The Legitimacy 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 and statistical methods 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 is 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, structural topic model, natural language processing, text mining

1 Introduction

Climate change and the need to reduce greenhouse gases call for rapid transformations of national systems of energy generation and usage. Often termed as 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 to employ 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, namely the technology’s context and sentiment and salience of the various topics or issues that contribute to cognitive, normative, regulatory, and pragmatic legitimacy.

The remainder of the paper is structured as follows: 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.

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 of 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, or social values and norms (Markard, 2018). 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 sociotechnical system. Institutions give structure to social interactions and are themselves socially constructed (Markard et al., 2016). Institutions are belonging to the context of the focal technology. Common frameworks of legitimacy regularly divide the institutional structure into different dimensions or pillars (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 (Table 1). 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). Furthermore, pragmatic legitimacy 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 pillar most susceptible to change by policies or stakeholder behavior (Jansma et al., 2020; Suchman, 1995). 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.

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

Type of institution	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?	

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.

Technology legitimacy acknowledges that the context or external conditions can change. External conditions of technology comprise the institutional structures, other innovation systems, political structures, or other global developments. 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, we argue that media coverage is a well-suited indicator to assess legitimacy. This section aims to point out the importance 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 and Suchman, 2017, p. 14). In the following, we argue that media is a significant source of legitimacy due to its close relations to other potential sources. The process of framing in which news texts are produced was described as the social interaction of journalists with political and societal actors that each bring their vested interests to the

table, albeit lately framing studies largely ignored these basic premises (Carragee and Roefs, 2004; Entman, 2007; Vliegenthart and van Zoonen, 2011). Therefore, it is reasonable to assume that different sources of legitimacy can be reflected in media accounts, or, to put it in Deephouse's (1996, p. 1027) words: when matters arise that render an organization's actions illegitimate, "comments and attacks will occur, and the media will report such comments". With regard to technology, the production of legitimacy has been depicted as a framing struggle of the involved actors, where media attention is argued to be the best indicator for public attention (Geels and Verhees, 2011, p. 916). Therefore, we hold that an analysis of the media's framing of the focal technology contributes to understanding technology legitimacy endorsed by the public.

A frequently used definition of framing is: "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). For our study, we are therefore particularly interested in the salience and sentiment of problems, interpretations, and evaluations that point to (mis-)alignment of wind power with institutions in its context.

Scholars have assessed media coverage as a part of their studies to understand technology legitimacy (Binz et al., 2016; Geels and Verhees, 2011; Jansma et al., 2020; Markard et al., 2016). However, their indicator sets consist mainly of *salience* (i.e., the frequency of the coverage of the focal technology) and *sentiment* (i.e., the tone of coverage), without assessing the content in detail. One recent exception is a study by Jansma et al. (2020) that assesses media coverage based on a coding scheme developed based on the different types of institutions described above. Given the limited scope in terms of content analysis of the cited studies, we propose automated content analysis methods combined with statistical methods to explore the media as a source of technology legitimacy.

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 mostly 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 have been tried, we used “Windenergie* OR Windkraft*” (wind energy OR wind power) consistently 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. Surprisingly many texts from the original databases were found to be duplicated, which exposes text classification to the risk of biased results, as duplicates 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 of 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 a 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 that add 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.

