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A text-based monitoring tool for the legitimacy and guidance of technological innovation systems

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ABSTRACT

Disruptive technologies have to overcome their liability of newness and transition into their growth phase by achieving compliance with existing institutions and pursuing the most promising development paths. Technological innovation system (TIS) studies examined these two issues of legitimacy and guidance of innovation activities by investigating the public discourse with manual media analyses. However, these approaches are time-consuming, prone to subjectivity biases and limited in scope. Therefore, our paper proposes an automatic text analysis methodology based on unsupervised Latent Dirichlet Allocation (LDA) topic modelling and lexicon-based sentiment analysis. By processing 3423 German newspaper articles from the Nexis Uni database, we cover the development of battery-electric vehicles (BEV) in Germany from 2009 to 2019 and identify five socio-technical aspects. Our results indicate an intact legitimacy for the TIS, with Usability, R&D, and Industry being legitimate aspects, which also exhibit strong or improving guidance. In contrast, the Infrastructure and Policy aspects have been less legitimate and weak in guidance, suggesting the need for more holistic policy measures and infrastructure expansion to establish a mass market. Our proposed methodology adds to the toolbox of methods to analyze TIS and serves as a monitoring tool to reveal contested aspects and periods in the public discourse.

1. Introduction

In many sectors, successful sustainability transitions crucially depend on the introduction of new, potentially disruptive technologies. Arguably, such innovations often face problems of institutional compliance because their socio-technical features conflict with the existing preferences, norms, regulations, and business practices. Moreover, their progress is also affected by uncertainty and conflicting demands about their future development path, especially in relation to the existing technological solutions and methods [1,2]. Arguably, these considerations apply for battery-electric vehicles in Germany, where the achievement of the ambitious sustainability targets of the federal government depends on the diffusion of BEVs and the phase-out of combustion engine cars. However, due to their liability of newness and disruptive potential for the German car industry, they have been facing resistance by incumbents and hesitance by possible adopters [3,4]. The technological innovation system framework captures these concerns of technological development with the legitimacy and guidance of the search functions. As in the case of BEVs, it is essential to fulfil both functions to support the transition of the TIS into its growth phase, which initiates the broad diffusion of the focal technology. This process essentially depends on the TIS reconciling with its institutional environment, i.e., its context, and establishing complementary development paths for the mobilization of necessary resources [5,6].

A range of empirical TIS studies focus on the public discourse as an important domain affecting the legitimacy and guidance and proceed to capture its effects by manually analyzing the sentiment polarity and topical coverage in news media reporting [2,7–11]. However, these manual text analyses are prone to a range of drawbacks and can introduce biases that limit their scope of application. For example, they are time-consuming, restricted to a limited corpus of selected newspapers and influenced by the distortions of human interpretation [12–14]. Against this background, our paper aims to improve on the previous media analyses by exploiting automatic or computer-assisted text analysis [13] and demonstrate its further potential for the analysis of TIS [15]. We propose a comprehensive methodological approach based on unsupervised LDA topic modelling and lexicon-based sentiment analysis to overcome the issues of manual analyses and provide a flexible

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monitoring tool for mapping the public discourse in the news media. Herewith, we want to answer the following research questions: What are the key developments in the public discourse about BEVs in Germany, and which implications do they provide about the TIS legitimacy and guidance of the search? Which insights can we derive about the application of automatic text analysis in the TIS framework? By answering these questions, we want to demonstrate the usefulness of our approach for firms and policymakers and help them to construct a supportive TIS around the focal technology and foster its successful diffusion in society [5,16].

We apply our processing pipeline to a large corpus extracted from the Nexis Uni database consisting of 3423 German newspaper articles from the last ten years. Accordingly, we cover the politically and economically most relevant period of BEVs in Germany, starting with the introduction National Electromobility Development Plan in 2009. After training our LDA model and subsequently conducting an aspect-based sentiment analysis, we can reveal which of the five identified aspects of BEVs, i.e., *Industry, R&D, Infrastructure, Usability, Policy*, were the most prevalent and controversially discussed in the German public discourse.

Our results indicate an intact legitimacy for the battery-electric vehicle innovation system (BEV-TIS) in Germany, considering that, by and large, the reporting in the news media has been quite positive in the last ten years. This aggregated legitimacy is conceptualized to consist of more and less legitimate aspects. In particular, the aspects *Usability* and *R&D* exhibit an increasing and consistently positive reporting, indicating a sound legitimacy and guidance. Relatedly, our results also indicate a considerable improvement for the *Industry* aspect in the most recent years. In contrast, *Infrastructure* and *Policy* have a highly fluctuating sentiment and lacking media coverage. Likewise, contrary to the other three aspects, the guidance of the search function is not fulfilled for the *Infrastructure* and *Policy* aspects. The ongoing issues with the legitimacy and guidance of *Policy* and *Infrastructure* are represented in the varying public opinion across regions in Germany and emerge from the disparate electromobility progress in the federal states, with states like Saxony-Anhalt lacking far behind leaders such as Baden-Wurttemberg and Rhine-Westphalia. Thus, in line with recent advisory reports and studies, our results suggest the need for a more holistic policy approach, including more consumer-oriented support measures, greater coordination between the national and federal governments and an acceleration of the charging infrastructure and electricity grid expansion to accompany the increasing number of BEVs. These measures are necessary to manifest the overall legitimacy and guidance of the BEV-TIS and establish a mass market with a broad diffusion in Germany.

In essence, our study adds to the much-needed toolbox of methods to analyze TIS and exemplifies that automatic text analysis serves policymakers and firms as a suitable monitoring tool for mapping the effects of the public discourse on legitimacy and guidance over the long term. In particular, our method reveals which aspects and time periods were heavily discussed in the public discourse and, in turn, allows us to identify the underlying issues by manually reading the associated documents with a high topic probability and polarizing sentiment. Subsequently, the concrete insights and issues derived can be considered to formulate detailed policy recommendations, which aim to promote the further development of the TIS. Future studies can build upon our methodological approach and expand our exemplary analysis by contrasting different technologies, countries, and text corpora. Our chosen LDA evaluation measures help researchers to find a parsimonious model that allows for a straightforward interpretation of TIS and context structures. This provides an effective tool to compare competing or complementary TIS and get a first overlook into their spatial, industrial or sectoral development dynamics regarding legitimacy and guidance. Moreover, our approach can complement existing TIS research methods such as historical event analysis, interviews, or qualitative text analysis, by providing a large-scale analysis that can reveal important aspects and time periods to provide a basis to apply human analysis more cost-efficiently.

Our paper is structured as follows. First, we introduce our theoretical framework, including the concepts of legitimacy and guidance of the search in TIS and how they are related to the public discourse. Second, we give a brief overview of BEVs in Germany as our empirical case. Thirdly, the methodological section discusses our database, processing pipeline and text analysis algorithms used. Fourthly, we describe our results related to the media attention and sentiment polarity of BEVs in Germany. Finally, the last two sections discuss the implications of our results for the legitimacy and guidance of the BEV-TIS and highlight the usefulness of automatic text analysis for TIS analysis while pointing out some limitations of our endeavour.

2. Theoretical framework

In innovation research, the concept of technological innovation systems emerged as a central concept to analyze technology dynamics from a systemic point of view. The structural elements of a TIS comprise a heterogeneous set of interacting actors, networks, and institutional structures, which shape the development and diffusion processes of the focal technology. Contrary to other innovation system approaches, a TIS has no territorial boundaries and includes various nations, regions, and sectors. Moreover, the TIS itself is situated in a larger context, which comprises all factors outside its boundaries that can influence its development. This includes other structural elements, competing or complementary TIS, and broad societal changes [17–19].

In recent years, the functional approach has become the most prominent scheme to analyze TIS using quantitative and qualitative indicators. Besides scientific advances and economic activities, it stresses the importance of legitimacy creation and guidance of the search for the development of technologies. Herewith, TIS consider the compliance with the relevant institutional structures in the context and incentive mechanisms guiding entrepreneurial activities [2,18,20,21]. We focus on these two functions because they are essential for the transition of the TIS into its growth phase, which depends on it reconciling with its institutional environment, i.e., its context, and choosing the most applicable development paths for the mobilization of necessary resources. This is especially important for sustainable technologies because they face resistance by incumbents and hesitance by possible adopters [5,6].

The legitimacy function refers to the (mis-)alignment of a TIS with its institutional environment regarding conformity with the relevant regulations, norms, preferences, design rules, and practices given its context. Although legitimacy is often viewed as being inherited by the TIS as a whole, it is also possible to distinguish between technology legitimacy and legitimation of the actors involved in the system [2,22]. Our study focuses on the former, which is attained once the socio-technical characteristics of the focal technology are increasingly regarded as appropriate and desirable by the most important stakeholders, like consumers, manufacturers, policymakers, industry associations, and scientists. In particular, socio-technical features do not only comprise performance criteria but also the industrial development, scientific advancements, and policies associated with the technology [23]. TIS legitimacy is perceived as the aggregation of more and less legitimate aspects of the focal technology. In other words, not all facets of the focal technology have to be aligned with the institutional environment to achieve legitimacy.

Relatedly, the guidance of search function (or influence on the direction of search function) is concerned with incentive mechanisms that determine in which competing technological opportunities, market segments, and business models the actors of the TIS invest their resources in and focus their innovation activities on. Similar to the legitimacy function, guidance is not entirely determined by a specific actor or group of actors alone but rather by the accumulation of a wide array of possible factors in the TIS and its context [18,20,22]. This can include

political objectives, regulations, demographic changes, developments in competing or complementary TIS, changing prices of critical commodities, and, particularly significant for our study, the public opinion regarding the focal technology. Nevertheless, guidance is often presumed to be established by top-down governmental policies and targets directed at the focal technology [18,24].

In essence, legitimacy refers to the aggregated compliance of the focal technology with its institutional environment, e.g., the conformity of BEVs with the emerging sustainability values in society. By comparison, guidance is more concerned with specific technological choices taken, e.g., cheap short-range versus expensive long-range BEVs. Nevertheless, both functions are interrelated to each other and inhibit mutual influence. On the one hand, existing institutional conformity for a certain technology incentivizes the allocation of resources and guides innovation activities accordingly [20]. On the other hand, providing guidance for the purpose of the technology, for example, through the implementation of supporting policy regulations or political goals, encourages entrepreneurs and other key actors to engage in its development and, thus, creates a certain degree of legitimacy [25].

As legitimacy and guidance are constituted as inherently collective processes, our study focuses on the public discourse as an important domain affecting both TIS functions. Accordingly, Bergek et al. [21]; Konrad et al. [8] and Bento and Fontes [5] emphasize the role of expectations and visions. Collective expectations, which comprise beliefs, hopes and promises about future technological capabilities [26], are actively shaped in a bottom-up process through discourse activities among different actor groups. In particular, given the institutional environment, proponents communicate their positive outlooks and perceptions and try to join forces with other actors to improve the public image of the technology regarding its socio-technical aspects. These different expectations present in the public discourse reinforce or weaken each other, which, in turn, leads to the formation of collective expectations on the aggregated level through a process of sense-making among actors [23,27,28]. Although these collective expectations are not necessarily shared by all actors, they represent an institutionalized reference point concerning the specific aspects of the technology, reducing uncertainty and providing guidance for actors aiming to enter the field [21,29]. Moreover, they affect the perceptions, attitudes and valuations of other relevant actors in the TIS and context, possibly initiating actions like the mobilization of resources from policymakers and investors or gaining support from regulatory agencies and the general public [30]. This enables the alignment of the technology's socio-technical features with the relevant institutions to improve legitimacy and constitute guidance by incentivizing actors to participate in the most promising technological development paths [8,24,31].

