Assessing Technology Legitimacy with Topic Models and Sentiment Analysis – The Case of Wind Power in Germany

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Abstract

Legitimacy is a crucial factor determining the success of technologies in the early stages of development and for maintaining resource flows as well as public and political support across the technology life cycle. In sustainability transitions that unfold over long periods of time, the maintenance of legitimacy of technologies identified as vital for sustainability becomes a key challenge. In the energy sector, wind power contributes to the transition to an energy system with low greenhouse gas emissions. In Germany, wind power recently faced a series of lawsuits and decreasing investment activity. Therefore, we assess the legitimacy of wind power in Germany by analyzing newspaper articles from four national newspapers from 2009 to 2018. A large amount of articles motivates the use of topic models, sentiment analysis, and statistics to shed light on the changing alignment of wind power with its context. The results show that various issues temporarily gain prominence on the agenda. Lately, the legitimacy of wind power in Germany has been increasingly challenged by adverse effects on humans, animals, and landscapes. Policymakers and project developers may address aspects of pragmatic legitimacy, such as civic participation and the local distribution of profits.

Keywords

Technology legitimacy; wind power Germany; energy transitions; structural topic model; natural language processing; text mining

1 Introduction

1.1 Motivation and Contributions

Climate change and the need to reduce greenhouse gases call for rapid transformations of national systems of energy generation and usage. Often termed sustainability transitions, research acknowledged that transitions unfold over long periods and are subject to intense societal and political conflicts (Meadowcroft, 2009). Within sustainability transitions, technology deployment and technological change play a key role (Markard et al., 2012).

A key factor linked to technology's success within society is legitimacy (Bergek et al., 2008b; Markard et al., 2016). Whether a focal technology is perceived as aligned with societal values and beliefs is vital to maintain resource flows, political support, and deployment (Hekkert et al., 2007). An essential aspect of legitimacy is its processual character: over time, the legitimacy of technology may change (Markard et al., 2016). Such temporal dynamics become particularly relevant in long-term transitions when the legitimacy of technologies commonly identified as crucial for a more sustainable future must be continuously reproduced.

A technology that is pivotal for reducing greenhouse gas emissions in the energy sector is wind power. While its first deployment for electricity generation dates back several decades, large-scale deployment only took off in the 1990s, with Germany being one of the lead markets (Bergek and Jacobsson, 2003). While potential conflicts with societal norms and values have been pointed out early on by acceptance research (Rand and Hoen, 2017), renewable energies were awarded an “exceptionally high degree of legitimacy […] in German society” (Jacobsson and Lauber, 2006, p. 272). Recently, wind power projects in Germany have been hampered by a series of lawsuits (Fachagentur Wind an Land, 2019) while investment activity slowed down. Therefore, this article's first contribution is a detailed account of the legitimacy of wind power in Germany and its development over the last decade.

To pursue this research question, we investigate a large set of newspaper articles from four national German newspapers from 2009 until 2018. As the number of articles available is high, we make a second contribution to the research on technology legitimacy and the relations of technology and society in general. We propose employing methods from the toolboxes of natural language processing to explore the context structures and institutional (mis-)alignment of the focal technology. With the proposed approach, we can assess technology legitimacy's key elements: the technology’s context and sentiment and salience of the various topics or issues that contribute to cognitive, normative, regulatory, and pragmatic legitimacy. The methodology is designed to account for temporal dynamics and change in newspaper coverage; therefore, it adds to the method sets of socio-technical transitions, where long time horizons and discursive changes are of particular concern.

The results draw a rich picture of the political struggles emerging in the face of a gradual delegitimation of a technology pivotal for energy transitions. While wind power in Germany today still must be considered a legitimate source of electricity generation, alleged health, environmental, and landscape conflicts have become an important topic in the discourse. Together with missing options to participate in the benefits of wind power, such issues became a barrier in the deployment of wind power, causing the need for policy adjustments. Conceptually, this process of delegitimation, which starts on a local level and diffuses to the broader public, resembles the process of legitimation (Johnson et al., 2006).

The remainder of the paper is structured as follows: Section 1.2 gives an overview of the case of wind power in Germany. Section 2 introduces the technology legitimacy framework, discusses the role of media, and provides a literature review of existing media studies on wind power. Section 3 discusses the available data and describes the usage of Structural Topic Modeling (STM, Roberts et al., 2016a) to assess large text corpora and statistical methods to assess STM output. Section 4 discusses the results of our analysis by first delineating the context structures of wind power and topics relevant to legitimacy. Section 5 concludes the paper.

1.2 Wind Power in Germany

The support of wind power development in Germany dates back to the oil crisis in the 1970s when the R&D expenditure for renewable energy sources was raised to about DM 20 million and increased throughout the following decade (Jacobsson and Lauber, 2006). However, market expansion was still limited – until 1989, 20 MW of wind power capacities were installed (Jacobsson and Lauber, 2006). At the end of the 1980s, the first deployment policies were enacted that guaranteed payments for wind power produced and fed to the common grid from demonstration projects (Jacobsson and Lauber, 2006). Finally, in 1991, the first feed-in law ensured grid connection and viable payments for electricity from wind turbines. When in 2000 the renewable energy act (*Erneuerbare-Energien-Gesetz, EEG*) was introduced, about 6.1 GW of wind power was installed (AG Energiebilanzen e. V., 2019). The feed-in law was flanked by several industry policies on the federal and state level. Additionally, the states' explicit land allocation for wind turbines supported the development of a large national wind power industry (Bergek and Jacobsson, 2003). The EEG enacted in 2000 introduced fixed feed-in tariffs for electricity from renewable sources (Hake et al., 2015). In the following decade, installed wind capacities rose to 25.7 GW in 2009 (AG Energiebilanzen e. V., 2019), and capacities continued to grow afterward. In 2011, after the nuclear accidents in Fukushima, Japan, the German government decided to phase out nuclear power, an event that is often associated with the term “Energiewende” (energy transition) and a regime shift towards renewable sources (Strunz, 2014). However, concerns over the costs of renewable energies increased, and measures to limit uncontrolled renewable capacity expansion were introduced (Lauber and Jacobsson, 2015). In the EEG amendment in 2017, tenders for wind power capacities were introduced (Leiren and Reimer, 2018). In general, the EEG is inclined to favor large-scale wind turbines and wind parks due to economies of scale and the remuneration per kilowatt-hour produced (Nordensvärd and Urban, 2015), a trend that might be even reinforced by the introduction of renewable energy tenders that fosters competition and further price declines in the wind power market. By the end of 2018, 6.4 GW offshore and 52.6 GW onshore wind power capacities were installed (AG Energiebilanzen e. V., 2019), but participation in onshore wind auctions decreased, and new installations of wind turbines decreased below political targets. A trend that prevails until today (2020). These developments may be linked to issues of local acceptance and legal conflicts (Fuchs, 2020). Already in 2017, critical voices claimed that the German energy transition had lost its momentum (Kemfert, 2017).

2 Theoretical Background and Literature Review

This section summarizes the technology legitimacy framework employed to understand the usage of wind power in Germany and its context relations. Furthermore, we motivate why media accounts are an essential source of legitimacy worth close investigation. We close with a review of what is known from previous research on wind power in media studies.

Markard et al.'s (2016) framework of technology legitimacy rests upon a systemic view of technology production and deployment. It draws on Technological innovation systems (TIS), whose core constituents are actors such as producers, users, vendors of a focal technology, networks in which actors connect by knowledge exchange or coalitions, and institutions such as regulations, social values, and norms (Markard, 2020). For example, wind power’s TIS consists of several turbine manufacturers, project developers, and investors that operate in a market majorly determined by renewable support schemes. The TIS literature further acknowledges that innovation systems cannot be fully understood without considering their context (Bergek et al., 2015). The TIS framework also includes notions of change and dynamics. It aims at showcasing how, by the complex interplay of actors in networks, certain institutions and developments are produced in feedback loops of cumulative causation (Hekkert et al., 2007). A fruitful line of conceptualization has identified seven core functions of a TIS that help describe dynamic processes within the TIS (Bergek et al., 2008a; Hekkert et al., 2007). The creation of legitimacy is a core function of a TIS that governs its relations to its (institutional) environment (Hekkert et al., 2007; Markard et al., 2016).

2.1 Technology Legitimacy

The relation of a focal technology to its institutional environment has been termed technology legitimacy (Markard et al., 2016). Legitimacy has a long tradition in organization theory (e.g., Aldrich and Fiol, 1994; Deephouse et al., 2017). Legitimation understood as a set of activities leading to legitimacy, is a crucial function of innovation systems, particularly in the formation phase (Bergek et al., 2008b). In later phases, legitimacy helps maintain political and public support, and a loss of legitimacy can contribute to the decline of technologies and industries (Geels and Verhees, 2011). Within sustainability transitions, maintaining legitimacy is particularly important, as transitions require long-lasting societal support (Geels et al., 2017; Geels and Verhees, 2011). The decisive role of policy and the long-term orientation of sustainability transitions elevate the relevance of the maintenance of technology legitimacy.

Markard et al. (2016) define technology legitimacy as the "[…] commonly perceived alignment (or misalignment) of a focal technology with institutional structures in its context." (Markard et al., 2016, p. 333), and we adopt this perspective within our study. In the following, we discuss the main concepts of this definition.

In contrast to the organization theory literature that focuses on organizations striving for legitimacy, technology legitimacy emphasizes the *focal technology* as the main object of inquiry (Markard et al., 2016). Manufacturers, technology companies, installers, or other organizations involved in the technology innovation system can take actions to maintain their legitimacy strategically. Technology legitimacy can be seen as contributing to the legitimacy of actors involved in the TIS. It can thus be expected that those actors will also engage in maintaining technology legitimacy. However, it is essential to note that technology legitimacy focuses on the technology instead of actors' legitimacy and actions within the TIS (Markard et al., 2016, p. 333).

Institutional structures comprise societal norms, values, beliefs, traditions, or regulations that apply to actors active within the socio-technical system. Institutions give structure to social interactions and are themselves socially constructed (Markard et al., 2016). Institutions are part of the context of the focal technology. Common frameworks of legitimacy regularly divide the institutional structure into different dimensions[1] (Table 1) (Binz et al., 2016; Geels and Verhees, 2011; Markard et al., 2016; Suchman, 1995). The cognitive dimension refers to the knowledge about a technology and its purpose in general, and, in its highest form, may reach a state of taken-for-grantedness, where the deployment of technology is beyond questioning (Aldrich and Fiol, 1994). The normative dimension refers to the alignment with informal rules such as norms and values. The regulatory dimension refers to formal standards and regulations that the focal technology can be misaligned with (Markard et al., 2016). To Markard et al.'s (2016) legitimacy framework, we add pragmatic legitimacy that refers to stakeholders' self-interest and the possibilities to participate in its deployment (e.g., Harris-Lovett et al., 2015; Suchman, 1995). Staying in terms of Markard et al.'s (2016) 'diagnostic questions', such questions could be "Do stakeholders of the technology profit from the technology? How can they participate?" (Table 1). Pragmatic legitimacy has been described as the dimension most susceptible to change by policies or stakeholder behavior (Jansma et al., 2020; Suchman, 1995). Particularly participation has been repeatedly identified as an essential element of the acceptance of local wind power projects (Langer et al., 2018; Sonnberger and Ruddat, 2017). Therefore, a detailed account of pragmatic legitimacy can enhance the usefulness of the technology legitimacy framework for policymakers.

[1] The distinction between the dimensions of legitimacy should be understood analytically, meaning that in real-world arrangements, an event or action affecting legitimacy likely affects several dimensions. Deephouse and Suchman (2008, p. 68) provide the example of the regulatory approval of a new pharmaceutical, which, apart from regulatory legitimacy, provides evidence of alignment with health (normative l.), enhances 'cognitive' comprehensibility, and showcases that the new product is useful (pragmatic l.).

Table 1: Dimensions in the technology legitimacy framework (adapted from Markard et al., 2016).

Dimension	Content	Diagnostic questions	Specifics
Cognitive	Understanding and purpose of technology	What is wind power? What is its purpose, what problem can it solve?	
Normative	Major design principles	What is a 'good' wind power plant? What are unwritten rules or guiding principles for building and operating wind power plants?	
Regulatory	Socio-technical materialization	How do wind power plants look like? What are typical technology characteristics? How are they operated?	Plant size, construction, ownership, and operation
Pragmatic	Self-interest and participation	Do stakeholders of wind power profit from the technology? How can they participate?	

An essential factor of legitimacy is the *context* of the focal technology. The TIS literature has identified various context structures relevant to shaping innovation and the operation of a TIS (Bergek et al., 2015). Such context structures can be political systems, sectors, other technological systems, and the like. It is important to note that each context element comes with its own institutional structure of regulations, norms, or rules that shape a context element's operations. An electric vehicle may, for example, need to comply with traffic regulations of the transport sector, while at the same time, it must obey the rules of the electricity system in order to recharge batteries. Therefore, the alignment of a technology with institutions from different contexts is vital for legitimacy. It is also here, in the context, where actors, such as politicians or customers, are situated that "need to be convinced that something is appropriate, right or desirable" (Geels and Verhees, 2011, p. 913) and whom themselves contribute to the creation of legitimacy.

Another aspect of legitimacy is that it can be described as a social process and is thus construed by different actors such as policymakers, companies, or end-users (Johnson et al., 2006). The processual character is also reflected in the fact that legitimacy might be contested and supported repeatedly over time, and technology struggles for legitimacy (Geels and Verhees, 2011). *Commonly perceived alignment* thus refers to this characteristic as it defines legitimacy "[...] as an overall or integral perception of how well a specific technology is aligned to the context, or not" (Markard et al., 2016, p. 333), where alignment and misalignment can happen at the same time. Technology can comply with individual institutions while not being aligned with others. For example, nuclear energy has the prospects of delivering electricity with low CO_2 emissions while at the same time bearing the risks of radiation exposure. Therefore, legitimacy is the product of a weighting process of different aspects of a focal technology. A further implication of describing legitimacy as a social process is a link to the temporal dimension: Within the legitimation process, actor coalitions and institutions can change, inducing alterations of commonly perceived alignment and changes of the weights of different aspects.

