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Who cares about coal? Analyzing 70 years of German parliamentary debates on coal with dynamic topic modeling

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Abstract

Despite Germany's Paris Agreement pledge and coal exit legislation, the political debate around carbon-intensive coal remains heated. Coal power and mining have played an important, yet changing role in the history of German politics. In this paper, we analyze the entire parliamentary debate on coal in the German parliament (Bundestag) from its inception in 1949 to 2019. For this purpose we extract the more than 870,000 parliamentary speeches from all protocols in the history of the Bundestag. We identify the 9,167 speeches mentioning coal and apply dynamic topic modeling – an unsupervised machine learning technique that reveals the changing thematic structure of large document collections over time – to analyze changes in parliamentary debates on coal over the past 70 years. The trends in topics and their varying internal structure reflect how energy policy was discussed and legitimized over time: Initially, coal was framed as a driver of economic prosperity and guarantee of energy security. In recent years, the debate evolved towards energy transition, coal phase-out and renewable energy expansion. Germany's smaller and younger parties, the Greens and the Left Party, debate coal more often in the context of the energy transition and climate protection than other parties. Our results reflect trends in other countries and other fields of energy policy. Methodologically, our study illustrates the potential of and need for computational methods to analyze vast corpora of text and to complement traditional social science methods.

Keywords: coal transition, energy policy, parliamentary debates, topic modeling, computational text analysis, framing

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1. Introduction

A swift coal phase-out is essential for keeping global warming well below 2°C [1, 2]. Coal is the most carbon-intensive fossil fuel and one of the biggest contributors to CO_2 emissions across the globe [3]. Committed emissions by current coal infrastructure seriously endanger the achievement of global climate targets [4]. However, how a global coal exit can be organized over the next few decades remains unclear [5]. In countries that heavily rely on coal power, complex political economy factors often hinder transformative processes that decrease this dependence [6, 7, 8]. Here, we investigate the political economy of coal in Germany applying computational methods to better understand the shifting frames in parliamentary debates that accompany political decisions.

The phase-out of coal is part of the larger transition towards sustainable energy systems. This transition is socio-technical, as changes occur in several dimensions [9]: Not only do the technical systems evolve, but the social networks, regulatory frames, and discourses that support them evolve in concert. Besides technical innovations, successful transitions therefore need accompanying institutional and social adjustments in the form of policies or habits that strengthen new and destabilize old industries [10, 11]. Transitions in the energy system have therefore often occurred over rather long periods of time, even though the feasible rate of change of a low-carbon transition is debated [12, 13, 14, 15, 16, 17].

Public and political debates stabilize or change the current energy system [18, 19]. In political discourses, language is used to promote ideas, arguments and positions, to set and organize support for political agendas, to persuade opponents, and to prepare and implement decisions [20, 21]. Especially in democratic states, institutionalized discussion and deliberation is at the heart of policy development and implementation. Policy makers act and exert power by speaking and writing, and it is through speeches, announcements, debates, bills and reporting about them in the media that citizens recognize what is happening in the political system [22]. Shifting discourses are therefore crucial to make policies supporting low-carbon transitions feasible. By establishing and coordinating goals, they enable changes in institutions [21, 23]. Supportive narratives and frames can push new technologies while destabilizing incumbent regimes [24].

Discourse analysis operationalizes the study of spoken or written language in social contexts. Varieties of discourse analysis have been developed in different fields such as frame analysis [25, 26, 27], network discourse analysis [28], historical discourse analysis [29, 30] or critical discourse analysis [31, 32, 33]. Different applications of discourse analysis have been used to advance our understanding of energy transitions at the political level [34, 35, 36]. For example, based on an analysis of dominant frames in UK energy policy, Scrase and Ockwell [37] argue that frames can be leveraged for a low-carbon transition. The study by Rosenbloom [38] identifies the frames used in the struggle over the phase-out