Many TIS studies consider the pivotal role of mass media to capture the dynamics of the public discourse and its effects on the legitimacy and guidance functions [2,9,11,18,21,28,32]. The media acts as an intermediary in innovation systems by connecting the different actor groups [33] and, thus, serving as a communication platform to facilitate the public debate about competing opinions and expectations [34]. Besides its intermediary role, the media can also influence the discourse activities due to its agenda-setting and framing. The former refers to the topics and issues the media chooses to report on, while the latter reflects whether these topics and issues are portrayed and discussed in a positive or negative light [35]. Hence, it does not only enable communication but also fulfils a controlling and opinion-forming function, actively shaping the public discourse [15,36,37]. Given these points, the media is recognized as a forum for different sources of legitimacy such as interest groups, governmental agencies or industry associations that compete with each other to reach the broader public through mass communication. Moreover, the media itself acts as an agent of legitimation by controlling which actor groups gain access to the public discourse [33,38]. Likewise, mass-mediated discourses enable actors to voice their expectations and preferences on the public stage. By communicating, prioritizing and framing these individual articulations, the media helps to shape and establish collective expectations among the broader public. Thus, because of its agenda-setting and framing as well as its close relations to actors that actively legitimate the technology and articulate expectations concerning its development, mass media reporting is seen as a reflection of the prevailing collective expectations that affect TIS legitimacy and guidance [8,32,33].

Against this background, we stylized the role of the media and its influence on the legitimacy and guidance of TIS in Fig. 1 to summarize our theoretical framework.

As depicted, the public discourse encompasses the exchange of individual perceptions, visions, demands and expectations between a wide range of heterogeneous actors and institutions from the TIS (inner box) and its context (dashed outer box). In particular, the actors and institutions are represented as consumers, science, policy, and industry, considering exemplary domains participating in the public discourse. The mass media takes centre stage in the public discourse, enabling communication and actively shaping the debate activities (dashed inner circle). Conditioned by the media's agenda-setting and framing, the different actors voice their opinions and expectations on the public stage using mass communication outlets. In particular, they aim to advance their interest by making statements about the technology's socio-technical features while taking account of the institutional environment in terms of relevant regulations, preferences, design rules and practices [23]. These claims reinforce or weaken each other, leading to the formation of collective expectations that act as a reference point, which, through further mass communication, affects the perceptions and actions of other relevant actors in the TIS and context. Ultimately, this shapes the overall legitimacy and guidance of the TIS [8,24,31].

3. Short overview of battery-electric vehicles in Germany

To examine the effects of the public discourse on the development dynamics of a TIS, we consider the BEV-TIS in Germany. Compared to hybrid and fuel cell vehicles, BEVs rely on the propulsion of an electric motor, which is powered by a battery that can only be externally charged [39,40]. Notably, policymakers and car companies view BEVs as one of the most promising technologies to propel the sustainability transition of the German mobility sector, which contributes about 21 % to the overall CO2 emissions of the country [40]. Moreover, given the importance of the domestic car industry for employment and the GDP, the transition to electric mobility is not only essential for achieving the ambitious emission targets set by the federal government but also crucial for the German economy as a whole [41].

With the announcement of the National Electromobility Development Plan in late 2009, BEVs entered the political stage and initiated public support measures for research and development (R&D) investment, grid integration, and charging infrastructure. In the following year, the National Platform for Electric Mobility (NPE), which was later supplanted by the National Platform Future of Mobility (NPM), was introduced as an advisory body aiming to establish Germany as a lead market and a lead supplier of electric mobility. The NPE considered three development periods to achieve this aim by 2020, which are described in the following.

The first period from 2010 to 2014, called market preparation, focused on research and development, education and skills while starting the diffusion of electric vehicles. The NPE recommended introducing support programs, building a public charging infrastructure for 100,000 vehicles and establishing demonstration projects to increase user acceptance and international visibility. The initial support measures from 2009 were followed by the Electromobility Government Plan in 2011 and an extension of the BEV tax exemption in 2012. In 2013, the first German BEVs were announced at the International Motor Show Germany by BMW and Volkswagen. In the following year, the milestone of 10,000 BEVs was reached [40,42]. A subsequent evaluation of the market penetration period highlighted the positive developments in the German car industry and the progress of the research and education

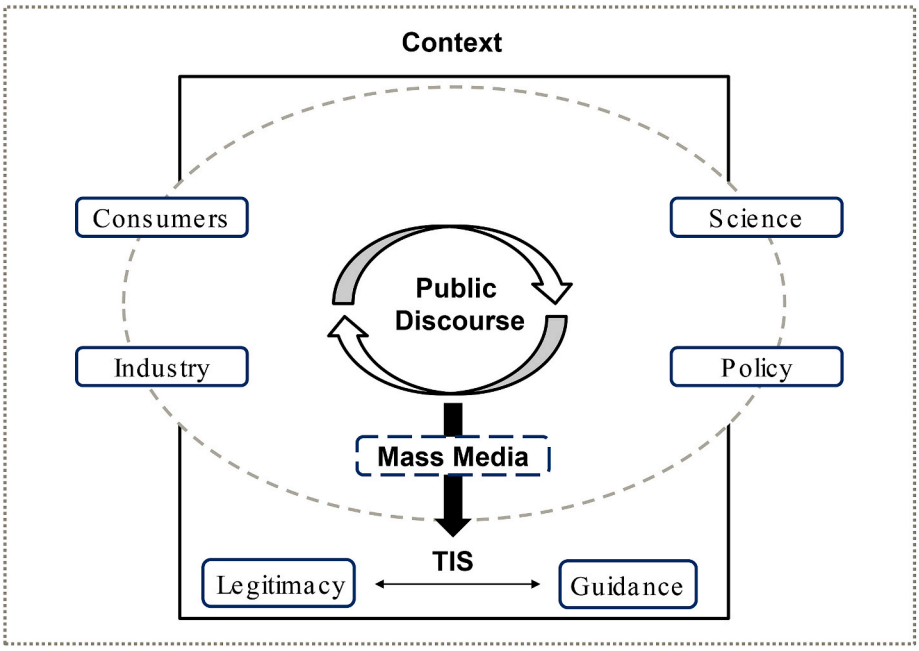

Fig. 1. The interplay of the public discourse, legitimacy, and guidance of the search in a TIS, own illustration with reference to Waldherr [33] and Kayser [15].

system. However, both the diffusion of electric vehicles and expansion of the charging infrastructure were still lacking behind and needed additional public support measures to catch up to the leading electromobility countries like the USA, Norway and the Netherlands [43].

The second period from 2015 to 2017, called market ramp-up, shifted the focus towards an acceleration of electric vehicle adoption to enable economies of scale in the production system and strengthen the international competitiveness of the German car industry. The enactment of the Electric Mobility Act in 2015 marks the beginning of this period of more ambitious policy support and approved specific privileges for electric vehicles in traffic. Following, a measures package of user-oriented support measures, including purchase subsidies, tax exemptions, as well as charging infrastructure build-up and standardization, was released in 2016 [42]. In 2017, the European Battery Alliance was established to regain a competitive edge in the development of new battery solutions for BEVs. The developments in this period helped to establish Germany as an international lead supplier of electric vehicles, achieving similar market shares in other countries than with combustion vehicles. Moreover, the research system continued to perform on a high level, as every third electromobility patent is of German origin. The implemented support measures also improved Germany's position as a lead market with a relatively high share of electric vehicles and an ongoing expansion and standardization of its charging network. However, a domestic battery cell production to decrease the dependence on Chinese and Korean imports is still missing, and further improvement of the electricity grid is needed to accompany the strong growth of the electric vehicle fleet [3].

The final period of the NPE plan marks the beginning of the mass market from 2018 until 2020, which is characterized by self-sustaining demand and business models. The period began with passing the next milestone of 50,000 BEVs in Germany, which was met with a comprehensive master plan in 2019 to ensure the nation-wide coordination of the charging infrastructure expansion and enhancement of the electricity grid. In the same year, the cost of batteries reached 100 Euro/kwh. Compared to the cost of 400 Euro/kwh in 2013, this decrease marks one key technological accomplishment, as the battery contributes the most to the overall cost of BEVs [42].

Although there are undoubtedly positive developments as emphasized by the NPE and NPM, missing the initial target of one million electric vehicles in 2020 exemplifies that there are still barriers hampering the large-scale diffusion of BEVs in Germany. Besides the missing domestic battery production and the urgency to improve the charging infrastructure, recent advisory reports have highlighted the crucial role of addressing the different aspects of the technology's institutional compliance and collective expectations to continue the formation of a competitive BEV market [3,4,44]. In light of the above, mapping the public discourse and its influence on the legitimacy and guidance should allow us to further understand the lacking socio-technological aspects of the BEV-TIS and help policymaking to reach the imposed sustainability targets.

4. Methodology

Before describing our employed methods in detail, we will briefly discuss the differences between manual and automated text analysis to motivate the chosen approach in the study.

In the TIS literature, several studies tried to gain insights into the effects of the public discourse using qualitative and quantitative media analysis [2,7–11]. Specifically, the sentiment polarity and topical coverage in national newspaper articles are proposed as possible indicators to capture the influence of the public discourse on the TIS legitimacy and guidance in a country [2,10,18,21,28].

These previous studies are confined to manual text analysis of media data. Human interpretation allows for a detailed interpretation of complex and abstract concepts while being sensitive to the circumstances surrounding the chosen empirical case, such as spatial, historical or technological specificities that have to be considered when drawing further conclusions and suggesting policy recommendations. However, a manual analysis is extremely time-consuming and only allows to handle a relatively small corpus of text data, restricting the scope of application and hampering cross-comparisons across different technologies or industries.

Moreover, because such studies have to be confined to selected media sources, usually the most prominent newspapers, they are influenced by the active framing and agenda-setting of the respective publishers. In this respect, newspaper outlets are conditioned by proximity news values, i.e. they tend to report about developments that are geographically, politically or economically close [33]. Such regional

developments are critical for spatially sticky technologies like wind energy, whose TIS functioning is greatly influenced by local embeddings [45,46]. However, although manual analysis can be conscious about these differences in reporting, results based on a small set of media outlets should not be considered representative of the public discourse and its effect on legitimacy and guidance on the national level [32]. The latter is more important for production-led technologies like BEVs, which are characterized by locally embedded production and knowledge systems but depend on a national or global valuation system for the creation of legitimacy, allocation of resources and formation of markets [45].

Additional drawbacks of manual text analysis are the reliance on coding protocols, which are often ambiguous and incomplete, as well as the subjectivism introduced due to confirmation biases and other beliefs about what to expect to see from the data [14]. These can impair reproducibility, especially when different research domains and languages are considered [12,13].

Considering these drawbacks, more and more technology-related studies began to implement automatic text analysis methods to complement manual analyses (e.g., Refs. [30,47–51]). As such methods have not yet been fully exploited for TIS research, we propose a methodological approach based on natural language processing (NLP) to investigate the legitimacy and guidance functions. More specifically, to map the topical coverage and sentiment polarity in the public discourse as indicators, we employ unsupervised topic modelling and lexicon-based sentiment algorithms. Topic models are used in NLP to summarize extensive text data into several groups of words that represent semantically meaningful topics. Sentiment analysis is employed to detect opinion bearing phrases in documents to evaluate whether a negative or positive sentiment is expressed in the text [52]. Both approaches can be applied to any type of documents without the need for pre-labelled training data, which is usually very rare in the social sciences. Moreover, the associated algorithms are usually easy to access, thoroughly documented, and editable [13,15]. Hence, in contrast to human coding, our approach enables a low-cost and large-scale analysis that can be quickly adjusted to different technologies, industries and nations, while being accessible and reproducible for other researchers [13,52]. This enables us to process as many newspapers as possible to achieve a representative picture of the public discourse on the national level. Furthermore, the proposed methods do not rely on a priori interpretative rules or perceptions such as the substance or subcategories of each topic, which does not only mitigate researcher bias and the need for extensive coding training but also allows the identification of aspects and themes that were not known beforehand [53]. Lastly, the employed algorithms capture the sentiment of a news article on a continuous scale and depict its content by a set of topic probabilities. This enables to complement interpretive with statistical validation of the results while also opening up many possibilities for subsequent quantitative analyses [54].

