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Unveiling the marginal role of energy storage solutions in Italy: Insights from semantic network analysis of online news

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ABSTRACT

Adopting energy storage systems is crucial in the transition to sustainable energy sources. However, significant obstacles hinder their widespread use, often attributed to socio-cultural factors such as low user awareness. In this study, we examine the societal awareness of energy storage in Italy by analyzing online news, through innovative methods and tools of text mining and network analysis. Our analysis of over 143,000 energy-related articles published on major Italian news outlets identifies prominent discourse topics, specifically focusing on energy storage, and assesses their semantic context. Our results demonstrate that media coverage can play a vital role in increasing awareness and societal acceptance of energy storage solutions, thus facilitating their potential market uptake. Leveraging the visibility of these themes and connecting the concept of storage with specific arguments in the energy discourse could help engage a broader audience in implementing this technology. Our approach provides valuable insights into media narratives and can inform future communications strategies. We present metrics that are useful as marketing tools and can help policymakers and organizations assess their communication strategies.

1. Introduction

In the last decades, the global orientation towards energy production and use had to counteract the extreme consumption of non-renewable energy sources and face the emerging problems of global warming. Renewable Energy Systems (RES) represent the ultimate focus in the avant-garde energy development sector, which is currently struggling to replace traditional fossil energy with more sustainable alternatives [1]. However, renewable energy sources' inconsistent and intermittent nature inevitably bears non-negligible operational risks for power systems, such as voltage stability [2–4]. In this context, energy storage solutions represent a promising advancement since they store energy during off-peak hours to be later used when needed [5]. Moreover, the utilization of these solutions in distributed energy systems can bring about a notable enhancement in energy efficiency, leading to a considerable reduction in operational expenses [6]. The enormous potential of these new technologies, together with the rapid expansion of the energy market, has fostered extensive research on Energy Storage Systems (ESS) [7]. Ipsakis et al. [8], for example, studied hydrogen ESS based on photovoltaic and wind power generation and also developed the corresponding power management strategies (PMS). Mouli et al. [9] evaluated using solar energy to charge electric/hybrid vehicles in the Netherlands. At the same time, Fabiani and colleagues investigated the potential use of palm oil [10] and animal fat-based [11] phase-change materials for both active and passive building applications.

Indeed, despite the extended research background, most energy storage technologies are still commercially underused [12,76]. Some researchers claim that pumped hydro systems represent the most mature technology (accounting for more than 90 % of the global capacity installed worldwide and more than 127 GW of installed power) [13]. On the other hand, the sudden spread of electric mobility has led to the extended use of electrochemical ESS, especially Li-ion and lead-acid batteries [14]. Thermal energy storage (TES) systems, conversely, can play an important role in seasonal energy storage and net-zero energy buildings, for example. In these systems, heat is stored using sensible, latent, or thermochemical processes [15]. Systems based on Sensible Heat Storage (SHS) take advantage of the large heat capacity of the substrate: when the storage medium absorbs heat, the temperature rises,

Abbreviations: SBS, Semantic Brand Score; NLP, Natural Language Processing; ERT, Energy-Related Terms.

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whereas it drops when it is released [16]. In Latent Heat Storage (LHS) systems, energy is absorbed or released when the storage medium undergoes a phase change, e.g., from solid to liquid [17], while in Thermochemical Heat Storage (THS), energy is retained or released through reversible chemical reactions [14]. Among the three storage solutions, SHS is the readiest to the large market uptake, while the other two are still being researched and are still seldom used in real-life applications [16], highlighting a clear mismatch between the research and the market readiness level. As Carbajo and Cabeza suggest [18], the role of researchers in the implementation process of new energy technologies is crucial. In this sense, several researchers worldwide have assessed the topic of technology diffusion, both concerning renewable energy applications and energy storage solutions, to identify important patterns driving this phenomenon [19–21]. For example, Reddy and Painuly [19] interviewed various stakeholders to identify prominent barriers to exploiting renewable energy technologies. Each of these stakeholders reported different prevailing issues. However, two of them were consistently identified as possible barriers against the diffusion of RES: economic sustainability and the awareness of the involved subjects [19]. In a similar study about the diffusion of Ground Source Heat Pumps (GSHPs), Karytsas and Choropanitis [20] investigated the views of the main stakeholders involved in the Greek GSHP sector regarding its future challenges and the most crucial dissemination barriers, as well as the main actions that could boost their adoption in the future. They identified four crucial factors that could affect GSHP diffusion: the lack of public awareness about the selected technology and its benefits, the economic recession, the lack of adequate economic subsidies, and the large installation and other start-up costs. Likewise, Martiskainen et al. [22] showed the need for deep involvement of different user groups to facilitate heat pump transitions by identifying the role of users as one of the critical explanatory elements of the transition process. The development and diffusion of Swedish marine energy until 2014 was the focus of a study carried out by Andersson et al. [21], which found the lack of informed political direction to be the most critical hindrance factor for the diffusion of the considered technology. In this view, specifically tailored energy policies could play a crucial role in increasing the global attractiveness of renewables and, even more so, of TES solutions [23].

Based on these results, it seems clear that important obstacles exist in the diffusion of renewable energy technologies as well as in all kinds of energy storage systems [24]. This mismatch between the technology development and the actual implementation of thermal energy storage systems has been investigated in the literature by several studies and explained by socio-cultural factors [25,26]. Low user awareness is often identified as a crucial obstacle to the large-scale implementation of several energy technologies [24,27]. In addition, most studies consider specialized stakeholders, often neglecting the inputs and the massive potential coming from the general public or the end users – which are neither involved in the technology development process nor are subject experts [28]. This can result in the interests and needs of a significant portion of citizens and potential customers being undervalued. However, in our increasingly knowledge-driven society, big data and its analytics can prove to be valuable resources that can help bridge information gaps and provide policymakers with critical insights to make informed decisions. Moreover, these resources can aid in the development of intelligent solutions [29,30] that are responsive to the needs and expectations of end-users, resulting in more effective energy systems [31] that cater to a wider audience. Researchers often focused their efforts on the analysis of online research publications.

