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Understanding the framing of hydrogen technology: a cross-national content analysis of newspaper coverage in Germany, Saudi Arabia, UAE, and Egypt

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Introduction: The implementation of national hydrogen strategies targeting zero-emission goals has sparked public discussions regarding energy and environmental communication. However, gaining societal acceptance for hydrogen technology poses a significant challenge in numerous countries. Hence, this research investigates the framing of hydrogen technology through a comparative analysis of opinion-leading newspapers in Germany, Saudi Arabia, the United Arab Emirates, and Egypt.

Methods: Utilizing a quantitative framing analysis based on Entman's framing approach, this research systematically identifies media frames and comprehend their development through specific frame characteristics. A factor analysis identified six distinct frames: Hydrogen as a Sustainable Energy Solution, Benefits of Economic and Political Collaboration, Technological and Scientific Challenges, Governance Issues and Energy Security, Industrial and Climate Solutions, and Economic Risk.

Results: The findings reveal that newspapers frames vary significantly due to contextual factors such as national hydrogen strategies, media systems, political ideologies, article types, and focusing events. Specifically, German newspapers display diverse and balanced framing, in line with its pluralistic media environment and national emphasis on green hydrogen and energy security, while newspapers from MENA countries primarily highlight economic and geopolitical benefits aligned with their national strategies and state-controlled media environments. Additionally, the political orientation of newspapers affects the diversity of frames, particularly in Germany. Moreover, non-opinion articles in Germany exhibit greater framing diversity compared to opinion pieces, while in the MENA region, the framing remains uniform regardless of article type due to centralized media governance. A notable shift in media framing in Germany was found after a significant geopolitical event, which changed the frame from climate mitigation to energy security.

Discussion: This study underscores the necessity for theoretical and methodological thoroughness in identifying frames, as well as the considerable impact of contextual factors on the media representation of emerging sustainable technologies.

KEYWORDS

hydrogen technology, framing, hierarchical influence model, content analysis, renewable energy, comparative research, media system, focusing event

1 Introduction

This research examines the framing of hydrogen technology in six opinion-leading newspapers from Germany, as well as two each from Saudi Arabia, the UAE, and Egypt. As hydrogen technology is becoming increasingly vital in the global pursuit of decarbonization and sustainable energy transitions (Ball and Wietschel, 2009; Ursua et al., 2012). Nevertheless, the mere technological potential does not ensure successful adoption or societal acceptance of this technology. In this regard, media portrayals play a crucial role in shaping public perception, affecting policy debates, and ultimately influencing the acceptance and adoption of a technology (Entman, 1993; Scheufele, 1999).

Comprehending the way newspapers frame hydrogen technology is essential, as the media plays a pivotal role in influencing societal debates and political decisions. Although such influence may also arise from mediated explicit assessments of a technology, a large body of research indicates that framing serves as a broadly impactful, more implicit, and more universal mechanism for media effects (Scheufele and Lewenstein, 2005; Lecheler and De Vreese, 2019). Framing theory posits that the media actively shapes reality by choosing and highlighting particular aspects of complex issues (Entman, 1993). Frames define problems, identify causes, provide moral judgments, and propose solutions, significantly affecting how audiences view and react to technological innovations (Entman, 1993; Matthes, 2009). Considering the strategic significance of hydrogen technology in global climate and energy dialogues (Magnusson et al., 2021; Häußermann et al., 2023), it is vital to systematically identify and analyze the frames that newspapers utilize to address this technology.

In light of hydrogen's growing significance, there is a noticeable lack of research concerning the media representation of hydrogen technology, especially when examining it from a cross-national perspective that includes both developed countries and those in the Global South. Previous research mainly focuses on established renewable energy sources, like wind and solar, while the media framing of hydrogen technology has received limited attention in the existing literature (Horsbøl, 2013; Magnusson et al., 2021; Arlt et al., 2025). To address this research gap, the core of this study lies in identifying distinct media frames, examining how these frames are constructed through specific frame elements, and exploring the influence of contextual factors on their development. By examining these diverse contexts, this research explores the following primary question:

RQ1a: How do opinion-leading newspapers from Germany, Saudi Arabia, UAE, and Egypt frame hydrogen technology?

Furthermore, this research not only emphasizes identifying frames in newspapers but also examines how these frames are developed by exploring their characteristics. Much of the existing research on framing offers ambiguous operationalizations of the concept since there is no universally accepted definition of a frame. Previous research has typically employed hermeneutic, linguistic, manual, or computer-assisted methods to code frames holistically. Matthes and Kohring (2008) addressed this issue by proposing the division of Entman's framing elements into more precise sub-variables, enhancing reliability, validity, and depth of understanding. Utilizing sub-variables allows for identifying frames through statistical

techniques such as cluster or factor analysis, facilitating clear interpretation. The variables associated with frame elements are considered frame characteristics, simplifying the process of naming and interpreting frames. Grounded in this methodological perspective, the following research question is addressed:

RQ1b: How do newspapers' frames emerge based on the specific frame elements (frame characteristics)?

Media frames are not randomly constructed; they are profoundly influenced by contextual factors. The hierarchical influence model proposed by Shoemaker and Reese (2014) illustrates how such contextual factors shape media framing. It is assumed that factors such as national hydrogen strategy, the media landscape, the political orientation of newspapers, article types, and focusing events may affect how newspapers frame hydrogen technology. Given the differences among the selected countries—ranging from Germany's pluralistic media landscape to the centralized media systems in the Middle East and North Africa region—and considering notable geopolitical events such as the Russian invasion of Ukraine, the following research question is examined:

RQ2: How do contextual factors such as national hydrogen strategies, media systems, political ideologies, types of articles, and the focusing event influence the framing of hydrogen technology?

In order to systematically investigate how newspapers frame hydrogen technology, it is crucial to first establish a theoretical basis for comprehending media frames. Thus, the following section delves into the concept of framing, its theoretical foundations, and the methodological obstacles in identifying frames. This discussion is followed by a review of relevant literature on the framing of renewable energy technologies, which offers the essential context for this study. Following that, the theoretical framework that guides the analysis of contextual factors' influence is detailed, leading to an in-depth explanation of the research design and methodology. The findings from the cross-national content analysis are subsequently presented. Finally, the paper concludes with a discussion of theoretical implications, practical recommendations for media practitioners and policymakers, along with an exploration of its limitations and recommendations for future research.

2 Frame and framing

This section provides a concise overview of framing theory and explicitly justifies the adoption of Entman's (1993) operationalization of frames for systematically analyzing the newspaper coverage of hydrogen technology.

The concept of framing has been extensively examined across various disciplines, yet no universally accepted definition exists due to the diverse viewpoints found in the literature. Framing has been described as “a continuous process where the results of specific processes act as inputs for future processes” (Scheufele, 1999, p. 114). Scheufele (1999) provides an important differentiation in framing research by categorizing the types of framing analyzed (media frames versus audience frames) and the manner in which frames are

operationalized (as independent or dependent variables). While media frames represent the interpretive frameworks utilized by journalists to shape how information is presented, audience frames pertain to the cognitive frameworks that audiences employ to understand and interpret media content. Additionally, Scheufele highlights that the frames can be investigated as results influenced by various factors (dependent variables)¹ or as elements that affect audience perceptions and behaviors (independent variables). Following Scheufele's classification, this research specifically first looks at media frames operationalized as independent variables to investigate how hydrogen technology is framed in newspapers.

For operationalizing the framing concept, it is essential to adopt a definition of framing that can be effectively applied in quantitative analyses. In this context, Matthes's (2009) systematic review distinguishes two categories of framing definitions. The first group includes definitions that offer a broad understanding of frames without detailing specific operational parameters. For example, Gamson and Modigliani (1989) describe media frames as the foundation of media discourse, enabling meaning-making by emphasizing pertinent events and pinpointing the main issues involved. Likewise, Scheufele (1999) views frames as mechanisms that convert otherwise unclear and indistinguishable occurrences into recognizable events (p. 106).

The second category, as identified by Matthes (2009), consists of definitions that offer explicit guidelines for empirical operationalization. One of the most influential definitions within this category is that of Entman (1993), who states:

"To frame is to select some aspects of a perceived reality and make them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described" (Entman, 1993, p. 52).

Even though there is no theoretical and methodological agreement on a single definition of framing, Entman's conceptualization offers a systematic way to operationalize the framing process in empirical studies (Matthes, 2009). This definition differentiates framing from related constructs, including themes, perspectives, and arguments, as well as distinctions between episodic and generic frames within communication research. Clearly defined frames are especially important in empirical research, as they contribute to both validity and reliability (Matthes and Kohring, 2008). Therefore, this study employs Entman's (1993) definition of framing as a foundation for the current empirical analysis.

Identifying and measuring frames in research presents persistent difficulties due to various methodological limitations. Conventional techniques—such as hermeneutic, linguistic, and manual holistic methods—often face challenges concerning reliability, validity, and the influence of researcher bias (Gamson, 1989; van Gorp, 2005). For example, the hermeneutic approach relies on qualitative interpretations, which frequently lack methodological clarity, raising issues about selection bias and the arbitrary categorization of frames

(Tankard, 2001). Likewise, linguistic methods, while structured, are limited by their narrow focus on textual elements and lack a cohesive approach for synthesizing these elements into cohesive frames (Pan and Kosicki, 1993). Manual holistic techniques also have significant drawbacks, as they depend on researchers' interpretations, which can introduce bias and undermine replicability (Meyer, 1995; Wirth, 2001). Additionally, deductive methodologies, although organized, are constrained by their dependence on predefined frames, which hinders their capacity to capture newly emerging frames in media discussions (Semetko and Valkenburg, 2000). While computer-assisted methods such as frame mapping provide increased objectivity, they frequently reduce frames into simple word clusters, missing out on the deeper narrative and structural connections within media texts (Hertog and McLeod, 2001; Carragee and Roefs, 2004). As Matthes and Kohring (2008) noted, many of the current methodologies remain within a so-called "methodological black box," where processes for identifying and categorizing frames lack transparency and empirical support (Tankard, 2001; van Gorp, 2005).