Besides these advantages, there are several drawbacks one has to consider when using automatic instead of manual text analysis. Firstly, although topic models have a high correspondence to human-coded results, they still rely on manual validation and interpretation with regard to the underlying research case [13]. Secondly, automated sentiment analyses should be adapted to the specific technology, industry or nation investigated in order to achieve reliable results [55]. Thirdly, the gain in efficiency when applying automated methods certainly comes with a loss in meaning that can inhibit the validity of the study if the results are not accordingly interpreted [13]. The latter constitutes a trade-off between the choice of these two text analysis approaches, which we will return to in the discussion section.

Next, we will describe our employed algorithms and the associated processing pipeline. For our topic modelling, we rely on the LDA algorithm developed by Blei et al. [56]; which processes each document in its bag-of-words representation. It derives probabilities for a set of words to appear together based on word frequencies and patterns of co-occurrence. In doing so, each document in the corpus can be represented by a distribution of topics, which are by themselves constituted by a distribution of topic keywords. To reduce computation time, we employ the modified LDA approach of Hoffman et al. [57]. Moreover, following Jacobi et al. [58] and Huang et al. [59]; we use the term frequency-inverse document frequency (TF-IDF) as a feature selection of our LDA model because it provides better performance than the usual bag-of-words approach. We rely on the coherence score [60] and Hellinger distance [61–63] as evaluation metrics to guide the selection of our LDA model, specifying the number of topics and cut-off values for the most frequent and infrequent words as our model parameters.[1] Herewith, we aim to derive a parsimonious model with a high interpretability and minimal overlap between topics. In addition to common German stopwords, we also take corpus-specific stopwords into account to further increase the performance of our LDA model [52,64,65]. We tested different document levels and word groups as inputs for our LDA model to calibrate the model parameters. In particular, the document levels included individual sentences, paragraphs, or articles, while the word groups included nouns, verbs, or adjectives.[2] In doing so, our final model of choice does not only suit our research design but also exhibits the best values for our evaluation metrics.

For our sentiment analysis, we employ a lexicon-based approach combining the SePL [66] and SentiWS [67] opinion phrase lists. The former has a particular advantage over other available lexicons because it consists of multiple word phrases incorporating negations, intensifiers, and idioms. However, we added the SentiWS to expand the coverage of sentiment-bearing words. Following van Atteveldt et al. [55]; we adapt the final opinion phrase list to our research case to enhance the reliability of our results. In particular, we adjust the sentiment polarity of the most frequently occurring opinion phrases in our corpus to better suit the word meanings to BEVs. Building on the search algorithm of Rill [66]; our sentiment analysis is conducted on the sentence level to allow for a high level of disaggregation and to achieve the highest possible accuracy. We interpret the inferred topics of the LDA model as specific aspects of the technology to allow for a fine-grained sentiment analysis [47,49,68–71]. This enables us to provide a more comprehensive insight into the development of TIS legitimacy and guidance by systematically revealing which aspects of the technology are more positively or negatively depicted in the media.

Fig. 2 gives a simplified overview of our processing pipeline. In a first step, as proposed by the NLP literature [52,64,72], we employed several preprocessing steps, like the removal of stopwords, numbers, special characters, and irrelevant parts of the articles, the replacement of abbreviations, part-of-speech (POS) tagging, and lemmatization to increase the performance of our algorithms. After preprocessing the extracted newspaper articles, the LDA model is trained, and the topics and word distributions are computed.

Thereupon, we interpret the retrieved topics as specific aspects of BEVs and let the LDA model assign each article in our corpus to its most probable aspect. Next, using our constructed sentiment lexicon, we assign a sentiment score to each sentence in an article. We end up with a dataset on the article level, in which every article is listed with its most probable topic and its aggregated sentiment score across all entailed sentences, scaled from −1.0 to 1.0. In a final step, the sentiments for each article are aggregated to the topic and year level. In doing so, we retrieve the associated means and standard deviations, which serve us as a measure of the overall sentiment of the articles.

We follow the related TIS studies and consider newspaper articles as our text corpus since they tend to have a greater influence on the perception of readers and enjoy a higher trust than other forms of media [73,74]. Notably, news articles are considered as one of the most

[1] The values for the alpha and eta parameters are learned from the corpus [57].

[2] Using only specific word groups can increase the efficiency of LDA topic models [107].

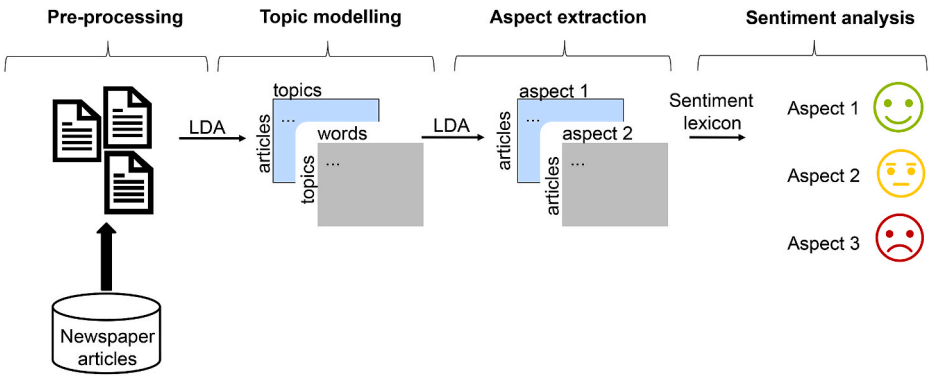

Fig. 2. Processing pipeline.

important written media outlets where relevant debates about technologies are conducted by a diverse set of actors and communicated to the broader public [75–77]. Moreover, especially nation-wide newspapers reach a large audience and are viewed as having a significant impact on public discourse activities [34]. In addition, newspaper articles provide a high text quality for NLP, given that their content is editorially checked and proofread [15]. To achieve the most representative reflection of the public discourse and capture the prevailing collective expectations on the aggregated national level, we extracted all available German newspaper articles from the Nexis Uni database[3] until December 31, 2019, using keywords[4] to delineate BEVs from other powertrain technologies. After deleting duplicate articles,[5] we end up with a final corpus of 3423 articles from January 01, 2009 to December 31, 2019. Herewith, we cover the aforementioned period in which BEVs took the stage and exhibited a surge in political and economic interest and cover media outlets from important regions in the German car industry like Berlin, Baden-Wurttemberg, Bavaria, Lower Saxony, North Rhine-Westphalia and Saxony-Anhalt, which have a relatively high employment share in the car industry or adjacent supplier industries [78].

In accordance with the related literature, we define the following relations between the results of the media analysis and the two TIS functions. First, a high or low media attention with positive sentiment, aggregated across all topics, indicates increasing legitimacy. As discussed in the theory section, legitimacy is thereby driven by more and less legitimate aspects of the technology. Vice versa, a high media attention with negative sentiment indicates a contested legitimacy in the public [2,28]. Second, a high media attention for a particular aspect of the technology is a sign of strong guidance. More specifically, if the increasing coverage is accompanied by a positive sentiment, the TIS actors are incentivized to focus their innovation activities on that particular socio-technological aspect. On the contrary, if a negative or weak sentiment accompanies the increasing coverage, the further progress of that aspect is hampered, and actors are driven out of the associated development path [18].

Based on these relations and considering BEVs as production-led technology, we focus on the historical dynamics of the public discourse on a high level of aggregation. Accordingly, the aggregated media attention and sentiment we retrieve from the newspapers reflect the accumulated perceptions across individual actors in terms of collective expectations as a result of the public discourse [9]. In turn, these drive the national valuation system that affects the legitimacy and guidance of the BEV-TIS in Germany. Although we primarily focus on the dynamics on the aggregated level, we will also check the discourse dynamics of the most important media outlets in our dataset to understand how represented the national discourse is across regions and examine whether there is a substantial divergence [46].

5. Results

After a comprehensive grid search over different parameter values and document levels as training data, our evaluation measures recommend an LDA model with five topics using the nouns and verbs of whole articles while cutting off words that appear in no more than 20 % of the corpus and in at least 55 articles.

To label and interpret the topics, we follow the procedure of Dehler-Holland et al. [32]. First, we let two researchers read the topic words and news articles with the highest topic proportions to independently come up with a label and brief description for each topic. Second, the results were compared, and final descriptions and labels formulated. Third, the topics were interpreted as specific aspects of the BEV-TIS and mapped to TIS and context structures [79]. Thereby, we identify the five topics, *Industry*, *Research and Development (R&D)*, *Infrastructure*, *Usability* and *Policy*. The associated LDA topic keywords and their probabilities of belonging to the respective topic are listed in Table A1 in the appendix. In particular, there is no noticeable overlap between the word distributions or substantially large word probabilities that would imply that the topics are not clear-cut or that some words are overrepresented due to insufficient preprocessing [52,64].

The first topic, *Industry*, is concerned with the industrial development and transformation process of the German car industry. Given its role as an industry leader, the topic covers the challenges of restructuring the German production system from combustion engines towards BEVs. Specifically, the assigned articles discuss the international competitiveness of the German car industry, firm's electromobility strategies, changes to the value chain and assembly lines, displacement of jobs, and the procurement of specific resources for lithium-ion batteries. We consider the topic to cover structures from the supply system of the BEV-TIS such as suppliers, manufacturers, assembly producers or maintenance providers.

The second topic, *R&D*, comprises scientific and technological advancements of BEV technology, e.g., batteries, powertrains, vehicle design, and production processes. In particular, it describes ongoing research and pilot projects of German universities, research institutes, and their cooperation with car manufacturers. Hence, we regard this topic to cover the research and education system of the BEV-TIS, emphasizing the importance of R&D for the future of Germany's industrial leadership.

[3] https://www.lexisnexis.com/en-us/products/nexis-uni.page, accessed on 31.01.2020.

[4] The used keyword search is: *elektro and auto or* fahrzeug *or batterie or e-auto or e-fahrzeug or e-mobilität and not brennstoffzelle and not hybrid*.

[5] We deleted articles with the same content but from different publishers, as this would otherwise bias our LDA results because it puts more weight on the associated word and topic distributions.

The third topic, *Infrastructure*, is concerned with the role of public and complementary infrastructure for the BEV-TIS [20]. The former covers the electricity system, including grid development to accommodate an increasing BEV fleet as well as synergies with renewable energies (vehicle-to-grid). The latter refers to the expansion of recharging stations, parking privileges for electric cars, and coordination between actors in local energy markets. Herewith, the topic highlights the critical role of TIS and context structures such as energy providers, municipal institutions and utilities, as well as renewable energy producers.

The fourth topic, *Usability*, considers the demand structures of the BEV-TIS and entails issues and opportunities that drive the adoption of BEVs in Germany. Specifically, it takes a consumer perspective and discusses how well the offered car models match the demands and needs on the demand side. The assigned articles discuss performance criteria such as range, price and vehicle design, often with a comparison to combustion engine vehicles, which are critical for the adoption decision of consumers. Furthermore, it covers issues like recharging time and compatibility as well as using BEVs as energy storage for households.

Finally, the fifth topic, *Policy*, captures all content about policy measures. In particular, it involves evaluations of ongoing policy programs from different stakeholders, discussions about political targets and elaborations on the effectiveness of BEV support measures. This includes issues like accessibility, financing, coordination and effectiveness of the implemented support measures. Furthermore, considering the comparatively slow transformation towards electromobility in Germany, the articles also compare the ongoing policy programs with the developments in other countries. All in all, this topic covers the politics, policy and institutional structures in the BEV-TIS.

First, we will take a look at the descriptive statistics of our data that are presented in Table 1. The table shows the number of articles with a non-missing sentiment score (n) and the mean sentiment (mean) with its standard deviation (sd) for each year in our data set. The total number of distinct articles is 3423. In the first column, we see the sentiment score and number of articles aggregated across all topics. By and large, in the last ten years, the overall sentiment was positive with scores between 0.03 and 0.05, while the media attention quadrupled from 144 articles in 2009 to 567 articles in 2019. Furthermore, the standard deviations of the yearly sentiment scores based on all topics depicted in the first column are quite stable, with 0.22–0.24. In the following columns, we depict the same statistics for the individual topics. Overall, we see that the sentiment and article count are very heterogenous from topic to topic. The sentiment scores vary between −0.05 and 0.1, suggesting that there are no heavily controversial aspects in the observed period. Specifically, topics like *Usability* and *R&D* only show positive mean sentiments and a high as well as increasing media attention. In comparison, topics like *Policy* or *Infrastructure* exhibit negative reporting as well, while their article count is relatively low and more or less stagnating. Besides these differences, the standard deviations of the sentiment scores for each topic are relatively similar across topics and time, with most values being between 0.20 and 0.25. At first sight, this suggests that the public opinion is rather coherent across the aspects of BEVs over time. Nevertheless, the aggregated standard deviation could overshadow a hidden heterogeneity and, thus, possibly a meaningful divergence in the public discourse. The latter further motivates us to consider whether there are systematic differences in media reporting due to regional circumstances.

