often requiring coordinated action across technologies, institutions, and stakeholder networks (e.g., Grodal & O'Mahony, 2017; Vakili & McGahan, 2016). Though, corporate responses frequently remain incremental: firms acknowledge climate risks and experiment with decarbonization initiatives while preserving core business models rather than pursuing transformative change (Wright & Nyberg, 2017; Nyberg & Wright, 2022). However, decarbonization is iterative, combining efficiency gains in existing systems with a transition strategy toward low-carbon production (Fankhauser et al., 2022). In this context, particularly in hard-to-abate industries, innovation and capability development are pivotal (Glenk et al., 2023). Yet incumbents may hesitate to commit at scale because returns are uncertain and new capabilities can threaten existing ones (Falcke et al., 2023). While scholars have begun to illuminate this strategic challenge in the energy and mobility sectors (e.g., Eklund & Kapoor, 2019) it remains unclear how firms in hard-to-abate industries adapt their strategic focus amid the high degree of complexity and uncertainty of decarbonization.

However, corporate strategies unfold against biophysical constraints that strategy can no longer treat as peripheral: when firms respond slowly or incrementally, they risk misaligning firm-level action with planetary boundaries and the regenerative limits of natural systems (Bansal et al., 2025). To avoid the most severe climate impacts and limit warming to 1.5°C, regulators have institutionalized the IPCC's timeframe with the tripartite temporal demand consisting of short-, mid- (until 2030), and long-term horizons (until 2050). This provides a setting that quantifiably extends the prevalent dichotomous view of temporal orientations (Slawinski & Bansal, 2015). A central concern of corporate climate strategies is thus to create a temporal fit with this demand (Blagoev et al., 2024) to avoid being “selected out” (Pérez-Nordtvedt et al., 2008: 797), such as through rising carbon costs under instruments like the EU Emissions Trading System. Thus, climate change, and the temporal demands institutionalized in regulation, has critical strategic implications for firms, making it essential to uncover not only the topical focus of decarbonization strategies but also their temporal structure.

However, a key challenge in externally assessing firm strategies is that strategic commitments are mainly visible through public reports. These disclosures shape investor and stakeholder evaluations and are widely perceived as financially material, particularly by long-term investors (Zavyalova et al., 2012; Amel-Zadeh & Serafeim, 2018). As strategic artifacts, reports help firms interpret regulatory pressure, justify capital allocation, and link near-term actions to longer-term transition pathways (Cenci et al., 2023; Coen et al., 2022). Yet reports are not neutral reflections of action: disclosures can enable both credible signalling and strategic obfuscation, creating heterogeneity in how decarbonization strategies are reported (e.g., Bromley & Powell, 2012; Crilly et al., 2016). While regulation can improve comparability, most reports have remained voluntary, complicating systematic large-scale analysis (Coen et al., 2022). Prior work addresses this by extracting clearly articulated initiatives from recurring syntactic patterns and classifying them deductively (Cenci et al., 2023; Carlson & Burbano, 2025; Feuerriegel et al., 2025). I advance this stream by shifting attention from discrete initiatives to inductive structuring of decarbonization strategies, comparing firm-specific semantics rather than syntactic cues.

Methodology

Data & Sample

To inductively map how firms in hard-to-abate industries articulate and temporally structure their climate change mitigation strategies, I apply a multi-step, data-driven text-analytic approach. I construct a panel of 114 EU-based publicly listed firms in hard-to-abate industries regulated under the EU Emissions Trading System (EU ETS), identified via LSEG, covering 2016 (Paris Agreement) to 2024. To ensure comparability of decarbonization challenges, I restrict the sample to manufacturing industries with high direct emission intensities (>1 kg CO₂/€ GVA) listed on the EU ETS Carbon Leakage List, resulting in 13 NACE-coded industries. After excluding misclassified firms, companies without EU production sites, and those lacking consistent reporting histories, the final sample comprises 114 firms. I manually collected sustaina-