In contrast, Entman's (1993) framing approach offers a structured and operationalizable framework that improves both the reliability and validity of framing research. By conceptualizing frames as configurations that stress particular problem definitions, causal attributions, moral evaluations, and treatment recommendations, Entman's approach allows for a systematic and replicable method for frame identification. This supports content analysis by enabling researchers to break down frames into quantifiable frame elements, thus minimizing the subjectivity that tends to accompany holistic coding methods (Entman, 1993). Moreover, statistical methods such as cluster analysis and factor analysis provide empirical techniques for identifying frames by systematically grouping articles that share similar frame elements (Kohring and Matthes, 2002). By coding individual frame elements and utilizing statistical classification techniques, researchers can reveal latent patterns that may not be evident through traditional qualitative or manual coding methods. This methodological approach not only improves intercoder reliability but also allows for the recognition of emerging frames in dynamic media discourses, making it a more rigorous and flexible alternative to standard framing methodologies (Matthes, 2009). By applying Entman's (1993) framing definition together with factor analysis, this research seeks to identify recurring patterns of frame elements in newspapers coverage of hydrogen technology. These identified patterns will then be interpreted as distinct frames.

3 Media framing of renewable technology

This chapter reviews existing literature on the media framing of renewable energy technologies, particularly hydrogen, highlighting essential findings and critical gaps that directly inform this comparative analysis.

Research on hydrogen technology in the media has mainly focused on the German context. Firstly, hydrogen has received less media focus than other energy sources like heating, solar power, and wind energy, with media discussions often centered on green hydrogen (produced using renewable energy sources with zero emissions), while grey (produced from natural gas with high emissions) and blue hydrogen (also produced from natural gas with

¹ The Hierarchy of Influences Model from Shoemaker and Reese (1991, 2014) explains the factors that influence the media framing.

lower emissions than grey) are infrequently mentioned (Arlt et al., 2025). Secondly, the discussion leading up to the Russian invasion of Ukraine highlighted the National Hydrogen Strategy, hydrogen's contribution to climate change mitigation, and funding for regional projects, which later transitioned to issues of energy security after the invasion (Loewe et al., 2024). Nonetheless, this event did not lead to a significant increase in hydrogen-related coverage. Thirdly, an earlier study indicated that media narratives tend to concentrate on the economic and technological innovation facets of hydrogen, often overlooking practical issues like infrastructure readiness or public skepticism (Schmidt and Donsbach, 2016). With the current technological advancements and the adoption of national hydrogen strategies by various countries, this research anticipates an evolution in the media representation of hydrogen technology.

Despite valuable insights, existing studies often lack a comprehensive framing analysis. Previous research has employed automated methods to assess the intensity of media coverage on hydrogen technology (Arlt et al., 2025) and utilized a topic modeling approach to examine the impact of the Russian-Ukrainian war on the German hydrogen discourse (Loewe et al., 2024). Additionally, qualitative inductive approaches have been applied to identify dominant frames and reframes in media portrayals of hydrogen technology (Schmidt and Donsbach, 2016). However, these studies exhibit limitations in the rigorous operationalization of the framing concept, which constrains their ability to capture deeper narratives and overarching patterns in media coverage of hydrogen technology. Given this significant research gap, the present study has reviewed existing literature on other sustainable energy sources to create an analytical instrument for the examination. Media portrayals of sustainable energy technologies reflect a variety of framing approaches, often influenced by geographic, cultural, and institutional factors. Across several studies, economic and technological frames are prevalent, while social and environmental issues often receive less focus. Horsbøl (2013) and Magnusson et al. (2021) both observed positive representations of sustainable technologies in Denmark, though Horsbøl pointed out a deficiency of international perspectives and political discussions in local coverage, whereas Magnusson et al. highlighted social themes such as community collaboration and local advantages. Likewise, Trisiah et al. (2022) and Stauffacher et al. (2015) examined geothermal energy in Indonesia and Switzerland, respectively, noting a shared emphasis on economic prospects and environmental challenges, although local resistance to geothermal development was more evident in Indonesia. Collectively, these studies underscore a recurring focus on economic advantages and technical viability, with insufficient attention to the perspectives of local communities or marginalized groups, especially in emerging markets.

The impact of national priorities and institutional frameworks on media framing is apparent in comparative analyses like Djerf-Pierre et al. (2016), which highlighted Sweden's neutral framing of environmental and economic prospects in renewable energy, in contrast to Australia's emphasis on economic challenges for households and industries. Likewise, Brazilian hydropower coverage focused on economic development while downplaying environmental and social impacts (Mourão et al., 2022) —a pattern mirrored in Nigeria (Mbamalu, 2020), Canada (Ganowski et al., 2018), Serbia (Mišić and Obydenkova, 2022), where community interests were often dominated by industrial and governmental viewpoints. Major events

like the Fukushima disaster Rochyadi-Reetz et al. (2019) or seismic activity in Switzerland Stauffacher et al. (2015) also illustrate how risk and crisis reframe public narratives around energy technologies. These insights highlight how structural factors and salient events interact to shape media narratives, while also exposing thematic and geographic deficiencies—particularly the lack of representation for social and equity-based viewpoints in media landscapes that emphasize economic growth and industrial advancement.

Despite these shared trends, notable geographic gaps persist in understanding how media framing reflects and affects sustainable energy transitions comparatively. While studies like Delicado et al. (2015) on nuclear fusion and Djerf-Pierre et al. (2016) on renewable energy investigate cross-national differences, much research tends to overlook regions from the global south, narrowing the scope of worldwide analysis. Furthermore, studies such as Zukas (2015) and Boyd and Paveglio (2014) demonstrate the potential of strategic communication in shaping media narratives, yet this remains inadequately investigated in developing areas.

In summary, this section points out distinct thematic, methodological, and geographic gaps in the literature concerning renewable technology framing, explicitly illustrating how the comparative approach and rigorous operational framework of this research address these gaps and contribute meaningfully to the broader environmental communication scholarship.

4 Influence of contextual factors on media framing

The majority of research on framing has traditionally concentrated on identifying frames in media discourse; however, comparatively less scholarly attention has been devoted to the factors influencing media framing and the construction of frames (Scheufele, 1999; Reese, 2007). In response to this research gap, O'Neill and Schäfer (2017) advocate for a more systematic investigation into the frame-building process. They propose conceptualizing the prevalence of various media frames as dependent variables and examining the determinants of frame construction within the media production process as independent variables (Scheufele, 1999). A viable approach to this investigation would be to assess the impact of national strategies, media systems, political stance, types of articles, and focusing events on the framing of hydrogen technology. This section outlines the theoretical underpinnings of each factor and presents the corresponding hypotheses.

Research has shown notable differences in how sustainable energy sources are represented in the media across different countries, influenced by diverse contextual and structural conditions. Institutional theory (Lammers and Barbour, 2006) and the hierarchy of influences model (Shoemaker and Reese, 1991, 2014) provide complementary approaches to understanding the impact of contextual factors on media framing. While institutional theory centers on the wider structural environment, highlighting the significance of institutional rules, standards, and systems in shaping media narratives, studies like those conducted by Djerf-Pierre et al. (2016) and Rochyadi-Reetz et al. (2019) illustrate that renewable energy is portrayed differently depending on the national context. For instance, media coverage in Sweden typically highlights the environmental and economic benefits, which reflects the country's progressive energy

policies, whereas, in Australia, the emphasis is on the financial burdens that renewable energy imposes on households and businesses. In addition, [Rochyadi-Reetz et al. \(2019\)](#) discovered that nations with lower renewable energy production framed renewable resources more positively, while those with medium to high production tended to adopt a more critical viewpoint. Other research, including [Mourão et al. \(2022\)](#) on hydropower in Brazil and [Magnusson et al. \(2021\)](#) on grassroots innovations in Denmark, Sweden, and the Netherlands, further demonstrate that media framing is influenced by national energy priorities, media systems, and socio-political contexts. These discrepancies highlight the critical role that contextual factors play in shaping media representations of energy transitions.

Drawing from existing studies, this research anticipates that national hydrogen strategies, media systems, newspaper political ideologies, article types, and focusing events will significantly impact the framing of hydrogen technology. This arrangement of contextual factors aligns with the hierarchy of influence model ([Shoemaker and Reese, 1991, 2014](#)), which provides a multi-layered lens for analyzing media framing.

In Germany, the National Hydrogen Strategy emphasizes the essential part that green hydrogen plays in the nation's goal of achieving climate neutrality by 2045. This focus is in line with Germany's broader agenda for renewable energy transition and sustainability, stressing the importance of developing electrolysis capacity, hydrogen infrastructure, and fostering international collaborations to secure hydrogen imports ([BMWK, 2023](#)). In contrast, Saudi Arabia and the UAE embed hydrogen development within their expansive economic diversification initiatives, highlighted by Saudi Vision 2030 and the UAE Energy Strategy 2050. Saudi Arabia optimizes its natural gas reserves for blue hydrogen production while incorporating renewable energy for green hydrogen projects, aiming to establish itself as a global leader in hydrogen exports ([IEA, 2022](#)). Similarly, the UAE intends to utilize its vast solar and wind resources to generate green hydrogen, positioning itself as a key player in the hydrogen economy as it supports its net-zero emissions target for 2050 ([UAE Ministry of Energy, 2024](#)). For Egypt, hydrogen strategies are closely linked to issues of energy security, economic advancement, and strategic partnerships with European countries. The national low-carbon hydrogen strategy reveals Egypt's aspiration to emerge as a regional hydrogen hub, leveraging its renewable energy assets and strategic location to facilitate exports to Europe ([Rezk et al., 2023](#)). The distinct national hydrogen strategies set countries apart from one another; therefore, the following hypothesis is proposed:

H1: The national hydrogen strategies of individual countries have a significant impact on the framing of hydrogen technology.

Given that current research focuses on media from the MENA region, it is essential to view media systems as contextual factors within these regions. According to the press freedom index from [Reporters Without Borders \(2024\)](#), Germany holds the 10th position, indicating a "good" press freedom situation, in contrast to the UAE (160th), Saudi Arabia (166th), and Egypt (170th), which face "very serious" restrictions characterized by censorship and limited journalistic autonomy. Utilizing the media system typology proposed by [Hallin and Mancini \(2004\)](#), the unique structural and political contexts of these nations serve as a basis for comprehending the differences in media framing of hydrogen technology. Germany's

democratic corporatist media landscape is marked by a free press, diverse ownership, and high journalistic standards ([Hallin and Mancini, 2004](#)). This environment encourages a media culture that promotes balanced, varied, and critical reporting on hydrogen technology. Public broadcasters like ARD and ZDF, along with private companies such as Axel Springer, maintain considerable editorial freedom, allowing them to explore the complex aspects of hydrogen technology, including its environmental, economic, and social effects ([Humphreys, 1996](#)). The focus on neutrality and investigative thoroughness guarantees that topics related to the viability of sustainable technology and energy transition challenges are rigorously assessed ([Richter and Kozman, 2021](#)).