To reduce this gap, we present a new approach that can be used for the analysis of the online (and offline) discourse of different stakeholders – considering, for example, the message conveyed by online news or on social media and specialized discussion forums. In this exploratory research, we focus on online news, as a proxy of societal awareness of energy storage technologies, to evaluate their importance trends, potential diffusion in the energy market, and associated themes – as well as learn more about consumers' expectations and the specific needs of the energy sector. To this purpose, we combine methods and tools of text mining and social network analysis [32].

The paper is structured as follows. Section 1 discusses the impact of online news on societal awareness and social behavior. Section 2 presents the research methodology; furthermore, it describes the investigated sample and the data collection procedure used in this research. In Section 3, we present the study results, which are later discussed in Section 4. Section 5 concludes and presents some important economic and policy implications.

In our modern, connectivity-centric ecosystem, social media and online news represent a pivotal source of information, largely available and easily accessible to the public. News has a strong influence on public sentiment and citizens' behavior, and their analysis often leads to new forecasting indicators of social, economic, and political phenomena [33–36]. During the COVID-19 pandemic, for example, some researchers made use of sentiment and discourse analysis to assess the general mood towards sensitive issues, such as domestic violence and depression [37,38]. Previous analyses leveraged social media and news media data to understand brand importance in the fashion industry [34] or make political forecasts [34,39]. Similarly, Conzo et al. [36] investigated the effect of negative and positive discourses about immigration on pro-sociality at different levels of societal ethnic diversity. Gómez-Marí et al. [40] analyzed the impact of information campaigns about functional diversities – including Asperger's syndrome, rare diseases, and autism. They concluded that different media and social platforms should deliver good dissemination campaigns to reach different audiences and effectively promote a realistic and inclusive view of functional diversities. Online news has also been used to investigate and eventually increase awareness of specific topics. Pasek et al. [41], for example, examined political awareness in terms of factual knowledge of political issues and candidates. Gil de Zúñiga et al. [42] estimated the relationship between social media news and political engagement, while Boulianne [33] revealed the significant indirect effects of online news on civic awareness and political engagement. Online news also significantly affected people's awareness of delicate environmental issues [43]. Relevant studies suggest that media attention could be a better predictor of air pollution than dedicated environmental policies [44] and highlight the crucial role of news media in critical environmental issues – such as protecting coral reefs from bleaching and degradation [45].

Research in energy-related issues and technologies has recently transcended technical and economic optimization [46], addressing the relationship between energy production, distribution, and consumption, among others, and the overall users' awareness of these topics [47]. In this context, several studies stressed the issue of energy technology deployment, trying to understand the most critical mechanisms behind energy transition. Yoon and Hernández [48], for example, made use of thematic analysis to examine more than 500 news media articles about household energy insecurity, highlighting the key role played by the media in sprouting public response to policy and manipulating the nature of this response. Haber et al. [49] used natural language processing (NPL) techniques to analyze the discourse on social media and investigate public acceptance and knowledge of renewable energy technologies. Huang et al. [50] employed relational analysis to question the role of opinion leaders and followers in the effective dissemination of public policies aimed at promoting green energy and low carbon emissions. Other studies considered specific energy technologies. Antal [51] analyzed 1500 news pieces to better understand and explain the slow development of wind and solar energy in Hungary. Lyytimäki et al. [52], for instance, focused on biogas production in Finland. They found that the future of this technology is strongly shaped by public perception and information flows driven by media coverage. The significant state-by-state variation of wind power diffusion characterizing the U.S. was, instead, analyzed by Fischlein et al. [53], considering online news and stakeholder interviews. The researchers argued that the role of public discourse is as important as wind resources patterns and State policy in shaping wind power diffusion. Other contributions stressed the role of

media coverage on niche-level energy technologies, such as nuclear power [54] and hydrogen storage and conversion [55]. Finally, in 2022, Chen and Rowlands [56] analyzed articles in two Chinese newspapers on energy storage solutions, arguing that the media play a crucial role in understanding the socio-political context of the low-carbon energy transition and in shaping public perceptions.

Accordingly, online news can be regarded as a useful proxy of social awareness regarding key societal issues – as well as a crucial tool for leading the market uptake, increasing public awareness about specific topics, and ultimately influencing citizens' behavior. This is particularly important for energy-related behaviors, which are significantly related to users' educational background and habits [57].

2. Methods

Building on past research, e.g. [58], our paper presents an innovative approach that combines text mining and social network analysis tools to address the complex interplay between energy issues and social dominance. In this work, we used the Semantic Brand Score (SBS) indicator to assess the media importance of Energy-Related Terms (ERTs) and investigate the general awareness and acceptance of energy storage solutions in Italy. In particular, we used the SBS BI web app [59] and the computing resources of the ENEA/CRESCO infrastructure [60].

2.1. Measuring semantic importance

The SBS is a measure of semantic importance, applicable to words and concepts (set of words), appearing in (large) text corpora. This indicator is composed of three dimensions: (i) prevalence, (ii) diversity, and (iii) connectivity, which are described in the work of Fronzetti Colladon [32] and briefly recalled in this section. Following these metrics, the importance of an ERT is high when (i) it is frequently mentioned (prevalence), (ii) it has heterogeneous and less common textual associations (diversity), and (iii) it is deeply embedded in the discourse (connectivity). Indeed, prevalence measures the frequency of use of a specific word, or set of words, in a corpus. It could be considered as a proxy for the recognition and recall [61] of specific terms or concepts. Diversity measures the heterogeneity and uniqueness of the words that are frequently associated to each ERT, while connectivity expresses the brokerage power of ERTs, i.e., their ability to link different discourse topics. The formulas for calculating diversity and connectivity are derived from centrality metrics of social network analysis – distinctiveness centrality [62] and weighted betweenness centrality [63], respectively. For their calculation, a preliminary transformation of the text documents into a network of co-occurring words is required.