To get a clearer picture of the public discourse, we will now illustrate the dynamics over time and topics graphically. In doing so, we are focusing on their sentiment and article count in relation to the three development periods previously outlined by the NPE. Before we provide a deeper interpretation and evaluation for the legitimacy and guidance in the next section, we describe our results on three different levels of observation: the aggregated dynamics over all aspects, the specific developments for the individual aspects, and the reporting of the ten publishers with the most articles in our data.

Starting with the aggregated dynamics, Fig. 3 illustrates the overall media attention for BEVs in the German public discourse. It displays the absolute frequency of all articles published each year. Overall, we observe a rise in the number of articles, with a decrease during the market preparation period until the beginning of the market ramp-up in 2015. The upward trend corresponds to the increasing policy support since 2015, major technological breakthroughs in BEV technology like increased battery performance, and the overall aim to stimulate market demand during this period [42]. The public presence continues to increase in the mass market period, going hand in hand with the accelerating diffusion of BEVs in Germany, represented by the increase from

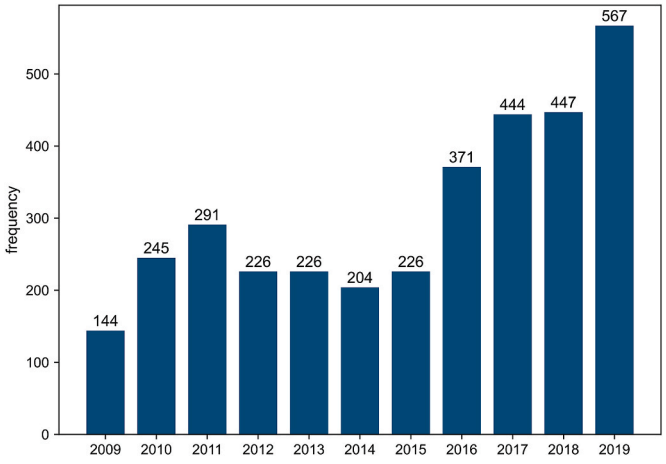

Fig. 3. Absolute frequency of articles over time.

Table 1
Descriptive statistics of mean sentiment scores and their standard deviations.

Year	All topics		*Industry*		*R&D*		*Infrastructure*		*Usability*		*Policy*	
	mean *(sd)*	count	mean *(sd)*	count	mean *(sd)*	count	mean *(sd)*	count	mean *(sd)*	count	mean *(sd)*	count
2009	0.05 *(0.24)*	144	0.04 *(0.23)*	30	0.07 *(0.30)*	16	0.09 *(0.18)*	6	0.04 *(0.24)*	86	−0.05 *(0.22)*	6
2010	0.05 *(0.22)*	245	0.05 *(0.24)*	48	0.05 *(0.21)*	66	0.03 *(0.13)*	5	0.06 *(0.23)*	112	−0.02 *(0.22)*	14
2011	0.05 *(0.22)*	291	0.06 *(0.23)*	45	0.06 *(0.21)*	70	0.05 *(0.23)*	12	0.05 *(0.23)*	150	−0.03 *(0.23)*	14
2012	0.05 *(0.22)*	226	0.02 *(0.18)*	31	0.05 *(0.22)*	57	0.01 *(0.20)*	10	0.05 *(0.24)*	116	0.01 *(0.24)*	12
2013	0.04 *(0.22)*	226	0.02 *(0.20)*	30	0.03 *(0.24)*	45	0.10 *(0.19)*	12	0.04 *(0.23)*	127	0.01 *(0.12)*	12
2014	0.05 *(0.24)*	204	0.06 *(0.22)*	26	0.08 *(0.24)*	43	0.10 *(0.23)*	20	0.05 *(0.25)*	105	0.05 *(0.32)*	10
2015	0.04 *(0.22)*	226	0.02 *(0.22)*	45	0.07 *(0.23)*	39	0.05 *(0.24)*	10	0.05 *(0.23)*	114	0.00 *(0.21)*	18
2016	0.04 *(0.23)*	371	−0.01 *(0.22)*	58	0.05 *(0.23)*	56	0.04 *(0.20)*	19	0.05 *(0.24)*	169	0.02 *(0.22)*	69
2017	0.04 *(0.23)*	444	0.03 *(0.24)*	104	0.06 *(0.21)*	86	0.00 *(0.19)*	19	0.04 *(0.24)*	200	0.03 *(0.21)*	35
2018	0.05 *(0.23)*	447	0.04 *(0.22)*	93	0.10 *(0.22)*	86	0.01 *(0.15)*	33	0.05 *(0.23)*	210	0.03 *(0.28)*	25
2019	0.03 *(0.22)*	567	0.03 *(0.22)*	147	0.03 *(0.23)*	110	0.02 *(0.20)*	45	0.04 *(0.23)*	234	−0.01 *(0.20)*	31

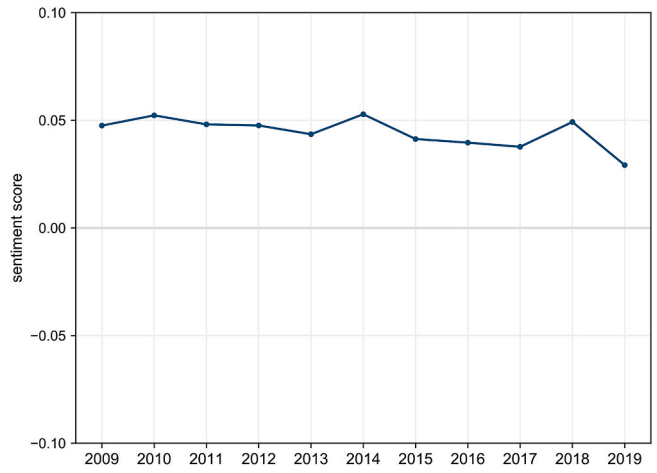

Fig. 4. Aggregated mean sentiment over time.

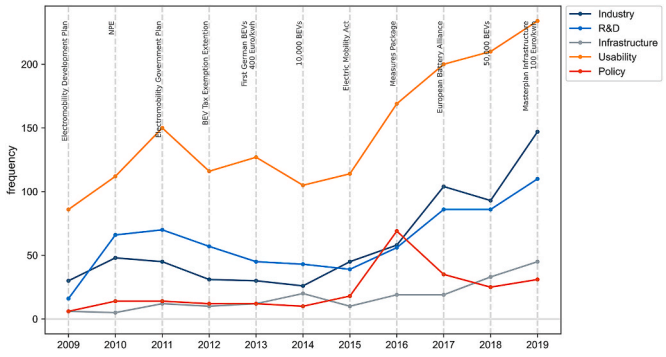

Fig. 5. Absolute frequencies of articles by BEV aspects over time.

just about 1500 vehicles in 2010 to more than 80,000 in 2019 [80]. Fig. 4 depicts the overall mean sentiment towards BEVs over time. In short, we observe a relatively stable sentiment over the last ten years, with no substantial diverge from the overall positive trend.

In the following, we will take a closer look at the individual dynamics for each topic. First, we examine which topics were the most prevalent in the public discourse over time. Fig. 5 depicts the number of articles per topic over the last ten years. As already shown in Fig. 3, we observe an overall increase in media attention for BEVs over time. However, the media attention varies considerably across topics, not only in terms of the absolute number of articles but also in the growth rate. Accordingly, *Usability* clearly dominates the public discourse about BEVs throughout all three periods, followed by the *Industry* and *R&D* aspects. In stark contrast, *Policy* and *Infrastructure* have the lowest coverage and only start to pick up in media attention in the mass market period, although we observe a distinctive peak for *Policy* corresponding to the implementation of the measures package in 2016.

Next, we examine which aspects of the BEV-TIS are controversially discussed in the public discourse. Fig. 6 depicts the average sentiment score of each topic per year. Overall, in line with the aggregated sentiment in Fig. 4, these results present a quite positive sentiment over time, especially since 2012.

Nevertheless, the sentiment trends are quite heterogeneous across the aspects of the BEV-TIS. Among all examined topics, *Usability* has the most consistent positive sentiment and is not noticeably affected by any historical developments. Similarly, *R&D* shows comparatively stable and favourable media reporting, with a distinct peak following the announcement of the European battery alliance in 2017 and reaching the 50,000 BEVs milestone in 2018.

The *Infrastructure* aspect has a positive coverage, but the actual sentiment dynamics are highly fluctuating. At first, we observe a stark positive increase in 2013 with the announcement of the first German BEVs during the market preparation period. Subsequently, the sentiment strongly declines until the end of the market ramp-up in 2017, even though several support measures were enacted. Still, the reported sentiment improved slightly in the most recent years of the mass market period, which coincides with the introduction of more ambitious policy measures like the Masterplan Infrastructure in 2019.

Likewise, *Industry* is depicted positively and experiences a peak in 2014 when the diffusion passed the first milestone of 10,000 BEVs in Germany. In the following years of the market ramp-up, the reporting decreases into a negative tone in 2016, although new policy measures were implemented. Similar to *Infrastructure*, we notice an increasing sentiment in the most recent years.

With the introduction of the first policy measures, the aspect *Policy* went from a negative sentiment in 2009 to a positive one at the end of the market preparation phase in 2014. However, an immediate drop into negative sentiment follows in 2015. Notably, this coincides with the enactment of the Electric Mobility Act. Similar to *Infrastructure* and *Industry*, the sentiment recovers to a more positive tone in the most recent years, which is in line with the implementation of more ambitious policy measures. However, the sentiment weakens again during the mass

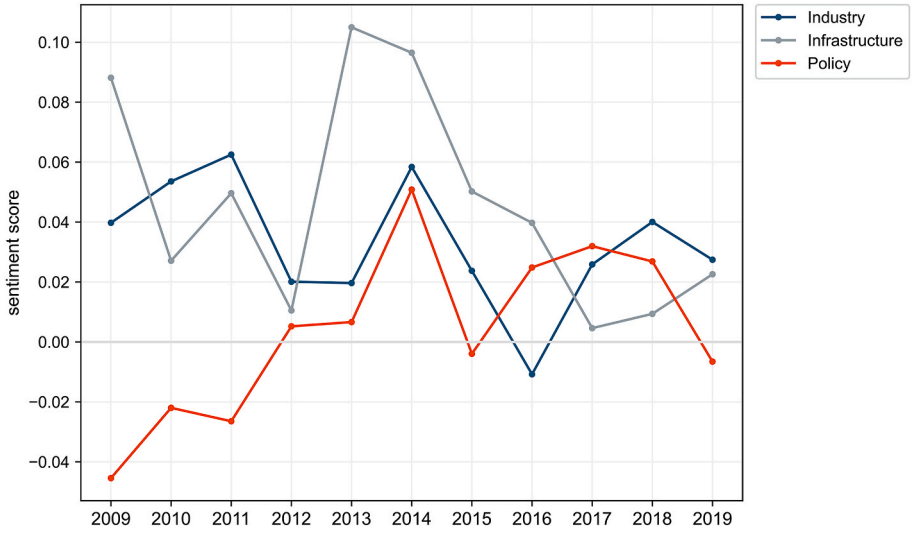

Fig. 6. Annually aggregated sentiment score by BEV-TIS aspects over time.