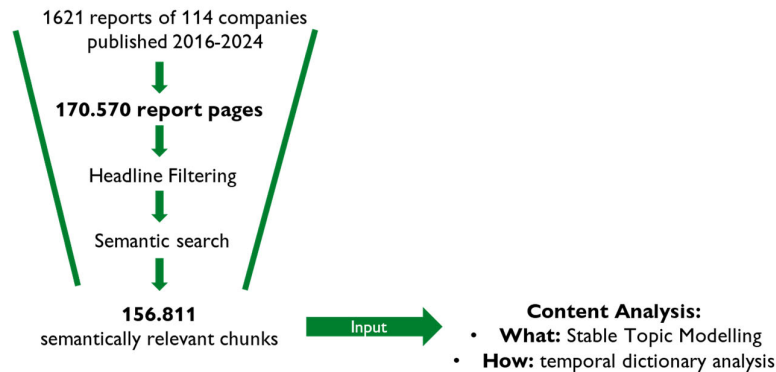


Figure 1: Summary of the text preprocessing and analysis steps

bility, integrated, and annual reports, yielding 1,621 reports (170,570 pages). All PDFs were converted to markdown files; non-English reports were translated via DeepL and validated through manual screening and back-translation.

From this corpus, I applied a broad filtering algorithms to reduce noise and use semantic search to extract climate mitigation strategy passages, producing a strategy-focused sub-corpus. I then apply stable topic modelling to inductively surface dominant strategic themes (the topical structure) and complement this with a dictionary-based temporal analysis to detect short-, mid-, and long-term cues (the temporal structure). A summary of the methodological approach is depicted in Figure 1. This pipeline enables a systematic mapping of the topical and temporal structure of mitigation strategies.

Detecting Semantically Relevant Passages

Non-standardized corporate reports pose major challenges for systematic text analysis due to heterogeneous structures, inconsistent disclosure practices, and substantial semantic noise (Cenci et al., 2023; Coen et al., 2022; Amel-Zadeh & Serafeim, 2018). I implemented a two-stage filtering pipeline. First, leveraging the structural information embedded in markdown-formatted reports, I extracted 484,412 section and subsection headlines from 1,621 reports. Using an iteratively refined set of 60 high-level climate-strategy keywords (e.g., *strateg**, *emission**, *transition*, *capex*), I retained pages associated with matched headlines plus adjacent pages to avoid overly restrictive filtering. This reduced the corpus from 170,570 to 76,141 pages, substantially lowering noise while prioritizing recall.

Second, I isolated relevant strategy passages using embedding-based semantic search. While some recent studies build on approaches build on Large Language Models (LLMs), prompt-based LLM classification can impose predefined decision boundaries and limit reproducibility due to researcher-dependent prompting and black-box interpretation (de Kok, 2025; Carlson & Burbano, 2025). To inductively discover heterogeneous and evolving decarbonization strategy patterns, I thus relied on continuous semantic similarity measures (Ash & Hansen, 2023). I split the reduced corpus into 436,471 paragraph-level text chunks, embedded them with

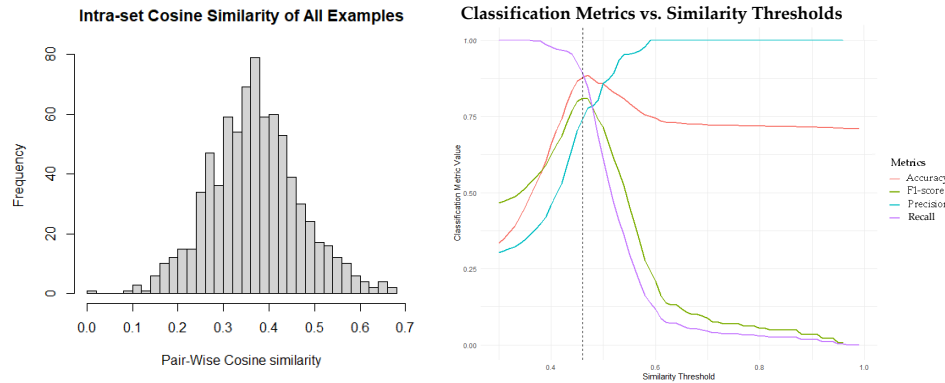


Figure 2: Left-Pairwise cosine similarity distribution of semantic anchors, Right-Classification performance metrics across cosine similarity threshold values

the Qwen3-Embedding-0.6B model, and defined the semantic target space using 40 semantic “anchors” that describe firm-level mitigation strategies; anchors were sampled across firms/years, de-identified, and iteratively refined to avoid bias. Pairwise cosine-similarity checks ensured a coherent but non-restrictive target space (Figure 2, left).