of a Canadian coal-fired power plant and reveals their role in negotiations be-
tween competing interests. Fisher et al. [39] and Fisher and Leifeld [40] apply
discourse network analysis to climate policy in the US and find that discus-
sions over the types of climate policy instruments and their economic impacts
drive polarization. Using the same method, Schmidt et al. [41] identify a pre-
viously overlooked goal in energy policy making in Germany: to strengthen the
competitiveness of the national energy technology industry. The method has
also been used to inform theory explaining changes in advocacy coalitions [42].
Leipprand et al. [43] study plenary speeches about energy policy in the German
parliament and trace how the discussion about the German energy transition
became hegemonic. Leipprand and Flachsland [44] focus on the discourse about
the future of coal in Germany and identify coalitions between political parties,
governments, business organizations, unions and NGOs. They show that desta-
bilization of the incumbent coal technology is associated with intense conflict,
but the status-quo defending coalition begins to lose traction. A similar study
showed that narratives in support of coal are dominant in Japan and that a ma-
jority of stakeholders support the continued high share of coal in the electricity
mix [45]. Other studies exclusively analyze media coverage on energy policy,
such as the study by Osička et al. [46] on the future of coal in Germany, Poland
and Czech Republic. It finds that public media largely mirrors the decision
makers' and energy policy stakeholders' perspectives.

Traditional discourse analysis methods are inherently limited by our capacity
to manually classify, code and analyze large collections of text. For example,
all of the above-mentioned studies use comparatively small samples of textual
data to come to their conclusions. To evaluate how debates develop over long
time periods, researchers need to assess large numbers of documents. There are
many vast and often fast-growing digital archives of text from newspapers, blogs,
and social media as well as different forms of political text (legislation, party
documents, treaties etc.) that are highly relevant for energy social science ('big
literature' [47, 48, 49]). Restricting the analysis of vast text archives to small
samples of text, exposes the analysis to the criticism of 'cherry-picking' [50, 51].
Furthermore, traditional methods bear the danger of including subjective bias
into the analysis [33, 31].

Computational tools from the fields of natural language processing (NLP)
and computational linguistics provide scalability and can help in conducting
content analyses of large document collections [52, 53, 54] where hand-coding
methodologies would need unfeasible amounts of work. This is a particular
advantage when it comes to the analysis of sources that are difficult to pre-
filter such as social media and text collections that span over long periods.
Even though they can certainly not replace qualitative methods, for example
to identify the rhetoric and arguments in specific documents, they can help to
uncover coarse patterns in large collections of documents. Furthermore, they do
not make a strict pre-selection necessary and can classify political texts based
on quantitative criteria. They can thereby reduce selection bias and guide and
focus analyses carried out with qualitative techniques.

Analyses in political science increasingly use topic modeling (e.g. [55, 56,

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57, 51]). Topic modeling is a promising content analysis tool from the NLP toolbox that can uncover the appearance and development of themes in large and otherwise unstructured document collections [58]. Using topic modeling, researchers in political science can explore and synthesize topics in debates comprising thousands of contributions. In combination with metadata evaluation, this allows researchers to explore the topical structure along various dimensions [59, 60, 53, 54]. So far, there have only been limited applications in the context of energy policy. Using topic modeling, Isoaho et al. [61] studied the creation of the European energy union, and Benites-Lazaro et al. [62, 63] evaluated public discourses on ethanol production in Brazil. Other NLP techniques, sometimes in combination with network analysis, have been used to study patent data to evaluate biofuel research [64]; newspaper articles, government documents and scientific papers to investigate agenda setting in ethanol policy [65]; and policy documents to assess municipal climate action plans [66, 67].

In this paper, we apply dynamic topic modeling [68] to study the political debates of energy and climate policy around the issue of coal in Germany over seven decades. Because of their continued political contestation in Germany, coal policies are a suitable topic for a long-term analysis of energy policy. We build our analysis on German parliamentary speeches mentioning coal from the period between 1949 and 2019. In particular, the study sets out to answer the following research questions:

1. How does the parliamentary debate on coal in Germany evolve over time? In which contexts is coal discussed in different periods and how are coal policies framed?
2. How do topics evolve over time? Can shifts in the debate be related to events in energy and climate policy and broader political developments?
3. How do actors from different parties and regions speak about issues around coal? Which topics do they mention together and how is coal thus contextualized?
4. What are strengths and limitations of dynamic topic modeling for the analysis of political debates over long time periods?

To our knowledge, this is the first study using dynamic topic modeling in the context of energy policy and a data set extending over such a long time period. Based on our German case study, we show how applying dynamic topic modeling is interesting for the analysis of political debates as it enables us to analyze them from three different perspectives: First, we trace the emergence and disappearance of different topics over time via their topic scores; second, we observe changes in language within a particular topic over time, and third we identify high-scoring documents in the corpus that are representative for a topic during a particular period. The last perspective allows us to enrich the quantitative topic modeling results with insights from the primary sources.