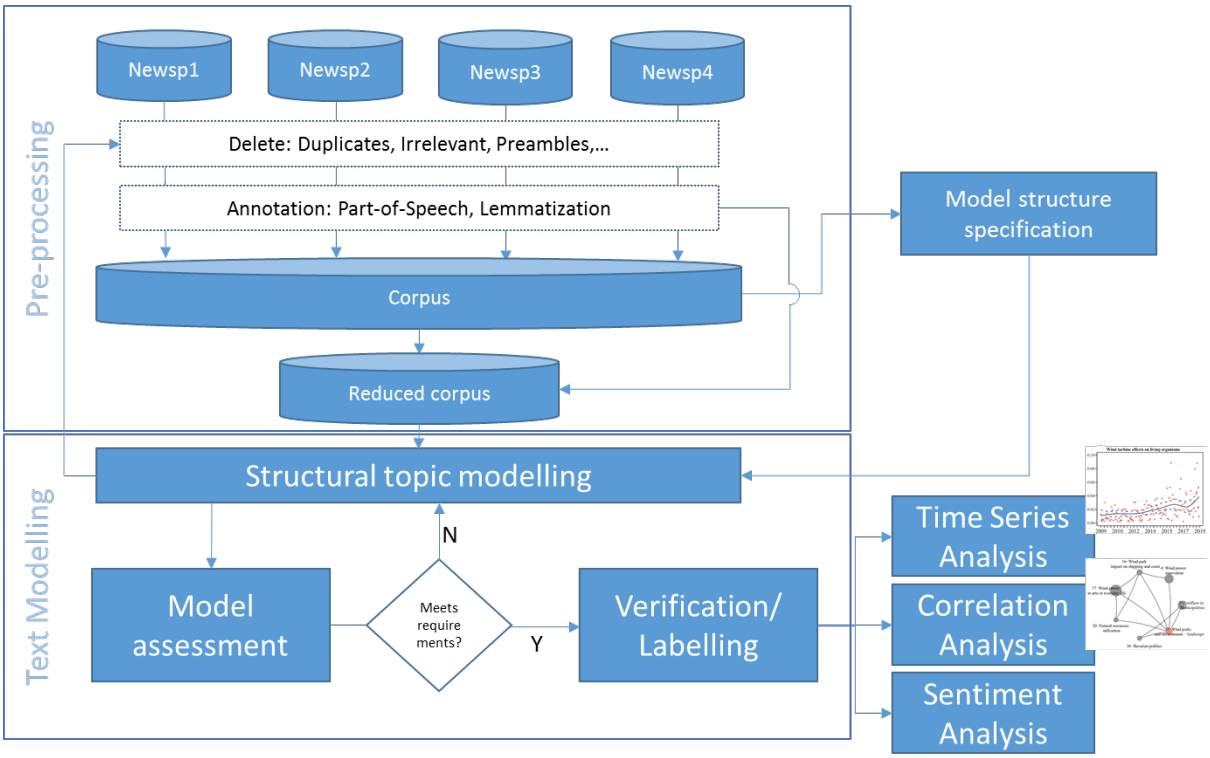

Figure 1: Schematic representation of Pre-processing, modeling, and analysis steps.

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 next 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 2 in Section 4.2) 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 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). To ensure that topics do properly account for semantic regularities of the whole set of articles, we have assessed a sample of articles on top of analyzing statistical measures of semantic coherence. 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.

3.6 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 the analysis of 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 understand their relations to legitimacy better. 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. 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*.

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.

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 a short overview of the history of wind power development in Germany to set the scene for the following analysis. Then, we assess the overall salience of wind power in four national newspapers. We delineate three context structures, assess newspaper coverage sentiment, and the changing prevalence of the three context structures over time. Based on this overall assessment, we discuss selected topics and their contributions to the perceived alignment of wind power with 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 4.

4.1 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).

4.2 Change Points, Sentiment, 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 2). Generally, coverage is characterized by long periods of relative 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 4). The attention to this case ceased fast in the same period.