Conversely, the authoritarian media frameworks in Saudi Arabia and the UAE closely align with state interests, reflecting the political and structural realities of these nations ([Rugh, 2004](#)). Media operations in these countries are under strict state control or within ownership structures connected to ruling elites, resulting in narratives that underpin national development and innovation ([Mellor, 2005](#)). Egypt's mixed media system, combining aspects of state control and private ownership, creates a unique framing landscape ([Elmeshad, 2021](#)). Although the presence of private media ownership might imply some level of diversity, the preeminence of state-aligned conglomerates and the influence of military and intelligence agencies ensure that media narratives align with governmental aims ([Richter and Kozman, 2021](#)). In Egypt, news narratives are largely influenced by the country's longstanding dependence on state-run news agencies and the concentration of private media ownership under state-aligned corporations ([Sakr, 2013](#)). These contrasts highlight the significant effect media systems have on framing critical issues. This structural variation illustrates the critical function of media systems in shaping public discourse surrounding global challenges like energy transitions and climate change, as they influence societal perceptions and responses to emerging technologies ([Hallin and Mancini, 2004](#)). Therefore, this study proposes the second hypothesis:

H2: The framing of hydrogen technology is more diverse in Germany than in countries (e.g., Saudi Arabia, UAE, and Egypt) that operate under state-led media systems.

Another important contextual factor is the political orientation of the media. Examining the political bias of news outlets is essential for comprehending how information is framed, shared, and interpreted, which in turn has a direct impact on public opinion, political actions, and policy decisions ([Jengelly and Clawson, 2019](#); [Jungkunz, 2021](#); [Selvik and Høigilt, 2021](#); [Shultziner and Stukalin, 2021](#); [Santo, 2024](#)). News media, especially newspapers, play a vital role in shaping societal narratives, and their ideological stance often dictates which issues are prioritized, how they are framed, and which individuals or groups are emphasized or overlooked ([Schindler et al., 2017](#); [Cushion et al., 2018](#); [Ellger et al., 2024](#)). Research has repeatedly shown that political orientation affects not just the amount and tone of coverage, but also its framing and biases in issue selection, as evidenced by varying representations of topics like climate change, immigration, and public health across left- and right-leaning media outlets ([Barkemeyer et al., 2017](#); [Worthington and Scourfield, 2024](#)). These trends underscore the media's dual function as both a mirror of societal polarization and an active agent in reinforcing it. Understanding these dynamics is especially important in polarized

environments, where media can amplify echo chambers, obstruct cross-ideological discussions, and distort perceptions of democratic legitimacy (Lelkes, 2016; Barkemeyer et al., 2017). Analyzing a newspaper's political orientation can reveal the mechanisms behind agenda-setting, intergroup polarization, and declining trust, thereby suggesting ways to foster balanced reporting and promote informed civic engagement. Since existing studies indicate that the political leaning of newspapers greatly influences the variety and balance of perspectives in reporting, which subsequently affects societal polarization and institutional trust, the present study puts forth the following hypothesis:

H3: The political leaning of newspapers has a significant effect on the framing of hydrogen technology, with left-leaning outlets highlighting its environmental advantages and its role in combating climate change, while right-leaning outlets concentrate on economic feasibility, national security, and technological challenges.

The current study posits that the type of news article is fundamental in shaping issue framing, as the primary aim and structure of an article directly affect how an issue is presented. Research has shown that factual formats, such as news reports and special reports, are more inclined to follow journalistic standards of neutrality, allowing for the inclusion of a wider array of actors and viewpoints (Patterson, 1998; Benson, 2009). Special reports, in particular, are known for enhancing content diversity by offering detailed information and showcasing differing perspectives, leading to multi-perspectival framing (Humprecht and Büchel, 2013; Masini et al., 2018). On the other hand, opinion-oriented articles such as editorials, opinion pieces, and letters to the editor generally favor specific viewpoints or arguments, often compromising the representation of diverse perspectives (van Gorp, 2005). This distinction underscores how the selection of article type affects public comprehension: special reports contribute to more balanced narratives, whereas opinion-oriented formats focus on selective framing aimed at persuasion. Therefore, the current study hypothesizes that:

H4: Non-opinionated articles are more likely to present a variety of frames regarding hydrogen technology in comparison to opinionated articles.

Aside from national strategies, media systems, and political biases, this research also argues that focusing events influence the framing of hydrogen technology. A focusing event is a significant and often sudden event that captures widespread attention, such as a natural disaster, economic downturn, terrorist incident, or major technological failure (Birkland, 1998). These events are often unexpected and reveal particular issues or deficiencies in current systems. The focusing events theory, based on agenda-setting theory, explains how policies change after unexpected events. It shows how politicians use these events to get support for change (Birkland, 1997). This study uses the Russian invasion of Ukraine in 2022 as a focusing event to analyze the shift in the framing of hydrogen technology. The 2022 Russian invasion of Ukraine was a significant focusing event that changed global energy discussions, including the framing of hydrogen technology. This geopolitical crisis disrupted energy supply chains and highlighted Europe's dependence on

Russian gas, leading to a shift in media narratives. For example, in Germany, the framing of hydrogen shifted from primarily being viewed as a mechanism for climate mitigation and innovation to being seen as a strategic option for achieving energy independence and national security (Loewe et al., 2024; Arlt et al., 2025). These changes show how focusing events interact with national interests to change media framing (Rochyadi-Reetz et al., 2019). Since Germany was heavily affected by this event, therefore, the following hypothesis is proposed:

H5: Following the Russian invasion of Ukraine, the framing of hydrogen technology in newspapers shifted from climate change mitigation to energy security in Germany.

5 Method

5.1 Country selection and sampling

To answer the research questions and to test the hypotheses, a quantitative content analysis was conducted on how newspapers frame hydrogen technology in Germany, the UAE, Saudi Arabia, and Egypt. The selection of these countries for this cross-national analysis is based on their different roles in the emerging hydrogen economy and their varying political, economic, and media systems. Germany, as an industrialized country and future hydrogen importer, is actively pursuing climate neutrality goals and depends on collaborations with exporting countries to meet its hydrogen needs. Saudi Arabia, the UAE, and Egypt are strategically positioning themselves as hydrogen exporters, using their renewable energy resources and infrastructure to benefit from the global decarbonization trend. This importer-exporter relationship shows a reciprocal relationship, where Germany is focused on energy security and technological advancement, while the MENA countries are prioritizing economic diversification, global presence, and regional influence.

This study notably concentrates on conventional news media—especially newspapers—despite the emergence of a media landscape that prioritizes social platforms. Newspapers continue to be key agenda-setters and institutional intermediaries in environmental communication, particularly influencing elite discussions, validating political agendas, and forming collective narratives regarding energy transitions (Boykoff and Boykoff, 2007). Although digital and social media platforms enhance public engagement, legacy newspapers maintain a crucial role in sifting through scientific information, interpreting policy discussions, and framing complex environmental issues for both decision-makers and the general public (O'Neill et al., 2015). Through sustained coverage, editorials, and investigative journalism, newspapers play a crucial role in holding both governments and corporations responsible, raising awareness about environmental issues, and encouraging political action. Their institutional credibility and agenda-setting power make them central actors in the broader communicative process of environmental governance (Schäfer, 2012). This aspect is particularly relevant for hydrogen technology, where new technical discourses necessitate clarification and validation through reliable media sources. Consequently, newspapers serve as an important focus for analyzing the representation of hydrogen technology within both democratic and state-directed media environments.

The period of analysis spans July 1, 2018, to September 30, 2023. This period encompasses significant policy developments, including Germany's National Hydrogen Strategy introduced in 2020, along with subsequent initiatives in Saudi Arabia (2020), the UAE (2021), and Egypt (2022). Additionally, the 2022 invasion of Ukraine by Russia marked a crucial geopolitical shift that transformed energy security discussions on a global scale.

Considering Germany's leading role in the global hydrogen economy as a primary importer and its extensive media focus on energy transition issues, six major daily newspapers were picked to encompass a variety of viewpoints. These newspapers consist of Frankfurter Allgemeine Zeitung (FAZ), Süddeutsche Zeitung (SZ), die tageszeitung (TAZ), Die Welt, Bild, and Der Tagesspiegel, representing an array of political orientations from conservative to liberal-green. Conversely, two English leading newspapers from each MENA nation were chosen to illustrate the political and economic interests of hydrogen-exporting countries. The selected MENA newspapers—Arab News and Saudi Gazette (Saudi Arabia), Khaleej Times and Gulf Today (UAE), Daily News Egypt and Egyptian Gazette (Egypt)—provide a range of viewpoints within a context where media systems tend to be more centralized. The disproportionate representation of six German newspapers compared to two from each MENA country reflects Germany's more pluralistic media environment and its comprehensive discourse surrounding hydrogen, facilitating an in-depth analysis of the breadth and nuances of framing in a significant hydrogen-importing nation relative to emerging exporters in the MENA region.

For the majority of the newspapers, articles were obtained using the LexisNexis database. Articles from FAZ and SZ were accessed through their online archives, while those from Arab News, Gulf Today, and Egyptian Gazette were collected directly from their official websites. The search terms “hydrogen” for English-language publications and “Wasserstoff” for German publications were employed to gather articles published from July 2018 to September 2023. Initially, 9,346 articles were retrieved; however, only those focusing on hydrogen technology or the hydrogen economy were taken into account. Articles that were unrelated to these subjects, such as those mentioning hydrogen in the context of space exploration or nuclear weapons, were eliminated. A systematic random sampling method was applied to non-opinionated articles, adapted to the total number of articles per newspaper, ensuring that diverse coverage across the newspapers was represented (see [Appendix A](#)). All opinionated articles were included due to their significant role in framing analysis. Due to the relatively low coverage of hydrogen technology in MENA newspapers, a larger share of articles was systematically sampled from these newspapers to guarantee sufficient representation. In total, 1700 news articles and 592 opinion pieces were chosen for coding. The differences in sample sizes between Germany and MENA countries are consistent with the study's goal to thoroughly investigate the framing of hydrogen technology in regions with significantly different levels of media coverage, energy priorities, and socio-political structure.

5.2 Coding instrument

This research utilizes a manual framing technique that is especially effective for identifying frames in textual data. The framing analysis was directed by a codebook developed through both inductive and

deductive approaches, adhering to a systematic framework established by [Matthes and Kohring \(2008\)](#). Building on this foundation, the study adopted [Entman's \(1993\)](#) framing concept, which is widely recognized as a leading approach in media framing research ([Matthes, 2009](#)), for the deductive aspect. Entman's definition has been frequently applied in earlier studies to analyze media framing of sustainable energy resources ([Djerf-Pierre et al., 2016](#); [Bigl, 2017](#); [Zukas, 2017](#); [Rochyadi-Reetz et al., 2019](#); [Holmes et al., 2022](#)), making it a solid theoretical basis for exploring discussions on hydrogen technology. In this investigation, the codebook operationalizes Entman's four framing elements: (1) *problems and/or benefits* related to hydrogen technology, (2) *causes or reasons* for the adoption of hydrogen technology, (3) *treatment recommendations or solutions* to address obstacles in hydrogen adoption, and (4) *moral evaluations* of pertinent actors. These framing elements capture various perspectives, ensuring a comprehensive understanding of newspapers' framing of hydrogen technology.