For each text chunk, I computed the maximum cosine similarity to the anchor set. Based on manual classification of 1,000 randomly sampled chunks by an industry expert, I evaluated precision, recall, and F1 scores across cosine similarity thresholds. As depicted on the right side of Figure 2, a cosine cutoff of 0.46 maximized the F1 score (0.81) while maintaining high accuracy (0.88). Applying this threshold reduced the dataset to 156,811 semantically relevant text chunks (i.e. strategy-excerpts).

Uncovering Latent Strategic Topics

Based on our corpus of 156,811 strategy-excerpts, I first uncover recurring strategic themes using stable topic modelling (Yang & Subramanyam, 2023). Topic modelling identifies latent themes by detecting patterns of word co-occurrence, representing each document as a mixture of topics and each topic as a distribution over words (Blei et al., 2003). Due to the inductive nature, it has been used to advance theories in management and strategy research (e.g., Hannigan et al., 2019). I apply stable topic modelling, a refinement of standard Latent Dirichlet Allocation (50 topics) that addresses instability across model runs by structuring a Dirichlet-tree prior with corpus-specific clustered word embeddings (see Yang & Subramanyam, 2023 for a detailed methodological overview).

Uncovering Temporal Structure

To assess temporal orientation, I implement a multi-dimensional dictionary-based analysis at the sentence level (Crilly et al., 2016; see DesJardine & Bansal, 2019 for a detailed methodological overview). Temporality is conceptualized along three dimensions: 1) *Explicit temporal language captured* via RegEx dictionaries (e.g., “near term,” “by 2030,” “long run”), iteratively refined using prior literature and LLM-assisted expansion. 2) *Dynamic year references* classified relative to each report’s publication year (1–5 years ahead = short-term; 6–19 = mid-term; 20+ = long-term), ensuring context-sensitive categorization across reporting periods. 3)

Technology-based horizons, derived from International Energy Agency (IEA) classifications of technology maturity (IEA, 2025), assigning referenced technologies to temporal categories reflecting expected scaling and deployment timelines. For each text chunk, I count occurrences across these three temporal dimensions and aggregate them into composite short-, mid-, and long-term orientation measures at document and firm-year levels.

Results and Discussion

To interpret the topic model, I combine two sources of evidence: each topic’s top-ranked words (to label its core meaning) and high-scoring strategy-excerpts (to validate and illustrate how it appears in firms’ climate-mitigation disclosures). Overall, the model yields strong topic quality: the topics are highly coherent and exhibit only limited overlap, as both top-word lists and representative excerpts consistently point to distinct, rather than broad or ambiguous, categories. The full set of topics is listed in table 1.

Table 1: Summary of topic categories

Topic-Category Description	Relating Topics
1-Internal Control Systems	Sustainability & Compliance Management; (Efficiency) Improvements & Optimizations; (Quality) Control & Monitoring; Production Waste; Supplier Audits
2-Non-content-related Instrumental Text Parts	Past Years; Company Names; Report Boilerplates; International Regions Names
3-Planning, Foresight & Positioning	Strategic Planning; Target Setting & Progress; Consumer Trends & Market Growth; Trends & Developments; Market Positioning & Competitive Advantage
4-Inter-Firm Engagements & Collaborations	Collaborative Innovation; M&A; International Agreements
5-(Technological) Innovation & Projects	Low-Carbon Technology Projects; (Low-Carbon) Energy Sources; Circularity & Downstream Innovation; Novel Products
6-Emission Management	Emission Types; Emission Data; Emission Measuring; Mitigation Efforts
7-General Strategic Statements	Sustainability Strategy Overview; Climate Change Responsibility
8-Stakeholder-Centric & Systemic Perspectives	Community Engagement; Employees & Social Responsibility; Employee-Training; Human Rights; Stakeholder Engagement; Biodiversity; Biophysical
9-Firm-Internal Specifications & Processes	Internal Analysis; Financials specifications; Focal Products; Internal Governance; Building Materials; Industry Facility
10-Regulations	European Regulation; Regulatory Guidelines

Overall, the resulting topics span across strategic issues within and beyond firm boundaries (e.g., see category 1,4 & 8), as well as from strategic planning (e.g.,3,6) to implementation (e.g.,5). The resulting topics suggest that firms’ decarbonization strategies may be best understood as diverse portfolio-like configurations rather than as a single, unified response.