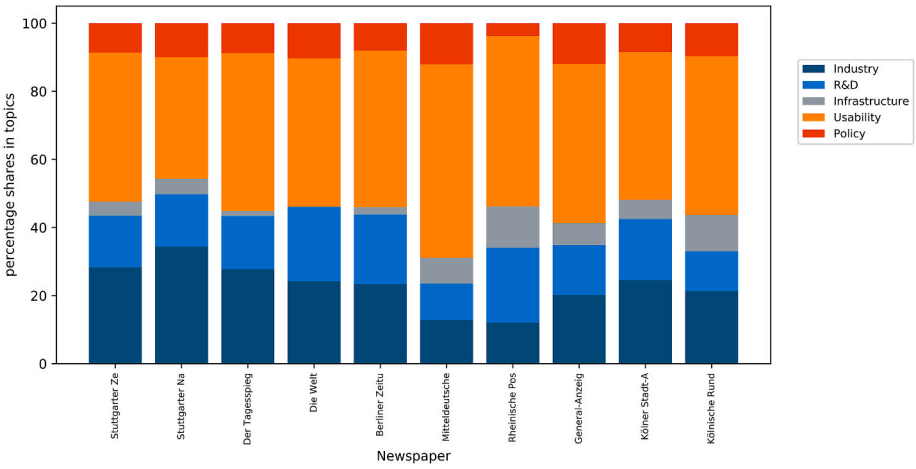

Fig. 7. Topical coverage of the ten most prevalent newspapers.

market period in 2019.

All in all, we also observe distinct sentiment dynamics when comparing the three market development periods outlined by the NPE. In the market preparation period, the sentiment of most aspects is quite fluctuating but increasing towards 2014. In contrast, the sentiments decrease during the ramp-up years before recovering again towards the mass market period.

Finally, we will take a closer look at the most important media outlets in our data to validate our results and investigate how represented the national discourse is across regions. Fig. 7 depicts the topical coverage for the ten publishers with the most articles in our dataset. Considering the aforementioned proximity news values [33], these publishers cover important regions such as Berlin (Die Welt, Berliner Zeitung), Baden-Wurttemberg (Stuttgarter Zeitung, Stuttgarter Nachrichten), North Rhine-Westphalia (Rheinische Post, Kölnische Rundschau), and Saxony-Anhalt (Mitteldeutsche Zeitung). Comparing the topic distribution from publisher to publisher, we see that the topic shares are heterogeneous but not to the extent that a publisher's reporting is apparent as an influential outlier from the national discourse.

Next, we investigate if we observe a distinct polarity among these publishers. Fig. 8 shows the average sentiment score for the individual media outlets as bars, with the standard deviation depicted as lines in the middle. In line with the previous results, we see that the sentiment is quite heterogenous, but the overall sentiment towards BEVs is rather positive, and the standard deviations are similar as well.

Fig. 9 presents the average sentiment scores for the individual aspects. Arguably, we only observe differences in the reporting for *Policy* as well as *Infrastructure*. For instance, we see a strongly positive reporting for *Infrastructure* in outlets from Berlin (Der Tagesspiegel, Berliner Zeitung) compared to a mixed sentiment in Baden-Wurttemberg (Stuttgarter Nachrichten, Stuttgarter Zeitung). For *Policy* the differences are more pronounced but rather inconclusive on the regional level with mixed sentiments in newspapers from Baden-Wurttemberg (Stuttgarter Nachrichten, Stuttgarter Zeitung), North Rhine-Westphalia (Kölner Stadt-Anzeiger, Kölnische Rundschau, Rheinische Post, General-Anzeiger), and Berlin (Berliner Zeitung, Die Welt, Der Tagesspiegel) compared to a negative reporting in Saxony-Anhalt (Mitteldeutsche Zeitung). These differences are in line with the fluctuating sentiment for these aspects on the national level as depicted in Fig. 6. In sum, we find no evidence of outliers in the reporting across publishers, which influence the aggregated media attention or public opinion towards BEVs in Germany. Nevertheless, this exercise revealed substantial regional differences for the *Policy* and *Infrastructure* aspects we will elaborate on in the following section.

6. The legitimacy and guidance of the German BEV-TIS

In this section, we reflect on our results and draw conclusions for the legitimacy and guidance of the BEV-TIS in Germany. Starting with legitimacy, the overall positive sentiment and increasing media attention suggest that there exist an aggregated compliance and alignment of the TIS with its institutional environment across all three periods. This is further supported by the positive and coherent overall sentiment across the top ten media outlets. However, given the increasing media attention accompanying the positive sentiment, the legitimacy during the market ramp-up and mass-market period are more pronounced than in the market preparation phase. In the latter, public attention was rather low, although events like the Electromobility Government Program, the announcement of the first German BEV models and passing the first milestone of 10,000 BEVs occurred. However, the policy measures were focused on knowledge development and getting users in touch with the new technology, while the subsequent ramp-up period was characterized by the introduction of demand-sided support measures. These were important to accelerate user adoption and incentivize German car manufacturers to offer more BEV models, which both helped to put the spotlight on BEVs as a serious alternative to combustion engine vehicles [3,44].

Next, we will examine how the overall legitimacy is composed and reflect on the guidance of the individual aspects of the BEV-TIS to identify weak points and factors that could undermine the future compliance with institutions and collective expectations. *R&D* and *Usability* have exhibited the most conformity and attention over the last ten years, indicating a strong guidance while strengthening the overall legitimacy throughout all periods. This suggests a strong research and education system as well as demand structures of the BEV-TIS. Accordingly, the earlier articles for *Usability* report about user experiences and sustainability while giving positive outlooks about the future development in terms of affordability, range and safety. While these older articles often portray BEVs as a second car for a household, newer articles see them as suitable for everyday use, highlighting improvements in cost, range and charging speeds. For *R&D*, the articles report about improvements of the manufacturing process in terms of cost and sustainability as well as innovations in energy management software. Notably, a lot of articles emphasize enhancements in battery technology, not only considering range and cost but also the diminishing dependence on scarce and controversial resources like lithium and cobalt. Solid-state batteries are mentioned as a game-changer for the future of BEVs, considering their higher energy density and reduced risk of fire or explosions. The reporting in our assigned articles for both aspects is in line with the actual scientific and technological improvements described in the literature, which led to falling prices and increased performance,

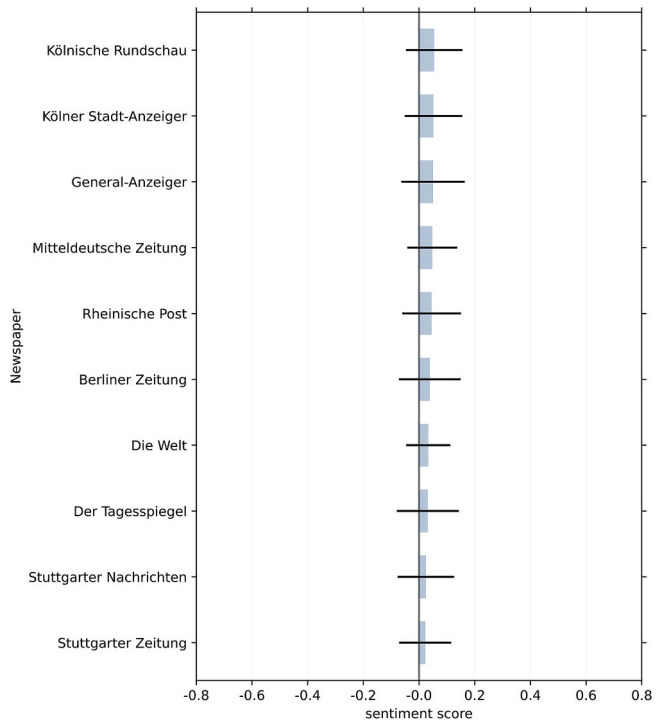

Fig. 8. Average sentiment and standard deviation across ten most prevalent newspapers.

compliance with consumer's expectations and turning BEVs into a serious alternative to the internal combustion engine [42,81].

On the contrary, the other aspects, *Industry*, *Infrastructure* and *Policy*, seem to have been at least somewhat contested with a weak guidance, especially considering their noticeable decrease in sentiment following the beginning of the market ramp-up period. During this period from 2015 to 2017, the articles negatively report about the staggering transformation of the car industry towards sustainable powertrain technologies, considering that manufacturers like Volkswagen, BMW and Daimler were often regarded as electromobility latecomers compared to their Japanese or American competitors [41,82]. Moreover, they highlight the missing domestic battery cell production that is needed for Germany's car industry to keep its leading position. Concerning *Infrastructure*, the articles voiced concerns about the slow public charging infrastructure expansion due to financing problems and extensive approval procedures, as well as compatibility issues with BEV models. The urgent expansion of complementary infrastructures like the electricity grid and the associated integration of BEVs was also mentioned. For *Policy,* the negative sentiment in 2015 was constituted by negative views about the currently implemented support measures. Although partly addressed in the Electric Mobility Act, the articles demanded more demand-oriented measures like purchase subsidies, tax exemptions for private and company vehicles, and the introduction of electrified public vehicle fleets. Again, the articles emphasized the need for additional support for the expansion of the charging infrastructure. Notably, these issues were addressed with the introduction of the measures package in 2016. These observations in the media reporting correspond to the aforementioned evaluation report by the NPE [3] and other reports emphasizing the need for more ambitious policy measures and infrastructure involvement as well as consumer involvement [83].

In the following mass market period since 2018, the sentiment and media coverage for *Industry* has improved noticeably, which contributes to the overall compliance while strengthening the guidance for the actors of the supply system in the BEV-TIS. Accordingly, the articles positively highlight progress in the domestic value chain of BEVs concerning the improving sustainability of manufacturing processes, an increasing portfolio of available car models, and the progressing development of a domestic battery production. Regarding the latter, one substantial step forward is the EU's approval of subsidies to the German firms BMW, Varta, Opel, and BASF in 2019 as part of the European Battery Alliance. Arguably, the latter acts as a positive sign for other firms and guides them to join the activities to establish a German battery production development path. The increasing incentives guiding actors towards BEVs are also illustrated by the strategic decision of Volkswagen, Germany's biggest car manufacturer, to massively expand its BEV production in the coming decades. As reflected by the increasing amount of German BEV models, this put pressure on the other manufacturers to follow suit [3].

In contrast, we do not observe a convincing increase in sentiment or surge in media interest for *Policy* and *Infrastructure* in the mass market period. The associated articles report about the ineffectiveness of the current BEV purchase subsidies and the need for more consumer incentives. Furthermore, there is an ongoing discussion about the staggering charging infrastructure and electricity grid expansion to accompany the growing BEV fleet. These insights are similar to the conclusions of previous studies on the acceptance of BEVs in Germany

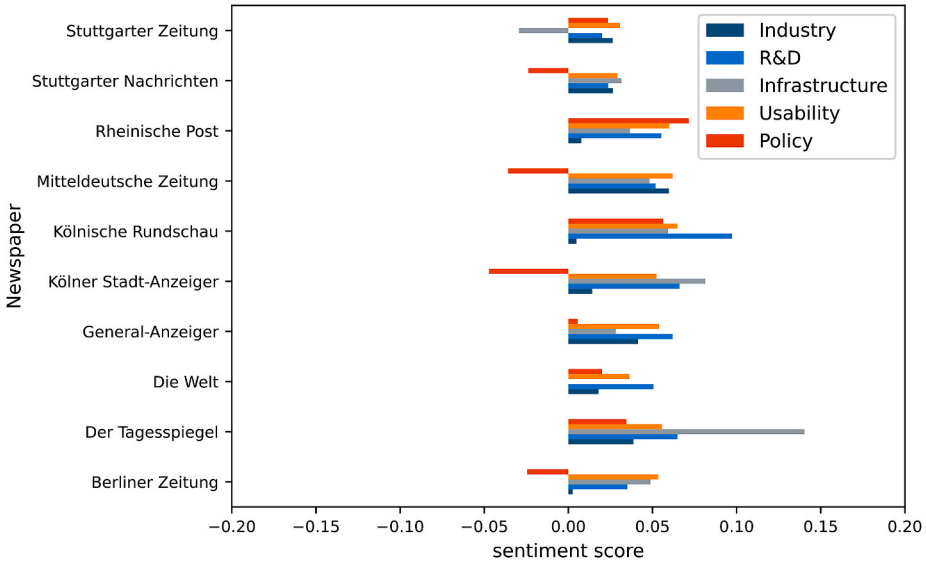

Fig. 9. Average sentiment across ten most prevalent newspapers.