We interpret the results in light of the distinction between salience and position of political issues. While the first describes the importance policy makers attach to specific topics or policies, the latter refers to their stance (i.e., in favor, neutral or against) with respect to a policy [69, 70]. We further relate

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topics to events and combine our topic model with metadata on speakers and their party affiliation to highlight differences between them.

The remainder of the paper is structured as follows: Section 2 provides details of the case study on coal politics in Germany. Section 3 explains in detail the collection and processing of the text data and the application of dynamic topic modeling to it. Section 4 presents the results of the analysis and puts them into context. Section 5 discusses the findings and concludes.

2. Coal politics in Germany

This study focuses on the role of coal in debates in the German parliament. The history of the political economy of coal in Germany dates far back to the industrial revolution, but we focus here on the time since the foundation of the Federal Republic of Germany in 1949.

In Germany, coal is the only fossil fuel that is domestically produced in significant amounts [71]. Therefore, coal production and use has been a main focal point in the country's energy policy. Coal comes in two main types: hard coal and lignite. Hard coal has a higher energy density and has been mined in underground mines mainly in the Ruhr area and the Saarland. In contrast, lignite is mined in open pits and has a lower quality: its combustion produces more greenhouse gas and air pollutant emissions.

Energy policy in the 1950s and the 1960s mainly focused on first increasing and then stabilizing the production of coal in West Germany [72]. Coal was the most important energy source: apart from electricity generation, hard coal was used in industry, while lignite was to a large extent used for heating (coal briquets). After losing its international competitiveness, German hard coal mining was protected politically via subsidies to counteract the decline of nationally produced hard coal. Because these subsidies were supported by the major parties well until the end of the century, the last German hard coal mine closed as late as 2018 [73].

In the 1970s and 1980s, the German energy mix was diversified: nuclear energy and oil complemented coal as major energy sources. The share of hard coal in the primary energy supply of West Germany dropped from 70% in 1950 to 19% in 1990 [74]. But the oil crises also showed the dependency of the energy system on oil imports, which made domestic coal an attractive alternative energy source.

Controversies over the security and waste management of nuclear energy dominated energy politics of the last three decades much more than issues related to coal power [75]. In the last two decades, energy policy has been strongly influenced by efforts to promote renewable energy and the energy transition [76]. Here, the debate about nuclear energy was formative for the conception of the energy transition [77] – one reason why the coalition of greens and social democrats at the turn of the millennium prioritized a nuclear over a coal phase-out.

Despite rising awareness of climate change and the need to curb emissions, further coal use was justified as a transitory technology ('Brückentechnologie').

This resulted in an extension of coal-fired power plants in the generation system [78]. In the mid 2000s, the second Merkel government with the liberals as coalition partner questioned the prioritization of the phase-out of nuclear over coal but their change of direction was rolled back after the Fukushima incident.

Today, lignite mining continues in three regions: Lusatia, Rhineland, and the Central German mining district, with most of the lignite being used for electricity generation [79, 80]. Hard coal is imported mainly from Russia, the US, and Australia to fuel the German hard coal plants [81].

Reducing coal power is a central leverage point for delivering Germany's Paris Agreement pledges and reaching its goal to climate neutrality by 2050. The history of German energy policy has shown that it is not sufficient to only ramp up renewable energies but that additional policies are needed to also squeeze out fossil fuels. The example of the UK has shown that this is possible with adequate policies [82]. Coal power still has a major share of the German energy mix with about 18% of total primary energy and about a third in the electricity mix in 2019 [83]. However, policies that enforce the phase-out of coal-fired power plants have not been a major issue until recently. It is only in recent years that a coal phase-out has been demanded by major parties and in the media [46] and become an issue in public debate and for policy making [44]. In 2019, the Commission on Growth, Structural Change and Employment (commonly referred to as the coal commission), which brought together representatives from industry, unions, politics, science and environmental NGOs, advised the government on a step-wise phase-out plan with shutdown of the last plants by 2038 [84]. Subsequent legislation has been adopted to organise the coal phase-out, but has been criticized for being too slow and for including too generous compensation for the industry. This might keep coal power plants in operation that would have become uneconomical earlier for other reasons like increasing prices of EU emissions certificates. The plan also bears the risk of missing the 2030 emissions targets that have been agreed at the EU level [85].