To deepen our understanding of variance in decarbonization strategies, I aggregated normalized topical and temporal features to the firm–year level and applied k-means clustering to inductively identify strategic “states” that firms may occupy over time as focus and temporal orientation shift (Feuerriegel et al., 2025; Kobayashi et al., 2018). Features were z-standardized and average silhouette width indicated k=3. Over the full sampling period, cluster membership is relatively stable: year to year, 85% of firms in cluster 1, 66% in cluster 2, and 79.5% in cluster

3 remain in the same cluster the following year. Furthermore, 37% of firms are assigned to only one cluster throughout 2016-2024, while 48% switch between two clusters at least once, and

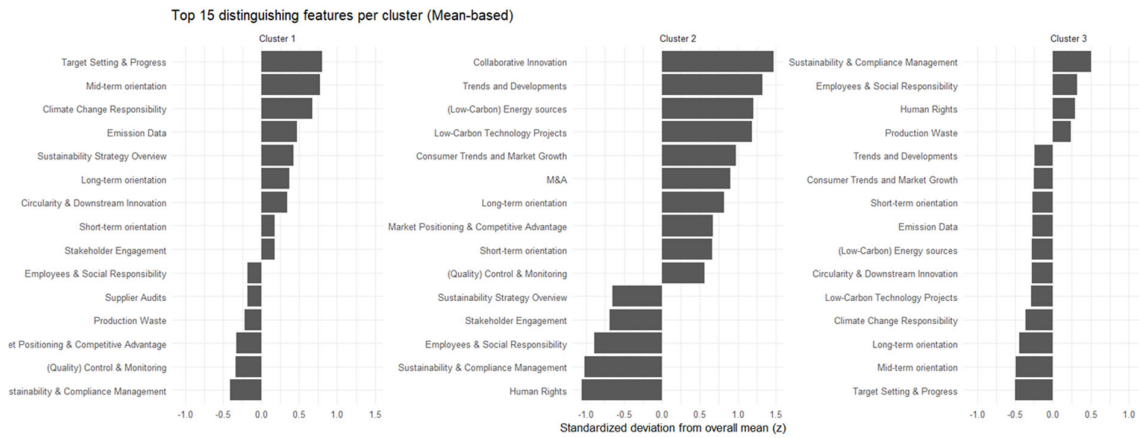


Figure 3: Distinguishing topical and temporal features for cluster 1, 2 & 3 (left to right)

15% move across all three clusters over time. To identify which topics and temporal orientations characterize each cluster, I computed cluster-specific feature profiles as standard deviations of cluster means from the overall mean, indicating which features are systematically over- or underrepresented, relative to the full sample (Kobayashi et al., 2018). Figure 3 shows three distinct decarbonization strategy archetypes defined by the heterogeneous topical and temporal profiles of the three clusters.

The first archetype, which I label “temporal strategizing,” emphasizes target setting and progress tracking and shows a strong mid-term (and slightly weaker long-term) orientation. Within our sample, companies in this cluster thus most explicitly align their strategies with the temporal demand imposed by policy, notably focusing on intermediate milestones (Blagoev et al, 2023; Pérez-Nordtvedt et al., 2008). Accordingly, firms in this cluster strategically focus on their climate change responsibility, also highlighting systemic strategic initiatives such as circularity and downstream innovation. In contrast, the cluster relatively deemphasizes more “myopic” strategic issues, including compliance management and market positioning (Slawinski & Bansal, 2015). Exemplary strategy-excerpts from firms consistently in this cluster combine 2030 milestones with 2050 net-zero targets and specify strategic pathway elements (e.g., alternative fuels and hydrogen positioning), as illustrated by Heidelberg Materials and Holcim. The second archetype, which I label “*technology innovation focus*,” is defined by a strong strategic emphasis on (collaborative) low-carbon technology projects, alongside a long-term orientation. In