To complement the deductive approach, an inductive method was used to uncover additional frame elements that might not have been included in the initial codebook. Eighty randomly selected articles were assessed without the established codebook, facilitating the recognition of new frames and enhancing the deductive framework. After this evaluation, the final codebook consisted of 61 frame components, categorized under economic, political, environmental, social, and technological dimensions. Specifically, the codebook comprised 16 *problems*, 13 *benefits*, 14 *causes*, 5 *solutions*, and 13 *moral evaluation* frame elements. A comprehensive operationalization of these frame elements is presented in [Appendix B](#). All sub-frame elements were coded as dummy variables (1 = present, 0 = not present), except the moral evaluation frame element, which was coded using a three-point ordinal scale (0 = neutral, 1 = praise, 2 = criticism). An article was deemed suitable for the coding process if it featured at least one of these frame elements.

The codebook was carefully assessed for its comprehensiveness, clarity, and reliability, considering the criteria established by [Krippendorff \(2018\)](#). Considering the study's cross-national focus, which includes various languages, cultures, and journalistic practices, special emphasis was placed on ensuring the codebook's reliability and relevance in different contexts. After several revisions to clarify ambiguities and enhance understanding, a training session was organized for four coders to help them grasp the operational definitions of all framing elements. During this training, in-depth discussions regarding the codebook occurred to address any discrepancies in interpretation or implementation. Following this, the codebook was subjected to a pretest, where all four coders independently applied the coding to the same collection of 20 articles. Intercoder reliability was assessed to confirm agreement among coders, and necessary modifications were made. Upon reaching an acceptable intercoder reliability level—specifically, an average percentage agreement of 89.5% and an average Krippendorff's Alpha of 0.72—the trained coders proceeded with coding the sample articles.

6 Results

6.1 Framing of hydrogen technology

As thoroughly outlined in the second chapter regarding the methodological advantages of utilizing Entman's definition for

operationalization, this research employed factor analysis to analyze and interpret the comprehensive range of frame elements extracted from newspaper reporting. Factor analysis enabled the condensation of an extensive list of frame elements into interpretable frames by uncovering the underlying patterns within the articles. By reducing frame elements into a smaller number of latent constructs, it enhances the clarity in recognizing and interpreting the primary media frames, consistent with the methodological approach proposed by Matthes and Kohring (2008). The factor analysis revealed six distinct factors, each illuminating a different facet of the newspaper's framing of hydrogen technology. These factors reveal the variety of narratives put forth by newspapers from four countries and highlight the multidimensional nature of the hydrogen discourse (see Table 1). The identified factors signify unique media frames used by newspapers in their coverage of hydrogen technology, thereby responding to RQ1a. Each factor includes particular frame elements, illustrating how each frame emerges and highlighting the internal structure of these frames. Examining the pattern of these frame elements clarifies the underlying characteristics of each frame, directly addressing RQ1b.

The first factor primarily merges cause and benefit frame elements, including elements like *poor conventional energy sources* (0.48), *limited fossil resources* (0.43), and the *cost-effectiveness of hydrogen* (0.44), along with its role as a possible *alternative to fossil fuels* (0.40), its potential for *environmental improvement* (0.41), and its *compatibility with existing infrastructure* (0.37). Collectively, these frame elements construct a narrative that frames hydrogen technology as a sustainable solution to traditional energy sources. This *Hydrogen as Sustainable Energy Solution* frame positions hydrogen as a crucial element in the energy transition, emphasizing its ecological and operational benefits.

The second factor focuses on the frame of economic and political cooperation, reflected in strong loadings on frame elements such as *international collaboration* (0.55), *economic growth* (0.46), and *international trade* (0.45). Additional elements, including *investment prospects* (0.40), *political support* (0.39), and *energy policies and regulations* (0.36), further support the narrative that hydrogen presents a chance for countries to improve their economic and geopolitical positions. This *Benefits of Economic and Political Collaboration* frame depicts hydrogen as a means to foster alliances and enhance economies through involvement in the emerging global hydrogen market. By stressing mutual advantages, the media emphasizes hydrogen's promise to establish nations as leaders in this pioneering sector.

The third factor highlights the technological and scientific challenges linked to hydrogen technology. Significant loadings on elements such as *technological challenges* (0.59), *scientific uncertainty* (0.50), and its inability to fully *mitigate climate change* (0.36) indicate a more cautious framing. The presence of elements like *runaway technology* (0.37) and *lack of development* (0.37) further implies that newspapers are addressing unresolved risks and the necessity for progress in hydrogen technology. This *Technological and Scientific Challenges* frame captures skepticism regarding hydrogen's readiness and underscores the challenges that need to be addressed for its effective adoption.

The fourth factor brings governance issues and energy security to the forefront, marked by frame elements like *political consequences* (0.50), *political instability* (0.44), and *lack of political support* (0.43). The inclusion of *energy security* (0.29) and *geopolitical crises* (0.29) emphasizes worries about the wider political and governance obstacles related to hydrogen's adoption. This *Governance Issues and Energy*

Security frame emphasizes the relationship between hydrogen technology and global politics, depicting it as both a remedy and a vulnerability in the context of energy security and international relations.

The fifth factor presents hydrogen technology within the context of industrial decarbonization. Frame elements such as *industrial decarbonization* (0.50), *heavy industrial applications* (0.38), and *hydrogen as a solution* (0.49) emphasize its significance in lowering emissions in energy-intensive sectors. This *Industrial and Climate Solutions* frame positions hydrogen as an essential energy source for meeting climate objectives.

Finally, the sixth factor highlights economic risks, with notable loadings on frame elements like *production costs* (0.41), *market uncertainty* (0.37), and *financial issues* (0.36). While these aspects highlight the difficulties related to funding and market fluctuations, the inclusion of *economic solutions* (0.47) points to a dual narrative. Media coverage showcases both the financial obstacles and the potential to overcome them through targeted investments and subsidies. This *Economic Risk* frame offers a balanced view of the economic challenges and opportunities surrounding hydrogen, advocating for policy measures to tackle economic barriers. Together, these frames demonstrate a multifaceted representation of hydrogen technology in newspaper coverage. Each frame conveys a unique viewpoint, ranging from optimism about hydrogen's promise to skepticism regarding its readiness and feasibility. This variety emphasizes the significance of recognizing contextual and thematic differences in framing to comprehend the broader discourse about hydrogen technology.

6.2 The influence of contextual factors

In order to answer RQ2 and evaluate the hypotheses, the subsequent sections present the mean value of each factor score corresponding to the different independent variables (contextual factors). For this analysis, frames are considered as dependent variables. A multivariate analysis of variance is conducted to examine the significance of differences among the various groups.

6.2.1 National Hydrogen Strategy

The results indicate that national hydrogen strategies greatly influence the framing of hydrogen technology, supporting the first hypothesis. In Germany, newspaper coverage reflects a balanced approach, highlighting various perspectives such as *Technological and Scientific Challenges* (0.27), *Governance Issues and Energy Security* (0.27), and *Hydrogen as a Sustainable Energy Solution* (0.15; see Figure 1). This distinct framing indicates a multifaceted discussion that critically evaluates hydrogen's potential while recognizing issues concerning governance, infrastructure, and funding. These frames are closely aligned with Germany's National Hydrogen Strategy, which emphasizes green hydrogen as a key element of its climate neutrality objectives by 2045, in conjunction with funding for hydrogen infrastructure and fostering international partnerships for energy security (BMW, 2023).

Conversely, in Saudi Arabia and Egypt, the media framing focuses on *Benefits of Economic and Political Collaboration* (0.22 and 0.49, respectively), reflecting their national hydrogen strategies and wider economic plans. Saudi Vision 2030 identifies hydrogen as a

TABLE 1 Factor loading of six frames and their characteristics (frame elements).

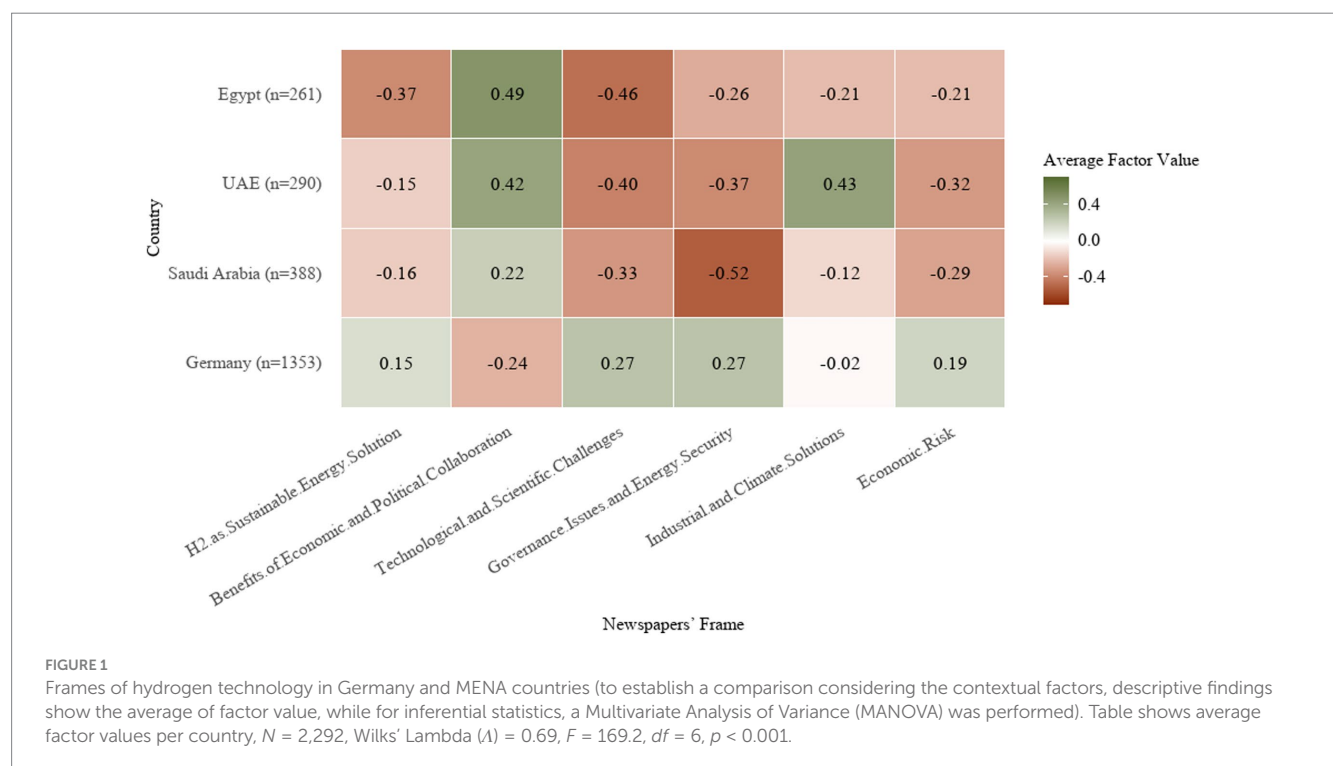
Frame Elements	H ₂ as Sustainable Energy Solution	Benefits of Economic and Political Collaboration	Technological and Scientific Challenges	Governance Issues and Energy Security	Industrial and Climate Solutions	Economic Risk
Poor Conventional Energy Source c	0.48					
Cost-effectiveness of Hydrogen c	0.44					
Limited Fossil Resources c	0.43					
Environmental Improvement+	0.41					
Alternative to Fossil Resources+	0.40				0.29	
Compatible with Existing Infrastructure+	0.37					
Efficiency and Energy Conversion c	0.33					
Diversification/Transformation c	0.26	0.26				
International Collaboration+		0.55				
Economic Growth+		0.46				
International Trade+		0.45				
Positive Political Ramifications+		0.42				
Investment Prospects+		0.40				
Political Support+		0.39				
Energy Policy & Regulations c		0.36			0.28	
Technological Challenges—			0.59			
Scientific Uncertainty—			0.50			
Lack of Research/Development—			0.37			
Runaway Technology—			0.37			
No Climate Change Solution—			0.36			
Political Consequences—				0.50		
Political Instability—				0.44		
Lack of Political Support—				0.43		
General Political Solution —				0.41		0.29
Moral Evaluation of Govt m				0.36		
Energy Security/Independence c				0.29		