While this process of legitimation has been described through four stages of (1) innovation, (2) local validation, (3) diffusion, and (4) general validation (Johnson et al., 2006), a comparable description of the process of delegitimation is missing in the literature. Delegitimation, understood as an increasing perception of misalignment of the focal technology with specific institutions (while the perception of other relationships may remain stable), can have consequences for policymakers in the pursuit of necessary technological change. Empirically, the technology legitimacy literature has described periods of delegitimation. Geels and Verhees (2011, p. 920) describe how nuclear energy became delegitimated in the Netherlands by an anti-nuclear movement whose roots can be traced back to initiatives against a specific nuclear energy project. Markard et al. (2016) sketch how the legitimacy of biogas technology in Germany became increasingly challenged, first in professional circles and by local initiatives; only

later the perception of misalignment diffused to the broader public. Both cases entailed a limitation of political support for the focal technologies. These empirical examples suggest that delegitimation follows a processual structure similar to legitimation. The perception of misalignment first emerges on a local level or in specialized societal groups. From here, it may diffuse to other situations, until eventually, the technology is regarded illegitimate in general. From the perspective of policymakers and technology managers, this processual conceptualization of delegitimation highlights the importance of legitimacy management starting from every single local project, even if the technology is generally validated. Drastically speaking, every single project may be the starting point of a spiral of delegitimation.

It is also important to note that technology legitimacy acknowledges that the context or external conditions can change. Changes in the context of a focal technology can contribute to (mis-)alignment and contribute to technology legitimacy (Markard et al., 2016).

2.2 Technology Legitimacy and the Media

In order to analyze technology legitimacy, it is crucial to understand how legitimacy is produced. The technology legitimacy framework identifies three mechanisms of the creation and change of legitimation: (1) technological change to comply with institutions; (2) changes in the institutional environment itself; and (3) the framing of the focal technology concerning its relations to the institutional structure (Markard et al., 2016, p. 332). It should be evident that the mechanisms of de-legitimation are the same. Particularly concerning the latter two, media coverage is a well-suited indicator to assess legitimacy. This section aims to point out the role of media in the production of legitimacy without neglecting that other sources of legitimacy exist and may add to our results.

Organizational scholars have recognized different sources of legitimacy, such as the state, regulatory agencies, interest groups, public opinion, or the media (Deephouse et al., 2017, p. 14). Particularly state authorities decide on the provision of resources or conduct evaluations, and such activities have been used as indicators for the legitimacy of organizations (Deephouse, 1996). Surveys of public opinion have been conducted to understand the legitimacy of organizations (Dowling and Pfeffer, 1975). However, media coverage has become an important indicator of legitimacy in the studies of organizations (Deephouse and Suchman, 2008) and, more recently, of technology legitimacy (Binz et al., 2016; Geels and Verhees, 2011; Jansma et al., 2020; Markard et al., 2016; Weiss and Nemeczek, 2021). This interest in studying media accounts is related to the fact that public opinion and media both influence each other mutually, making media both an indicator and a source of legitimacy (Deephouse and Suchman, 2008). Furthermore, media influences the political process (Walgrave and van Aelst, 2006), and therefore has an effect on the evaluation of technology by political actors who themselves are an important source of legitimacy. Additional arguments can be found in the framing literature that argues that media accounts are produced in the exchange of political and social elites with journalists and continuously emphasize certain issues over others (Carragee and Roefs, 2004; Entman, 2007; Vliegenthart and van Zoonen, 2011). We, therefore, expect that positions of actors from the technology's context and TIS are reflected in media accounts of technology. This perspective is also adopted in the study of technology legitimacy that "emphasizes that collective sense making takes place on public stages (e.g., public debates, media, newspapers). Social movements, industry associations, policy makers, and special-interest groups perform on these public stages and engage in discursive struggles that aim to influence collective discourses" (Geels and Verhees, 2011, p. 913). In the public discourse, actors from different contexts compete on the framing of technology and, indirectly, on the prospective provision of resources (Geels and Verhees, 2011; Jansma et al., 2020).

The manifold relations of media to public opinion and political and societal stakeholders motivate us to conduct a thorough newspaper content analysis to assess the legitimacy of wind power. While we do not strive to delve in detail into which actors shape technology legitimacy, we target at analyzing the manifestation of this discursive process which is assumed to have consequences for the legitimacy of technology. The commonly used definition “To frame is to select some aspects of a perceived reality

and make them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described." (Entman, 1993, p. 52) provides first guidance for our analysis of newspaper content. For our study, we are therefore particularly interested in the salience of problems, interpretations, and evaluations that point to (mis-)alignment of wind power with institutions in its context. Furthermore, general sentiment towards the focal technology has been regularly assessed in the study of technology legitimacy in newspapers (Jansma et al., 2020; Markard et al., 2016). However, we propose a more refined assessment of sentiment of specific topics emerging in the coverage of a focal technology (see section 3.5). As we shall see, this refined notion of sentiment helps to identify issues that pose threats or support legitimacy.

When it comes to sentiment and the directionality of newspaper contents, it is noteworthy that there is a general tendency of journalists to report societal problems and negative events rather than positive stories, a fact that can be traced back to psychological factors of the readership (Soroka et al., 2019). This could be a potential caveat to the legitimacy assessment via newspapers, as a technology could be generally framed more in light of problems than by positive accounts of its deployment. However, the literature suggests that positive expectations towards technologies are a regular part of news reporting (e.g., van Lente et al., 2013), and societal problems (e.g., climate change) also motivate the deployment of new technologies, particularly when it comes to renewable energies. These arguments show that also positive aspects of technologies make the news, and some societal issues contribute to legitimization. However, the general tendency to report on conflicts and problems should be kept in mind when interpreting the results. In the following, we provide some insights that the framing literature has produced on wind power in various national contexts.

2.3 Framing of Wind Power

Most renewable energy media studies use deductive approaches to scrutinize how renewable energy technologies are framed along economic, technological, environmental, and social dimensions (Rochyadi-Reetz et al., 2019). For the period between 2010 and 2012, Rochyadi-Reetz et al. (2019) find that renewables, in general, are primarily framed in (positive) economic terms, while countries with higher penetration (including Germany) also tend to report negative societal and environmental consequences.

Wind power frames have been analyzed with cross-sectional (multi-country) approaches (Djerf-Pierre et al., 2016; Fischlein et al., 2014; Rochyadi-Reetz et al., 2019; Stephens et al., 2009). In general, the cross-sectional studies emphasize the contingency of wind power frames. In the US, state-level wind discourses vary between states (Fischlein et al., 2014; Stephens et al., 2009). Djerf-Pierre et al. (2016) show that while discourse in Sweden was ambiguous, negative economic frames governed the agenda in Australia. In both countries, political and economic elites dominated the discourse.

Another set of studies provides insights into local specifics of public wind power discourse. In Australia, local wind projects encounter fierce debates while the government is little aware of such local conflicts (Hindmarsh, 2014). Zukas (2017) showed that wind energy discourse is primarily determined by politicians and industry stakeholders in Wisconsin, USA. In the discourse on German offshore wind, arguments on negative environmental impact are rarely used, although a survey showed them to be effective in influencing acceptance (Schmidt, 2017). Offshore wind has also been scrutinized in Norway, where economic frames, both positive and negative, were most frequently employed (Heidenreich, 2016).

Furthermore, few studies assessed media coverage of wind power with longitudinal sampling strategies or linked context changes to media accounts. In Ontario, Canada, Deignan et al; Deignan and Hoffman-Goetz (2013; 2015) assessed the effect of policy changes on the coverage of public health issues concerning wind power and found increased negative coverage. Gearhart et al. (2019) assessed US television coverage of wind power between 2001 and 2016, where coverage decreased over time and primarily displayed wind power as a political issue. Remarkably, also the reporting of positive

environmental effects of wind energy decreased over time. A further study suggests a bidirectional relationship between media and policymaking (Smith et al., 2016). Finally, Pralle and Boscarino (2011) analyze how climate change mitigation is traded off against local environmental and aesthetic concerns in wind power coverage.

Concluding this brief literature review, we found considerable variation in the findings of the different studies, indicating that the framing of wind power is strongly dependent on its context. Economic and political frames seem to dominate agendas, while environmental and aesthetic concerns are raised less frequently in media coverage. Hence, according to these studies, the legitimacy of wind power may be primarily determined by economic and political issues, but also environmental concerns may play a role, and legitimacy may vary between different national contexts and times. In general, media has rarely been scrutinized for changes in wind power coverage over long periods, a shortcoming that might be related to the difficulties arising from the large amount of data that must be processed. Furthermore, the wind power framing literature does not consider the importance of media for the legitimacy of wind power. With the paper at hand, we contribute to the literature by assessing wind power's legitimacy and proposing a statistical approach to analyze a high number of newspaper articles described in the following.

3 Methodology

A quantitative assessment of newspaper content to assess the legitimacy of wind power is an inherently data-intensive process. Within this section, we outline the collection of data and, due to the high amount of data available, we outline how we use Natural Language Processing (NLP) methods for detailed content analysis. We identify the Structural Topic Model (STM, Roberts et al., 2016a) as a suitable tool for our endeavor. Various preprocessing steps, model configuration, validation, and final data analysis have to be taken into account to make such an analysis operable. Different aspects of the methodology we followed in this article have recently been proposed (Dehler-Holland et al., 2020). As automated content analysis is a relatively new field, a detailed discussion of data collection, preprocessing, and method choices is necessary to understand the findings provided in this study and enhance reproducibility (Antons et al., 2020).

3.1 Data

In order to assess the legitimacy of wind power as comprehensive as possible, we collected newspaper articles from four national German newspapers: *Die Welt*, *Die Tageszeitung (TAZ)*, *Frankfurter Allgemeine Zeitung (FAZ)*, and *Süddeutsche Zeitung (SZ)*. While Welt and TAZ were retrieved from the LexisNexis academic database, FAZ and SZ were collected from the newspaper's archives. The newspapers were chosen based on their national coverage and their high circulation. Additionally, the four newspapers are well distributed geographically in Germany: The editorial offices of the SZ, FAZ, TAZ, and Welt are located in Munich, Frankfort, Berlin, and Hamburg, respectively, and local sections cover those regions. As the temporal scope of our analysis, we chose the period between 2009 and 2018. During those ten years, the support regime has changed substantially, and wind onshore and offshore capacities have been expanded.

After different combinations of words had been tried, we consistently used “Windenergie* OR Windkraft*” (wind energy OR wind power) in all databases. Other search terms such as “Windrad” (windmill) did also include irrelevant articles. The terms ensure that wind power is discussed in the article, and articles that mention only wind are excluded.

First, duplicates were removed using the Levenshtein distance (Levenshtein, 1966) for measuring text similarity. Duplicates expose text classification to the risk of biased results, as they may inadvertently put excessive weight onto specific categories. Second, texts were screened for sections such as *letters to the editors* or *table of contents* that have been excluded from the analysis.

After these two preparatory steps, 9,840 articles entered the analysis. The articles' length shows a broad distribution between 13 and 4,594 words, while the average article contained 593 words. Articles are not distributed evenly over the different news outlets (Table 2). The FAZ published most articles during the time, while in SZ, the fewest articles appeared, while, in turn, the average article discussing wind power was the longest.

Table 2: Descriptive statistics of newspaper data per source.

Newspaper	Number of articles	Average article length [words]	Median article length [words]	Max article length [words]	Min article length [words]
Die Welt	2141	610	545	2829	25
Die Tageszeitung	2639	483	391	4594	13
Frankfurter Allgemeine	3154	620	566	4523	20
Süddeutsche Zeitung	1906	681	605	3807	14
All	**9840**	**593**	**506**	**4594**	**13**

3.2 Content Analysis

Content analysis methods usually comprise quantitative methods to assess contents of communication, e.g., newspaper articles. The quantitative methods used to assess content can further be subdivided into manual and automated approaches. The latter have the advantage that large bodies of text can be evaluated at once, while manual methods are constraint in the number of texts that can be assessed for a specific research question by the number of researchers and time available. Given the large amount of data collected for our study, there are two options in pursuing a quantitative content analysis. First, one could reduce the number of texts by focusing only on the texts most relevant to the relevant research question and conduct a manual content analysis of a significantly smaller subset of texts. Second, we could use an automated approach to assess the entire dataset. Given that a thorough analysis of legitimacy should assess all context structures within which a focal technology is assessed, we opted for the latter.

Broadly, automated methods can be divided by whether categories of text are already known or not (Grimmer and Stewart, 2013). This distinction is essential, as different methods are available in each case. Based on this distinction, supervised or unsupervised methods can be applied (Grimmer and Stewart, 2013; Quinn et al., 2010). Supervised methods are used to learn categories predefined by the researcher, but large training sets are necessary to carry out meaningful research, and substantial knowledge is needed to provide those (Quinn et al., 2010). For example, Hughes, 2018 categorizes more than 11,000 one-minute speeches in the American House of Representatives manually to train different supervised algorithms up to an acceptable level of error. Unsupervised methods can be applied relatively fast, with minimal a-priori assumptions and low costs (Quinn et al., 2010). On the other hand, findings must be validated with care, and automated methods cannot replace careful manual validation (Grimmer and Stewart, 2013).

As the foundation of this study is a large number of texts that need to be classified, and categories of analysis have not been fixed, we have decided to follow an unsupervised modeling approach to define categories for the underlying texts. A popular class of unsupervised learning for text classification are topic models (e.g. Blei et al., 2003; Blei and Lafferty, 2007). Topic models are well in line with framing concepts (DiMaggio et al., 2013). Topic models have undergone rapid development within the last decades, and a recent achievement has been the consideration of meta-data within models. The Structural Topic Model (STM) allows the topic model to leverage information from covariates, such as time, in the classification step. This feature is the main reason for us to apply this technique, besides the rising number of accounts of its ability to produce valid results (Roberts et al., 2014; Roberts et al., 2016a; Roberts et al., 2016b). Furthermore, STM is a mixed membership model and allows that the occurrence of topics within a document follows systematic patterns across the whole set (Blei and Lafferty, 2007;

Roberts et al., 2016a). This feature allows the researcher to endeavor relationships between different topics across all documents that help to delineate the different contexts of wind power.