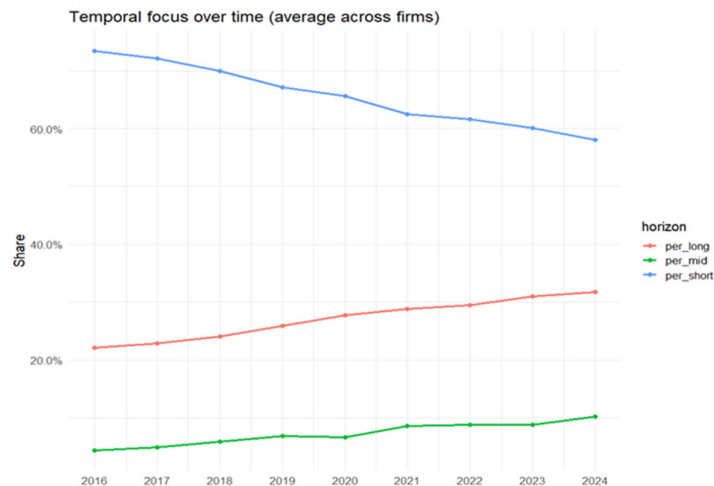


Figure 4: Share of aggregated short-, mid- and long-term cues per year across sample companies

contrast, firms in this cluster relatively deemphasize compliance management or systemic topics, such as stakeholder engagement. Exemplary excerpts suggest this strategy archetype is centred around commercializing low-carbon technologies and scaling value-chain offerings, often for smaller firms positioned as technology providers or solution specialists, as illustrated by cases such as Nel ASA and Cortus Energy. The third archetype, which I label “*reactive (compliance-based) strategizing*” is characterized by a dominant emphasis on compliance management and (efficiency) improvements, alongside a heightened attention to not directly emission-related issues such as social responsibility. In contrast to the other two, this archetype deemphasizes explicit temporal structuring, especially towards mid- and long-term orientations, and innovation-oriented decarbonization strategies. Exemplary excerpts confirm an emphasis on ensuring compliance rather than articulating intertemporal transformation pathways, as illustrated by cases such as Caltagirone SpA and Villeroy & Boch. Overall, the three archetypes suggest that firms are responding to the temporal demand imposed by policy in different ways, either strategizing for short-term alignment (3) or longer-term transformation (1 & 2) (Slawinski & Bansal, 2015). However, analysing the year-over-year developments, our results indicate an overall temporal rebalancing in decarbonization strategies, as shown in Figure 4.

Overall, while strategies remain predominantly short-term oriented, short-term cues steadily decline as mid- and long-term orientation rises. Importantly, although the mid-term dictionary is narrower, because firms express near- and long-term horizons with broader language while mid-term framing is typically anchored around 2030, our dictionaries are held constant over time, so year-to-year changes reflect shifts in temporal emphasis rather than measurement artifacts. The rising share of mid- and long-term orientation may thus suggest that firms increasingly seek temporal fit with the tripartite temporal demand since the Paris Climate Agreement (Blagoev et al., 2023; Pérez-Nordtvedt et al., 2008; IPCC, 2022). This shift is also mirrored in cluster composition: before 2020, 70% of firm-year strategies align with reactive compliance-based strategizing (cluster 3) versus 38% after 2020, while temporal strategizing (cluster 1) rises from 19% to 54%, with the technology innovation focus (cluster 2) remaining stable. Together, these shifts may indicate that firms increasingly confront the challenging temporal implications of decarbonization and the inherent tensions between conventional strategic imperatives and long-term systemic demands (Slawinski & Bansal, 2015; Bansal et al., 2025). In hard-to-abate industries, policy pressure and technological uncertainty may thus push firms to more explicitly temporally strategize to justify longer investment cycles and uncertain returns (Fankhauser et al., 2022; Glenk et al., 2023). Importantly, our results highlight the mid-term dimension as a crucial factor in our sample firms’ temporal strategizing for decarbonization.

To summarize, first I show that firms’ strategic responses to decarbonization policy pressure vary systematically, clustering into distinct decarbonization strategy archetypes that differ in the explicitness and distance of their temporal orientation (Slawinski & Bansal, 2015; Blagoev et al., 2023). Second, I map how European hard-to-abate firms (re)balance decarbonization strategies across short-, mid-, and long-term horizons in the post-Paris period, explicitly highlighting the important role of the mid-term (Amel-Zadeh & Serafeim, 2018; Coen et al., 2022; Cenci et al., 2023). Third, I introduce a scalable approach to extract and structure decarbonization strategies from unstructured disclosures and jointly analyze topical emphasis and temporal orientation, enabling large-scale study of heterogeneity, change, and temporal alignment with institutionalized temporal demands (DesJardine & Bansal, 2019; Cenci et al., 2023).

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