Text pre-processing is carried out and consists of several steps: the removal of web addresses, punctuation, stop-words, and special characters; the transformation of the whole text into the lower case; the computation of bigrams; the extraction of stems by removing the word affixes [64]. This procedure aims at reducing language complexity, retaining the most significant words, and eventually producing a network where nodes represent words and arcs indicate their text co-occurrences. Upon concluding this pre-processing, diversity and connectivity can be calculated. In particular, diversity derives from the distinctiveness centrality metric [62] and takes into account the number and uniqueness of the different words that co-occur with an ERT. The higher diversity, the more heterogeneous the semantic context in which an ERT is used. Connectivity is measured using weighted betweenness centrality [65], representing how often an ERT is an indirect link between all the other pairs of nodes (terms/concepts in the discourse). This measure is intended as a proxy of the brokerage power of an ERT, i.e., how much the ERT connects words and topics that are not directly co-occurring [32]. The SBS, i.e., our measure of semantic importance, is obtained by summing the standardized values of prevalence, diversity, and connectivity. Standardization is done by subtracting the mean and dividing by the standard deviation. Accordingly, negative values of the indicator are associated with concepts or terms that have a lower importance score than the average of the other discourse terms.

2.2. Data collection and definition of ERTs

Using the Telpress International platform (http://www.telpress.com), we were able to collect 142.692 online news articles dealing with energy-related themes. The dataset covers news published from January 2017 to October 2020. All news was written in Italian and published by major outlets and information websites in Italy. Indeed, we wanted to exclude possible confounding factors deriving from the consideration of multiple languages and countries – i.e., we chose to investigate the media importance of energy storage solutions within a well-defined lexical context. However, our approach could be easily replicated in other contexts and with other languages.

After downloading all the articles, we processed their text (as explained in the previous section) and extracted the main keywords using a Term-Frequency Inverse-Document-Frequency [66] approach, as allowed by the SBS BI app. Subsequently, two experts met to analyze this initial set of keywords and select and organize them into meaningful groups, each representing a specific concept/theme. Based on the experts' domain expertise and aligned with past research e.g. [67], these groups of keywords were carefully crafted by considering the primary themes in energy-related news and our research focus on energy storage. The experts were additionally supported by the Lexicon Augmenter tool available in the SBS BI app. This tool expands an initial list of words by identifying synonyms, hyponyms, hypernyms, and related terms (such as "global warming" if the input term is "climate change"). The tool uses the Wordnet lexical database and pre-trained word embedding models [68,69].

This work led to the identification of 15 groups of energy-related terms (see the full list and some examples of their most representative keywords in Table 1).

Because the main goal of the analysis was to understand the media importance of energy storage solutions, a first set of words was entirely dedicated to these technologies. Therefore, the ERT of storage is composed of synonyms of the word "storage" and of words representing energy storage technologies, such as tanks or batteries. The other groups of words were created with the aim of investigating the connection between energy storage and: (i) renewables in general and their most common technologies – geothermal energy, hydroelectric energy, solar energy, and wind energy; (ii) possible implementation categories – plant, building, electric mobility and energy community; (iii) some relevant economic features – cost and saving; (iv) significant energy and green transition concepts – environmental sustainability, efficiency, and self-consumption.

By analyzing importance time trends of ERTs, we can identify the impact of specific events and discuss local maxima and minima. We can also consider the three SBS dimensions and the image of each ERT in specific timeframes to understand what is driving the main indicator. This analysis can support the development of specifically tailored communication strategies meant to improve the awareness and adoption of storage technologies.

3. Results

Fig. 1 displays the time trends of SBS for the ERTs that were analyzed. This figure provides a visual representation of the changes in SBS over time for the specific ERTs that were studied. Upon comparing storage with the energy and green transition concepts, it becomes evident that the environmental sustainability is the most significant theme in online news. This trend consistently increases since 2017 and shows several large peaks throughout the years. For example, we notice a peak in the first half of 2019, which can be attributed to the debate on climate change raised by Greta Thunberg, a Swedish activist significantly mentioned in the news during this period. On March 15, 2019,

Table 1
Considered ERTs: example of keywords, and general description of the ERTs.

ERTs	Example of Keywords^	ERTs description
storage	storing, battery, batteries, storage tank, PCM, molten salt	Terms used to identify discourses about energy storage applications
geothermal energy	geothermal, aquifer	Terms used to identify discourses about geothermal energy
hydroelectric energy	hydroelectric, hydropower	Terms used to identify discourses about hydroelectric energy
solar energy	photovoltaic, solar collector, solar panel	Terms used to identify discourses about solar energy
wind energy	wind farm, wind blade, wind turbine, wind power, microwind, micro-wind, small wind turbine	Terms used to identify discourses about wind energy
plant	power plants, cogeneration, trigeneration, energy plant	Terms used to identify discourses about industrial facilities that generate electricity from primary energy
building	buildings, home, house, dwelling, housing, flat, flats	Terms used to identify discourses about private housing and structures
electric mobility	electric charging, electric vehicle, electric car, power point	Terms used to identify discourses about any form of vehicles, components, or structures related to forms of movement that make use of electric motors
energy community	energy community, energy exchange, micro-grid, micro grid, smart-grid, smart grid	Terms used to identify discourses about collective and citizen-driven energy actions towards clean energy transition
cost	costs, rates, rate, bill, bills	Terms used to identify discourses about economic parameters
saving	reduction, economic benefit, savings	Terms used to identify discourses about any eventual reduction in money, time, or another resource
efficiency	energy efficiency, performance, optimization, retraining, retrofit	Terms used to identify discourses about energy efficiency
Environmental sustainability	sustainable, environment, impact emission, circular economy	Terms used to identify discourses about the avoidance of the depletion of natural resources to maintain an ecological balance
renewables	renewable	Terms used to identify discourses about a natural resource or source of energy that is not depleted by its usage
self-consumption	self-consumer, self-sufficiency, self-reliance, self-consumptions	Terms used to identify discourses about a condition in which individuals or companies consume the energy produced by installations of production that are close to the consumers, e.g., photovoltaic panels or mini wind generators.