(Continued)

TABLE 1 (Continued)

Frame Elements	H ₂ as Sustainable Energy Solution	Benefits of Economic and Political Collaboration	Technological and Scientific Challenges	Governance Issues and Energy Security	Industrial and Climate Solutions	Economic Risk
Crisis/War x				0.29		
Industrial Decarbonization c					0.50	
Hydrogen Technology s					0.49	
Heavy Industrial Application c					0.38	
Climate Change Mitigation +					0.36	
Economic s						0.47
Cost—			0.41			0.42
Market Uncertainty—	0.27			0.28		0.37
Financial Issues—			0.27	0.28		0.36
Eigenvalue	1.83	1.68	1.54	1.45	1.26	1.10

$N = 2,292$, KMO = 0.83, Bartlett's Test of Sphericity ($\chi^2 = 11055.24$, $df = 595$, $p < 0.001$), Tucker Lewis Index = 0.885, RMSR = 0.02, RMSEA = 0.03 [Since the frame elements are dummy variables except for the moral evaluation frame element, which is measured on an ordinal scale, therefore, a Polychoric correlation matrix has been utilized for the factor analysis. A total of 35 frame elements (including 11 problem elements, 10 benefits, 10 causes, 3 solutions, and 1 moral evaluation frame) were included in the factor analysis, while the remaining frame elements (primarily the moral evaluation frame elements) did not significantly contribute to the factor loading], BIC = -1884.44, Explained Variance = 25.3%, (+ is benefit frame element, — is problem frame element, c is cause frame element, s is solution frame element, m is moral evaluation), used the threshold to omit <0.25 factor loading, Varimax rotation method is applied.



fundamental component for economic diversification and geopolitical leverage, utilizing natural gas reserves to produce blue hydrogen and renewable sources for green hydrogen (IEA, 2022). Likewise, Egypt's National Low-Carbon Hydrogen Strategy connects hydrogen advancement to energy security and strategic alliances with Europe (Rezk et al., 2023). The framing from the UAE prominently features *Benefits of Economic and Political Collaboration* (0.42) and *Industrial and Climate Solutions* (0.43), aligning with its Energy Strategy 2050 and commitment to achieving net-zero emissions by 2050. The media

in the UAE emphasizes hydrogen's dual function in industrial decarbonization and its economic positioning as a global hydrogen hub, highlighting its ambition to lead in the hydrogen economy. These findings support the H1 that national strategies affect the framing of hydrogen technology.

6.2.2 Media systems

The same indicator (Country) has been used to test the H2. The democratic corporatist media system in Germany promotes balanced

and varied narratives, which is reflected in the moderate positive values across several frames, except for *Benefits of Economic and Political Collaboration* (−0.24). German newspapers criticize the economic, political, and technological obstacles related to hydrogen while recognizing its potential as a sustainable energy source (see Figure 1). This diversity of frames is consistent with Germany's strong journalistic standards and its free press environment (Hallin and Mancini, 2004).

In contrast, the authoritarian media systems in Saudi Arabia, the UAE, and Egypt show less diversity in their framing. These countries mainly focus on *Benefits of Economic and Political Collaboration*, reflecting national strategies that closely align with national interests. The media in the UAE also highlight *Industrial and Climate Solutions*, however collectively, newspapers from MENA (Middle Eastern and North African) countries ignore frames related to *Governance Issues*, *Energy Security*, or *Technological and Scientific Challenges*. This aligns with the limitations of state-controlled media systems, which generally amplify state narratives while marginalizing critical or diverse viewpoints (Rugh, 2004; Mellor, 2005). These results prove the H2 that the media system affects the newspaper framing of hydrogen technology.

6.2.3 Newspaper's political leaning

The findings demonstrate how the political orientation of newspapers can affect the framing of hydrogen technology, while also uncovering some unexpected trends. In Germany, it was anticipated that left-leaning newspapers would primarily present positive frames, showcasing *Hydrogen as a Sustainable Energy Solution*. However, all three left-leaning newspapers (SZ, TAZ, der Tagesspiegel) predominantly emphasized frames that represent the challenges related to hydrogen technology, drawing attention to the *Technological and Scientific Challenges*, *Governance Issues and Energy Security*, as well as *Economic Risks* tied to hydrogen

technology (see Figure 2). Notably, SZ highlighted both positive and negative aspects concurrently: *Industrial and Climate Solutions* (0.24), alongside a considerable focus on *Technological and Scientific Challenges* (0.35), *Governance Issues and Energy Security* (0.41), and *Economic Risks* (0.31), pointing to a nuanced and critical environmental evaluation rather than solely an optimistic viewpoint. In a similar vein, TAZ, despite its strong emphasis on *Hydrogen as a Sustainable Energy Solution* (0.93), also significantly addressed *Technological and Scientific Challenges* (0.44), *Governance Issues and Energy Security* (0.39), and *Economic Risks* (0.17), indicating a critical yet constructive stance towards hydrogen technology. Der Tagesspiegel maintained a moderate focus on *Governance Issues and Energy Security* (0.23) and *Economic Risks* (0.24), but devoted limited attention to *Industrial and Climate Solutions* (0.05), reflecting a more cautious and balanced perspective.

Newspapers with the right political leaning, such as the Frankfurter Allgemeine Zeitung (FAZ) and Bild, tend to emphasize economic and technical issues while showing less engagement with environmental narratives. For example, FAZ focuses on *Technological and Scientific Challenges* (0.43) and *Economic Risk* (0.21), which aligns with the priorities of right-leaning media that highlight economic viability, technological hurdles, and practical solutions (Schindler et al., 2017). In particular, Bild largely downplays all frames apart from a minimal focus on *Governance Issues* (0.02), reflecting a more skeptical perspective on hydrogen technology's transformative potential. Likewise, die Welt concentrates on *Governance Issues and Energy Security* (0.45), but displays notable negative loadings for *Benefits of Economic and Political Collaboration* and *Industrial and Climate Solutions*, indicating a more cautious perspective on hydrogen's potential for transformation. The H3 for Germany is partially supported. Political orientation influences framing, with right-wing media focusing on economic and technical aspects, while

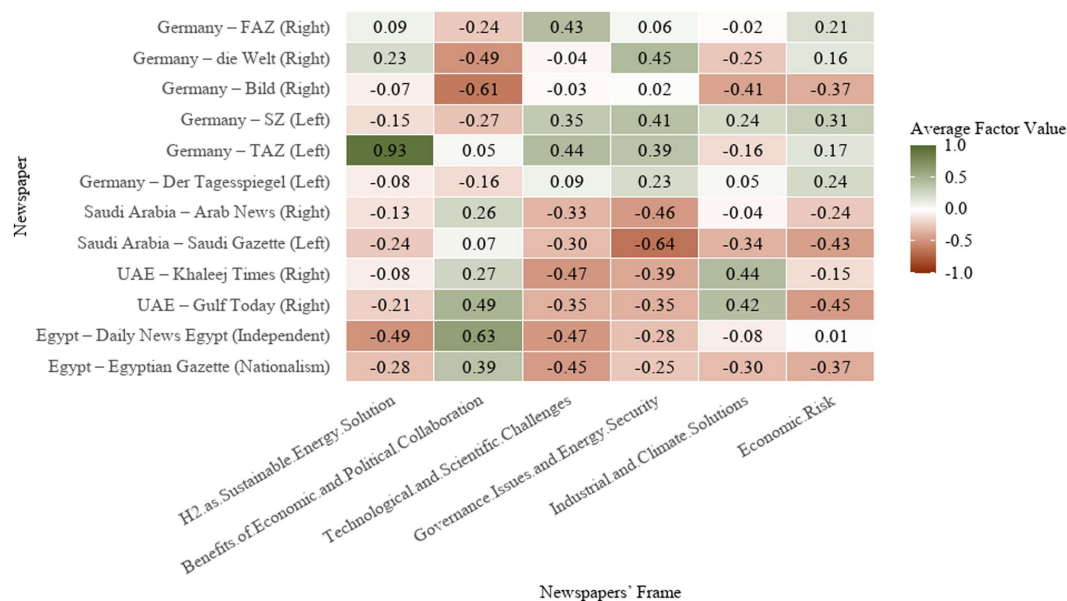


FIGURE 2

Frames of hydrogen technology in newspaper with different political-leaning. Table shows average factor values per newspaper, $N = 2,292$, Wilks' Lambda (Λ) = 0.67, $F = 183.1$, $df = 66$, $p < 0.001$.

left-wing media adopt a more critical and balanced stance rather than focusing solely on environmental benefits.