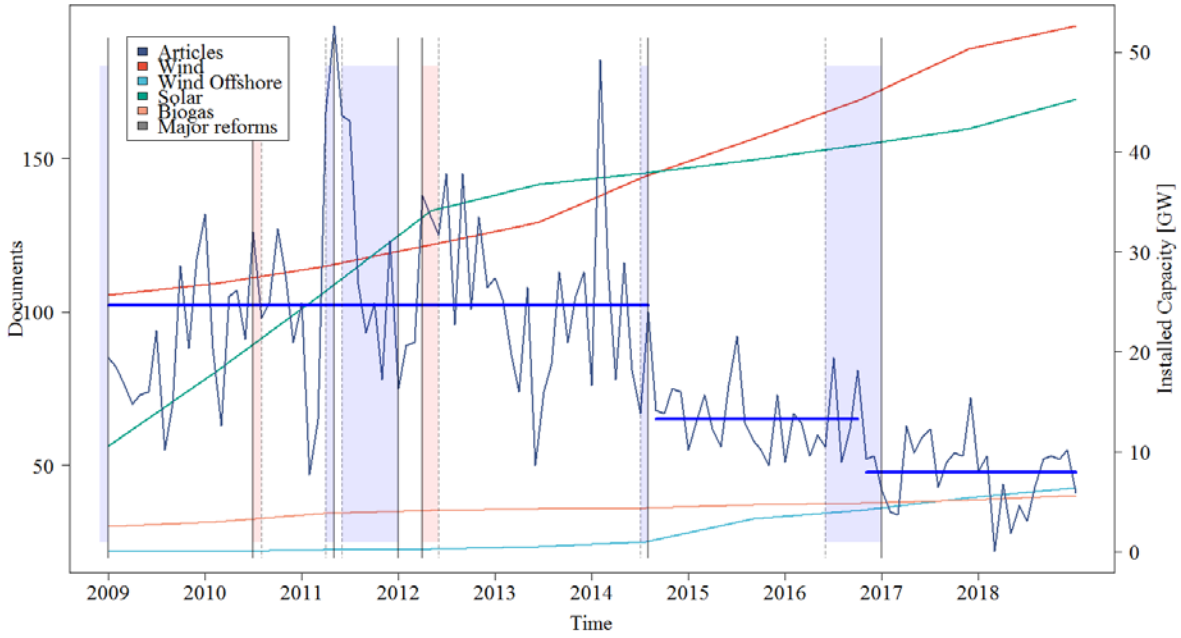

Figure 2: Changepoint analysis of the number of documents per month. Vertical lines indicate EEG amendments. Dashed vertical lines indicate when the amendment passed parliament. The time between parliamentary approval and commencement is shaded blue or red. On the right axis, installed renewable energy capacities of different technologies are plotted.

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 3). Overall, the topic sentiment is negative for 29 out of 44 topics (Figure 3a). Mean (-0.03) and median (-0.01) are both negative. 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 3b). 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. In the following, we will scrutinize the drivers of change in sentiment in more detail by exploring the topic modeling results. We start with exploring the contexts of wind power to assess the institutions that wind power is (mis-)aligned with.

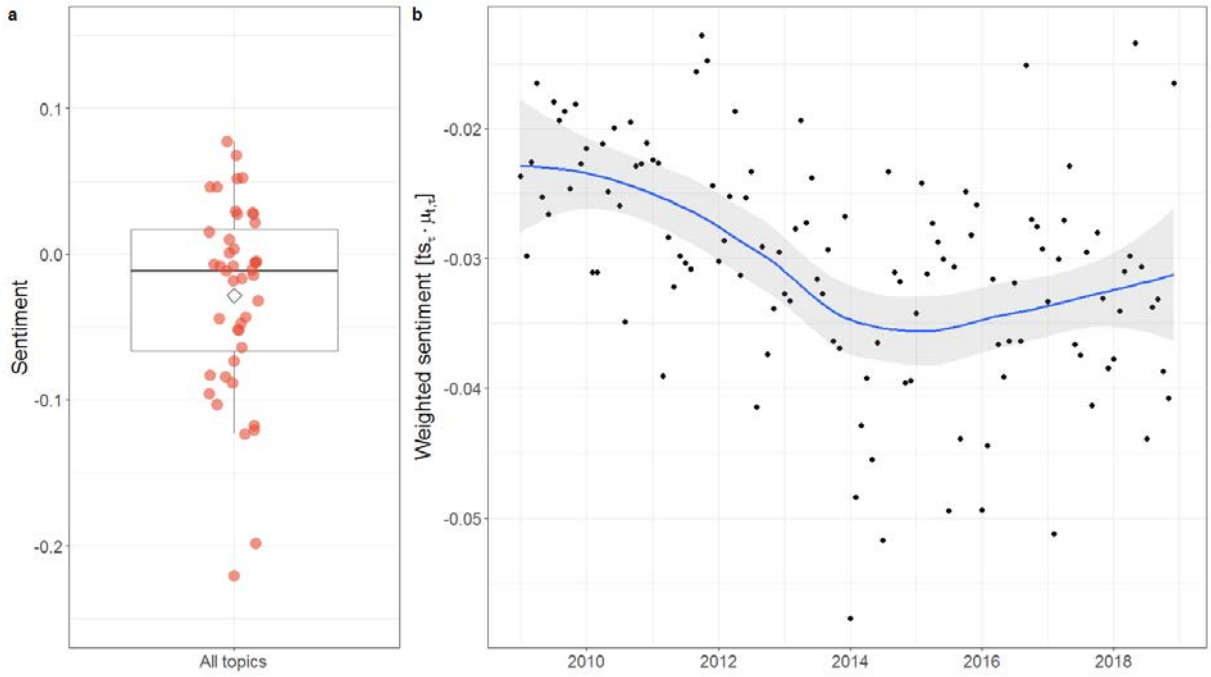

Figure 3: Sentiment analysis of the 44 topics. a) Topic sentiment of all 44 topics. b) Topic sentiment weighted by topic proportions over time. To depict the trend, we fitted a LOESS model, with 0.95 confidence intervals.

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 3.6, 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 its production environment, the *wind industry*[1] (Table 3, Table 4). We now turn to discuss the three context structures in more detail, emphasizing context institutions related to wind power.

The *energy supply system* context comprises of 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 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.

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).