[83–87] and survey results on the preferences and concerns of consumers [44,88]. Likewise, the media reporting is in accordance with recent advisory reports recommending an additional measures package for the BEV infrastructure, focusing on the harmonization and acceleration of infrastructure approval procedures, a strengthening of the long-term grid integration, and an improvement of site selection conditions for recharging stations [89]. Other reports point out the need to continue broad political support measures for BEV adoption and to promote the consistent implementation of the Electric Mobility Act in all municipalities. In addition, they argue for persistent financial subsidies for R&D, especially considering the lack of domestic battery technology research and production [3,4,44].

The ongoing issues with the *Policy* and *Infrastructure* aspects are reflected in our results comparing the reporting across media outlets. Contrary to the rather coherent reporting for the other aspects, the sentiment for *Policy* and *Infrastructure* varies considerably across regions and does not allow for a conclusive comparison. Arguably, this underlines their contested legitimacy and weak guidance, which is represented by the disparate electromobility progress in the federal states. While states like Berlin, Baden-Wurttemberg and Rhine-Westphalia have experienced a strong development in terms of the amount of BEVs and charging stations, often in line with the presence of large car manufacturers, eastern states like Saxony-Anhalt lack behind, especially in their rural regions. As discussed in the associated news articles, these differences between regions are still prevalent and stress the need for an increased policy adaption and coordination considering the regional circumstances and responsibilities between the federal states and the national government in infrastructure provision [44,90,91].

7. Discussion and conclusion

All in all, our results suggest an intact legitimacy for the overall system and a strong or improving guidance for three of the five identified socio-technical aspects of the BEV-TIS in Germany. In particular, we observe coherent compliance and expectations for *R&D* and *Usability* over the last ten years and an improvement for *Industry* in the most recent years. Nevertheless, we mentioned the development of a domestic battery cell production as a crucial point for Germany's car industry to stay abreast of the international competition and establish an independent BEV value chain. In contrast, *Policy* and *Infrastructure* have been problematic aspects and could hamper the further progress of the BEV-TIS in the ongoing mass market period. The identified issues in the public and complementary infrastructures and the politics, policy and institutional structures in the BEV-TIS correspond to the findings and recommendations of related advisory reports, surveys and studies. On top of that, our additional results revealed that there exists a substantial regional heterogeneity underlying the issues of these two aspects. Accordingly, to successfully establish a mass market for BEVs in Germany, policymakers should consider a more holistic policy approach, including more consumer-oriented measures and more intensive coordination between the national and federal governments as well as local municipalizes, utilities and renewable energy providers.

Besides our insights for the BEV-TIS in Germany, our study exemplifies the usefulness of automatic text analysis in offering a comprehensive overview of the national public discourse and its potential effects on TIS legitimacy and guidance over the long term. Specifically, our methodology and choice of unsupervised text analysis algorithms can be quickly adapted to different domains, which allows for a broad comparison between other technologies, countries, and text documents. Herewith, it can be used to get a first overlook into the regional, industrial, or sectoral development dynamics of different TIS regarding their legitimacy and guidance. In addition, we choose evaluation measures that allow researchers to find a rather parsimonious LDA model with a high interpretability and minimal overlap between topics to promote a straightforward assessment of lacking TIS and context structures.

By leveraging media reporting as an indicator of TIS legitimacy and guidance, our methodology provides firms and policymakers with an efficient monitoring tool for the societal part of technological development and adds to the much-needed toolbox of methods to analyze TIS. Accordingly, we are able to reveal which aspects and time periods were heavily discussed and identify the underlying issues by manually reading the associated text articles with a high topic probability and polarizing sentiment. In turn, we are able to reveal concrete insights and issues to consider for a subsequent analysis to derive detailed policy recommendations. Possible methods to complement our examination include historical event analysis (e.g., Ref. [25]), interviews (e.g., Refs. [79,92]), or qualitative text analysis (e.g., Refs. [2,8,9]), which can build-up on the large-scale automatic analysis of a text corpus, to retrieve the most important documents, aspects or periods to investigate further. Herewith, the researchers could undertake a more focused analysis and save up on the time and cost of human coding, potentially allowing them to conduct cross-case comparisons. For historical event analysis, we see the opportunity for future research to use our proposed method as a complementary assessment tool to human coding that allows rating a particular event as negatively or positively for a pre-assigned function. It might be even possible to use machine learning algorithms to identify and assign the events to particular functions if the model is trained on a large corpus of pre-labelled training data.

Despite the contribution, our study has some limitations, which provide several opportunities for future research. Firstly, as with all automatic text analysis, our approach is prone to possible errors due to falsely derived sentiment scores or topic assignments, e.g., because of sarcasm, complex negations, or by neglecting the possibility that more than one topic is discussed in one article [52]. Therefore, our algorithms could be improved by using approaches like multi-grain LDA [68], sliding window LDA [93,94], structural LDA [95], and machine learning-based sentiment scoring [68,93]. However, one has to consider the conflict between the increased accuracy of such algorithms and their reduced flexibility because costly training data and domain expertise are needed.

Secondly, our mapped dynamics of the public discourse might be influenced by the choice of keywords and associated articles found in the database, which might not be indicative of the individual regions in Germany and all TIS and context structures of the BEV-TIS. Accordingly, we only use newspapers as one possible data source to capture the public discourse. Although they constitute a viable source to analyze legitimacy and guidance issues considering the socio-political environment from the perspective of a large addressable audience, they might be less sensitive to subtle changes within the actor networks in the German car industry, interest groups or political parties. Such insights depend on text sources for very specific audiences [32]. Thus, there are other text sources of public debate that play an important role, like social media, scientific articles, policy documents, surveys, and analyst reports, which might be more representative of certain TIS and context structures [96]. Therefore, subsequent studies could confirm our results with different keywords or databases and use a wider array of text sources to further advance the insights provided by our methodological approach.

Thirdly, our results should not be seen as actual evidence between the public discourse, legitimacy creation and strengthening of TIS guidance but rather as a starting point for further empirical examinations. This results from the aforementioned trade-off between manual and automatic text analysis methods. While the former enables the reconstruction of how legitimacy and guidance are created through careful reading of the text and understanding the relations between TIS and context structures, the latter only allows a superficial analysis, although over a much larger dataset. Therefore, compared to manual analysis, our method is built to capture legitimacy on a high level of aggregation, neglecting the actual determinants of compliance and expectations on the micro-level [9]. By the same token, our analysis is confined to the specific perspective on technology legitimacy and guidance of search in the context of TIS, which, in turn, is characterized

by a strong focus on the focal technology rather than the individual actors or interest groups in the system [2]. According to that, we need a further understanding of the interactions between different actors in the public discourse and the associated effects of the process of collective sense-making on the two TIS functions. Hence, for a full understanding of the legitimacy and guidance of a TIS, our approach should be complemented by a subsequent manual text analysis, which could elaborate on the specific frames brought forward in the public discourse and compare them to other engine technologies [97] or with relation to tailpipe emissions [98].

Finally, although we briefly looked into the regional heterogeneity, we need a further investigation on how the national valuation system of a production-led TIS is influenced by the regions of a country and how important the media reporting in individual regions is for the discourse activities on the national stage. Furthermore, we need theoretical and empirical work in relation to other notions of social acceptance and collective expectations in the wider literature [28,99,100]. Given these points, future work could expand our automatic text analysis and try to capture different concepts of legitimacy, e.g., cognitive, normative, pragmatic, and regulative legitimacy (e.g., Refs. [9,30]), the social or public acceptance of technologies (e.g., Refs. [101–103]), or different forms of collective expectations, e.g., specific or generalized expectations, and frames (e.g., Refs. [97,98,104–106]), and investigate the regional dynamics of legitimacy and guidance in relation to production-led technologies (e.g., Ref. [46]).

Author contribution

Daniel Weiss: Conceptualization; Data curation; Formal analysis; Methodology; Visualization; Roles/Writing – original draft; Writing – review & editing. Fabian Nemeczek: Conceptualization; Data curation; Formal analysis; Methodology; Visualization; Roles/Writing – original draft; Writing – review & editing

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Data availability

Nexis Uni database provided by LexisNexis: https://www.lexisnexis.com/en-us/professional/academic/nexis-uni.page.

Declaration of competing interest

None.

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Appendix A

Table A1
LDA topic keywords and probabilities

Topic	Distribution of the most important topic keywords
Industry	0.005*"milliarde" + 0.004*"bus" + 0.003*"konzern" + 0.003*"produktion" + 0.003*"kamenz" + 0.003*"mitarbeiter" + 0.003*"elektrobus" + 0.003*"produzieren" + 0.002*"projekt" + 0.002*"verkaufen" + 0.002*"batteriezelle" + 0.002*"branche" + 0.002*"elektromotor" + 0.002*"werk" + 0.002*"bereich" + 0.002*"industrie" + 0.002*"zulieferer" + 0.002*"firma" + 0.002*"investieren" + 0.002*"geschäft"
R&D	0.004*"e-bike" + 0.003*"team" + 0.003*"projekt" + 0.003*"firma" + 0.003*"motor" + 0.003*"idee" + 0.003*"einsatz" + 0.003*"professor" + 0.003*"technologie" + 0.003*"akku" + 0.003*"rennen" + 0.002*"material" + 0.002*"thema" + 0.002*"meter" + 0.002*"welt" + 0.002*"institut" + 0.002*"mobilität" + 0.002*"lithium" + 0.002*"hochschule" + 0.002*"fahrrad"
Infrastructure	0.005*"ladestation" + 0.005*"stadtwerke" + 0.004*"standort" + 0.004*"ladesäule" + 0.003*"akku" + 0.003*"station" + 0.003*"wagen" + 0.003*"laden" + 0.003*"tesla" + 0.003*"meter" + 0.003*"anlage" + 0.003*"netz" + 0.003*"minute" + 0.003*"fahrer" + 0.003*"steckdose" + 0.003*"fahrt" + 0.003*"dauern" + 0.002*"kilometerprostunde" + 0.002*"leistung" + 0.002*"monat"
Usability	0.006*"tesla" + 0.004*"wagen" + 0.003*"ampera" + 0.003*"akku" + 0.003*"idrei" + 0.003*"leaf" + 0.003*"sekunde" + 0.003*"model" + 0.003*"fahrer" + 0.003*"steckdose" + 0.003*"laden" + 0.002*"dollar" + 0.002*"ladestation" + 0.002*"haus" + 0.002*"pferdestärke" + 0.002*"meter" + 0.002*"netz" + 0.002*"stromer" + 0.002*"hören" + 0.002*"technik"
Policy	0.006*"prämie" + 0.005*"antrag" + 0.005*"kaufprämie" + 0.004*"zelle" + 0.004*"diesel" + 0.004*"kaufen" + 0.003*"staat" + 0.003*"bund" + 0.003*"beantragen" + 0.003*"verein" + 0.003*"verbrennungsmotor" + 0.003*"förderung" + 0.003*"milliarde" + 0.003*"wirtschaft" + 0.003*"bundesregierung" + 0.003*"firma" + 0.003*"bundesamt" + 0.003*"regierung" + 0.003*"rechnen" + 0.003*"verbraucher"