Because these trends in coal production and usage were important for industrial development and international security, they have been discussed throughout in the German national parliament, the Bundestag. But not only there: Germany has a federal political system, which is why the states (Länder) – and particularly those with stakes in the coal mining industry – have been important in the discussion and decisions on energy policy.

We focus here on plenary speeches of the German Bundestag. In the plenary, bills are proposed, critizised and defended. While the technical discussions mostly take place in the commissions of the Bundestag, all bills go through two or three readings in parliament where the main arguments and positions are presented. Apart from these readings, the plenary discussions also comprise government policy statements, question-and-answer sessions and discussions of motions. Plenary speeches are therefore particularly suitable to analyze the main narratives and frames related to coal policy making, and how they change in time and differ between parties. They thus provide evidence about the salience as well as the positions of parliamentary groups with respect to decisions on coal policies.

The two most influential and formative parties in the German Bundestag have been the conservative party (CDU) and the social democrats (SPD). After the foundation of the Federal Republic of Germany, the liberal party (FDP) also played a major role in facilitating government majorities. The entry of the green party (Bündnis 90/Die Grünen) in 1983 marked the end of this three-party system, with the predecessor (PDS) of the left party (Die Linke) entering the first all-German Bundestag in 1990. In the current Bundestag, the right-wing populist party (AfD) is also present.

The coal topic is particularly suitable for a long-term longitudinal analysis because it has constantly been discussed in the German Bundestag. As such, German coal politics is of particular interest because Germany is still one of the biggest producers of lignite, but has now committed to a complete phase-out of this energy source. Understanding and learning why this transition took so long but how it was finally possible can inform coal exits in other major coal countries and thus help them to comply with the Paris agreement.

3. Methods and Data

In this section, we describe the research process in terms of data and methods and provide details on the evaluation procedures for the results in a way that should guarantee reproducibility of our results and conclusions [86, 87]. This paper applies dynamics topic modeling (DTM) in a longitudinal case study. Fig. 1 provides an overview of the different steps in the research process: after data extraction and selection, we preprocess the data for use in topic model estimation. We then run, evaluate and compare topic models to choose the appropriate hyperparameter settings. Finally, we analyze the selected topic model in detail.

3.1. Data sources and processing

The aim of this study is to comprehensively map out the debate on coal in the German Bundestag plenary sessions. For this, we first construct a database of all speeches from the archive of the German Bundestag and then filter out those speeches related to coal. Throughout the paper, speeches are used as the unit of analysis. Here, speeches refer to coherent utterances by the same speaker. For the analysis, we discard interjections by other members of parliament that sometimes interrupt the speeches.

We construct our data set from the complete parliamentary archive of plenary protocols in the German Bundestag. The collection used here starts with the 1st session of the 1st parliamentary period on September 7, 1949 and ends with the 108th session of the 19th period on June 28, 2019. We develop several parsers that identify speeches, speakers and interjections (e.g. on reactions from the plenary) from the plenary protocols.[1] We put all this information into a relational database that allows us to transparently and flexibly manage, filter and

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[1] In detail, we combine three different types of procedures to get a database with text

Process   Results

| Data extraction, cleaning and enrichment |

| Data selection | → | Speeches on coal |

| Set hyperparameters |

| Text pre-processing | → | Word frequencies in speeches |

| Topic model estimation | → | Topic scores in speeches, word scores in topics |

| Topic model comparison and evaluation |

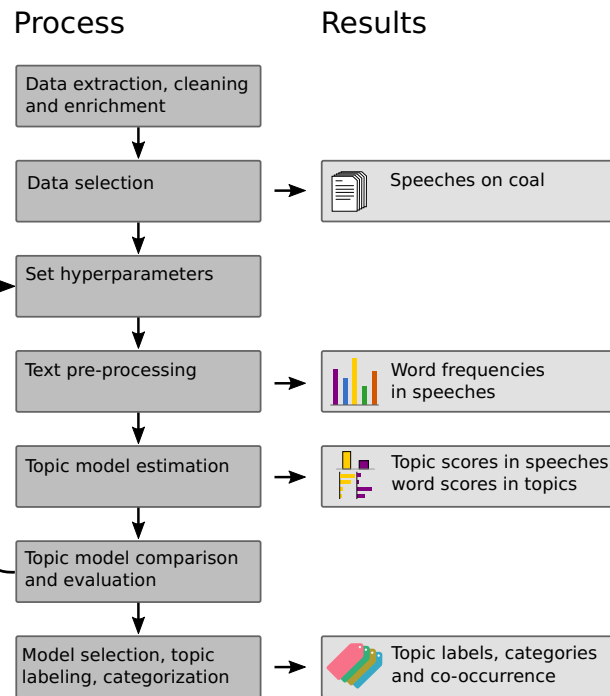| Model selection, topic labeling, categorization | → | Topic labels, categories and co-occurrence |