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

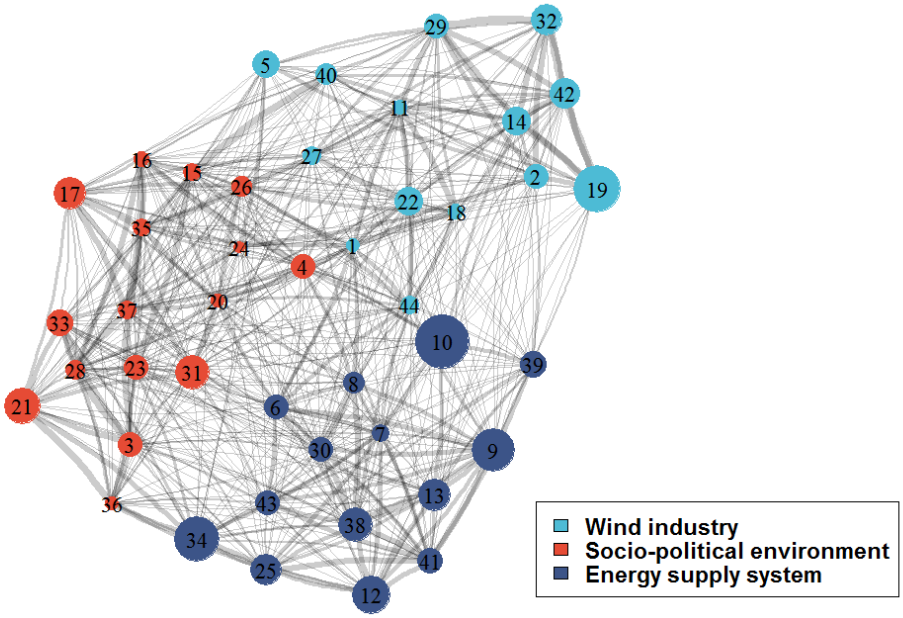

Figure 4: Topic correlation graph. Community structures as identified by optimal modularity. Vertices scaled proportionally to topic prevalence. Edges are scaled proportionally to the correlation coefficients. Please refer to Table 3 and Table 4 for more detailed information on the context and topics.

Table 3: Short description of the three context structures identified by correlation analysis.

Context	Description
Energy supply system	Topics associated with the electricity system and the secure, sustainable, and economical provision of electricity
Socio-political environment	Topics associated with socio-political conflicts and the relationship of wind power to its social and natural environment
Wind industry	Topics associated with aspects of the production and the marketing of wind turbines

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).

To understand the contributions of the different contexts to the media agenda over time, we assess the development of prevalence and sentiment of all three contexts (Figure 5). The analysis shows that the socio-political environment has become most prevalent over time. However, its sentiment constantly decreases. Both developments indicate that friction with the socio-political environment increases. The energy supply system was intensely covered between 2010 and 2015, just after the government announced the German energy transition. At the time of highest prevalence in 2013, it reaches its lowest sentiment, indicating legitimacy issues. The 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.

After analyzing the broader contexts of wind power, in the following, we will discuss our model results in the light of the framework of technology legitimacy. We, therefore, scrutinize our model taking into account the four pillars of technology legitimacy.