Automated content analysis has high requirements concerning the format in which text data is provided to classification algorithms. Texts from different sources cause the need for normalization in order to be comparable without introducing bias. Various steps are required to ensure that texts have the same encoding, that words with the same meaning are mapped onto each other, and to reduce the dimensions of the data set as much as possible to speed up model estimation (Lucas et al., 2015). Thus, pre-processing is a time-consuming task in our content analysis endeavor.

3.3 Pre-processing

As the text data used in this study stems from different sources, the texts had to be brought into a standard format. Documents were imported into an R data frame. Once in a standard format, normalization procedures can be applied. Figure 1 provides an overview of all the steps necessary to analyze the results.

To derive a meaningful text model, words inflected from the same base form (such as singular and plural of a noun, or *use* and *used*) must be associated with one another. Two major approaches exist. The simple approach is to "chop off" the end of each word and including only the stem of words for later analysis, and for many languages such as English, stemming yields satisfactory results (Lucas et al., 2015). However, as German is more richly inflected, lemmatization is preferable (Jacobi et al., 2015). Lemmatization is the task of inferring the canonical form of a word from the inflected form and its context (Manning et al., 2009). For this study, we used the Treetagger, a well-tested software that provides lemmatization and Part-of-Speech (PoS) tagging for German and can be coupled with R (Schmid, 1994; Schmid, 1999). The algorithm is based on the classical language model that assumes that texts are created as Markov chains (Schmid, 1994). For Markov chains, the derivation of transition probabilities plays a significant role. Schmid (1994) addresses this problem by using decision trees that decide on the size of the context that should be taken into account when assessing a specific word (such as analyzing trigrams, bigrams, or unigrams) and PoS tags of previous words. The algorithm has been improved to assess German texts and achieves highly accurate results (Schmid, 1999). The PoS tagging results were used to reduce the corpus to include only words adding semantic meaning to the texts. Furthermore, classical stop word removal based on a comprehensive lexicon has been applied (Diaz, 2016). Lemmata are included in the reduced corpus whenever they are available. If unknown to the lemmatization algorithm, we included the term how it appeared in the original text.

The reduced corpus is the foundation for any further classification efforts. The corpus was translated to a document-term matrix consisting of 9,840 documents and 17,418 terms to be assessable by numerical text models. Based on the pre-processing of textual data, a Structural Topic Model was developed that explicitly considers the temporal dynamics of discourse by leveraging the patterns of overall attention to wind power.

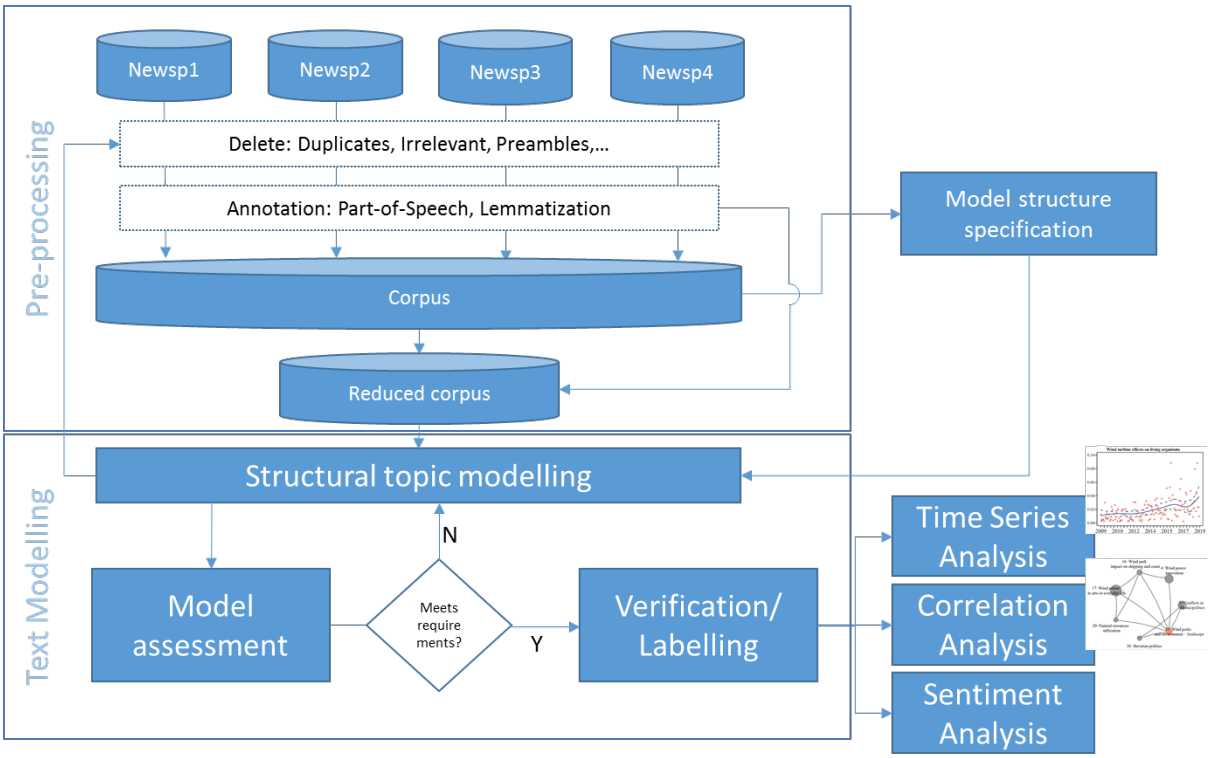

Figure 1: Schematic representation of Pre-processing, modeling, and analysis steps.

3.4 Structural Topic Modeling

In general, topic models and other unsupervised learning algorithms infer the contents of a set of texts rather than presuppose categories beforehand (Roberts et al., 2014, p. 1066). A fundamental assumption is that categories or, in our case, topics are defined by the frequent usage of the same vocabulary. Based on this assumption, word counts per document and their distributions give essential information on documents' content. This concept is also referred to as “bag-of-words”, as the order of words is not considered. The algorithm must “know” how a document is generated to estimate the underlying distributions of words; thus, topic modeling assumes an a-priori mechanism that produces texts (Blei et al., 2003). Topic modeling assumes that a corpus contains a fixed number of k topics, where each topic is defined by a distribution of words. Each document is composed of those k topics to varying shares. Each document now is assumed to be produced by a process that (1) draws a document length and then, (2) word-by-word, draws a topic from the distribution of k topics, (3) draws a word from the associated distribution, and (4) goes on with the following word (Blei et al., 2003). The underlying distributions can be estimated using Bayesian statistics techniques given a set of documents (Blei et al., 2003).

The specific innovation of structural topic models is that the distribution of topics (*prevalence*) may depend on covariates, such as time or publisher (Roberts et al., 2014; Roberts et al., 2016a). This is the main feature we will exploit in our analysis of technology legitimacy, as legitimacy, as conceptualized above, is highly dynamic or time-dependent (Johnson et al., 2006; Markard et al., 2016). Thus, a crucial step of our analysis is to decide on the STM's structural specification, namely how to include the temporal dimension. First, we chose the month of publication of articles as a covariate so that the model can infer common features from an appropriately sized number of articles. Second, the leading developers of STM propose spline models to include temporal variables into the model structure (Roberts et al., 2019), and we follow this advice. The basic assumption of STM is then that the *mean prevalence* $\mu_{\tau,t}$ (the share of a topic τ in all documents at a given point in time t) can be expressed by piecewise third-degree polynomials to allow for non-linear changes over time as follows:

$$\mu_{\tau,t} = \sum_{i=1}^{N} b_{\tau,i} \cdot bs_i(t),$$

given a base of splines bs and $N = \#knots = degrees\ of\ freedom$ when we use natural splines to avoid erratic behavior at the domain bounds. In defining a spline model for our text model specification, choosing the number and placement of the knots (i.e., the points where two polynomials meet) is the next critical step.

Often, the choice of knots is made based on separating the data in quantiles, and a low number of knots is generally enough to represent the data adequately (Harrell, 2015). However, if prior information is available, the choice of knot positions according to expected data changes can improve the model quality (Harrell, 2015, p. 26). Therefore, to get a first idea of the temporal dynamic of newspaper coverage, we assess the time series of document counts per month. We apply a changepoint analysis algorithm that detects changes in mean and variance of time series by testing data distribution changes (Killick et al., 2012; Killick and Eckley, 2014). The analysis reveals that data can be separated into contiguous phases, and we set the knots accordingly to the phase bounds (compare Figure 3 in Section 4.1) and between bounds to bestow sufficient flexibility to the model.

Another fundamental decision concerns the number of topics that suffice to analyze the corpus. The decision can be formulated as a trade-off between the different topics' separability and their semantic coherence. The decision ultimately requires a judgment call by the researchers based on the research question at hand but can be guided by statistical measures. The above trade-off can be formalized by measuring, for a given model, the exclusiveness of terms in a given topic compared to other topics (Airoldi and Bischof, 2016). Semantic coherence can be formalized by the co-occurrence of words (Mimno et al., 2011). We estimate models with $k = 20, \ldots, 100$ and assess the models based on statistical measures (Figure A. 1 in Appendix). Solutions that locally dominate other solutions are investigated manually based on frequently occurring terms. Finally, we decided on a model including 44 topics, which appears to be a reasonable trade-off that enables us to investigate our research questions but does not lead to a high number of topics that increases validation need and introduces topics that do not contribute to the research questions.

3.5 Statistical Analysis of Context Structures and Topic Sentiment

We performed time series modeling, graph analysis, and sentiment analysis of topics to explore the contents and their changes over time. In the following, we provide insights into the procedures applied to assess technology context and sentiment.

Essential aspects of technology legitimacy are the different contexts in which the focal technology is embedded. We strive for empirically identifying wind power's context structures by assuming that they are inherently represented in the topic model structure by the way topics are discussed alongside each other regularly. This factor can be measured by the correlation of topic prevalence time series. To analyze the relations of topics within the corpus, we assess correlations as a graph structure. The edges in the graph are given by the Pearson product-moment correlation between the topic time series. As the individual topic distributions are strongly skewed and show high kurtosis, we apply a rank-based transformation to normality. The transformation has been found to have favorable properties, and the Pearson correlation coefficient may underestimate the relationship between variables (e.g., Bishara and Hittner, 2012, p. 408; Kowalski, 1972). To understand the context structures of wind power, we divide the graph structure induced by correlations into sub-graphs of highly correlated topics. More technically speaking, we assess the graph's modularity to identify context elements that showcase higher correlations internally but lower correlations to external elements. Given the relatively low number of vertices (i.e., topics) in our graph, we can maximize modularity without falling back to heuristics (Brandes et al., 2008). The procedure delivers both the optimal number of sub-graphs and the topics each sub-graph contains. We use the igraph package in R to estimate graph structures (Csardi and Nepusz, 2005).

Another critical property of text in analyzing technology legitimacy is the sentiment expressing texts' emotional content. In legitimacy analysis, negative sentiment has been used as an indicator for legitimacy being challenged, while positive sentiment is associated with higher legitimacy (e.g., Binz et al., 2016). Sentiment analysis is an important subfield of NLP in fast development (Pang and Lee, 2008). Often, the sentiment of a text, sentence, or aspect is expressed as a polarity score, e.g., in $[-1,1]$ (Feldman, 2013). In that regard, our approach to assessing the sentiment associated with topics originating from a topic modeling procedure does not differ. We recently proposed analyzing topic sentiment by assessing the expected sentiment of topics given a specific sentiment lexicon (Dehler-Holland et al., 2020). For German, SentiWS provides a comprehensive sentiment lexicon with more than 3,000 words (Remus et al., 2010).

Based on a sentiment lexicon W, we define the *topic sentiment* ts_τ per topic τ as the weighted sum of all sentiment scores $s_w \in [-1,1]$ of words w from the vocabulary V of the entire corpus and the word occurrence probabilities $\beta_{w,\tau}$ estimated by a topic model. We rescale the expected value to $[-1,1]$, as not all words in the vocabulary V are necessarily also to be found in the lexicon and define

$$ts_\tau = \frac{\sum_{w \in V} \beta_{w,\tau} \cdot s_w}{\sum_{w \in V \cap W} \beta_{w,\tau}}.$$

This definition allows us to assess the different topics' emotional content to better understand their relations to legitimacy. In our case, 8.9% of the words from the corpus vocabulary are also part of the sentiment lexicon, as naturally, many words of natural language do not carry unambiguous sentiment. This percentage is in line with previous studies using the same lexicon (Dehler-Holland et al., 2020; Remus et al., 2009). In order to assess the development of sentiment over time t, we evaluate the time series of $ts_\tau \cdot \mu_{t,\tau}$, where $\mu_{t,\tau}$ denotes average prevalence of topic τ in time t, as an indicator of the contribution of a single topic to the entire corpus's sentiment. Henceforth, we refer to $ts_\tau \cdot \mu_{t,\tau}$ as *weighted sentiment*.

Now that we have formally introduced the concept of topic sentiment, it is important to develop an intuition for it and how it can inform the study of technology legitimacy. We note that topic sentiment appoints a sentiment value to each topic instead of individual texts. We remind the reader that each topic is, in fact, a distribution of words (Section 3.4), and topics differ in that some words are more likely to appear than others. Topic sentiment is essentially an average of the lexicon's sentiment scores weighted by the probability of words to appear within a specific topic. The value of topic sentiment indicates whether the topic predominantly comprises words associated with positive (e.g., 'good', excellent', 'perfect') or negative (e.g., 'bad', 'wrong', 'harmful') sentiment scores. We emphasize that topic sentiment is linked to the emotional content of the topic and not necessarily to sentiment directly associated with the focal technology.