^ Keywords were translated from the Italian language.

millions of students worldwide take to the streets to demand action on climate change, triggering widespread media attention and generating a great deal of discussion around sustainability. This surge in interest was also reflected in the Italian press, where articles on sustainability saw a notable increase in prominence during this period. On the other hand, the semantic importance of storage, efficiency, and renewables, appears steadier and more consistent during the whole period. Finally, the concept of self-consumption shows an essentially flat time trend.

When comparing storage with ERTs related to buildings, plants, energy communities, and electric mobility, we can see that the last two implementations categories are less relevant in the energy discourse. The semantic importance of building and plant, on the other hand, often exceed that of storage. Building ERTs, in particular, increase their relevance in the discourse over time.

Upon analyzing the storage SBS in comparison to the main renewables selected for this analysis, it is evident that storage is a more prevalent subject in the news. Each individual renewable energy source has little discussion with the exceptions of two occasional peaks for geothermal energy. The first, in September 2017, was due to the Ministerial Conference of the Global Geothermal Alliance, which was held on 11–12 September 2017 at Palazzo Vecchio in Florence. Analysis of news articles during this period reveals that the most frequently occurring words related to geothermal energy were associated with this conference, suggesting that scientific dissemination events can significantly increase media visibility of specific energy themes. On the other hand, the peak of November 2018 was the result of a debate between former President of the Region of Tuscany, Enrico Rossi, and the former Minister of Economic Development, Luigi Di Maio, regarding the exclusion of geothermal energy from renewable energy incentive schemes. This debate created a media buzz, leading newspapers to cover geothermal-related renewables. The SBS trend of hydro and wind energy remains almost constant, whereas the SBS of solar and geothermal energy show greater peaks achieving significant semantic importance in the second half of considered time period. Economic features such as cost and savings show comparable semantic importance with storage, but their SBS value oscillates over time.

Fig. 2 shows the SBS of the different ERTs. The median value of the storage SBS is higher than the median values of the four ERTs that monitor the semantic importance trends of specific renewable energy sources (solar, geothermal, wind, and hydroelectric energy). This indicates that, for at least 50 % of the weeks analyzed, there is more discussion about the concept of storage than the individual renewable energy sources. However, storage is not as prominent as broader themes such as environmental sustainability, building, cost, efficiency, and plant. Environmental sustainability, in particular, is a central theme in the analyzed energy-related news and has a high SBS. Therefore, we can consider environmental sustainability as the benchmark, representing the most frequently discussed ERT in the energy context.

Analyzing the average contribution of each SBS dimension, we notice that the storage ERT has low connectivity, suggesting that its technology solutions are usually discussed in narrow contexts and do not embrace the energy discourse as a whole (which environmental sustainability does, being a cross-cutting theme).

In general, the average SBS of storage is higher compared to all other technical ERTs such as energy community, renewables, and self-consumption. The box plots not only give a general idea of the dispersion of the weekly SBS of the ERTs, but they also allow us the identification of noteworthy data points. Specifically, when looking storage, Fig. 1b shows three outliers that represent positive peaks in the storage SBS trend. These peaks occurred during the weeks of January 13–19, 2020 (SBS = 12.59), September 21–27, 2020 (SBS = 12.74), and December 17–23, 2018 (SBS = 14.05) and they helped us to investigate what the semantic context of storage was in the news published during these weeks.

We extended our analysis to evaluate similarities among the images of ERTs – represented by their textual associations (see Fig. 3a). We started by constructing an ERT-term matrix where each column represents a different term connected to each ERT, and the cells are populated with association frequencies. Row vectors represent the words associated with each ERT, and when they are similar, it suggests that the ERTs are presented in similar ways in the news or connected to similar discourse themes. To measure similarity, we used cosine similarity [70] and then multidimensional scaling [71] to obtain a two-dimensional

Fig. 1. SBS trends over time for the different ERTs.

visualization. The closer two ERT appear on the graph, the more similar their images.

Fig. 2.b shows the degree of similarity of the Storage image with that of the other ERTs.

The storage image is, on average, closer to that of plant, cost, geothermal energy, and environmental sustainability. These ERTs are mostly associated with words like “state”, “system”, “electric”, “gas”, “capacity”, and “efficiency”. This result highlights the presence of a narrative trend that links the theme of energy efficiency in buildings by means of renewable sources with storage systems. This process of energy transformation could be incentivized by financial interventions of the state and individual regions.