References

[1] F.W. Geels, The multi-level perspective on sustainability transitions: responses to seven criticisms, Environ. Innov. Soc. Transitions. 1 (2011) 24–40.
[2] J. Markard, S. Wirth, B. Truffer, Institutional dynamics and technology legitimacy - a framework and a case study on biogas technology, Res. Pol. 45 (2016) 330–344, https://doi.org/10.1016/j.respol.2015.10.009.
[3] NPE Nationale Plattform Elektromobilität, Fortschrittsbericht 2018 - Markthochlaufphase, Gemeinsame Geschäftsstelle Elektromobilität der Bundesregierung, Berlin, 2018.
[4] NPM Nationale Plattform Zukunft der Mobilität, Fortschrittsbericht 2019, Bundesministerium für Verkehr und digitale Infrastruktur, Berlin, 2019.
[5] N. Bento, M. Fontes, Emergence of floating offshore wind energy: technology and industry, Renew. Sustain. Energy Rev. (2019), https://doi.org/10.1016/j.rser.2018.09.035.
[6] J. Markard, The life cycle of technological innovation systems, Technol. Forecast. Soc. Change 153 (2020) 119407, https://doi.org/10.1016/j.techfore.2018.07.045.
[7] A. Bergek, Shaping and Exploiting Technological Opportunities: the Case of Renewable Energy Technology in Sweden, Chalmers University of Technology, 2002.
[8] K. Konrad, J. Markard, A. Ruef, B. Truffer, Strategic responses to fuel cell hype and disappointment, Technol. Forecast. Soc. Change 79 (2012) 1084–1098, https://doi.org/10.1016/j.techfore.2011.09.008.
[9] C. Binz, S. Harris-Lovett, M. Kiparsky, D.L. Sedlak, B. Truffer, The thorny road to technology legitimation - institutional work for potable water reuse in California, Technol. Forecast. Soc. Change 103 (2016) 249–263, https://doi.org/10.1016/j.techfore.2015.10.005.
[10] D.R. Walwyn, The use of the technological innovation systems framework to identify the critical factors for a successful sustainability transition to rooftop solar in low-income communities within South Africa, in: A.F. Zobaa, S.N. Afifi, I. Pisica (Eds.), Sustain. Energy - Technol. Issues, Appl. Case Stud., IntechOpen, Rijeka, 2016, https://doi.org/10.5772/65293.
[11] K. Isoaho, J. Markard, The politics of technology decline: discursive struggles over coal phase-out in the UK, Rev. Pol. Res. 37 (2020) 342–368, https://doi.org/10.1111/ropr.12370.

[12] V.B. Kobayashi, S.T. Mol, H.A. Berkers, G. Kismihók, D.N. Den Hartog, Text classification for organizational researchers: a tutorial, Organ. Res. Methods 21 (2018) 766–799, https://doi.org/10.1177/1094428117719322.
[13] D. Riffe, S. Lacy, B.R. Watson, F. Fico, Analyzing Media Messages: Using Quantitative Content Analysis in Research, Routledge, 2019.
[14] S. Sbalchiero, M. Eder, Topic modeling, long texts and the best number of topics. Some Problems and solutions, Qual. Quantity 54 (2020) 1573–7845, https://doi.org/10.1007/s11135-020-00976-w.
[15] V. Kayser, Comparing public and scientific discourse in the context of innovation systems, Technol. Forecast. Soc. Change 115 (2017) 348–357, https://doi.org/10.1016/j.techfore.2016.08.005.
[16] S.O. Negro, F. Alkemade, M.P. Hekkert, Why does renewable energy diffuse so slowly? A review of innovation system problems, Renew. Sustain. Energy Rev. 16 (2012) 3836–3846, https://doi.org/10.1016/j.rser.2012.03.043.
[17] B. Carlsson, R. Stankiewicz, On the nature, function and composition of technological systems, J. Evol. Econ. 1 (1991) 93–118, https://doi.org/10.1007/BF01224915.
[18] M.P. Hekkert, R.A.A. Suurs, S.O. Negro, S. Kuhlmann, R.E.H.M. Smits, Functions of innovation systems: a new approach for analysing technological change, Technol. Forecast. Soc. Change 74 (2007) 413–432, https://doi.org/10.1016/j.techfore.2006.03.002.
[19] A. Bergek, M. Hekkert, S. Jacobsson, J. Markard, B. Sandén, B. Truffer, Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics, Environ. Innov. Soc. Transitions. 16 (2015) 51–64, https://doi.org/10.1016/j.eist.2015.07.003.
[20] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the functional dynamics of technological innovation systems: a scheme of analysis, Res. Pol. 37 (2008) 407–429, https://doi.org/10.1016/j.respol.2007.12.003.
[21] A. Bergek, S. Jacobsson, B.A. Sandén, "Legitimation" and "development of positive externalities": two key processes in the formation phase of technological innovation systems, Technol. Anal. Strat. Manag. 20 (2008) 575–592, https://doi.org/10.1080/09537320802292768.
[22] A. Bergek, Technological innovation systems: a review of recent findings and suggestions for future research, in: Handb. Sustain. Innov, Handb. Sustain. Innov., Edward Elgar Publishing, 2019, pp. 200–218, https://doi.org/10.4337/9781788112574.00019.
[23] D. Rosenbloom, H. Berton, J. Meadowcroft, Framing the sun: a discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, Canada, Res. Pol. 45 (2016) 1275–1290, https://doi.org/10.1016/j.respol.2016.03.012.
[24] X.S. Yap, B. Truffer, Shaping selection environments for industrial catch-up and sustainability transitions: a systemic perspective on endogenizing windows of opportunity, Res. Pol. 48 (2019) 1030–1047, https://doi.org/10.1016/j.respol.2018.10.002.
[25] M.P. Hekkert, S.O. Negro, Functions of innovation systems as a framework to understand sustainable technological change: empirical evidence for earlier claims, Technol. Forecast. Soc. Change 76 (2009) 584–594, https://doi.org/10.1016/j.techfore.2008.04.013.
[26] M. Borup, N. Brown, K. Konrad, H. Van Lente, The sociology of expectations in science and technology, Technol. Anal. Strat. Manag. 18 (2006) 285–298.
[27] J. Musiolik, J. Markard, Creating and shaping innovation systems: Formal networks in the innovation system for stationary fuel cells in Germany, Energy Pol. 39 (2011) 1909–1922.
[28] F.W. Geels, B. Verhees, Cultural legitimacy and framing struggles in innovation journeys: a cultural-performative perspective and a case study of Dutch nuclear energy (1945-1986), Technol. Forecast. Soc. Change 78 (2011) 910–930, https://doi.org/10.1016/j.techfore.2010.12.004.
[29] K. Konrad, The social dynamics of expectations: the interaction of collective and actor-specific expectations on electronic commerce and interactive television, Technol. Anal. Strat. Manag. 18 (2006) 429–444.
[30] S.R. Jansma, J.F. Gosselt, K. Kuipers, M.D.T. Jong, Technology legitimation in the public discourse: applying the pillars of legitimacy on GM food, Technol. Anal. Strat. Manag. 32 (2020) 195–207, https://doi.org/10.1080/09537325.2019.1648788.
[31] H. Van Lente, C. Spitters, A. Peine, Comparing technological hype cycles: towards a theory, Technol. Forecast. Soc. Change 80 (2013) 1615–1628, https://doi.org/10.1016/j.techfore.2012.12.004.
[32] J. Dehler-Holland, M. Okoh, D. Keles, The Legitimacy of Wind Power in Germany, Karlsruhe Institute of Technology (KIT), 2021.
[33] A. Waldherr, The mass media as actors in innovation systems, Innov. Policy Gov. High-Tech Ind. Complex. Coord. (2012) 77–100, https://doi.org/10.1007/978-3-642-12563-8_4.
[34] U. Zschache, S.V.C. Taubadel, L. Theuvsen, Die öffentliche Auseinandersetzung über Bioenergie in den Massenmedien. Diskursanalytische Grundlagen und erste Ergebnisse, Department für Agrarökonomie und Rurale Entwicklung (DARE), Universität Göttingen, 2009.
[35] P. Moy, D. Tewksbury, E.M. Rinke, Agenda-setting, priming, and framing, Int. Encycl. Commun. Theory Philos. (2016) 1–13.
[36] A. Schmidt, A. Ivanova, M.S. Schäfer, Media attention for climate change around the world: a comparative analysis of newspaper coverage in 27 countries, Global Environ. Change 23 (2013) 1233–1248, https://doi.org/10.1016/j.gloenvcha.2013.07.020.
[37] A. Mallett, J.C. Stephens, E.J. Wilson, R. Langheim, R. Reiber, T.R. Peterson, Electric (dis) connections: comparative review of smart grid news coverage in the United States and Canada, Renew. Sustain. Energy Rev. 82 (2018) 1913–1921.
[38] T.A. Ten Eyck, M. Williment, The national media and things genetic: coverage in the New York Times (1971–2001) and the Washington Post (1977-2001), Sci. Commun. 25 (2003) 129–152.
[39] J. Köhler, W. Schade, G. Leduc, T. Wiesenthal, B. Schade, L.T. Espinoza, Leaving fossil fuels behind? An innovation system analysis of low carbon cars, J. Clean. Prod. 48 (2013) 176–186, https://doi.org/10.1016/j.jclepro.2012.09.042.
[40] I. Kleinert, Strukturwandel in der Automobilindustrie: Wandel der Innovationssysteme der deutschen Automobilindustrie durch Elektromobilität, Technische Universität Kaiserslautern, 2017. http://nbn-resolving.de/urn:nbn:de:hbz:386-kluedo-45316.
[41] T. Altenburg, E.W. Schamp, A. Chaudhary, The emergence of electromobility: comparing technological pathways in France, Germany, China and India, Sci. Publ. Pol. 43 (2016) 464–475.
[42] A. Karle, Elektromobilität: Grundlagen und Praxis, fourth ed., Carl Hanser Verlag GmbH Co KG, München, 2020.
[43] NPE Nationale Plattform Elektromobilität, Fortschrittsbericht 2014 - Bilanz der Marktvorbereitung, Gemeinsame Geschäftsstelle Elektromobilität der Bundesregierung, Berlin, 2014.
[44] BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., Meinungsbild E-Mobilität, Fakten und Argumente, 2019.
[45] C. Binz, B. Truffer, Global Innovation Systems—a conceptual framework for innovation dynamics in transnational contexts, Res. Pol. (2017), https://doi.org/10.1016/j.respol.2017.05.012.
[46] S. Rohe, C. Chlebna, A spatial perspective on the legitimacy of a technological innovation system: regional differences in onshore wind energy, Energy Pol. 151 (2021) 112193.
[47] N. Melton, J. Axsen, D. Sperling, Moving beyond alternative fuel hype to decarbonize transportation, Nat. Energy. 1 (2016) 1–10, https://doi.org/10.1038/nenergy.2016.13.
[48] M. Kriechbaum, J. López Prol, A. Posch, Looking back at the future: dynamics of collective expectations about photovoltaic technology in Germany & Spain, Technol. Forecast. Soc. Change 129 (2018) 76–87, https://doi.org/10.1016/j.techfore.2017.12.003.
[49] C. Mejía, Y. Kajikawa, Technology news and their linkage to production of knowledge in robotics research, Technol. Forecast. Soc. Change 143 (2019) 114–124, https://doi.org/10.1016/j.techfore.2019.03.016.
[50] M. Al-Razgan, A. Alrowily, R.N. Al-Matham, K.M. Alghamdi, M. Shaabi, L. Alssum, Using Diffusion of Innovation Theory and Sentiment Analysis to Analyze a.
[51] S.-J. Ahn, H.Y. Yoon, Y.-J. Lee, Text mining as a tool for real-time technology assessment: application to the cross-national comparative study on artificial organ technology, Technol. Soc. 66 (2021) 101659, https://doi.org/10.1016/j.techsoc.2021.101659.
[52] H. Lane, C. Howard, H.M. Hapke, Natural Language Processing in Action (Understanding,analyzing, and Generating Text with python), Manning Publications Company, 2019.
[53] P. DiMaggio, M. Nag, D. Blei, Exploiting affinities between topic modeling and the sociological perspective on culture: application to newspaper coverage of US government arts funding, Poetics 41 (2013) 570–606.
[54] P. DiMaggio, Adapting computational text analysis to social science (and vice versa), Big Data Soc 2 (2015), 2053951715602908.
[55] W. van Atteveldt, M.A.C.G. van der Velden, M. Boukes, The validity of sentiment analysis: comparing manual annotation, crowd-coding, dictionary approaches, and machine learning algorithms, Commun. Methods Meas. 15 (2021) 121–140.
[56] D.M. Blei, A.Y. Ng, M.I. Jordan, Latent dirichlet allocation, J. Mach. Learn. Res. 3 (2003) 993–1022.
[57] M. Hoffman, F.R. Bach, D.M. Blei, Online learning for latent dirichlet allocation, in: Proc. 23rd Int. Conf. Neural Inf. Process. Syst, Curran Associates Inc., Vancouver, British Columbia, Canada, 2010, pp. 856–864.
[58] C. Jacobi, W. Van Atteveldt, K. Welbers, Quantitative analysis of large amounts of journalistic texts using topic modelling, Digit. Journal. 4 (2016) 89–106, https://doi.org/10.1080/21670811.2015.1093271.
[59] L. Huang, J. Ma, C. Chen, Topic detection from microblogs using T-LDA and perplexity, in: 24th Asia-Pacific Softw. Eng. Conf. Work, IEEE, 2017, pp. 71–77.
[60] M. Röder, A. Both, A. Hinneburg, Exploring the space of topic coherence measures, in: WSDM 2015 - Proc. 8th ACM Int. Conf. Web Search Data Min, 2015, pp. 399–408, https://doi.org/10.1145/2684822.2685324.
[61] V. Rus, N. Niraula, R. Banjade, Similarity Measures Based on Latent Dirichlet Allocation, 7816, LNCS, 2013, https://doi.org/10.1007/978-3-642-37247-6_37.
[62] A. Beykikhoshk, O. Arandjelović, D. Phung, S. Venkatesh, O. Arandjelovic, D. Phung, S. Venkatesh, Discovering topic structures of a temporally evolving document corpus, Knowl, Knowl. Inf. Syst. 55 (2018) 599–632, https://doi.org/10.1007/s10115-017-1095-4.
[63] F. Kuhr, M. Bender, T. Braun, R. Moller, Maintaining topic models for growing corpora, in: Proc. - 14th Int. Conf. Semant. Comput. ICSC 2020, IEEE, 2020, pp. 451–458, https://doi.org/10.1109/ICSC.2020.00087.
[64] J. Boyd-Graber, Y. Hu, D. Mimno, Applications of topic models, Found. Trends Inf. Retr. 11 (2017) 143–296, https://doi.org/10.1561/1500000030.
[65] A. Schofield, M. Magnusson, D. Mimno, Pulling out the stops: rethinking stopword removal for topic models, in: 15th Conf. Eur. Chapter Assoc. Comput. Linguist. EACL 2017 - Proc. Conf, 2017, pp. 432–436, https://doi.org/10.18653/v1/e17-2069.
[66] S. Rill, Themenerkennung in Twitter unter Berücksichtigung von Meinungsäußerungen, Johann Wolfgang Goethe-Universität Frankfurt am Main, 2016.