The findings indicate that the political stance of newspapers from MENA countries does not influence the framing of hydrogen technology, except for the Egyptian Gazette, which frames hydrogen in line with its nationalist orientation. Despite a minor variation in ideological orientations, a pronounced and consistent focus on the *Benefits of Economic and Political Collaboration* frame appears across MENA newspapers. This shared emphasis highlights hydrogen's critical role in promoting economic progress and strengthening geopolitical ties, reflecting the strategic interests of these countries. For instance, Arab News (Right-leaning) and Saudi Gazette (Left-leaning) stress this frame with loadings of 0.26 and 0.07, respectively, while diminishing the importance of *Governance Issues*, *Energy Security*, and *Technological and Scientific Challenges*. This uniformity suggests a state-driven narrative that positions hydrogen as a means for political and economic advantages, irrespective of political alignment.

Interestingly, Khaleej Times and Gulf News, both with right-leaning, broaden this narrative by also portraying hydrogen as a means for industrial decarbonization, with loadings of 0.44 and 0.42 on the *Industrial and Climate Solutions* frame. This distinct approach indicates a further emphasis on hydrogen's role in reducing emissions within energy-intensive sectors, mirroring national goals to reconcile economic advancement with climate objectives. Conversely, the Egyptian Gazette adopts a nationalist framing that emphasizes *Benefits of Economic and Political Collaboration* (0.39) while downplaying engagement with other frames, such as *Hydrogen as a Sustainable Energy Solution* and *Governance Issues and Energy Security*. These results highlight that while political affiliations influence framing in Germany, MENA newspapers tend to converge around narratives centered on state interests, underscoring the economic and geopolitical importance of hydrogen. Therefore, H3 is not confirmed for the MENA region.

6.2.4 Types of articles

The findings provide strong evidence that the types of news articles have a significant impact on the framing of hydrogen technology, proving the hypothesis (H4) that non-opinionated articles are more likely to present a variety of frames compared to their opinionated articles. This difference is especially evident in Germany, where non-opinionated articles demonstrate a balanced and multifaceted approach to framing hydrogen technology, covering aspects like *Hydrogen as Sustainable Energy Solution* (0.26), *Technological and Scientific Challenges* (0.26), and *Governance Issues and Energy Security* (0.18; see Figure 3). In contrast, opinionated articles in Germany tend to concentrate on particular frames, providing critical analyses of *Economic Risks* (0.11), *technological challenges* (0.27), and *governance issues and energy security* (0.46), while largely neglecting environmental frames.

In the MENA region, the effect of article type on framing appears to be less prominent, rejecting the H4 for MENA region. Both opinionated and non-opinionated articles reveal limited variety in their framing. Non-opinionated articles prioritize *Benefits of Economic and Political Collaboration* (0.49) and *Industrial and Climate Solutions* (0.05), indicating a focus on state-aligned narratives regarding economic development and industrial decarbonization (see Figure 4). Meanwhile, opinionated articles do not engage critically with any specific frame, showing consistently low or negative loadings across all frames. This lack of diversity in both types of articles highlights the centralized nature of media systems in the MENA region.

6.2.5 Focusing events

The findings provide strong evidence supporting the hypothesis (H5) that the Russian invasion of Ukraine in 2022 served as a pivotal event, significantly altering the framing of hydrogen technology in Germany. Prior to the invasion, German media mainly framed hydrogen technology through the frames of *Technological and Scientific Challenges* (0.34), *Industrial and Climate Solutions* (0.19),

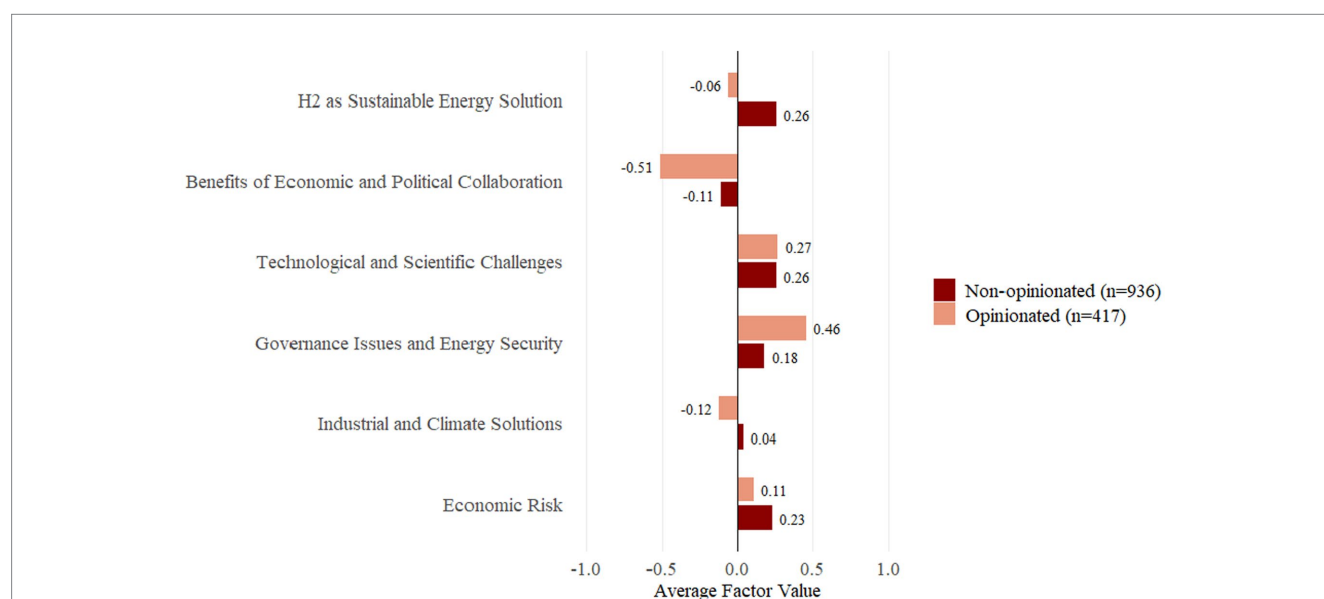
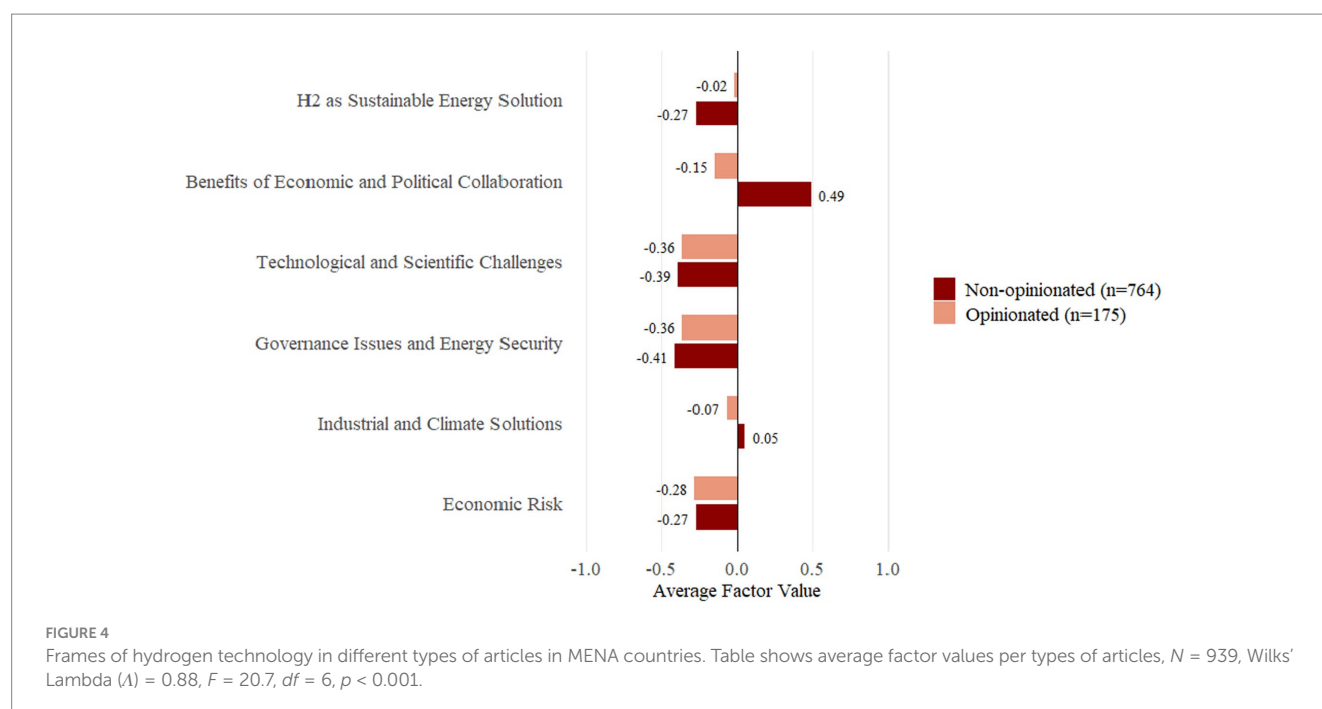


FIGURE 3

Frames of hydrogen technology in different types of articles in Germany. Table shows average factor values per types of articles, $N = 1,353$, Wilks' Lambda (λ) = 0.9, $F = 19.2$, $df = 6$, $p < 0.001$.



and *Economic Risk* (0.27; see Figure 5). These frames illustrated a critical assessment of hydrogen's capacity to decarbonize industries and the practicalities surrounding its technical and economic viability. However, following the invasion, the framing notably shifted towards *Governance Issues and Energy Security* (0.49) and *Hydrogen as a Sustainable Energy Solution* (0.38). This change highlights the geopolitical urgency prompted by disruptions in energy supplies, with hydrogen being redefined as an essential resource for gaining energy independence and enhancing national security.

In the MENA region, the invasion had a similar impact on how newspapers framed the hydrogen technology, though with a more limited range. Before the invasion, MENA publications focused on *Industrial and Climate Solutions* (0.21) and *Benefits of Economic and Political Collaboration* (0.12), reflecting the region's role as a significant contributor to hydrogen-related industrial decarbonization and global energy markets (see Figure 6). After the invasion, the framing increasingly centered on *Benefits of Economic and Political Collaboration* (0.46), demonstrating a clear emphasis on positioning MENA nations as alternative energy suppliers to Europe in place of Russia. This reframing aligns with the strategic goals of MENA countries seeking to capitalize on their geopolitical significance within energy supply chains.