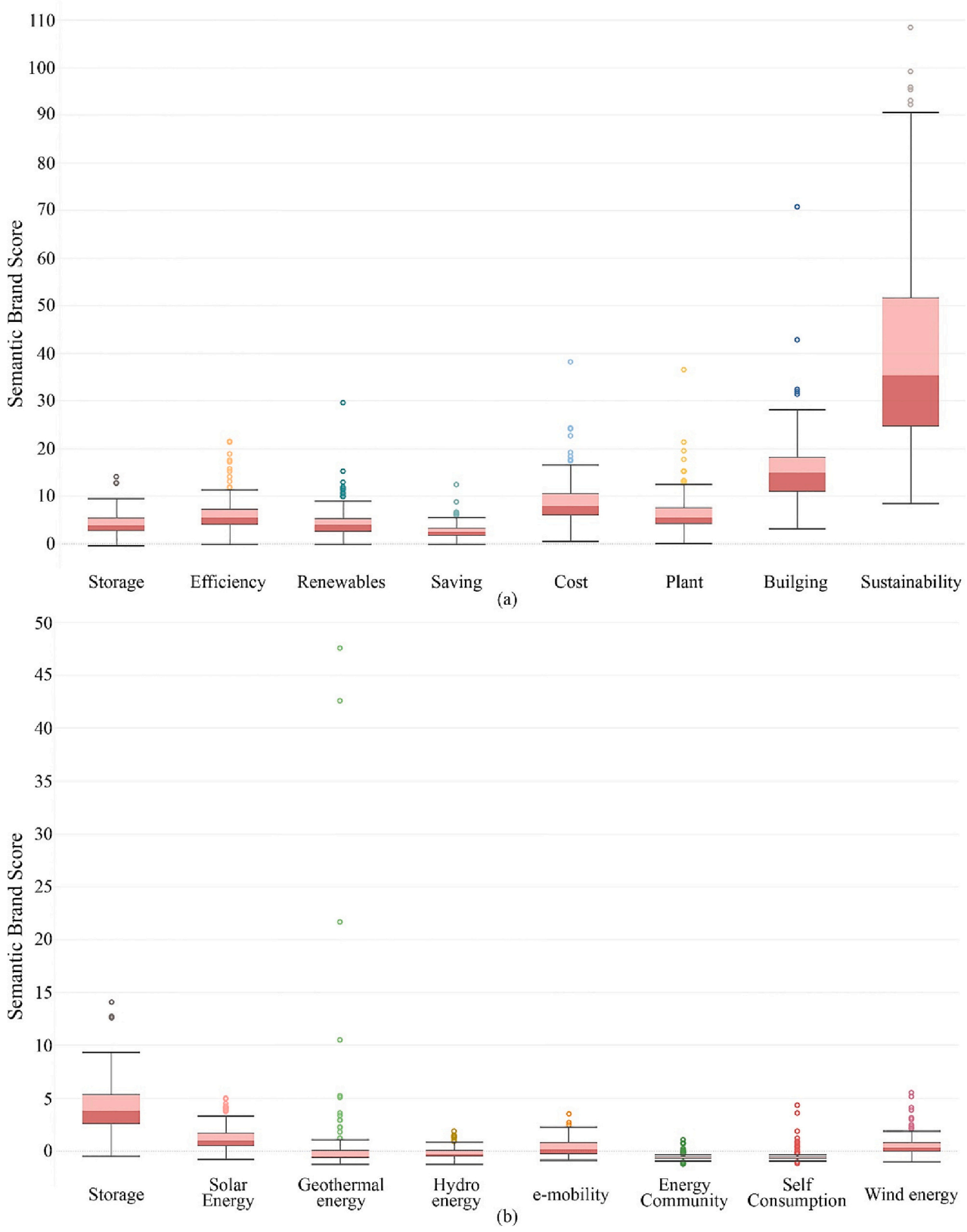

Fig. 2. SBS boxplot displaying the ERTs categorized by their average SBS into two groups: (a) ERTs of higher importance and (b) ERTs of lower importance in the energy discourse, all compared to storage.

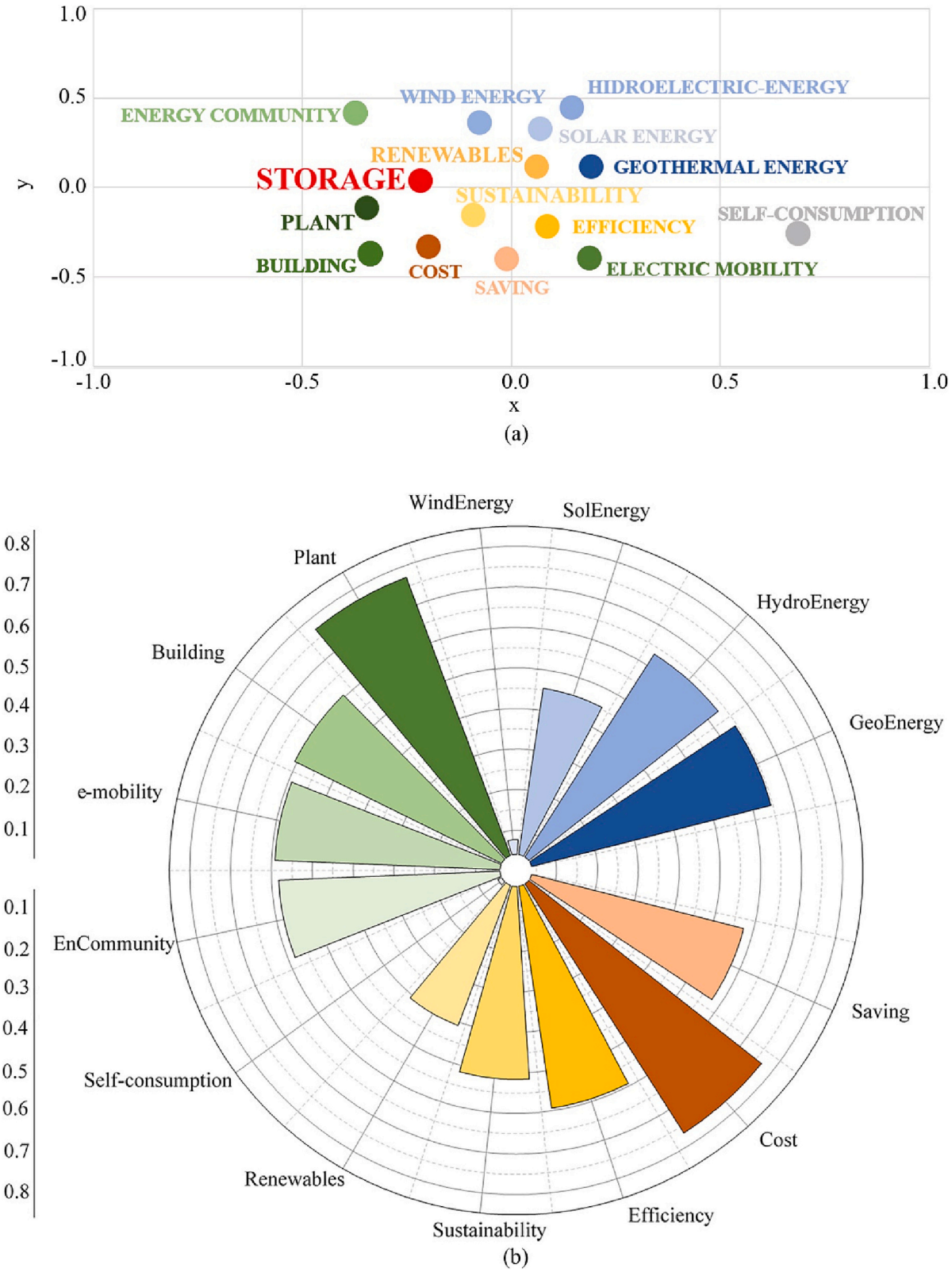

Fig. 3. (a) Similarity among the images of ERTs and (b) similarity between Storage and the other ERTs images.