From this discussion, it also should become clear that positive (negative) topic sentiment alone is not sufficient to conclude towards legitimation (delegitimation) of the technology. As a broader societal issue may determine the topic's content, it is crucial to understand further the positioning of the technology towards that issue, i.e., whether it amplifies the issue at hand or possibly contributes to its resolution. As an example from our results, the topic *nuclear energy* (#43, $ts = -0.09$) discusses a technology highly controversial in Germany, where public opinion is critical about its deployment. In this discourse, wind power is framed as an alternative to nuclear energy, wherefore the topic contributes to the legitimacy of wind power, despite or because of its negative sentiment.

To showcase the trend of prevalence of a specific topic or wind power's context elements, we performed regression on the non-linear time trend formalized by natural splines as defined in Section 3.4. Combining the above procedures allows for a rich analysis of the underlying data, highly informative on trends and relations in newspaper coverage of wind power.

3.6 Validation

The use of an unsupervised content analysis method makes careful validation of the final model indispensable (Grimmer and Stewart, 2013), even though STM has a remarkably high accordance rate with human coding procedures (Roberts et al., 2014). We remind the reader that STM identifies topics not predefined by the researchers, and the content of these topics must be assessed qualitatively to derive meaning from the purely statistical results. While topic modelers often use word lists of the most probable terms for each topic to derive labels for each topic, we have additionally assessed a sample of articles on top of analyzing statistical measures of semantic coherence to ensure that topics do properly account for semantic regularities of the whole set of articles. For each topic, the first two researchers independently read (at least) the ten articles that showcase the highest topic proportions. Both researchers independently formulated a label for the topic based on close reading and the word lists of most probable terms per topic and wrote a short description of its content. Then, the results were compared, and common labels and descriptions were formulated. In general, there was already a high agreement on most of the topics from the start. In 73% (32 of 44) of the cases, both researchers agreed on topic labels and descriptions already in the first step. In nine cases, the label's wording deviated, but both researchers agreed on the content and its description. Therefore, consensus could be found quickly. For three topics, both researchers assessed additional articles from the sample and rediscussed labels and topic descriptions until consensus on the topics' content was reached. The consolidated labels and topic descriptions are summarized in the Appendix in Table A. 1. The validation results build the foundation of the interpretation of time series, correlation analysis between topics, and topic sentiment.

3.7 Operationalization of Technology Legitimacy

The preceding sections have clarified how we perform a content analysis of newspaper articles concerning wind power. First, we use topic modeling to delineate different topics within the corpus. Second, natural splines are used to model changes in the prevalence of topics over time. Third, we aim to analyze the context structures of wind power with correlation graphs, thereby formalizing a key concept in the definition of technology legitimacy. Fourth, we defined topic sentiment to assess the emotional content of topics. In this section, we lay out how we use the results of the content analysis exercise to assess the legitimacy of wind power.

As we have already argued in section 2.2, newspaper articles provide a good proxy to assess legitimacy that is produced in the continuous exchange of actor positions. However, we have not yet addressed two critical issues of how the content analysis can inform technology legitimacy: (1) the identification of topics relevant for the legitimacy of wind power; and (2) the evaluation if a topic indicates (mis-)alignment of wind power with certain institutions. We discuss our approach to both issues in the following.

From our theoretical discussion (section 2.1), we learned that relevant institutions are situated within the broader context structures of the focal technology. The literature proposes four dimensions that are relevant in the assessment of legitimacy: cognitive, normative, regulatory, and pragmatic legitimacy. After we assessed the context via correlation graph partitioning, we formulated broad assumptions on the institutions relevant in each context (section 4.1). To refine this first analysis, we assessed the topics provided by the model by referring to the four legitimacy dimensions with the help of diagnostic questions as proposed by Markard et al. (2016) in Table 1 and the topics' qualitative descriptions (Table A. 1). This approach sheds light on two different aspects of legitimacy: first, it addresses the context, where each context also relates to a specific set of actors, infrastructure, and related interests (Figure 2). Second, the legitimacy dimensions analytically help pinpoint why a specific topic impacts legitimacy, e.g., because the content of a specific topic reveals that the deployment of wind power is related to costs, which conflicts with stakeholders' self-interest (pragmatic legitimacy).

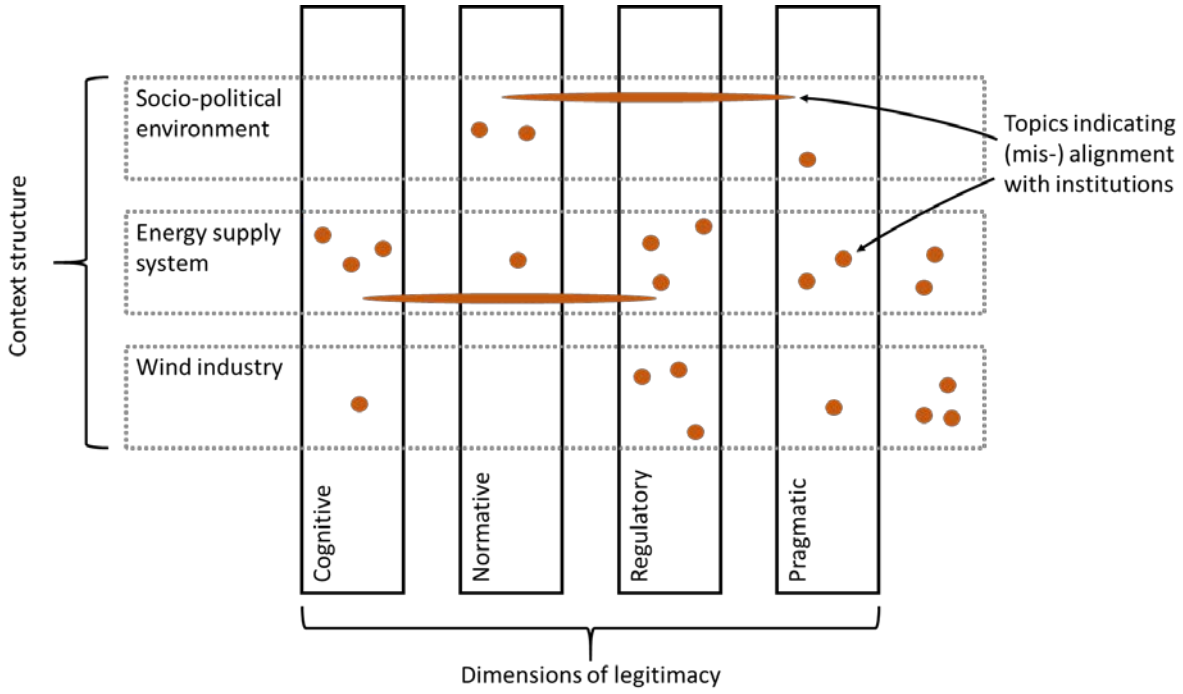

Figure 2: Illustration of the identification and matching procedure of legitimacy dimensions and topics.

In order to evaluate whether a topic indicates (mis-)alignment with relevant institutions, we used the topic's qualitative descriptions derived during validation (section 3.6), their prevalence over time, and topic sentiment. In general, we took high prevalence and a topic sentiment strongly diverging from zero as the first indication that a topic might represent a legitimacy issue. This was further qualified by the qualitative assessment of the topic's content and explorations of the topic's correlation graph neighborhood. A high correlation with a topic that pointed at societal or political conflicts (e.g., the topic *legal conflicts and law-making*, #33) was taken as an additional indicator for (mis-)alignment. Together, topic prevalence, sentiment, correlation with conflict topics, and qualitative assessment allow the conclusion that a particular topic contributes to or undermines legitimacy. In order to identify the timing of (mis-)alignment, we used weighted sentiment that provides a composed indicator of prevalence and sentiment over time.

Based on this operationalization of technology legitimacy with the help of detailed automated content analysis, we can draw a rich picture of the legitimacy of wind power in Germany. The nature of the unsupervised topic modeling procedure, where topics are determined automatically and not by the researchers' prior knowledge, inevitably also produces topics that are uninformative on legitimacy. However, it also allows minimizing potential bias in the coding procedure and costs (Quinn et al., 2010).

4 Results and Discussion

In this section, we present the results of the change-point analysis of the number of articles and discuss the results of the content analysis using a structural topic model with 44 topics in detail. We start with an overall assessment of the salience of wind power in four national newspapers. We delineate three context structures and discuss the changing prevalence of the three context structures over time. Furthermore, we assess topic sentiment across the entire corpus and derive the weighted sentiment of the three context structures as a first indication of where legitimacy issues might come into play. Afterward, we discuss selected topics and their contributions to the perceived alignment of wind power with institutions in its context structures – i.e., wind power's legitimacy in Germany. We close this section with reflections on the framework of technology legitimacy and some remarks on our methodology. Because it is, admittedly, not an easy task to follow the 44 topics through the results

section, we usually refer to the topic number (#) and topic sentiment (ts) in the text for quick reference in Table 3.

4.1 Change Points and the Context of Wind Power

The analysis of change points in the newspaper coverage of wind power serves two goals. While we use the results to inform the text model on the temporal structure of coverage, we also learn that coverage has decreased since 2014 (compare Figure 3). Generally, coverage is characterized by long periods of relatively stable attention towards wind power. Interest in wind power drops in 2014 and 2016. At first appearance, the drop in attention coincides with significant amendments to the renewable energy act (EEG). However, delving more into the details of coverage reveals that the salience of wind power in 2014 is strongly driven by the insolvency of Prokon, a wind power project planner and investor that issued profit participation rights to a large number of small investors (Topic #5, Table 3). The attention to this case ceased fast in the same period.

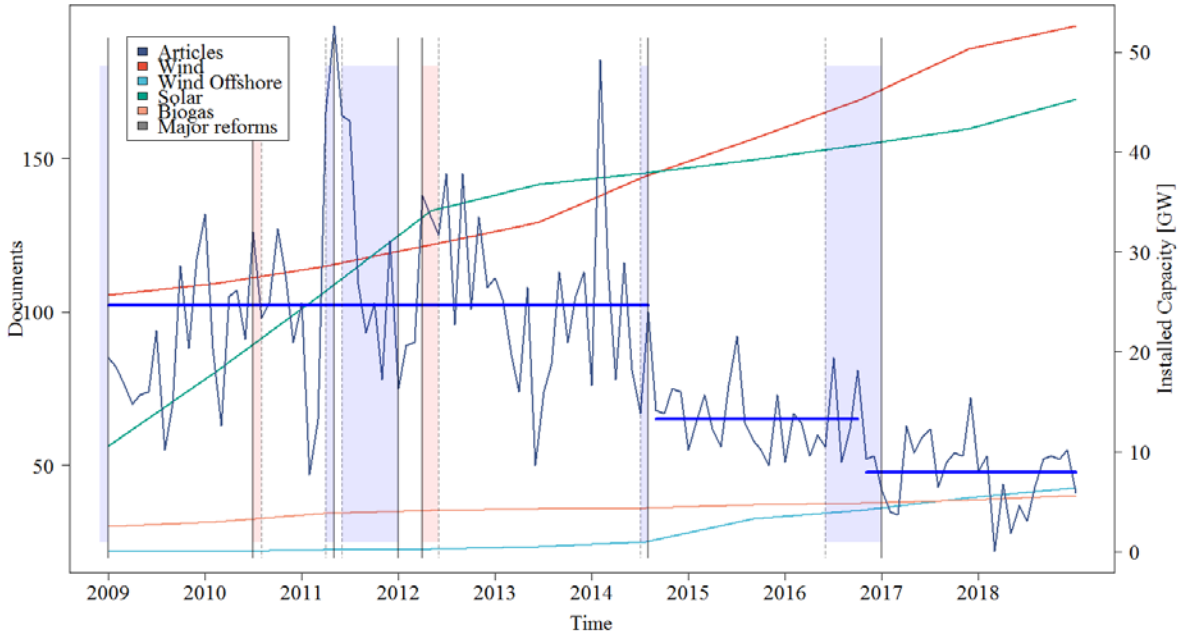

Figure 3: Changepoint analysis of the number of documents per month. Vertical lines indicate EEG amendments. Dashed vertical lines indicate when the amendment passed parliament. The time between parliamentary approval and commencement is shaded blue or red. On the right axis, installed renewable energy capacities of different technologies are plotted (AG Energiebilanzen e. V., 2019).

The context of the focal technology is vital to understand institutions that play a role in the legitimacy of a technology. To explore the context of wind power in newspaper accounts, we analyze the topic correlation graph (Figure 4). As described in Section 3.5, we identify sub-graphs by optimizing modularity. We find that three contexts are particularly important in reporting wind power. Based on the sub-graphs, we distinguish wind power's context as its *socio-political environment*, the *energy supply system*, and the *wind industry*[2] (Table 3). We now discuss the three context structures in more detail, emphasizing context institutions related to wind power.

The *energy supply system* context comprises topics that are related to the provision of energy. Several topics are associated with centralized energy production and the transition to renewable energy generation (#10, 39, 43, and 38). Two topics are associated with the share of energy carriers in energy

[2] Remarkably, the context structures we identified by optimizing modularity resemble the environments in the triple embeddedness framework proposed by Geels (2014).

demand and developments of wind capacities (#9 and 13). Wind power is associated with topics related to the security of supply (#25 and 41). Two topics address the costs and the marketing of renewables and wind power (#12 and 30). Storage of electricity by, for example, the production of hydrogen (#8) is closely related to several key topics in the energy supply system. Federal, EU, and international climate politics (#6, 7, and 34) appear to be more associated with issues in the energy supply system context than the socio-political environment. The topics indicate that the often perpetuated goals of the energy supply system of affordability, minimization of environmental impact, and security of supply (Helm, 2002; Schmidt et al., 2019) play a role in shaping the relationships of this context and wind power.

Within the *socio-political environment* of wind power, topics associated with wind power's relation and conflicts with its social and natural environment are clustered. The socio-political environment comprises topics associated with wind power interaction with its environment (#16, 20, 28, and 37). Several topics are associated directly with legal and regional conflicts (#3, 15, 23, and 33). Wind power also relates to the population's everyday life (#17, 24, and 26). Two topics are associated with a (sustainable) development of society as a whole and, more practical, on a regional level (#31, 35). Interestingly, state-level policymaking is embedded in wind power's socio-political environment (#21, 36). The topics point show that, in general, issues of local projects and wind power deployment shape the relationship between the socio-political environment and wind power.