Figure 1: Illustration of the research process employed in this paper. The data input to the process are the parliamentary protocols and metadata of members of parliament from the German Bundestag. The loop indicates an iterative process to find hyperparameters that generate meaningful and robust topic model instances.

analyze the data. A relational database comprises table-like objects that can be linked via entries referring to rows of other tables. Each speech is assigned to either one of the 4,071 parliamentarians (of which only 850 are female) from 18 parties[2] or to speakers from outside the parliament, like ministers or state secretaries without a seat in parliament. We add further metadata to politicians (party, constituencies, etc.) provided by the open data service of the German Bundestag.[3] The entire database contains more than 870,000 speeches, 2 million paragraphs, 2 million interjections and a total of over 198 million words. In total, we process about 2 GB of text to build the relational database.

To obtain the sample of speeches analyzed in detail in this paper, the speeches in the complete database are then searched with the regular expression query

$$(?<!\text{Gemeinschaft für })\text{kohle}(?!\text{nwasser})(?!\text{nstoff})(?!\text{ndiox})(?!\text{nmonox})(?!\text{rnte}).$$

This query is used to exclude the most common compounds of the simpler search query 'kohle' that are not related to coal as an energy carrier. For example, the German words for carbon dioxide (Kohlendioxid) or cabbage harvest (Kohlernte) contain the stem 'Kohle'. All other compounds containing "Kohle" are used to identify speeches (see Fig. S1 in the supplementary material [SM] for the frequencies of compounds in our sample). Overall, our search yields 9167 speeches.[4] We validate a sample of 50 random speeches to ensure the quality of the text passages in our search. This reveals that some speeches in our dataset are only partially on coal issues, only mention coal as an example or contain side notes to the issue. While a small fraction are only procedural comments, the majority of speeches are political statements on coal and energy policies. This sample of speeches from the database with mentions of coal is used in all the following analyses.

With the search strategy we use here, the selected subcorpus is not a thematic corpus in the sense that the documents are all centered on coal issues or exclusively linked through issues around coal [29]. While we acknowledge the limitations of such an approach to filtering speeches, namely including many

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data as complete as possible with automatic text processing. First, for protocols from the 1st to the 13th parliamentary period and parts of the 18th period, we build a parser to process the pdf scans provided in the xml files of the open data service of the German Bundestag (available at: `https://www.bundestag.de/services/opendata`). Second, for protocols from the 13th to the 18th period, already preprocessed data from the Polmine project is used and put into our database [88]. Third, for the current parliamentary period (19th), the xml version provided by the German Bundestag is parsed with a script adapted to the new format in which the protocols of the 19th period are published. The code for the parsers (`https://github.com/mcc-apsis/plpr-scraper/`) and the database structure (`https://github.com/mcallaghan/tmv`) are published open source.

[2]Besides the major parites, these comprise many smaller parties from the first parliamentary periods, which we group in the following under "others".

[3]Available at: `https://www.bundestag.de/resource/blob/472878/d681fa07c6b7896caad63b900c5c95fa/MdB-Stammdaten-data.zip`

[4]A table with the texts and metadata of the sampled speeches is provided here: `https://github.com/mcc-apsis/coal-discourse/tree/master/datasets`

other topics that might blur the results, we deliberately choose to consider all speeches that mention coal because it generates the most comprehensive overview of the discussion using automated techniques. Furthermore, a manual selection of speeches would have come with its own limitations: It would require some pre-selection of speeches, for example by filtering by the title of sessions in which they appear. However, this would have unnecessarily limited the corpus, as coal is also discussed in sessions that do not have any reference to coal or energy in their titles.

Our broad selection criterion is suited to the goal of understanding how the framing of coal has changed over time. If we were only analyzing debates on coal directly, we would miss important information about the discussion of coal in different contexts. For example, when economic development or climate change is discussed, speeches may not focus on coal, but might mention coal at some point. By reviewing speech samples, we find that speeches that only contain a single mentioning of coal (about half of the speeches in our sample, see Fig. S2) often use coal as an example. Such speeches thus provide further information for our analysis about the context in which coal is usually mentioned and on how politicians think it fits the context. Similar search strategies that filter speeches by keywords have been applied for the analysis of parliamentary debates on other topics [89].