Moreover, we noted that during the weeks in which storage becomes more important, its semantic context changes and is prevalently associated with "environmental sustainability", "savings", and "electric mobility", this could suggest that conveying information about storage solutions through these themes would allow more citizens to learn about this new technology.

As the last step, we wanted to understand which themes, other than those already identified by the two experts, were associated with storage and if other topics emerged from a broader analysis of energy-related news. Accordingly, we modeled the main discourse topic using a

network approach – i.e., through cluster analysis of semantic networks, using the Louvain algorithm [72]. The SBS BI app selects the most pertinent words in each topic based on their weighted degree and the proportion of internal and external links, as proposed by Fronzetti Colladon and Grippa [59].The results of this process are shown in Fig. 3.a through word clouds. Each word cloud represents a topic, and the size of words is related to their relevance within the topic. Moreover, using this word weight information, the app measures the relevance of the identified topics in the analyzed discourse (as shown in Fig. 3b). The greater the relevance, the more prominent the topic is within the news.

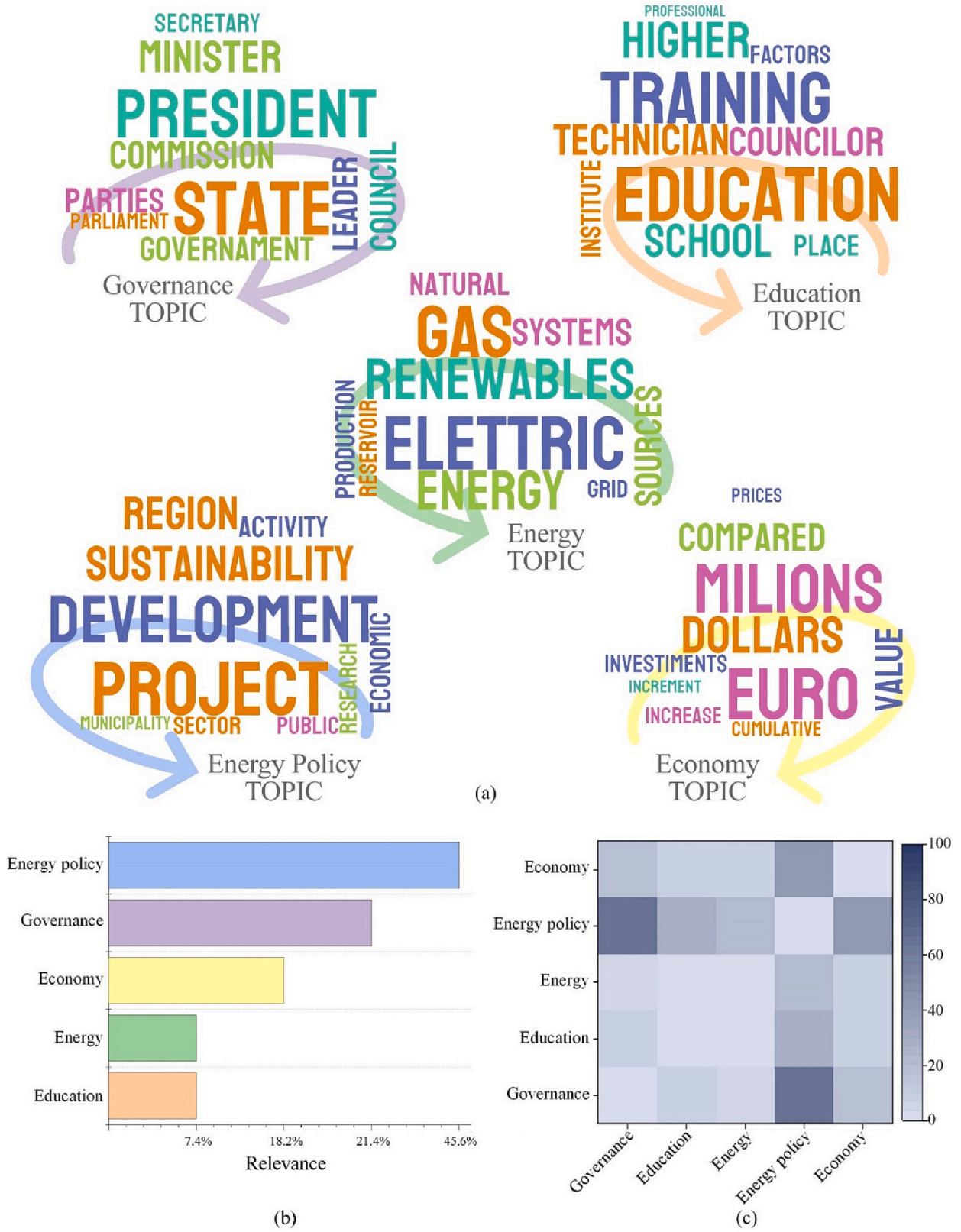

Fig. 4. (a) Main Topics, (b) relevance of each topic in the energy discourse, and (c) heatmap of the connections among topics.

We found 5 main discourse topics: the first one refers to the broad topic of "Governance" grouping words like "president", "state", "government", and "minister". The second topic is about "Education", as its word cloud shows terms like "training", "institute", and "school". The third topic regards "Energy" and includes energy-related terms like "renewables", "electric", "energy", "grid", "systems". The fourth topic also refers to energy issues but with a more operational perspective. For this reason, we label this topic "Energy policy". In its word cloud we find words such as "sustainability", "project", "activity", and "development". Finally, the last identified topic refers to economic aspects; it is composed of a set of words like "euro", "prices" and "investments" and is therefore indicated as the "Economy" topic. Like in all other images and tables, we translated Italian to English for the sake of readability.