[67] R. Remus, U. Quasthoff, G. Heyer, SentiWS - A Publicly Available German-language Resource for Sentiment Analysis, LREC, Citeseer, 2010.
[68] B. Lu, M. Ott, C. Cardie, B.K. Tsou, Multi-aspect sentiment analysis with topic models, in: Proc. - Int. Conf. Data Min, IEEE, 2011, pp. 81–88, https://doi.org/10.1109/ICDMW.2011.125.
[69] X. Fu, G. Liu, Y. Guo, W. Guo, Multi-aspect blog sentiment analysis based on LDA topic model and hownet lexicon, in: Int. Conf. Web Inf. Syst. Min, Springer, Berlin, 2011, pp. 131–138, https://doi.org/10.1007/978-3-642-23982-3_17.
[70] A. García-Pablos, M. Cuadros, G. Rigau, W2VLDA: almost unsupervised system for aspect based sentiment analysis, Expert Syst. Appl. 91 (2018) 127–137, https://doi.org/10.1016/j.eswa.2017.08.049.
[71] X. Li, W. Shang, S. Wang, Text-based crude oil price forecasting: a deep learning approach, Int. J. Forecast. 35 (2019) 1548–1560, https://doi.org/10.1016/j.ijforecast.2018.07.006.
[72] S. Vijayarani, M.J. Ilamathi, M. Nithya, Preprocessing techniques for text mining-an overview, Int. J. Comput. Sci. Commun. Networks. 5 (2015) 7–16.
[73] S. Kiousis, Public trust or mistrust? Perceptions of media credibility in the information age, Mass Commun. Soc. 4 (2001) 381–403, https://doi.org/10.1207/s15327825mcs0404_4.
[74] M. Kohring, J. Matthes, Trust in news Media: development and validation of a multidimensional scale, Commun. Res. 34 (2007) 231–252, https://doi.org/10.1177/0093650206298071.
[75] J.S. Jauhiainen, Men, money and mobile phones: tracing the technology discourse in Finnish newspapers, Technol. Soc. 29 (2007) 79–91, https://doi.org/10.
[76] A. Hansen, Environment, Media and Communication, second ed., Routledge, London, 2018.
[77] A. Leipprand, C. Flachsland, Regime destabilization in energy transitions: the German debate on the future of coal, Energy Res. Soc. Sci. 40 (2018) 190–204.
[78] P. Kropp, C. Leclerque, B. Fritzsche, Die Beschäftigungsstruktur in der Automobilbranche Sachsen-Anhalts, IAB-Regional, IAB S, Sachsen-Anhalt-Thüringen, 2020.
[79] M.P. Hekkert, S.O. Negro, G. Heimeriks, R. Harmsen, Technological Innovation System Analysis: a Manual for Analysts, Copernicus Institute for Sustainable Development and Innovation, Utrecht University, 2011.
[80] KBA Kraftfahrtbundesamt, Fahrzeugzulassungen (FZ) Bestand an Kraftfahrzeugen nach Umwelt-Merkmalen 1, Januar 2019, Flensburg, 2019.
[81] T. Wilberforce, Z. El-Hassan, F.N. Khatib, A. Al Makky, A. Baroutaji, J.G. Carton, A.G. Olabi, Developments of electric cars and fuel cell hydrogen electric cars, Int. J. Hydrogen Energy 42 (2017) 25695–25734, https://doi.org/10.1016/j.ijhydene.2017.07.054.
[82] S. Wappelhorst, The End of the Road? an Overview of Combustion-Engine Car Phase-Out Announcements across Europe, International Council on Clean Transportation (ICCT), 2020.
[83] E. Matthies, S. Bobeth, C. Klöckner, J. Schippl, Zur besseren Verbreitung von Elektroautos – was können wir in Deutschland von Norwegen lernen? Die Energiewende Verstehen - Orientier. - Gestalten (2017) 531–546, https://doi.org/10.5771/9783845278957-531.
[84] M. Ziefle, S. Beul-Leusmann, K. Kasugai, M. Schwalm, Public Perception and Acceptance of Electric Vehicles: Exploring Users' Perceived Benefits and Drawbacks, 2014, https://doi.org/10.1007/978-3-319-07635-5_60.
[85] K. Dudenhöffer, Akzeptanz von Elektroautos in Deutschland und China: Eine Untersuchung von Nutzungsintentionen im Anfangsstadium der Innovationsdiffusion, Springer-Verlag, Berlin, 2015.
[86] R. Kaut, K. Degirmenci, M.H. Breitner, Elektromobilität in Deutschland und anderen Ländern: vergleich von Akzeptanz und Verbreitung, in: IWI Diskussionsbeiträge, vol. 68, Institut für Wirtschaftsinformatik, Leibniz Universität Hannover, 2015.
[87] K. Mühlbäck, T. Hendrikx, The societal acceptance of private electro mobility in Germany and its perception by consumers: an empirical analysis of the status quo and the medium-term future expectations, in: 5th Int. Electr. Drives Prod. Conf., Conf, IEEE, 2015, pp. 1–7, https://doi.org/10.1109/EDPC.2015.7323225.
[88] A. Peters, M. Popp, R. Agosty, B. Ryf, Elektroautos in der Wahrnehmung der Konsumenten - Zusammenfassung der Ergebnisse einer Befragung in Deutschland, Fraunhofer ISI, Karlsruhe, 2011.
[89] NPM Nationale Plattform Zukunft der Mobilität, Sofortpaket Ladeinfrastruktur 2019, Bundesministerium für Verkehr und digitale Infrastruktur, Berlin, 2019.
[90] A. Auf der Maur, N. Brüggeshemke, M. Kutschera, Lade-Report, Entwicklung der öffentlich zugänglichen Ladeinfrastruktur für die Elektromobilität sowie Vergleich der Ladetarife in Deutschland, Prognos AG, 2020.
[91] NPM Nationale Plattform Zukunft der Mobilität, Flächendeckende Ladeinfrastruktur, Bundesministerium für Verkehr und digitale Infrastruktur, 2020. Berlin.
[92] R. Quitzow, Dynamics of a policy-driven market: the co-evolution of technological innovation systems for solar photovoltaics in China and Germany, Environ. Innov. Soc. Transitions. 17 (2015) 126–148, https://doi.org/10.1016/j.eist.2014.12.002.
[93] N. O'Hare, M. Davy, A. Bermingham, P. Ferguson, P. Sheridan, C. Gurrin, A. F. Smeaton, Topic-dependent sentiment analysis of financial blogs, in: Proc. 1st Int. CIKM Work, Top. Anal. Mass Opin, 2009, pp. 9–16, https://doi.org/10.1145/1651461.1651464.
[94] F. Xianghua, L. Guo, G. Yanyan, W. Zhiqiang, Multi-aspect sentiment analysis for Chinese online social reviews based on topic modeling and HowNet lexicon, Knowl. Base Syst. 37 (2013) 186–195, https://doi.org/10.1016/j.knosys.2012.08.003.
[95] C. Lucas, R.A. Nielsen, M.E. Roberts, B.M. Stewart, A. Storer, D. Tingley, Computer-assisted text analysis for comparative politics, Polit. Anal. 23 (2015) 254–277, https://doi.org/10.1093/pan/mpu019.
[96] J. Berger, A. Humphreys, S. Ludwig, W.W. Moe, O. Netzer, D.A. Schweidel, Uniting the tribes: using text for marketing insight, J. Mark. 84 (2020) 1–25, https://doi.org/10.1177/0022242919873106.
[97] M. Dijk, Technological frames of car engines, Technol. Soc. 33 (2011) 165–180, https://doi.org/10.1016/j.techsoc.2011.03.013.
[98] J. Maddison, R. Watts, The technological fix as a frame in media debates about tailpipe emissions, Technol. Soc. 33 (2011) 294–303, https://doi.org/10.1.
[99] M.C. Suchman, Managing legitimacy: strategic and institutional approaches, Acad. Manag. Rev. 20 (1995) 571–610, https://doi.org/10.5465/amr.1995.9508080331.
[100] W.R. Scott, Institutions and Organizations: Ideas, Interests, and Identities, Sage publications, 2013.
[101] G. Assefa, B. Frostell, Social sustainability and social acceptance in technology assessment: a case study of energy technologies, Technol. Soc. 29 (2007).
[102] B. Aydin, Public acceptance of drones: knowledge, attitudes, and practice, Technol. Soc. 59 (2019) 101180, https://doi.org/10.1016/j.techsoc.2019.101180.
[103] A. Shuhaiber, I. Mashal, Understanding users' acceptance of smart homes, Technol. Soc. 58 (2019) 101–110, https://doi.org/10.1016/j.techsoc.2019.01.003.
[104] A. Ruef, J. Markard, What happens after a hype? How changing expectations affected innovation activities in the case of stationary fuel cells, Technol. Anal. Strat. Manag. 22 (2010) 317–338, https://doi.org/10.1080/09537321003647354.
[105] M.G. Tyshenko, Nanotechnology framing in the Canadian national news media, Technol. Soc. 37 (2014) 38–48, https://doi.org/10.1016/j.techsoc.2013.07.001.
[106] P.K. Freeman, R.S. Freeland, Media framing the reception of unmanned aerial vehicles in the United States of America, Technol. Soc. 44 (2016) 23–29.
[107] F. Martin, M. Johnson, More efficient topic modelling through a noun only approach, in: Proc. Australas. Lang, Technol. Assoc. Work., 2015, pp. 111–115.

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