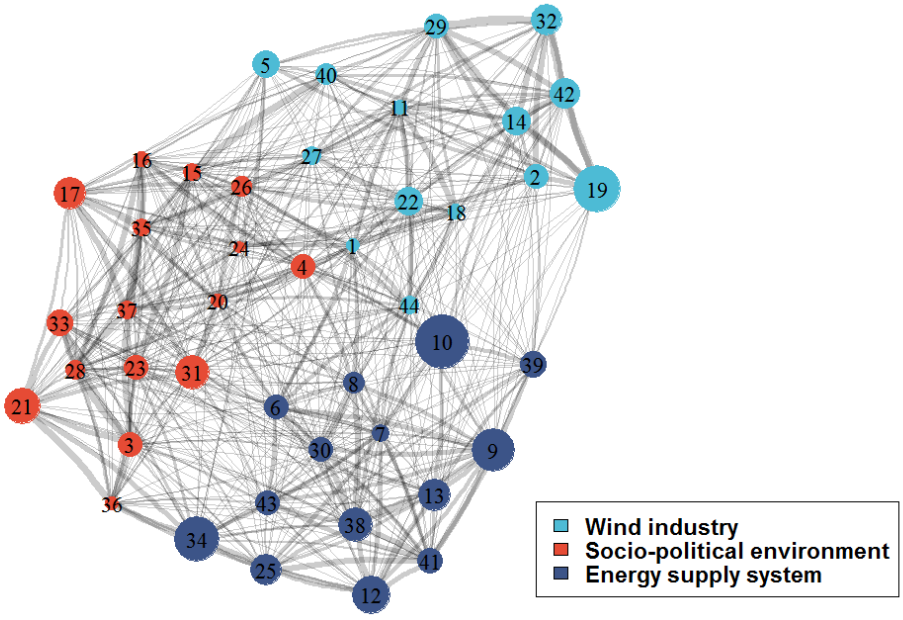

Figure 4: Topic correlation graph. Community structures as identified by optimal modularity. Vertices scaled proportionally to topic prevalence. Edges are scaled proportionally to the correlation coefficients. Please refer to Table 3 for more detailed information on the context and topics.

The *wind industry* context comprises topics associated with various aspects of the production and marketing of wind turbines. A large proportion of topics is devoted to economic aspects of the wind industry, such as investments (#2, 5), the performance of wind power companies (#32, 19), or market dynamics and company restructuration (#29, 42, 14). Wind power is regularly a topic in international affairs (#22, 27). An interesting set of topics is associated with the relations of the wind industry to other sectors and technology spillovers from other industries. Digitalization and innovation in chemical industries contribute to the production of wind power plant components and remote maintenance (#18,

44), as well as a multitude of small and medium-sized companies in Germany (#11). The German shipyards are in crisis and may profit from wind offshore installations (#40), while electricity from wind has the prospects of producing alternative transport fuels (#1). The topics indicate that economic performance and industry relations are important in the wind industry context.

To understand the contributions of the different contexts to the media agenda over time, we assess the development of prevalence of all three contexts (Figure 5). The analysis shows that the socio-political environment has become most prevalent over time. The energy supply system was intensely covered between 2010 and 2015 after the government announced the German energy transition.

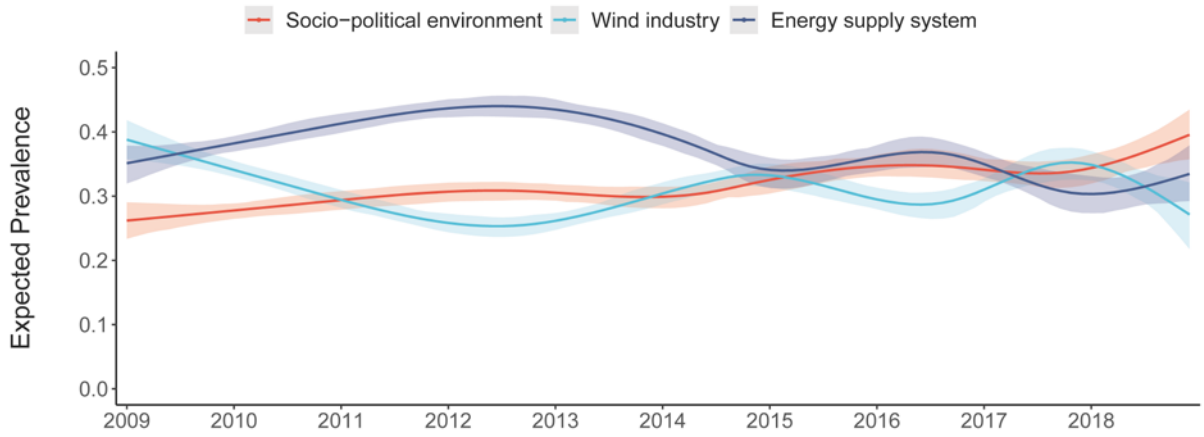

Figure 5: Prevalence of the three context structures. Prevalence is modeled by the spline model described in Section 3.4. The shaded areas depict model uncertainty (0.95 confidence intervals).

Table 3: Topic labels, context, and measures of sentiment and prevalence.

Context	#	Topic	Sentiment	Prevalence [%]
Energy supply system	6	Climate change and climate policy	-0.096	2.16%
	7	EU energy policy	-0.052	1.57%
	8	Electro-chemical energy production and storage	0.001	1.86%
	9	Share of energy carriers in energy demand	-0.007	3.80%
	10	Offshore wind parks	0.029	4.71%
	12	Electricity prices and EEG surcharge	-0.118	3.36%
	13	Wind power capacity development	-0.064	2.86%
	25	Grid expansion between north and south Germany	-0.052	2.72%
	30	Marketing of sustainable energy	0.052	2.13%
	34	Federal energy politics	-0.043	3.95%
	38	Transition of the energy system	0.028	3.01%
	39	Transformation of large electricity companies	-0.017	2.33%
	41	Security of supply	-0.103	2.23%
	43	Nuclear energy	-0.088	2.11%
Socio-political environment	3	Regional conflicts with wind projects	-0.048	2.17%
	4	Innovation in energy generation	-0.005	2.18%
	15	Offshore-Cluster North Sea	-0.005	1.56%
	16	Wind park impact on shipping and coast	-0.011	1.39%
	17	Wind power in culture and everyday life	0.046	2.84%
	20	Natural resources utilization	-0.083	1.18%
	21	Regional elections and coalitions	-0.006	3.21%
	23	Wind energy exhibition location	0.015	2.13%
	24	Private wealth building and taxation	-0.018	1.00%
	26	Education	0.077	1.79%
	28	Wind turbine effects on humans and animals	-0.221	1.71%
	31	Concepts of societal progress	-0.011	3.00%
	33	Legal conflicts and law-making	-0.198	2.36%
	35	Sustainable urban development	0.053	1.54%
	36	Bavarian politics	-0.014	1.22%
	37	Wind turbines' interaction with physical environment: landscape, weather, infrastructure	0.028	1.66%
Wind industry	1	Alternative fuels for transport	0.028	1.20%
	2	Investment in wind projects and the wind industry	-0.008	2.15%
	5	Prokon insolvency	-0.123	2.42%
	11	SMEs in the German industry	-0.044	1.26%
	14	Wind turbine world market	0.021	2.51%
	18	Digitalization of industry	0.068	1.36%
	19	Profit reports	-0.074	4.10%
	22	International politics and cooperation	0.010	2.52%
	27	Miscellaneous international news	-0.032	1.64%
	29	Acquisition of company shares	0.004	2.11%
	32	Stock market developments	-0.121	2.72%
	40	Shipyards demise	-0.084	1.92%
	42	Restructuring technology engineering companies	-0.008	2.69%
	44	Innovation in industry	0.046	1.67%

4.2 Sentiment

The tone of newspaper coverage has been argued as an essential variable to understand a technology's legitimacy. Based on the above notion of topic sentiment, we assessed the weighted sentiment of the wind power corpus over time (Figure 6). Overall, the topic sentiment is negative for 29 out of 44 topics (Figure 6a). Two negative outliers are remarkable: *wind turbine effects on humans and animals* (#28, $ts = -0.22$) and *legal conflicts and law-making* (#33, $ts = -0.2$) display distinctively negative topic sentiment. We notice that the weighted sentiment has a decreasing trend between 2009 and 2014 (Figure 6b). After 2014, the trend of sentiment seems to increase. However, it should be noted that the Prokon insolvency already discussed has a substantial impact on the topic sentiment's temporal development and is majorly responsible for the dent in 2014. Without topic #5 (*Prokon insolvency*), the weighted sentiment is decreasing steadily.

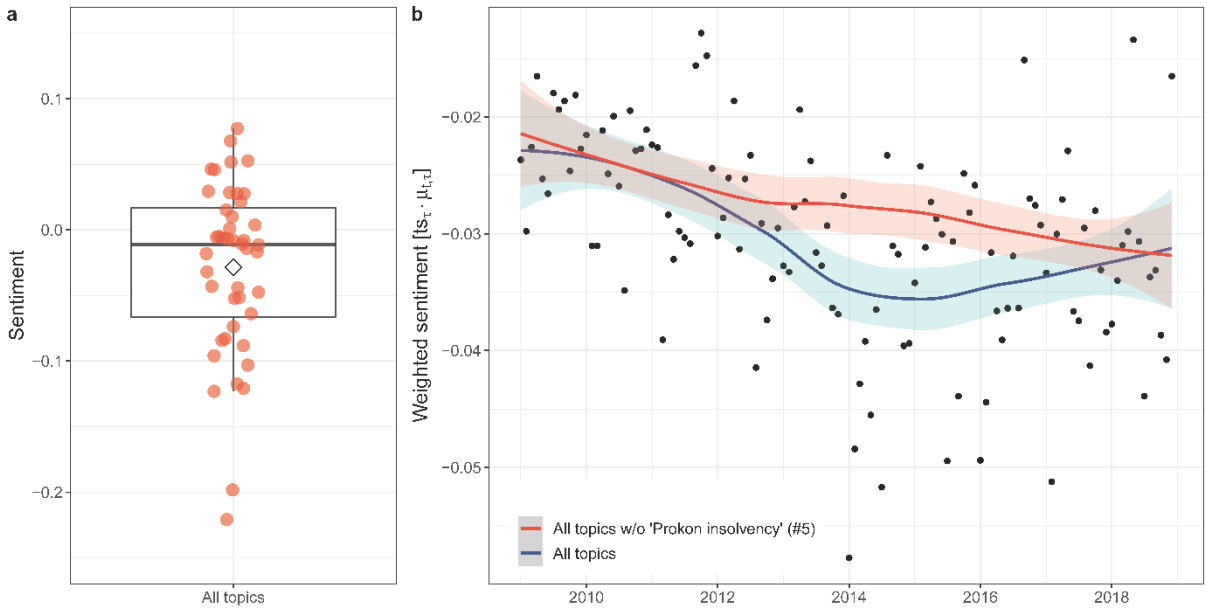

Figure 6: Sentiment analysis of the 44 topics. a) Topic sentiment of all 44 topics. b) Topic sentiment weighted by topic proportions over time. To depict the trend, we fitted a LOESS model with 0.95 confidence intervals. Black dots are monthly weighted sentiment. The red line depicts the trend of weighted sentiment in all topics, the blue line is the trend of weighted sentiment with topic #5 Prokon insolvency removed.

When splitting up weighted sentiment by the three context structures, we find that weighted sentiment of the socio-political environment constantly decreases over time (Figure 7). The weighted sentiment associated with the energy supply system reaches its lowest level around 2013, when costs related to the deployment of renewable energies were heavily discussed (*Electricity prices and EEG surcharge*, #12, $ts = -0.12$). The weighted sentiment associated with topics from the wind industry context appears relatively volatile on an aggregated level. However, a closer analysis of drivers of these changes in sentiment reveals that exceptional topics such as the *Prokon insolvency* (#5, $ts = -0.12$) is responsible for the low sentiment in 2014, and negative *profit reports* (#19, $ts = -0.07$), as well as the *shipyard demise* (#40, $ts = -0.08$) in the aftermath of the financial crisis in 2008/2009 decrease sentiment in 2009 and 2010.

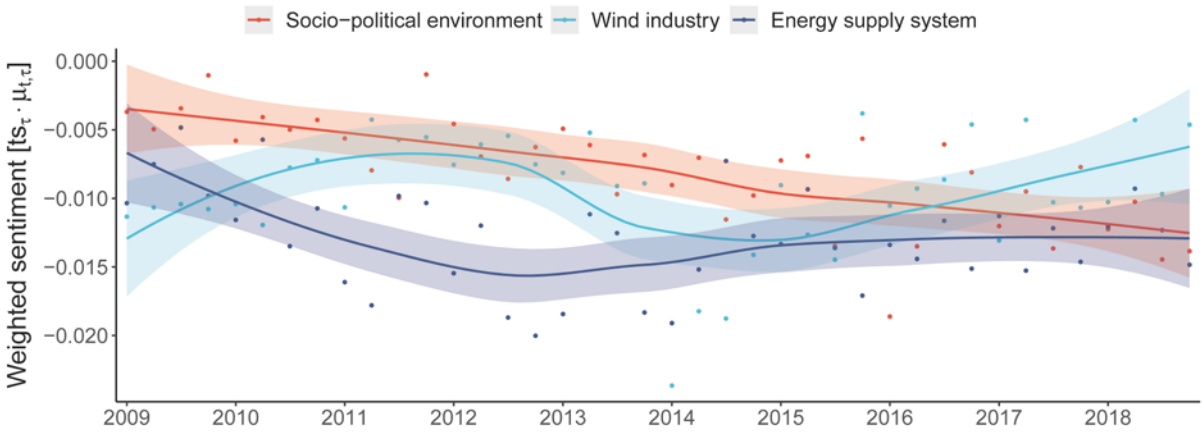

Figure 7: Weighted sentiment of the three context structures. For visualization, data points are fitted with a LOESS model. The shaded areas depict model uncertainty (0.95 confidence intervals).