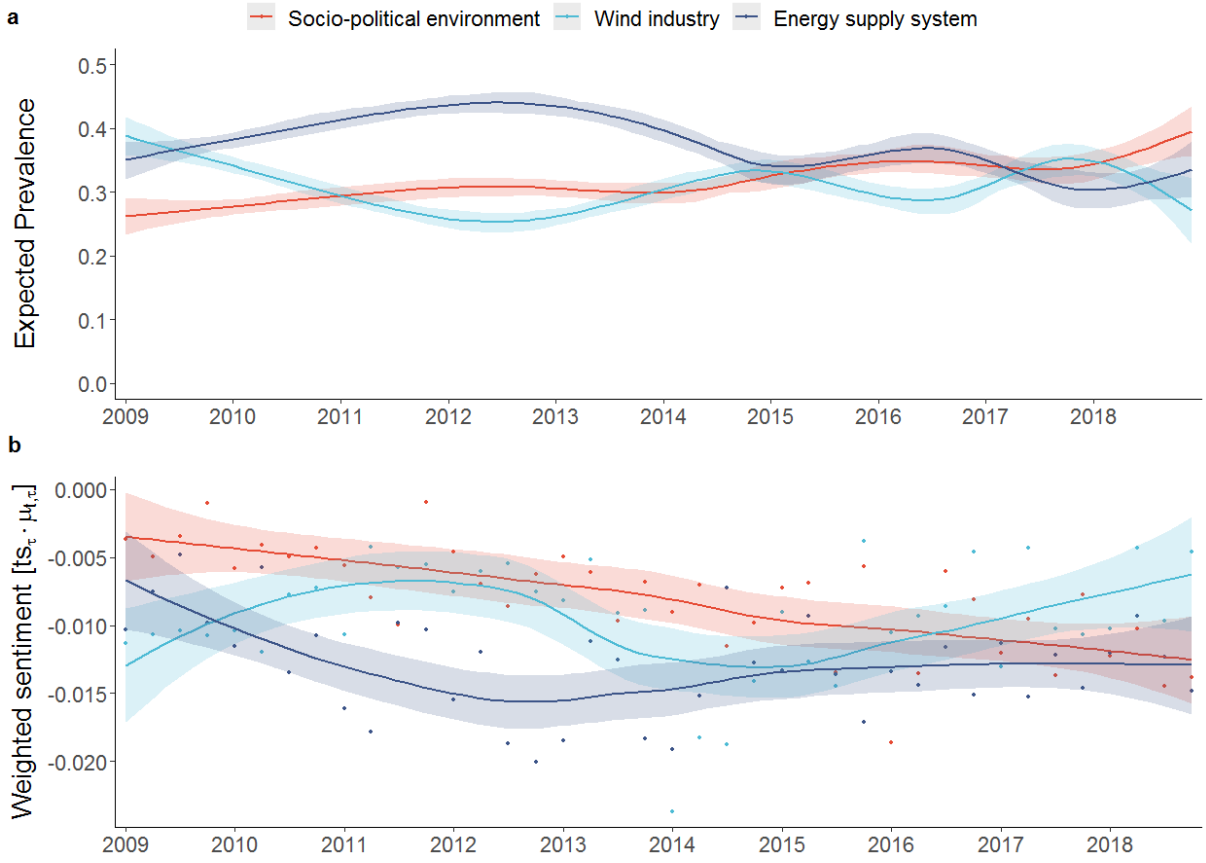

Figure 5: Prevalence and sentiment of the three context structures. a) Prevalence, modeled by the spline model described in Section 3.4. The shaded areas depict model uncertainty (0.95 confidence intervals). b) Weighted sentiment over time. For visualization, data points are fitted with a LOESS model. The shaded areas depict model uncertainty (0.95 confidence intervals).

Table 4: 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 investments 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%

4.3 The Legitimacy of Wind Power

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 sentiment and legitimacy over time. We discuss how the topics majorly responsible for sentiment contribute to the four pillars of legitimacy (cognitive, normative, regulatory, and pragmatic legitimacy). The area graph (Figure 6) depicts topic sentiment (ts), weighted by topic prevalence ($\mu_{t,\tau}$) over time (t).

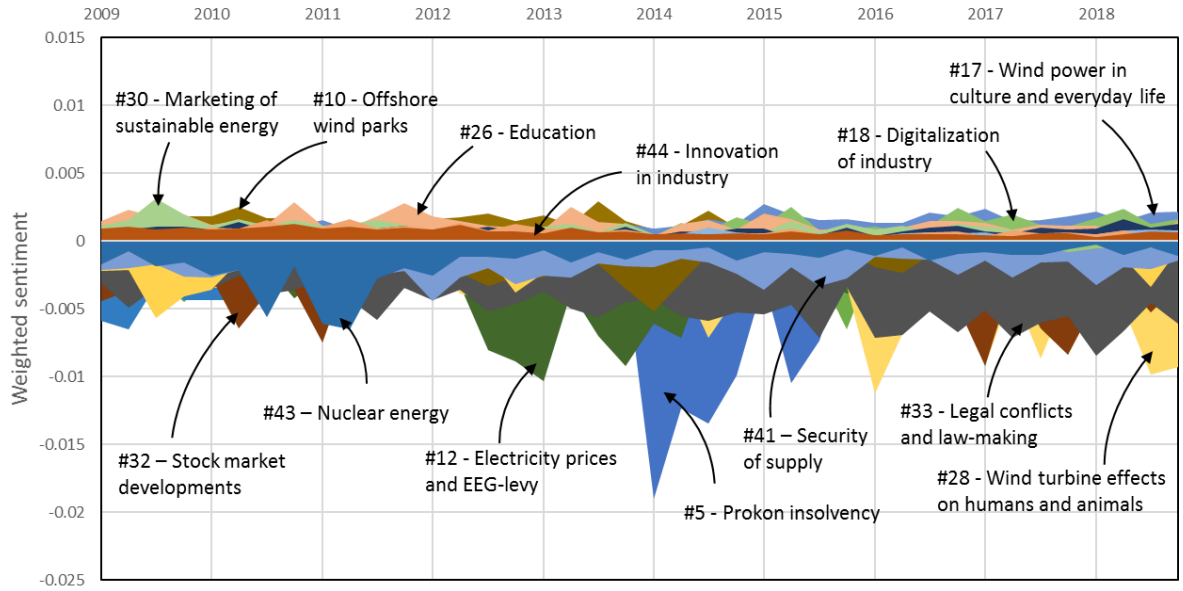

Figure 6: Area graph of topic sentiment weighted by topic prevalence over time ($ts_\tau \cdot \mu_{t,\tau}$). Topic labels of topics contributing most to the development of sentiment are highlighted.