Topic relevance is shown in Fig. 4.b, while the heatmap (Fig. 4.c) shows how strong are the connections among them. The "Energy policy" topic is, by far, the most prominent in the energy discourse. This result was expected since we chose as input online news that was related to energy-related issues. However, it is interesting to highlight the strong connection between this topic labeled "Energy policy" and the one related to governance. This strong connection might suggest the great responsibility that policymakers have in conveying information about sustainable energy solutions. Reading the content of news revealed that discussions on energy policy-related topics frequently arise when, for example, a minister commented on the approval of a decree law "The August decree-law approved definitively by the Chamber of Deputies contains important measures to support and relaunch the economy under the banner of sustainability [...] The decree also provides incentives for the production of thermal energy from renewable sources and for the increase of energy efficiency of small buildings used for school and hospital [...]". Similarly, related to debates among local governors regarding national energy policy choices "At the conclusion of the meeting at Mise, which was requested by several regions to address the exclusion of geothermal energy from the subsidy regime outlined in the decree on renewables, Enrico Rossi, the president of Tuscany, declared that they would continue their mobilization efforts for geothermal energy, despite its exclusion from the Lega-5Stelle contract." In addition, we notice that the topic referred exclusively to the more technical energy theme ("Energy") has weak connections to the topics of education and governance. This result may suggest a lack of social awareness regarding energy-related issues, which are often addressed by a small group of experts and not effectively communicated to the general public.

As a further investigation, we used the SBS app to evaluate how connected each of the main ERTs was with each topic, as a function of its lexical context. Storage is mostly associated with the two energy topics, i.e., "Energy" and "Energy Policy", while any further connection with the remaining ones is weak (see Fig. 5). A similar result can be observed for the Renewables ERT, while a more uniform link with different topics can be found for the other ERTs, e.g., those including environmental sustainability, plant, cost, and building.

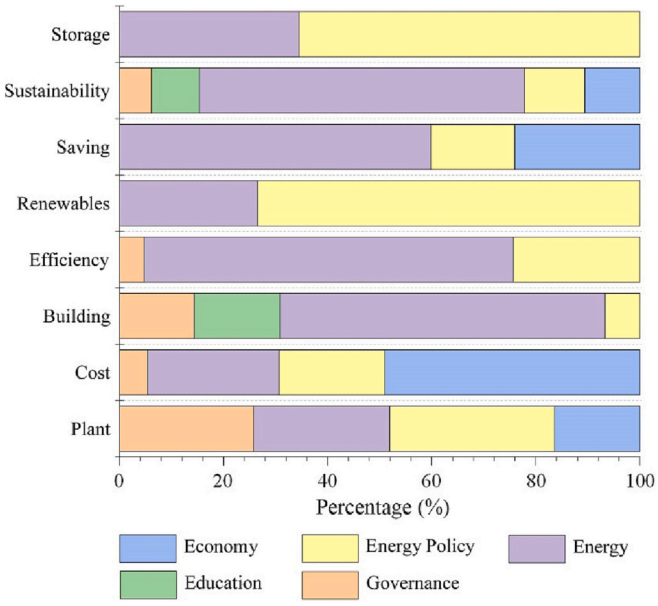

Fig. 5. Percentage of associations between ERTs and topics.

4. Discussions

Despite being debated in online news over the last years, energy storage presented relatively lower media importance than the general ERTs of energy efficiency and environmental sustainability. These findings support the idea of D'Oca et al. [26] that "information deficit" is one of the main obstacles limiting the implementation and diffusion of new energy technologies in Italy. Indeed, low media importance implies limited media coverage of the topic and, consequently, low likelihood that citizens will read and be informed about storage technologies. The comparison of storage and environmental sustainability in terms of Semantic Brand Score composition led us to investigate the substantial differences between the two ERTs. One of the main problems of storage is its extremely low value of connectivity. Storage solutions are often discussed in relation to very specific and niche topics, whereas they have the potential to complement many other technologies and, therefore, would deserve to become central in the energy discourse [2,46]. On the contrary, environmental sustainability is a cross-cutting theme with high prevalence, diversity, and connectivity. Previous research studies on users' awareness of nuclear fusion [54] and hydrogen [55] also showed the segregation of these topics within thematic news, producing lower awareness levels among the general public. Based on their results, the authors suggested promoting these technologies in a way that is of interest and comprehensible to the general public, not only to specialized practitioners. Accordingly, results from the SBS analysis suggest that societal awareness about storage could be tremendously improved if introduced within a more "popular" discourse. A possibility for increasing societal awareness of storage technologies could be to leverage the growing interest in electric mobility. This is aligned with the study of Lyytimäki et al. [52], who found that user awareness about biogas technology was strongly influenced by the action of prominent policymakers that were capable of presenting the technology as a promising and sustainable solution against energy poverty and resource depletion, using mass media (thus reaching a large public of end users). Our study suggests that a similar approach could also benefit the storage discourse. Indeed, results from topic modelling clearly show that the discourse about storage is relatively isolated. We found a relevant connection between the "Energy Policy" topic and storage. However, storage only represents a minor theme within the energy policy debate. The same applies for the "Energy" topic, which despite being the second most representative for storage, only tackles discourses about this technology in a limited way.

As previously discussed, references to storage are weak within the lexical context of the three remaining topics ("Economy", "Education", and "Governance"), also explaining its poor connectivity score. The evidence that storage has few connections to the topic of "Education" suggests that the Italian educational system should be included more in the process of raising awareness towards the energy transition by conveying knowledge about storage systems. Consistently, Hu et al. [73] showed that energy efficiency behaviors and awareness are mainly shaped by what users have learned from their academic environments and from their traditional energy-saving habits.

Another strategy to improve storage connectivity and SBS value, in general, could be to discuss its technologies in terms of expected economic benefits under a variety of realistic boundary conditions. Online news should describe different energy storage solutions and clearly

present their long-term sustainability. Direct connections should be made between current national energy policies and economic incentives and renewable and storage technologies. According to Carbajo and Cabeza [74], academia should work side by side with policymakers, and communication specialists to develop responsible campaigns aimed at informing the general public, clarifying the vague public profile of storage, and increasing societal awareness of this technology towards an effective engagement of a broad public in the use of more efficient technologies and systems. Previous research by Koirala et al. [75] showed that factors such as community trust, environmental concern, and energy independence could positively affect the overall awareness and acceptance level of renewable energy technologies. The authors suggest that the interest in local energy projects could boost the acceptance of renewables and increase their market share through community-based initiatives. Presenting the variety of energy storage technologies in the framework of local energy projects could further boost their overall acceptance on a local basis, as well as demonstrate their applicability in everyday activities.