These results, taken together with the previous analysis of the prevalence of the three context structures, show that the weights of newspaper coverage have changed over time: Where early attention was dedicated to the energy supply system, later, wind power is primarily discussed within its socio-political environment. Together with the constantly decreasing sentiment of the socio-political environment, one might be inclined to think that this already indicates upcoming issues within this context, possibly related to the legitimacy of wind power. However, as we have discussed in sections 3.5 and 3.7, linking the results of our analysis to legitimacy requires a more detailed analysis of the topics' content and its contributions to the four dimensions of legitimacy. Therefore, the next section is dedicated to scrutinize how different topics contribute to the four dimensions of legitimacy.

4.3 The Legitimacy of Wind Power

Surveys on wind power in Germany have repeatedly shown high approval rates (above 80%) (Fachagentur Windenergie, 2019). Wind power generation is supported by the German renewable energy act (EEG), and market development only slowed down in 2018 at the end of the observational period. These indicators suggest that wind power, in general, is considered a legitimate source of electricity, mainly due to its low carbon emissions. However, this section develops a more fine-grained understanding of legitimacy by scrutinizing the four dimensions of cognitive, normative, regulatory, and pragmatic legitimacy.

The previous section showed how the trend of newspaper coverage sentiment developed in the observational period and how wind power is embedded in its context. In this section, we scrutinize the model in more detail and analyze which topics contributed to different dimensions of legitimacy. We close the section by discussing these findings along the temporal dimension (section 4.3.5).

4.3.1 Cognitive legitimacy

Cognitive legitimacy refers to the purpose of wind power and the problems it may be able to solve in general (Table 1). In that regard, within the newspaper corpus, wind power is promoted as a solution or alternative to address environmental problems arising in the context of the energy system: *Nuclear energy (#43)* and *climate change and climate policy (#6)* show negative sentiment ($ts = -0.09$ and $ts = -0.10$ respectively). Nuclear energy has been a controversial issue in the German energy system for decades, and climate change entered political debates in the 1990s (Hake et al., 2015). Wind power is framed as contributing to a power system with low carbon emissions and without nuclear power. Both topics support the cognitive legitimacy of wind power, where the purpose of wind turbines surpasses mere electricity production and aligns well with climate and nuclear energy policy. These topics also show that the interpretation of sentiment as an indicator for legitimacy must be made cautiously, as negative sentiment may also be associated with issue reporting, of which the focal technology is supposed to be a solution.

Additionally, the increasing prevalence of *wind power in culture and everyday life* (#17, $ts = 0.05$) shows that depictions of wind power plants increasingly enter media as a "normal" part of life and landscapes. Wind turbines are described in movie and book reviews and descriptions of everyday life. Such "taken-for-grantedness" positively contributes to cognitive legitimacy (Suchman, 1995).

However, there are also challenges of cognitive legitimacy on the grounds of misalignment of wind power with energy security aspects as in most developed countries, security of electricity supply is taken for granted in daily life (Yergin, 2012, p. 347). Intermittency of electricity production from wind plants is a regularly reported issue concerning the *security of supply* (#41) with negative sentiment ($ts = -0.10$; Figure *10*). Increasing installations of wind parks in the windy northern part of Germany make grid expansions necessary, a fact that further challenges alignment of wind power with its energy system context, as grid expansions become a cause for regular protests (*grid expansion between north and south Germany*, #25, $ts = -0.05$).

4.3.2 Normative legitimacy

Normative legitimacy refers to the guiding principles of what a 'good' wind power plant is (Table 1). As described in section 3.7, we assume that topics covering conflicts are an indication of the misalignment of technology and institutions. We identified four topics associated with legal and regional conflicts (#3, 15, 23, and 33). Siting decisions concerning offshore wind infrastructure and the venue of a large wind power exhibition have been local issues in northern Germany (#15 and 23). *Legal conflicts and law-making* about wind power are reported regularly (#33). Within *regional conflicts with wind energy projects* (#3, $ts = -0.05$), local councils, state governments, and residents struggle over local wind projects during planning and installation. A correlation analysis (Figure 8) reveals two major normative conflict lines we discuss in the following.

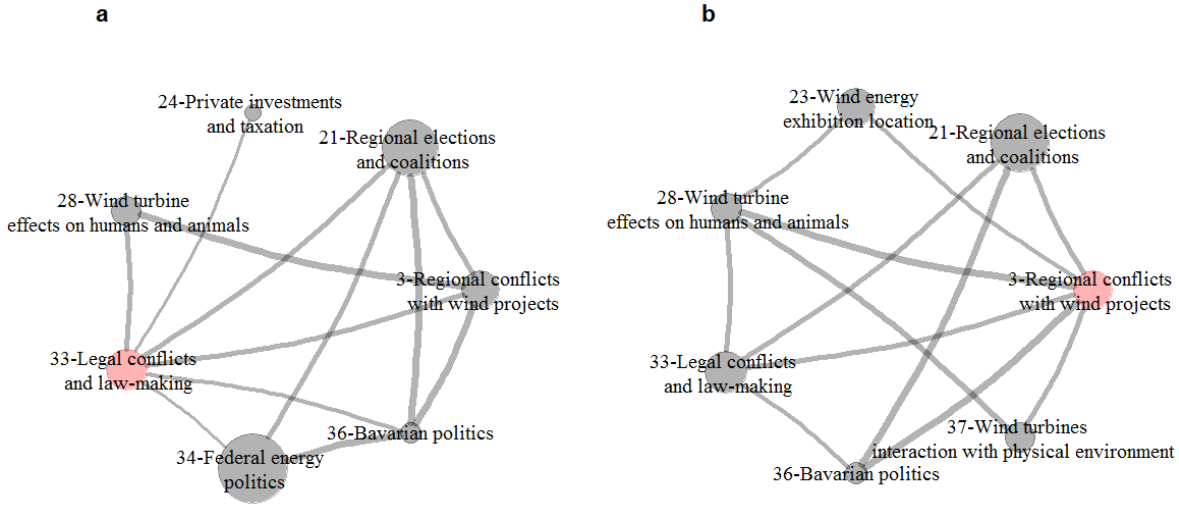

Figure 8: Neighborhood graphs of two conflict topics. a) Legal conflicts and law-making *(#33) relates to various political topics and to* wind turbine effects on humans and animals *(#28). b)* Regional conflicts with wind projects *(#3) relates to political topics as well as* Wind turbines' interaction with physical environment: landscape, weather, infrastructure *(#37), and* wind turbine effects on humans and animals *(#28). Only correlations higher than 0.5 are depicted.*

In the newspaper coverage of wind power, reports on *wind turbine effects on humans and animals* (#28) increase in prevalence over time. Wind power is reported to affect bird and bat life and human well-being by, e.g., infrasonic sound or shadow flicker. Ranking topics by prevalence reveals that their importance grew tremendously: ranked 39th out of 44 in 2009, the topic was ranked 5th in 2018 (Figure 9). Additionally, its sentiment is the lowest among all topics ($ts = -0.22$). Figure *10* shows that in 2018, wind turbine effects on humans and animals have become the most substantial source of negative sentiment in wind power coverage. Negative topic sentiment, increasing prevalence, and its correlation

to conflict topics indicate that wind turbines are perceived increasingly to conflict with societal and environmental values of preventing harm from humans and animals.

Another conflict line concerns wind turbines' placement in the physical environment (*Wind turbines interaction with physical environment: landscape, weather, infrastructure;* #37; $ts = 0.03$). The analysis of topic ranks shows that landscape issues have grown in importance over time (Figure 9). Topic sentiment and close-reading of a subsample of texts show that framing of landscape conflicts is more delicate than potential effects of wind turbines on humans and animals that can refer to specific adverse health effects. Negative impacts of wind turbines on landscapes are often conveyed by contrasting wind turbines' placement to poetic descriptions of landscapes, contributing to a moderately positive topic sentiment. This finding aligns with findings from acceptance research that the perception of landscape issues is more ambiguous and depends on individual characteristics (Ellis and Ferraro, 2016, pp. 34–35). However, the topic's growing importance in the corpus and its relation to regional conflicts on wind turbine projects show that wind turbines are increasingly perceived as misaligned with landscapes and infrastructure.

Both topics point to increasing normative conflicts of wind turbines with their environment. They also indicate that legitimacy issues increase on a local level, where particular projects are materialized. Adverse effects on animals and humans and perceptions of landscapes are already known for a long time from the acceptance literature (Rand and Hoen, 2017). Misalignment with societal values is therefore not a challenge of legitimacy per se, but only becomes an issue when society acts upon it or the misalignment is “commonly perceived” (Geels, 2014; Markard et al., 2016). These results point to an increasing violation of norms by growing wind installations. In a densely populated country, space that can be used uncontroversially to install wind power plants is scarce. The growing number of wind turbines installed in forests since 2011 contributes to this argument (Bunzel et al., 2019).

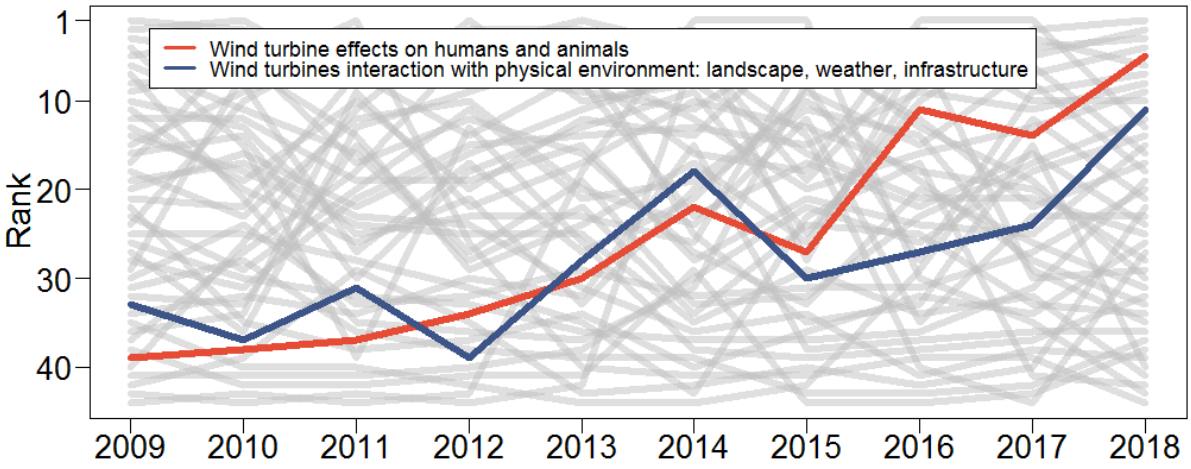

Figure 9: Rank of the topics wind turbine effects on humans and animals *(#28) and* wind turbines interaction with physical environment: landscape, weather, infrastructure *(#37) in the wind power agenda over time.*

4.3.3 Regulatory legitimacy

Regulatory legitimacy refers to the technical characteristics, and formal and regulatory standards wind power has to be aligned with (Table 1). In Figure 8, we have seen that health, environmental, and landscape issues (#28, 37) in the deployment of wind power described above relate to *legal conflicts and law-making* (#33, $ts = -0.2$), indicating that not only societal values are challenged by wind power, but also regulatory issues in moderating stakeholder interests come to the fore: The legal conflicts topic is associated with texts on lawsuits against regional wind power projects, but also general court rulings concerning wind power, including the rights of municipalities or environmental protection agencies with regard to the protection of wildlife, air traffic control, as well as conflicts between federal assembly and the federal parliament. In line with the increased prevalence of lawsuits, a recent study

found that a large fraction of wind power projects is currently sued (Fachagentur Wind an Land, 2019). The largest fraction of lawsuits are filed by environmental protection organizations, citizens‘ initiatives, and private citizens (Fachagentur Wind an Land, 2019). These findings indicate that the increasing wind power expansion leads to frictions of local wind power projects with planning regulations that are within the responsibilities of municipal and state-level governments in Germany. However, it is difficult to precisely pinpoint a general regulatory misalignment, as projects are approved on a case-by-case basis by regional authorities.

This increasing misalignment of regional planning regulations and wind power also manifests in the links of *legal conflicts and law-making* to the different layers of national policymaking (Figure 8) In *regional elections and coalitions (#21,* $ts = -0.01$*)*, wind power is a conflict topic in coalition talks between parties. Many state governments have implemented distance regulations for wind power plants (Fachagentur Windenergie and Land, 2019), with the strictest regulation implemented in Bavaria in 2014 having substantial impacts on wind capacity development (Stede and May, 2020). *Bavarian politics* (#36, $ts = -0.01$) has even been identified as a separate topic. *Federal energy politics* (#34, $ts = -0.04$) is often debated with the states in energy summits and through the legislative process in the federal assembly.

In the discussion of regulatory legitimacy, it is important to notice that we strived to delineate the underlying normative components of the political conflicts (normative legitimacy) from the related legal and political disputes. We distinguish between underlying societal norms (e.g., adverse effects on humans and animals) and the enforced laws and regulations to balance the conflict between norms and wind power.

4.3.4 Pragmatic legitimacy

Pragmatic legitimacy refers to the stakeholders' self-interest and the possibilities to participate in its deployment (Table 1). Figure *10* shows that from 2012 to 2014, *Electricity prices and EEG surcharge* (#12) played a decisive role in the newspaper coverage of wind power and showcased a low sentiment score ($ts = -0.12$). The increasing numbers of installed renewable capacities led to an increase in the surcharge added to electricity bills to refinance the renewable support scheme. Our results show that wind power is associated with increased costs affecting the self-interest of a large share of the population and industry. While benefits of wind power manifest on an abstract level, such as its contribution to an emission reduction of electricity production, its costs become visible for electricity consumers on the annual bills. During that time, an analysis of political debates shows how renewable energy was framed as a burden to electricity consumers (Lauber and Jacobsson, 2015, pp. 154–155).