4.3.1 Cognitive legitimacy and alignment with the energy supply system

Cognitive legitimacy refers to the purpose of wind power and the problems it may be able to solve. The context with which wind power's cognitive legitimacy is most associated is the energy supply system, as arguably the generation of electricity is the primary purpose of wind power. For the energy supply system, the policy literature proposes a set of institutions to be considered: economic efficiency of energy supply, the security of supply, and the minimization of environmental impact (Helm, 2002; Schmidt et al., 2019). Therefore, we seek to understand how wind power is aligned with these three core institutions in the energy system context.

Wind power is promoted as a solution or alternative to address environmental problems arising in the (institutional) 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). Events strongly drive both topics: nuclear energy contributes to coverage mostly in 2011, shortly after the nuclear accidents in Fukushima, Japan, that caused the decision for the German nuclear phase-out and a faster shift to renewable energies when fears about nuclear safety were highly prevalent. The topic ceases fast from the agenda afterward (Figure 6). Climate change becomes a topic mainly around the time of the Paris agreement in 2015. Those 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.

Figure 6 shows contributions to the overall sentiment of topics associated with costs and the marketing of wind power. At the beginning of the observational period (2009), the topic *marketing of sustainable energy* (#30) contributes to positive sentiment ($ts = 0.052$) (Figure 6). Articles describe the various

modes of how sustainable electricity is provided by cooperatives, municipal utilities, companies offering renewable tariffs, or regional energy concepts. Over time, the topic decreases in prevalence. 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 of the surcharge added to electricity bills to refinance the renewable support scheme. Our results show that wind power is strongly associated with those increasing costs affecting the self-interest of a large share of the population and industry in newspapers. 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). However, our results also show that the strong negative effect on wind coverage also ceased after the EEG amendments in 2014.

Additionally, cognitive legitimacy is challenged on the grounds of misalignment of wind power with energy security aspects. Intermittency of electricity production from wind plants is a regularly reported issue concerning the *security of supply* (#41), contributing to negative sentiment in coverage ($ts = -0.10$; Figure 6). 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 and alignment with the socio-political environment

Normative legitimacy refers to the guiding principles of what a 'good' wind power plant is. The context within which we expect normative conflicts to occur is the socio-political environment. The sentiment associated with the socio-political environment has been steadily decreasing over the observational period. Additionally, over time it grew to be the most prevalent context that wind power is associated with. Both developments indicate increasing misalignment with institutions situated in the socio-political environment. In the following, we analyze the socio-political environment further.

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 (#23). 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 7) reveals two major conflict lines we discuss in the following.