7 Discussion and conclusion

The main objective of this research was to identify the frames utilized by newspapers in their coverage of hydrogen technology and to evaluate how these frames have emerged in newspapers. Overall, the findings revealed that the newspapers frame hydrogen technology in six different ways: *Hydrogen as a Sustainable Energy Solution*, *Benefits of Economic and Political Collaboration*, *Technological and Scientific Challenges*, *Governance Issues and Energy Security*, *Industrial and Climate Solutions*, and *Economic Risk*. Together, these frames

illustrate the complexity of hydrogen discourse, reflecting its dual role as a global climate solution and an economic opportunity. The *Sustainable Energy Solution* frame emphasizes hydrogen's ecological benefits and its potential to transition from conventional energy sources, aligning with its portrayal as a cornerstone of decarbonization efforts (Ball and Wietschel, 2009). The *Benefits of Economic and Political Collaboration* frame underscores hydrogen's capacity to foster international partnerships and drive economic growth, showcasing its geopolitical importance (IEA, 2022). At the same time, the *Technological and Scientific Challenges* frame highlights unresolved uncertainties and the need for further innovation, reflecting skepticism about its readiness for large-scale adoption. This critical framing of hydrogen technology was lacking in the study of Schmidt and Donsbach (2016). This indicates that the media framing of hydrogen technology has changed over time from positive framing to critical, possibly due to the new advancements in hydrogen technology. The *Governance Issues and Energy Security* frame links hydrogen to broader political and security concerns, particularly in the context of global energy crises. Finally, while the *Industrial and Climate Solutions* frame positions hydrogen as a tool for reducing emissions in energy-intensive sectors, the *Economic Risk* frame emphasizes financial barriers and market uncertainties. Together, these frames depict hydrogen technology as a complex and contested topic, with optimism tempered by practical, economic, and political concerns.

While frames such as economic risks and environmental advantages may indirectly impact social aspects, the current study revealed that the newspapers' portrayal of hydrogen technology placed less emphasis on social framing. Although the codebook includes social frame elements, these elements were rarely seen in newspaper coverage, and therefore did not influence factor loadings. In contrast, earlier studies highlighted the importance of social frame elements in the framing of renewable energy sources (Stephens et al., 2009; Langheim et al., 2014; Feldpausch-Parker et al., 2015; Schmidt, 2017;

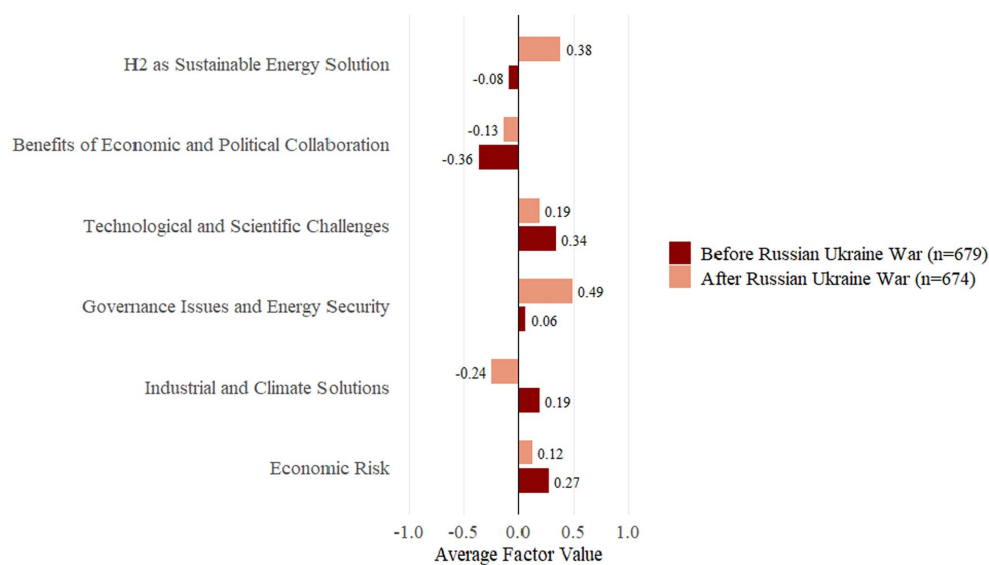


FIGURE 5

Influence of Russian-Ukraine War on the framing of hydrogen technology in Germany. Table shows average factor values before and after Russian Ukraine War, $N = 1,353$, Wilks' Lambda (Λ) = 0.86, $F = 34.65$, $df = 6$, $p < 0.001$.

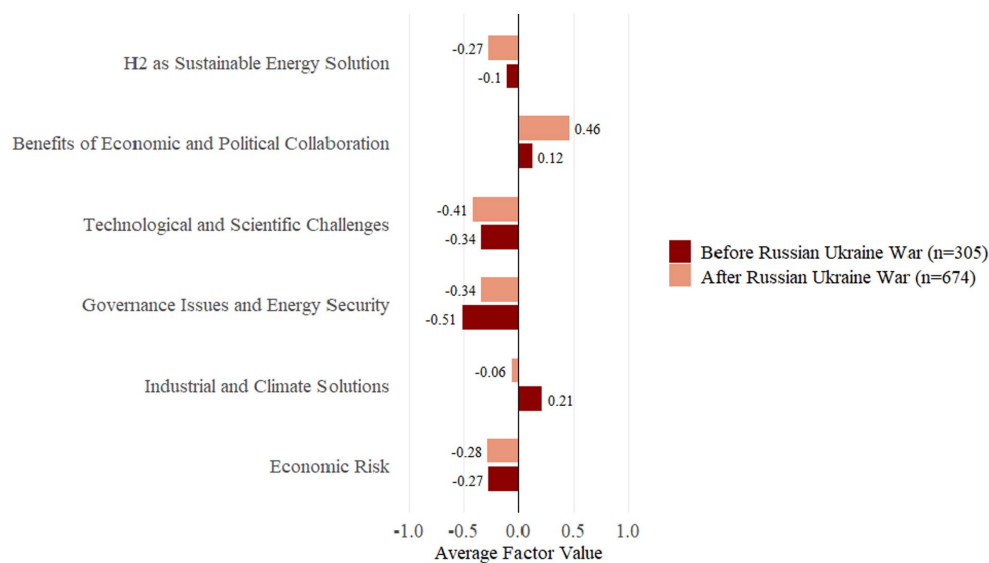


FIGURE 6

Influence of Russian-Ukraine War on the framing of hydrogen technology in MENA countries. Table shows average factor values before and after Russian Ukraine War, $N = 939$, Wilks' Lambda (Λ) = 0.92, $F = 13.7$, $df = 6$, $p < 0.001$.

Devitt et al., 2019). The lack of substantial social framing might be due to the early development phase of hydrogen technology, ongoing international conflicts, and the significant costs and environmental concerns tied to hydrogen production, especially for methods that are not yet sustainable. Furthermore, the global initiatives for hydrogen strategies aimed at reaching zero-emission objectives might have redirected media attention toward economic, technological, and policy-related frames, rather than societal considerations. This evolving framing indicates that the discourse around hydrogen is influenced by both its development path and the larger strategic goals of countries.

Though factor analysis indicated well-defined frames, there are methodological issues that require attention. The factor analysis revealed that some factors tend to consist of similar types of frame elements—such as benefits or problems—could be due to the inherent structure of media framing as conceptualized by Entman (1993). According to Entman's approach, frames often emerge as coherent narratives constructed from logically related elements (Matthes and Kohring, 2008). Thus, newspapers that emphasize particular benefits (e.g., economic growth or international collaboration) are likely to concurrently discuss related benefits, shaping coherent and internally consistent narratives (Entman, 1993; Matthes, 2009). Similarly,

newspaper articles highlighting certain problems (e.g., technological challenges or governance issues) tend to elaborate on them comprehensively, contributing to clearly identifiable thematic patterns (Matthes and Kohring, 2008).

Additionally, factor analysis illustrates medium to low factor loadings. Several methodological and data-related reasons explain why the factor loadings in this analysis are generally moderate rather than high. Firstly, the dataset consists primarily of dummy and ordinal variables, inherently limiting variability and possibly lowering factor loadings (DiStefano et al., 2009). Binary and ordinal data are less sensitive and thus can limit the strength of correlations among variables, leading to lower loadings (Fabrigar et al., 1999; Watkins, 2018). Additionally, certain frame elements loaded onto multiple factors simultaneously, reflecting conceptual overlap or shared thematic content. Such cross-loadings reduce distinctiveness, thereby diminishing the strength of factor loadings overall (Costello and Osborne, 2005). Lastly, media content, especially news articles, is typically nuanced and thematically interconnected, resulting in moderate factor loadings as frames are seldom exclusively constructed from clearly separable elements (Van Gorp, 2007; Matthes and Kohring, 2008).

Despite the moderate factor loading, factor analysis revealed six clear distinct factors. As Semetko and Valkenburg (2000) indicated, each factor identified through factor analysis can indeed be interpreted as a media frame, as it represents a specific configuration of frame elements systematically employed by newspapers to define and communicate complex issues (Entman, 1993; Matthes and Kohring, 2008). Factor analysis identifies latent structures within the data, grouping related elements based on how frequently they co-occur across articles. Hence, a factor can be conceptualized as an emergent pattern (frame) capturing the shared use of specific frame elements, reflecting distinct narrative strategies employed by newspapers to shape public perception and discussion (Matthes and Kohring, 2008; Watkins, 2018). In this way, factors summarize the underlying dimensions of how hydrogen technology is framed across media coverage.

The second aim of this research was to examine the influence of contextual factors on the framing of hydrogen technology. This research strongly supports Shoemaker and Reese's (2014) hierarchical influences model, confirming that media framing is systematically influenced by contextual factors. The results underline the significant differences in the framing of hydrogen technology across countries, which are closely linked to the underlying contextual factors. Aligned with institutional theory (Lammers and Barbour, 2006), this research illustrates how national hydrogen strategies influence narratives to correspond with economic, environmental, and geopolitical objectives, supporting the idea that the media not only convey information but also play a role in shaping reality based on national interests. German media provides a well-rounded perspective on hydrogen technology, highlighting sustainability along with the economic, political, and technological obstacles it faces. These representations align with Germany's national hydrogen strategy, which places green hydrogen at the forefront of its efforts to reach climate neutrality by 2045 (BMWK, 2023). On the other hand, newspapers from the MENA region concentrate on economic collaboration, reflecting the hydrogen export strategies of Saudi Arabia, the UAE, and Egypt. This contrast underscores how national priorities shape news coverage, with Germany focusing on

climate initiatives and energy security, while MENA countries frame hydrogen as a path to economic diversification and global energy leadership (IEA, 2022; Rezk et al., 2023). These findings are consistent with research indicating that media narratives mirror national energy policies and economic goals (Djerf-Pierre et al., 2016).