Furthermore, conflicts over participation in wind power are a common topic of articles associated with *legal conflicts and law-making* (#33). A significant event that showed the risks of profit participation for small investors was the case of the *Prokon insolvency* in 2014, with more than 75,000 persons holding profit participation rights (#5, $ts = -0.12$). The Prokon insolvency also triggered a new law for the protection of small investors (*Kleinanlegerschutzgesetz*) that has been accused of severely limiting participatory options for civic engagement in renewable energy projects (Janzing, 2014). Cooperatives and regional energy concepts are only covered peripheral in the topic we labeled as *marketing of sustainable energy* (#30), whose prevalence decreased over time, even though such citizen groups have been described as a success factor of the German "energy democracy" (Morris and Jungjohann, 2016). Taken together, these three topics indicate that over time, the perception of options to participate in wind power development became more dominated by risks and conflicts, wherefore we conclude that pragmatic legitimacy decreased compared to the beginning of the observational period.

4.3.5 Discussion

In this section, we discuss the presented results collectively and interpret them along with historical events concerning their contribution to the legitimacy of wind power. In line with the results of the

changepoint analysis, we distinguish three periods that structure the discussion (Figure 3). The area graph (Figure 10) depicts topic sentiment (ts), weighted by topic prevalence ($\mu_{t,\tau}$) over time (t).

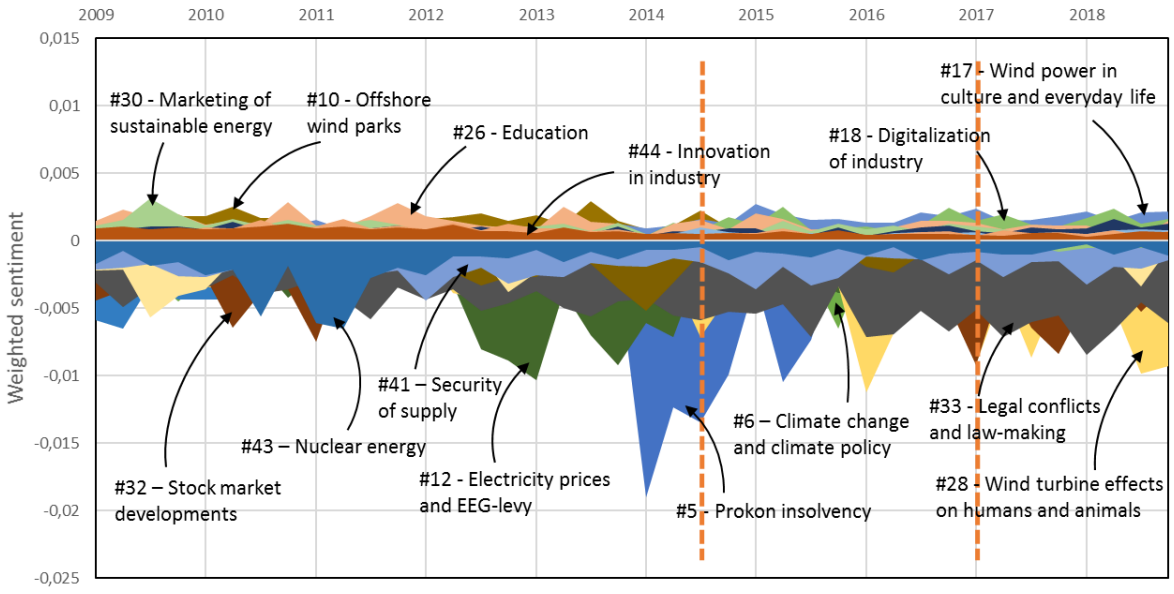

Figure 10*: Area graph of topic sentiment weighted by topic prevalence over time ($ts_\tau \cdot \mu_{t,\tau}$). Topic labels of topics contributing most to the development of sentiment are highlighted. We discuss three periods delineated by orange vertical lines in section 4.3.5.*

4.3.5.1 2009-2014

From the beginning, the wind power support by the EEG favored the development of wind power plants with increasing hub height, larger rotor diameters, and higher turbine capacities. Therefore, wind turbine projects increased their alignment with the centralized energy system. In this period, the prospective role of wind power in replacing nuclear energy after the nuclear incidents in Japan (2011), when fears about nuclear safety were highly prevalent that caused the decision for the German nuclear phase-out and a faster shift to renewable energies, contributes to the cognitive legitimacy of wind power by expanding the purpose of the technology (#43, Figure *10*). A source of misalignment with the centralized energy system are increasing wind turbine installations in the north, necessitating grid extension. Therefore, in 2011 a new legislation to align grid extension and renewable energy development was enforced (*Netzausbaubeschleunigungsgesetz, NABEG*).

Our results show that by the end of this period, two critical challenges to pragmatic legitimacy arose. The fast expansion of renewable electricity production increased the costs that electricity consumers bore via the EEG surcharge (#12, Figure *10*). Therefore, in 2014 the new government limited the expansion of wind power to target corridors and announced the introduction of auctions for wind power by 2017. Additionally, the financial issues and the final insolvency of Prokon in 2014 (#5, Figure *10*) vividly showcased the risks of participation in wind power, threatening pragmatic legitimacy.

4.3.5.2 2014-2016

In this period, the Prokon case rumbled on and finally triggered the introduction of a law that limited possibilities of participation in 2015. Also, the prospective introduction of tenders might have contributed to the disappearance of cooperatives and citizen groups from the media agenda after the first period. Participation has always been an essential source of pragmatic legitimacy of the German energy transition (Morris and Jungjohann, 2016).

In newspapers, the newspaper coverage weights started to shift, and the adverse effects of wind power on humans and animals (#28, Figure *10*) and environmental impacts became more prominent on the agenda (Figure 9), indicating increasing normative misalignment. As local planning law is the responsibility of state and municipal governments, wind power becomes controversial in state-level

election campaigns (#21, 33, 36). The most prominent regulation arising on the state level is the so-called 10H-rule introduced at the end of 2014 in Bavaria that enforced a minimum distance of wind turbines to dwellings of ten times the height of the turbine (Stede and May, 2020).

On the other hand, during that period, wind power was framed as part of climate change mitigation strategies around the Paris agreement 2015. As climate change faced decreasing attention until 2015, the Paris agreements seem to have contributed to the cognitive legitimacy of wind power (#6, Figure *10*).

4.3.5.3 2016-2018

The EEG amendments in 2016 introduced tenders for wind power to increase economic efficiency, and to decrease technology costs further. However, tenders were seen as critical, particularly concerning their effects on the participation of civic groups or cooperatives. Their lower ability to diversify risk and lower economies of scale was seen as increased barriers for successful participation in tenders (Leiren and Reimer, 2018). In the pursuit of higher economic efficiency, the amendments risked pragmatic misalignment. However, governing parties were aware of such issues, and their coalition contract aimed at increasing participatory options (CDU, CSU, SPD, 2018).

In this period, adverse effects of wind power on humans and environmental interaction remain high on the agenda (Figure 9, Figure *10*). The increasing prevalence of legal conflicts (#33, Figure *10*) contributes to the increasing perception of normative misalignment. A survey with wind project developers showcased a high fraction of wind turbines are being complained in court (Fachagentur Wind an Land, 2019), the majority due to alleged species protection issues.

When in 2018, the participation in tenders was well below the auctioned capacities, and wind expansion slowed down, an intense political debate broke loose in which court proceedings related to resident and environmental objections against wind power projects were held responsible for the slow-down. Therefore, a general distance of wind turbines to dwellings of 1000 meters was proposed to reduce friction with local residents' interests (BMWi, 2019a). After the fierce intervention of wind industry associations, the draft was stopped before it became law. Subsequently, the responsible ministry issued an action plan to increase local acceptance and to speed up the permission processes for individual projects (BMWi, 2019b). Legitimacy issues of wind power, therefore, contributed to institutional change in its context.

4.4 Methodological Reflections

In this section, we take a step back and reflect upon our approach's strengths and weaknesses to explore newspaper coverage and legitimacy. Specifically, we discuss which kind of information on legitimacy can be expected by assessing newspaper accounts of a focal technology. Furthermore, we discuss the prospects of the statistical methods employed to assess technology legitimacy.

First, we have already discussed why we think that newspapers are a particularly useful source to analyze legitimacy. From our results, we find that particularly issues in wind power's socio-political environment currently challenge the legitimacy of wind power. However, we would agree with the argument that newspaper coverage is an indicator more sensitive to detect friction in the socio-political environment, while it might be less sensitive for subtle changes in industry-internal dynamics. The main reason for that we see in the audience of newspapers. Issues addressed in newspapers must attract the attention of a large array of citizens, and socio-political issues are more likely to do so. Another source that may support the study of socio-political issues of legitimacy is social media such as Twitter or Reddit. We see the study of social media as a complementary source of legitimacy as very promising as it can include the variety of citizen's judgments of the focal technology while studying media more accounts for judgments of institutional evaluators (Etter et al., 2018). To gain more insights into legitimation strategies within the industry, one could include other sources, such as professional industry journals or stakeholder interviews. However, this was not the central goal of this study.

Second, the way we delineated context structures did not always divide the context along clear-cut system bounds, as, for example, it divided topics referring to politics into the socio-political environment and energy supply. The structures we have identified may well be described by Geels' (2014) triple embeddedness framework (TEF) as *industry regime*, *economic (task)*, and *socio-political environment*. However, a formal combination of TEF and technology legitimacy in a common framework was beyond this article's scope, mainly due to the partially different theoretical foundations of both concepts. We have to leave this potentially fruitful path of development for future research. On the other hand, the divide of context elements into the three environments proved highly informative, particularly regarding the separation of regional and federal political levels to different environments. The separation nicely shows which issues are focused on by different levels of policymaking.

Third, a shortcoming of our approach to measuring topic sentiment is that it is inherently independent of time and does not allow for changes in topic sentiment over time. While in the literature on product review sentiment, several approaches exist that combine sentiment analysis with topic modeling, none of them can also account for temporal changes in topics or sentiment (Alam et al., 2016; García-Pablos et al., 2018). As the temporal dynamics were of fundamental interest to our research endeavor, we decided to use STM that has proven significant performance improvements compared to classical topic modeling approaches when temporal structures are considered (Roberts et al., 2016a). We alleviated the dynamic limitations of our notion of topic sentiment by refining the model by a high topic resolution of 44 topics. The high topic resolution creates topics with a higher semantic coherence; therefore, we expect that changes in sentiment are also reflected in the topic structure changes. Our procedure of weighting topic sentiment with topic prevalence to create a temporal assessment of sentiment over time gives a good approximation of sentiment change.

5 Conclusions

The legitimacy of wind power is fundamental for policymakers to pursue ambitious climate and renewable energy targets. For stakeholders in the wind industry, legitimacy is a prerequisite to maintain stable relations with its environment and to ensure enduring resource flows. First and foremost, our study contributes to a detailed assessment of the legitimacy of wind power in Germany and may illustrate future developments in other national contexts.

To achieve that, we developed an approach combining natural language processing and statistics that incorporate the basic building blocks of technology legitimacy. Our approach was able to identify the contexts of wind power and quantify factors such as sentiment and salience for different topics or issues of wind power, and, equally important, allows us to analyze legitimacy's processual character. In investigating long-term processes of socio-technical change, scholars of technology legitimacy and sustainability transitions alike face the challenges of assessing large amounts of textual data over time and identifying changes of institutional arrangements within the data. Exploiting the advantages of STM to include covariates in estimating topic proportions, the set of methods we propose can account for both: large amounts of text and shifts of discursive patterns over time. Weighted sentiment serves as an indicator to identify arising controversies along the time axis. Another advantage of our approach is that we can assess the complete set of available articles from four newspapers. We can therefore reduce potential bias from single sources and include information that otherwise might be missed. We hold that our approach is very suitable to complement other methods in the pursuit of understanding technological and social change.

Legitimacy has been described as a social process in which legitimation first arises on a local level, diffuses to new situations, and finally becomes validated on a general level (Johnson et al., 2006). Our results indicate that a similar process may also be at play in the delegitimation of technology, a finding that contributes to the legitimacy literature and the socio-technical transitions literature that has increasingly become concerned with the politics of ongoing transitions (e.g., Markard, 2018). While wind power had a generally high level of legitimacy over the past decades, its legitimacy is increasingly challenged locally, where individual projects conflict with societal values and regional planning law.

The case study showed that these conflicts increasingly diffuse into the general perception of wind power and enforce regulatory action on a general, federal level. Also, local protest groups started to collaborate on a federal level and become more involved in federal politics. While wind power still is a legitimate source of electricity mainly due to its role in reducing carbon emissions, these results point to the need for continued political action, particularly on the regional level, where recent scholarship revealed that particularly pragmatic and normative legitimacy might be highly location-specific (Rohe and Chlebna, 2021).

Our results point to an increasing misalignment between the energy supply system institutions and the socio-political environment context. More specifically, the energy supply goals aim to increase the number of wind turbines to decrease greenhouse gas emissions of energy supply. The support scheme employed to pursue these goals is inclined to favor large-scale wind turbines and wind parks. The introduction of renewable energy tenders in 2017 to foster competition and further price declines even contributes to that. However, when space for turbines increasingly gets scarce, the expansion of wind power leads to increased friction with environmental values, health concerns, and perceptions of landscapes.

Such misalignment has severe consequences for the engagement of actors in the wind industry. Since 2018, the installations of onshore wind turbines have reduced, and the participation in renewable energy tenders is below the advertised capacities. Within the federal wind power policy, a debate on minimum distances of wind turbines to dwellings broke loose, threatening to reduce areas available for installing wind turbines even further.

Our results show that regional issues with health, environment, and landscapes have increased in prevalence over the past years, challenging wind power's legitimacy on normative grounds. Additionally, the risks of financial participation have come to the fore, along with regulations that may have adverse effects on the participation of civic groups, such as the introduction of tenders for wind power. This participation has long been said to be a cornerstone of the success of the German 'Energiewende' (Morris and Jungjohann, 2016), and participation is an essential ingredient of pragmatic legitimacy. Policymakers, therefore, could more actively engage with issues of participation and pragmatic legitimacy to make the benefits of wind power more visible to residents and balance the perceived adverse effects of wind power.