5. Conclusions

The ongoing energy transition towards energy de-carbonization through renewables represents one of the most important innovations in the energy sector since the early 1900s. Renewable energy sources, however, share a common downside that makes them particularly risky for large-scale market applications, i.e., their intrinsic performance variability due to the inevitable lack of continuity of most renewable sources. To mitigate this problem, renewable energy solutions are often integrated with energy storage systems. However, despite the great efforts in this field of research, previous analyses have shown that low stakeholder awareness can seriously hinder the diffusion of both renewable energy and storage systems in the market.

In this work, we leverage big data analysis – made through text mining and the study of semantic networks – to extract information from energy-related online news. The goal is to evaluate users' awareness and acceptance of energy storage systems. Results demonstrate the marginal role of the energy storage theme within the energy discourse and the need for an effective communication strategy aimed at improving the overall societal awareness of these technologies.

One solution could be to leverage the growing interest in electric mobility to also raise awareness on energy storage and thermal energy storage in general. Another effective strategy could be to highlight the expected economic benefits and the long-term sustainability of different storage systems by also referring to current national energy policies and economic incentives. Existing policies could be improved by taking advantage of people's interest in local energy projects and community-based initiatives that could represent the cornerstone for further boosting user acceptance of storage technologies. However, policymakers should also consider the regional- and scenario-dependent nature of every renewable energy system and technology, imposing an obligation to carry out detailed and context-specific analysis for properly assessing the economic, environmental, and system repercussions of every defined policy. In this view, a sophisticated yet transparent communication campaign, capable of effectively conveying the urgent necessity of resorting to a fully integrated and comprehensive energy network, could be the ultimate linchpin to energy transition and the right boost for the energy market. The approach we present in this work was, for the first time, applied to the energy sector, with the aim of quantitatively monitoring societal awareness of innovative green energy technologies towards their large-scale implementation and successful market uptake.

While our analysis provides valuable insights into the Italian media landscape, it is important to note that the results cannot be generalized to other countries. Nonetheless, our work represents pioneering research that lays the foundation for future studies that can be extended to the European media context about the storage topic or any other emerging energy-related solutions for heading to green energy transition.

To further investigate the level of social awareness of energy issues, we plan to analyze other social media platforms as a source of information, as future development of this work. This will enable us to directly capture and examine how citizens are discussing energy issues, if at all. By combining insights from traditional media and social media, we hope to gain a more comprehensive understanding of public opinion on this important topic.

In general, the SBS approach is applicable in a variety of energy and environmental contexts, potentially with the aim of supporting the diffusion of new standards, policies, and business models focused on energy saving and sustainable development. The same methodology has the potential to generate the identification of information gaps, which may be reduced through improved media coverage.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Results data will be made available on request. The authors do not have permission to share the news data.

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Appendix A

Stationarity assessment

We used two tests for checking the stationarity of the SBS time series, namely the Augmented Dickey-Fuller (ADF) test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. The ADF test checks for the presence of a unit root, which implies non-stationarity due to a long-run trend, while the KPSS test checks for the presence of a trend in the time series. Using both tests together provides a more comprehensive understanding of the properties of the time series. The results from the ADF and KPSS tests are reported in Table A1. Only three stationary SBS trends can be found, i.e., self-

consumption, hydro energy, and wind energy. The SBS of cost, saving, energy community, renewables, and efficiency are not stationary since they fail to reject the null hypothesis of the ADF test, but they still reject the null hypothesis of the KPSS, which means that these series are not trend stationary.

On the other hand, the SBS of electric mobility, geothermal energy, and solar energy are difference stationary. This means that these time series do not display a recognizable trend over time, but their variance and autocorrelations are not constant.

Lastly, the ERTs of storage, sustainability, building, and plant are all trend stationary. This implies that they are stochastic variations from which an underlying trend, which is solely a function of time, can be removed, resulting in a stationary process.

Table A1
Overall stationarity result and main outputs of the ADF and KPSS tests, i.e., significance level at 5 % (pValue), test statistics (stat), and critical value (cValue).

	ADF - Null hypothesis: Time series is nonstationary			KPSS - Null hypothesis: Time series is trend stationary			Overal Stationarity
ERTs	pValue	stat	cValue	pValue	stat	cValue	
Storage	0.729	0.010	−7.942	0.019	0.642	0.463	Trend Stationary
Sustainability	0.768	0.268	−7.939	0.010	1.184	0.463	Trend Stationary
Efficiency	0.701	−0.177	−7.940	0.100	0.176	0.463	Not Stationary
Renewables	0.079	−6.426	−7.945	0.083	0.386	0.463	Not Stationary
Self-consumption	0.001	−34.642	−7.947	0.019	0.639	0.463	Stationary
Building	0.750	0.148	−7.939	0.022	0.607	0.463	Trend Stationary
Electric mobility	0.001	−81.644	−7.948	0.097	0.354	0.463	Difference Stationary
Energy community	0.350	−2.492	−7.946	0.052	0.459	0.463	Not Stationary
Plant	0.354	−2.461	−7.943	0.017	0.667	0.463	Trend Stationary
Geothermal energy	0.001	−157.690	−7.946	0.100	0.269	0.463	Difference Stationary
Hydro energy	0.001	−75.841	−7.948	0.010	1.695	0.463	Stationary
Solar energy	0.001	−23.582	−7.947	0.100	0.134	0.463	Difference Stationary
Wind energy	0.001	−42.124	−7.946	0.010	0.833	0.463	Stationary
Cost	0.601	−0.835	−7.940	0.055	0.451	0.463	Not Stationary
Saving	0.370	−2.359	−7.944	0.100	0.067	0.463	Not Stationary

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