The noted alignment between national strategies and media framing indicates that policymakers and communicators have the potential to deliberately influence public discourse through their framing choices. In state-controlled media environments, emphasizing economic and geopolitical narratives may foster public support for national hydrogen agendas. In contrast, pluralistic media systems, such as Germany's, necessitate more nuanced and targeted messaging that appeals to a range of ideological viewpoints. Therefore, grasping these framing dynamics is critical for developing effective policy communication strategies that can enhance societal acceptance, stakeholder engagement, and facilitate the successful implementation of hydrogen initiatives.

Media systems emerge as a critical factor in framing (diversity) of hydrogen technology. Germany's democratic-corporate media landscape encourages diverse narratives, with newspapers covering a variety of viewpoints such as technical difficulties, economic risks, and governance issues. This supports Hallin and Mancini's (2004) argument that a pluralistic media system allows for balanced and critical coverage. On the one hand, authoritarian media systems in Saudi Arabia, the UAE, and Egypt limit the diversity of frames by emphasizing state-aligned narratives about economic and geopolitical benefits. These observations are consistent with Mellor's (2005) finding that centralized media systems often suppress critical views and reinforce state interests.

As suggested by Rochyadi-Reetz et al. (2019), the framing of renewable energies can be influenced by political orientation of newspapers, which not only shapes public opinion on climate change (McCright et al., 2013) but also impacts the societal acceptance of renewable technologies (Karlström and Ryghaug, 2014; Itaoka et al., 2017). Thus, the impact of the political orientation of newspapers on the framing of hydrogen technology is evident, particularly in Germany. Newspapers with the left-leaning stance, such as *Süddeutsche Zeitung* (SZ), *die tageszeitung* (TAZ), and *der Tagesspiegel*, focused on nuanced framing, covering both the environmental benefits and the substantial technological, governance, and economic challenges associated with hydrogen technology. This balanced yet critical approach aligns with their progressive stances (Schindler et al., 2017). Interestingly, TAZ emerged as the only German newspaper to somewhat emphasize economic and political partnerships, aligning with its liberal beliefs. The way left-leaning newspapers frame hydrogen technology aligns with the normative role of journalism, which is to examine new technologies and policies critically rather than uncritically endorsing them, even if they match certain ideological beliefs (Schudson, 2008). The scientific and technological uncertainties related to hydrogen production, storage, and economic viability might lead left-leaning newspapers to take a more cautious stance, with the goal of thoroughly and responsibly informing public discourse. On the other hand, right-leaning newspapers like *Frankfurter Allgemeine Zeitung* (FAZ) and *die Welt* highlighted economic problems and skepticism towards technology, which aligns with conservative views on energy transitions (Cushion et al., 2018). However, *die Welt* diverged its focus from typical conservative narratives by positively acknowledging hydrogen as a

sustainable energy solution. In the MENA region, however, state control largely suppressed the influence of political leanings, resulting in a convergence around economic and geopolitical frames across newspapers, irrespective of editorial orientation (Selvik and Høigilt, 2021).

This research also emphasized how different types of articles influence the framing (diversity) of hydrogen technology. In Germany, articles that are non-opinionated offered wider and more impartial coverage, whereas opinionated pieces tended to narrow their focus, frequently aligning with certain ideological perspectives. This observation supports existing literature that indicates that factual reporting upholds journalistic standards of neutrality, encouraging a range of narratives (Benson, 2009). In MENA countries, the lack of framing diversity across both article types reflects the limitations imposed by state-controlled media systems, as highlighted by earlier research (Rugh, 2004).

The last contextual factor, focusing events, unlike national strategies or media systems, is inherently unpredictable and can lead to substantial changes in institutional settings and media coverage. For example, the Russian invasion of Ukraine in 2022 altered the discussion surrounding hydrogen technology in Germany and the MENA region. In Germany, the conflict shifted the focus from climate mitigation to energy security, highlighting the pressing need to lessen reliance on Russian gas (Loewe et al., 2024; Arlt et al., 2025). In the MENA region, the invasion strengthened the focus on economic cooperation, positioning these nations as alternative energy suppliers. These observations validate Birkland's (1997) argument that focusing events can redefine the significance of issues and reshape media discourse.

This research offers several important theoretical contributions to the field of framing studies. First, it empirically supports Entman's (1993) framing theory as a strong conceptual framework applicable in various national contexts, thereby validating that his four main framing elements (which include problem definition, causal interpretation, moral evaluation, and treatment recommendations) hold explanatory power beyond Western-centric analyses. In addition, this research methodologically enhances the existing literature by reinforcing Matthes and Kohring's (2008) proposal, illustrating the importance of operationalizing frames through quantifiable sub-frame elements. By employing factor analysis to systematically uncover underlying structures, the present study emphasizes that framing analyses can greatly enhance reliability, validity, and objectivity. This method assists in reducing the interpretive biases often linked to solely qualitative techniques. Additionally, throughout the coding process, coders are kept unaware of the particular frame they are coding, which further enhances objectivity.

Finally, this research provides empirical support for Shoemaker and Reese's (2014) hierarchical influences model, showcasing how media framing is consistently influenced by various contextual factors, including national hydrogen policies, media systems, political ideologies, article types, and focusing events. In doing so, it enhances the theoretical comprehension of the frame-building process, highlighting the intricate interactions between national policies, media systems, and geopolitical events. Finally, by incorporating comparative viewpoints from both developed nations and the Global South, this research contributes to the comparative framing literature, underscoring notable differences shaped by institutional contexts. This comparative methodology fills an important gap in current theory, indicating that framing research can greatly benefit from a wider geographical representation, thereby enriching theoretical understanding of how national priorities and systemic factors influence media narratives.

In the context of energy communication, this research offers novel perspectives on the framing dynamics associated with hydrogen technology, highlighting the different ways media influence sustainable energy transitions and public perceptions in various geopolitical and cultural contexts. This comparative framing methodology not only questions but also enhances existing knowledge in the field of energy communication, providing important insights into the global evolution of sustainable energy narratives.

7.1 Limitations and future work

While this study advances the understanding of hydrogen technology framing, several limitations need to be recognized. First, the current research intended to analyze the framing of hydrogen technology across nations with varying national interests, specifically contrasting Germany as an importer with MENA countries as exporters, given their significant potential for hydrogen production. This approach effectively compares these nations in relation to their national hydrogen strategies and addresses a geographical gap by presenting an analysis from a Global South perspective. However, the comparison based on media systems did not provide much insight into the MENA countries, as the media in these nations are heavily regulated by the state. Future research might find it more compelling to examine hydrogen technology within more comparable media systems like those of the USA, UK, and Australia.

Second, the sample primarily represents German newspapers due to their substantial coverage, which constrained the analysis depth for MENA nations. Furthermore, the investigation focused solely on leading English-language publications from the MENA region, as local Arabic-language newspapers were inaccessible because of language proficiency issues and their limited presence in databases like LexisNexis. Future studies should incorporate Arabic-language newspapers from MENA to capture a broader and more localized viewpoint regarding hydrogen technology.

Third, while this research centered on contextual factors, it overlooked the impact of specific actors, such as policymakers, industry leaders, and advocacy groups, on media framing. Existing studies underscore the role of mass media as a forum for these stakeholders to influence public discourse according to their organizational goals (Esser and Strömbäck, 2014; Shoemaker and Reese, 2014). Future research should integrate actor-based frame analysis to investigate how various actors affect the framing of hydrogen technology within different media systems.

Fourth, while this research employed Entman's (1993) frame elements alongside Matthes and Kohring's (2008) methodological framework, it is vital to acknowledge specific theoretical limitations. The moderate factor loadings observed in this research highlight the inherent difficulties related to binary and ordinal data, as well as the possible conceptual overlaps among the various frame elements, such as the factor loading of economic problem frame elements on multiple factors. Furthermore, utilizing Entman's framing definition for operationalization improves reliability and validity by identifying frames based on data patterns and treating frame elements as variables. However, if certain frame elements are infrequently represented in the data, they will not make a significant contribution to the factor analysis. This is a limitation in comparison to holistic frame studies, where coding is done entirely by coders; nonetheless, reliability and validity are still concerns in these holistic investigations. Therefore, breaking down

frames into frame elements to enhance operationalization, methodological reliability, and validity is indeed advantageous, but the exclusion of less frequently mentioned frame elements (such as those appearing in under 5% of the data) from the analysis is a methodological weakness. Future research might explore an approach that integrates both holistic and element-based framing analyses to address this limitation and assurance a more comprehensive representation of frames.

Furthermore, prior research indicates that social acceptance of hydrogen technology varies between nations, with higher acceptance observed in Sweden (Haraldsson et al., 2006) and Japan (Itaoka et al., 2017; Ono and Tsunemi, 2017), whereas a lack of knowledge and critical views towards hydrogen technology exists in Germany (Häußermann et al., 2023). Future investigations could explore framing and media systems in countries characterized by low and high social acceptance of hydrogen technology.

Although this research demonstrated that national strategies and focusing events shape the framing of hydrogen technology, social framing remains insufficiently represented. It is possible that the discourse surrounding hydrogen technology in online blogs and public opinions on social media provide different viewpoints regarding this emerging technology. Future research might be intriguing to study online discussions about hydrogen technology, particularly employing automated methods.

Finally, the findings suggest several practical recommendations for policy communication and stakeholder engagement. For journalists and editors, the range of opinions seen across various media environments, like Germany, highlights the need to encourage editorial autonomy and to support journalistic efforts that showcase diverse perspectives, particularly on intricate sustainability topics. For environmental organizations and clean energy companies, understanding how different narratives resonate in diverse geopolitical contexts can improve strategic media interactions and message design. Collaborating on coverage that aligns with prevailing narratives (such as the economic opportunity in the MENA region or energy security in Germany) could increase receptivity among the public and policymakers. For advocacy groups, these findings demonstrate how geopolitical events (such as the conflict in Ukraine) can alter media narratives and potentially influence public opinion. This emphasizes the need for timely and contextualized communication strategies regarding new energy technologies, which can then shape the public discourse and accelerate the adoption of emerging energy technologies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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MA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. LH: Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Gen AI was used in the creation of this manuscript. For the revision of this work, ChatGPT has been utilized to refine the language, correct the grammar, and increase the readability of the revised paragraphs.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fcomm.2025.1600555/full#supplementary-material>

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