While wind power may be a particular case in some instances, it is important to note that wind power is a technology of high importance in transitions towards electricity systems with low emissions. Local conflicts and acceptance issues are, in fact, not a German particularity but have been observed in various countries (Ellis and Ferraro, 2016; Rand and Hoen, 2017). Therefore, the case study is informative beyond national borders and points to the challenges of legitimacy that wind power might also face in other national contexts. Additionally, we think that the continuous reproduction of legitimacy is an issue that might also be encountered by other technologies in the context of maturing long-term sustainability transitions.

From our case study, additional promising directions for future research can be delineated. As our sample was restricted to national newspapers, future research could delve into local newspapers to identify local specifics of different conflicts. While acceptance research has arguably contributed to an understanding of local conflicts (Reusswig et al., 2016; Wolsink, 2007), analysis of local media framing issues can yield insights into how such conflicts are communicated and reproduced (Hindmarsh, 2014). Our study focused on one primary data source to study legitimacy. Future research could include different perspectives, such as expert interviews or sector-specific journals and online media outlets or social media. Apart from research on the specific case, future research can show whether our proposition to conceptualize technology context with Geels' triple embeddedness is fruitful to understand technology legitimacy better.

6 Author contributions

JDH: Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - Original Draft, Visualization; MO: Software, Validation, Investigation, Data Curation, Writing - Review & Editing; DK: Writing - Review & Editing.

7 Declaration of interest

None.

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8 Vitae

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9 Appendix

9.1 Topics with description

Table A. 1: Topic labels and topic descriptions after close-reading a sub-sample of the most representative articles per topic.

#T	Topic	Summary	Mean Prevalence [%]	Rank
10	Offshore wind parks	Articles comprise news on offshore wind projects, on the start of projects, on the start of feed-in of power, or investment decisions and the repair of turbines.	4.71	1
19	Profit reports	Wind energy is mentioned in regular profit reports where different companies are presented along with key performance indicators.	4.10	2
34	Federal energy politics	The articles cover federal energy policy decisions: nuclear phase-out, the renewable energy act (EEG), offshore wind grid connections, and energy summits with the federal states. Some states are particularly interested in the EEG remuneration for wind and biogas.	3.95	3
9	Share of energy carriers in energy demand	The articles present the shares of energy sources in electricity and energy demand. They often emphasize the increasing shares of renewables in the electricity sector.	3.80	4
12	Electricity prices and EEG surcharge	The EEG surcharge is seen as a significant driver of the German electricity prices. While the surcharge decreases in 2017, household prices increase due to higher grid costs. Industry customers are exempted in parts. Wind power is associated with higher electricity prices.	3.36	5
21	Regional elections and coalitions	The articles discuss the politics of the federal states. Wind energy is a conflict topic between parties in the formation of governments and coalitions.	3.21	6
38	Transition of the energy system	The articles cover prospects and issues of an energy system transition holistically. The articles discuss the whole energy system, grids, demand, production, flexibility, storage, and heating and acceptance.	3.01	7
31	Concepts of societal progress	High probability articles comprise interviews or long comments of scientists or politicians on their visions of societal progress aligned with environmental values and climate change mitigation.	3.00	8
13	Wind power capacity development	The articles discuss the expansion of wind power capacities. From 2015 onwards, the new support regime is discussed along with its pull-forward effect and declining capacity installations in 2018.	2.86	9
17	Wind power in culture and everyday life	Several movies and books are discussed that include wind power plants in some form. Besides, descriptions of everyday life contain references to wind power plants.	2.84	10
25	Grid expansion between north and south Germany	Articles discuss the prospects of the planned grid expansion projects between north and south Germany. Most wind capacities are installed in the north, while electricity demand is also high in the south. There are bottlenecks in the transmission grid. Due to protests, the projects should install underground cables as opposed to overhead lines. The grid development plan (Netzentwicklungsplan) caused a peak in prevalence in 2012.	2.72	11
32	Stock market developments	The German stock market index (DAX) is reported regularly. The German turbine manufacturer Nordex is denoted in the TecDax. Over time, their stock price fluctuates with incoming orders and political developments. In 2018, Nordex was the weakest title in the TecDax (losing 57%).	2.72	12
42	Restructuring technology engineering companies	Articles discuss technology company developments. E.g., Siemens and General Electric restructure their companies by splitting up different fields. Siemens fusions its wind power company with Gamesa. Unions fear the loss of jobs.	2.69	13

#T	Topic	Summary	Mean Prevalence [%]	Rank
22	International politics and cooperation	Articles discuss world politics and relations between countries, particularly China and the USA. The Desertec initiative forms a consortium of European companies to produce renewable power in northern Africa.	2.52	14
14	Wind turbine world market	Articles follow the wind turbine world market's development: A low number of orders after the financial crisis 2009 and corresponding overcapacities are observed. Large competition from 2012 leads to low prices, which relaxed in 2014 when companies have gotten more efficient. In 2017 the market became more insecure again: world trade issues, low prices, and the new support regime in Germany increase uncertainty, in which German companies focus more on the international market.	2.51	15
5	Prokon insolvency	The wind park operator and investor files bankruptcy in 2014, more than 75,000 persons held profit participation rights. Investors press fraud charges and delayed filing of insolvency.	2.42	16
33	Legal conflicts and law-making	Wind power is the subject of legal proceedings of different legal issues and is a conflict topic between the federal assembly and parliament. This includes proceedings due to siting decisions, species protection, or property rights.	2.36	17
39	Transformation of large electricity companies	The articles discuss the large transformations that German utilities and PNE (a wind power planner) go through. The companies' restructuring with the ongoing energy transition is discussed and goes in hand with personnel changes. Wind energy is part of their portfolios.	2.33	18
41	Security of supply	The articles discuss the conventional power plant fleet and its importance for maintaining the security of supply. Particularly in the south of Germany, there is not enough capacity, and the grid connections to the north are not strong enough. On weekends, electricity in wholesale markets is cheap or has negative prices. The intermittency of wind is related to all issues.	2.23	19
4	Innovation in energy generation	Articles cover the technology development of wind power plants and related technologies. For example, wooden towers or damage detection by robots are discussed, as well as kites for power production. Also, other innovative technologies, such as wave energy, are mentioned.	2.18	20
3	Regional conflicts with wind projects	Municipalities, federal states, and local courts influence the installation process. Some block the process; some try to steer. There are many conflicts within local councils/governments and with residents. Many articles focus on the southwest of Germany: Communities in Baden Württemberg or Rheinland-Pfalz.	2.17	21
6	Climate change and climate policy	Articles discuss climate change and different climate policy approaches, from the R&D expenditure to CO_2 markets and subsidies for technologies. The Paris climate agreement is discussed. Wind power should play a role in low-CO_2 electricity production.	2.16	22
2	Investment in wind projects and the wind industry	The articles discuss the many options of sustainable investment, including wind power. A variety of fonds exist, but the market is relatively small. Investors are increasingly interested in sustainable investment. Also, risks and opportunities are revealed.	2.15	23
23	Wind energy exhibition location	Schleswig-Holstein (SH) and Hamburg fight for years over the right to organize the world's largest wind exhibition/fair (2011-2013). The conflict concerns the federal state governments as well as fair organizers and wind turbine manufacturers and affects the relations between Hamburg and SH. Other policies of regional importance are mentioned.	2.13	24

#T	Topic	Summary	Mean Prevalence [%]	Rank
30	Marketing of sustainable energy	The articles discuss different concepts of the provision of renewable energy to end-users. Different actors play a role: cooperatives, municipal utilities, companies offering renewable tariffs. Both heat and electricity are a topic, also coupled in regional energy concepts.	2.13	25
29	Acquisition of company shares	Companies buy shares or merge with other companies. Wind energy plays some role in all of the acquisitions.	2.11	26
43	Nuclear energy	The decisions on the phase-out of nuclear energy are discussed. Several countries decide to phase-out after the Fukushima nuclear accidents. Wind power is discussed as an alternative for power production, whose expansion should be enforced.	2.11	27
40	Shipyards demise	Shipyards in Germany struggle with the financial crisis in 2009; many shipyards search for new investors or go bankrupt. A wind manufacturer buys Nordseewerke to produce offshore wind components. The Nordseewerke file for bankruptcy in 2012.	1.92	28
8	Electro-chemical energy production and storage	Articles report innovation and research findings on fuel cells, electrolysis, methanation, osmosis power, redox-flow batteries. (Excess) wind energy can be stored with such technologies.	1.86	29
26	Education	The articles discuss study or education programs with a focus on renewable energies.	1.79	30
28	Wind turbine effects on humans and animals	Articles report that wind turbines endanger whales in the Baltic and northern sea by acoustic noise, (subsonic) noise is unhealthy for humans, or that wind turbines kill birds and bats.	1.71	31
44	Innovation in industry	The importance of innovation and progress in the industry for the German economy are emphasized. Different branches of the industry also contribute to the production of wind turbines by producing innovative materials.	1.67	32
37	Wind turbines' interaction with physical environment: landscape, weather, infrastructure	Articles describe landscapes and the positioning of wind turbines therein. Some wind turbines are in conflict with air traffic control. Also, storm damage is reported, or flashing lights on top of the turbines that have visual effects at night.	1.66	33
27	Miscellaneous international news	The articles discuss different countries and domestic issues, e.g., corruption or mafia structures, economic struggles, or remaining in the European Union (Brexit, UK). Wind power is a minor topic in most articles.	1.64	34
7	EU energy policy	The European Union implements the internal energy market, controls renewable support schemes, organizes summits for new energy efficiency measures, and adopts renewable targets.	1.57	35
15	Offshore-Cluster North Sea	Bremerhaven wants to build an offshore wind terminal and struggles over siting decisions and competition from Cuxhaven, where Siemens decided to build a plant for turbines in 2015, and Lower Saxony (Niedersachsen) plans an offshore wind cluster.	1.56	36
35	Sustainable urban development	Several projects are discussed that include renewable energies to urban development pursuing the creation of sustainable quarters in cities. Many projects convert existing infrastructure and include wind energy.	1.54	37
16	Wind park impact on shipping and coast	Articles discuss collision risks of ships and wind farms, new challenges for installers of offshore wind and wind parks on islands, as well as threats to the environment.	1.39	38
18	Digitalization of industry	Reports discuss the different aspects of the digitalization and usage of data analytics in the industry, including energy. Predictive maintenance and forecasting of weather conditions for wind turbines are an application.	1.36	39

#T	Topic	Summary	Mean Prevalence [%]	Rank
11	SMEs in the German industry	The German industry is comprised of many SMEs. Those are presented here. Some also produce parts for wind turbines and plants.	1.26	40
36	Bavarian politics	The conflict between Aigner and Seehofer is a common topic in Bavarian energy politics. Also, election outcomes are discussed, and the Bavarian "energy dialogue" within which Bavaria discussed the energy transition with stakeholders. Seehofer blocks the wind expansion by regulations that ensure a minimal distance to dwellings.	1.22	41
1	Alternative fuels for transport	Articles discuss electric vehicles, but also hydrogen fuel cell vehicles for personal transport. (Excess) Wind energy could be used to charge cars and produce hydrogen.	1.20	42
20	Natural resources utilization	Articles report on rare earth elements, agriculture, and bioenergy. Wind energy is regularly mentioned as an application field of rare earth materials and compared to bioenergy generation. From 2016 onwards, reports on environmental issues with insects or birds due to herbicide and insecticide usage and wind energy.	1.18	43
24	Private wealth building and taxation	Analysis of private investments profitability and tax advantages.	1.00	44

9.2 Exclusivity and semantic coherence

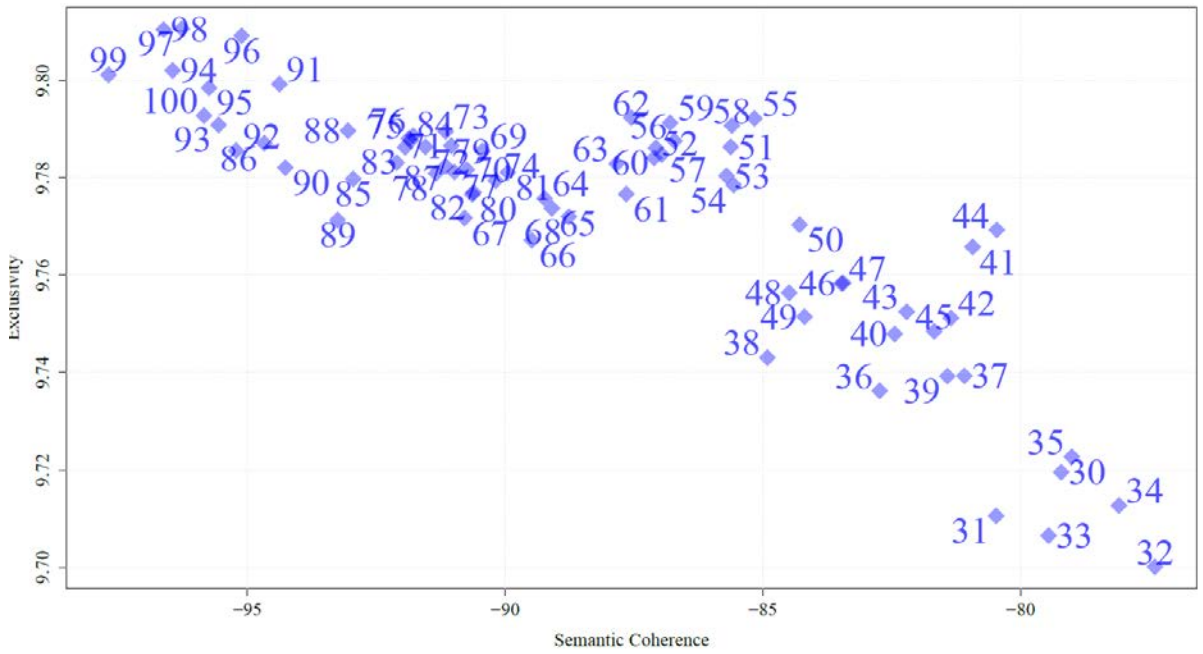

Figure A. 1: Semantic coherence and Exclusivity of topic models from 20 to 100 topics, given a spectral initialization.