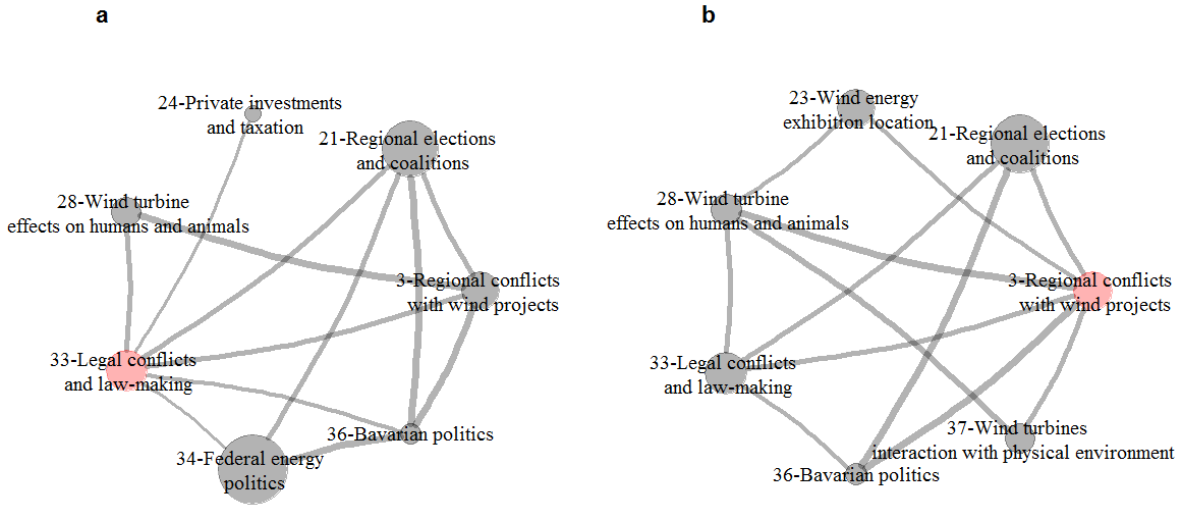

Figure 7: Neighborhood graphs of two conflict topics. a) Legal conflicts and law-making *(#33) relates to various political topics and to* wind turbine effects on humans and animals *(#28). b)* Regional conflicts with wind projects *(#3) relates to political topics as well as* Wind turbines' interaction 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 flickering. Ranking topics by prevalence reveals that its importance grew tremendously: ranked 39th out of 44 in 2009, the topic was ranked 5th in 2018 (Figure 8). Additionally, its sentiment is the lowest among all topics ($ts = -0.22$). Figure 6 shows that in 2018, wind turbine effects on humans and animals has become the most substantial contributor to negative sentiment in wind power coverage.

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 8). 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).

The increase of the importance of those topics points to the fact that legitimacy is increasingly challenged, even though 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).

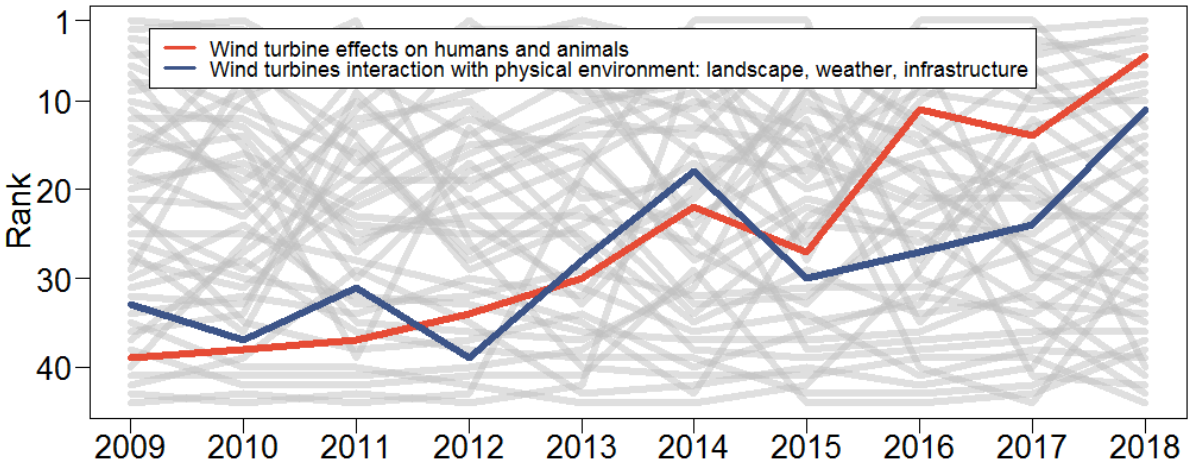

Figure 8: Rank of the topics wind turbine effects on humans and animals *(#28) and* wind turbines interaction with physical environment: landscape, weather, infrastructure *(#37) in the wind power agenda over time.*

4.3.3 Regulatory legitimacy

Regulatory legitimacy refers to the technical characteristics, and formal and regulative standards wind power has to be aligned with. Given that the wind turbine industry has a long history, with market growth in Germany already starting in the 1990s (Bergek and Jacobsson, 2003), the industry can be considered a mature one, with innovation processes having switched to component innovations (Huenteler et al., 2016). Those factors contribute to the expectation that wind power plants' designs broadly align with industrial norms and regulations during the observational period (Markard, 2018). Our analysis shows

no signs of conflict of technological aspects in the wind industry context with formal technology standards.

However, this does not hold for the deployment of wind power. Health and landscape conflicts (#28, 37) in the deployment of wind power described above also relate to *legal conflicts and law-making* (#33, $ts = -0.2$) that have an increasingly negative impact on the coverage of wind power (Figure 6), indicating that regulative legitimacy of the deployment of wind power is increasingly challenged. 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 is filed by environmental protection organizations, citizens‘ initiatives, and private citizens (Fachagentur Wind an Land, 2019).

Legal conflicts and law-making also links to the different layers of national policymaking, mainly through the legislative process that involves the federal assembly and the parliament. In *regional elections and coalitions (#21,* $ts = -0.01$*)*, wind power is a conflict topic in coalition talks between parties. As the state level is mainly responsible for regional planning law, many governments have implemented distance regulations for wind power plants (Fachagentur Windenergie and Land, 2019), with the strictest regulation implemented in Bavaria 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.

4.3.4 Pragmatic legitimacy

Pragmatic legitimacy refers to the stakeholders' self-interest and the possibilities to participate in its deployment. Various topics in our analysis provide evidence on the challenges of wind power's pragmatic legitimacy.

The deployment of wind power contributes to an increase of the EEG surcharge. Our results suggest that technology deployment costs redistributed to consumers by the *EEG surcharge* contribute to negative sentiment (#12). 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), even though such citizen groups have been described as a success factor of the German "energy democracy" (Morris and Jungjohann, 2016). Those results contribute to the impression that the perception of pragmatic legitimacy might be low.

On the other hand, the increasing prevalence of *wind power in culture and everyday life* (#17, $ts = 0.05$) shows that wind power plants' depictions 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" can positively contribute to legitimacy (Suchman, 1995).

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. 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 to 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. An additional 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.

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. Therefore, challenges to the legitimacy of wind power should not surprise politicians and industry. Additionally, our results show that federal energy policy is generally not associated with such regional issues. While this finding is a result of the German political system's federal structure, this finding can also be interpreted as a caveat towards federal policymakers to engage more with local issues when pushing for high renewable energy targets. The disconnect of citizens' local interests and political goals could challenge the legitimacy of support schemes or the entire "Energiewende" transition project. Policies could explicitly address issues of pragmatic legitimacy, namely, fostering regional participation and redistributing profits to residents to reconnect national renewable energy policy goals and citizens' interests.

While wind power may be peculiar 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 peculiarity 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 main 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 Appendix

8.1 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 investments and taxation	Analysis of private investments profitability and tax advantages.	1.00	44

8.2 Exclusivity and semantic coherence

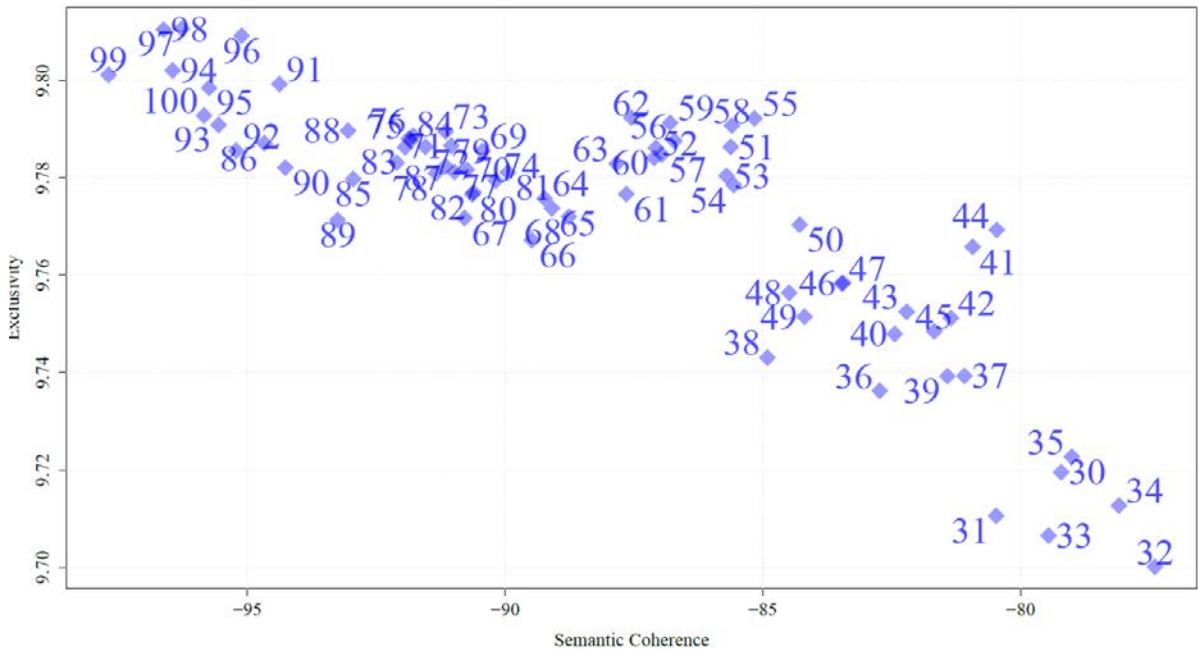

Figure A. 1: Semantic coherence and Exclusivity of topic models from 20 to 100 topics, given a spectral initialization.