3.2. Dynamic topic modeling

Topic models are unsupervised machine learning algorithms that can identify themes latent in large text collections. They are built on the assumption that systematically co-occurring words in documents of a collection indicate semantic proximity [58]. Topic models learn a number of topics that comprise different combinations of co-occurring words based on their frequency in the documents of a corpus. Topics are described mathematically as distributions of terms. The documents are assigned with different weights to the topics (so-called topic scores). Thus, topic models reduce the very high-dimensional frequency of terms in the documents to two lower-dimensional distributions: The distribution of words in the topics and the distribution of topics in the documents [90, 58].

There are several different methods for topic modeling, the most used one being Latent Dirichlet allocation (LDA) [90]. Subsequent methodological developments allow, for example, analyzing how topics evolve over time [68, 58] or identify hierarchies in trees of topics [58, 91]. Structural topic modeling (STM) [92, 59] also facilitates the study of the dependency of topics from other attributes of the documents. Methods such as non-negative matrix factorization (NMF) provide less computationally intensive variants to infer topics of a corpus [93] and have also been used to detect developments over time [94].

Most studies applying topic modeling for studying political texts use LDA (e.g. [51, 61, 63]), even if they highlight temporal aspects in the development of the analyzed debates. But LDA assumes the same priors for topics and words in each document and therefore does not reflect a temporal evolution in its basic structure. Törnberg and Törnberg [51] mitigated this shortcoming by running LDA models for each year and then examining overlapping topic categories.

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However, the temporal analysis with this approach relies on the categorization, which adds interpretative work at an early stage.

For our study we select dynamic topic modeling (DTM) [68] because it allows us to model topic changes over time in a consistent and integrated way. DTM is a variant of LDA that accounts for changes in topics over discrete time steps. We choose DTM over dynamic NMF because it allows us to reconstruct how topics change across time bins while dynamic NMF has a nested structure that only indirectly links topics from different time bins.

Like all topic modeling approaches, DTM uses the 'bag of words' representation, i.e. it reduces a document to word counts thereby disregarding the order of words. DTM is based on a generative statistical model that is fitted to the data assuming that the weights of terms in topics and topics in documents are drawn from Dirichlet distributions. In DTM, all documents are assigned to time bins. The weights of words in topics can change over time (see Fig. 2). The variance of the possible change is given by the hyperparameter σ (top_chain_var). This allows the model to trace shifts of word usage over time and thus developments within a topic.

In order to apply the topic model to the sample speeches, we pre-process our text data. The pre-processing we apply is common in topic modeling [90, 52] and can have considerable effects on results [95], which is why we report it here in detail. First, we apply a stemmer[5] that reduces single words to their stem such that different word types (like nouns, adjectives and verbs) are categorized as the same token. Second, we remove several so-called stop words using two lists: (1) a standard list of stop words for the German language[6] and (2) a custom made list of procedural terms from the German Bundestag that appeared in many topics and therefore hindered topic interpretation in preliminary test runs (see Sect. 2 in SM).[7] Third, very common words (occurring in more than 95% of the speeches) are discarded and the most common 20,000 of the remaining words are used as the vocabulary. Finally, the word lists are converted to word count vectors such that the documents can be represented as lists of integer numbers.[8]

To fit the model, we use the algorithm provided by Blei and Lafferty [68][9]. The algorithm uses stochastic sampling methods to estimate the model. This is why the results can vary depending on the seed given to the random number generator and the maximal number of interations[10].

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[5] We use the Snowball stemmer from the python nltk package [96].

[6] The standard list of stop words is from the python nltk package (nltk.corpus.stopwords.words("german")).

[7] This only removes the most common procedural terms that made the interpretation of topics harder initially. In an iterative process we stop when top-word lists of topics related to coal issue are no longer contaminated by procedural words. Research suggests that stop-word removal does not influence results strongly and thus only removing highly scoring procedural terms suffices [97].

[8] We did all preprocessing with the CountVectorizer function from the python package scikit-learn [98].

[9] Available at: https://github.com/blei-lab/dtm

[10] To guarantee reproducibility, we set the seed to 1 and the maximal number of iterations
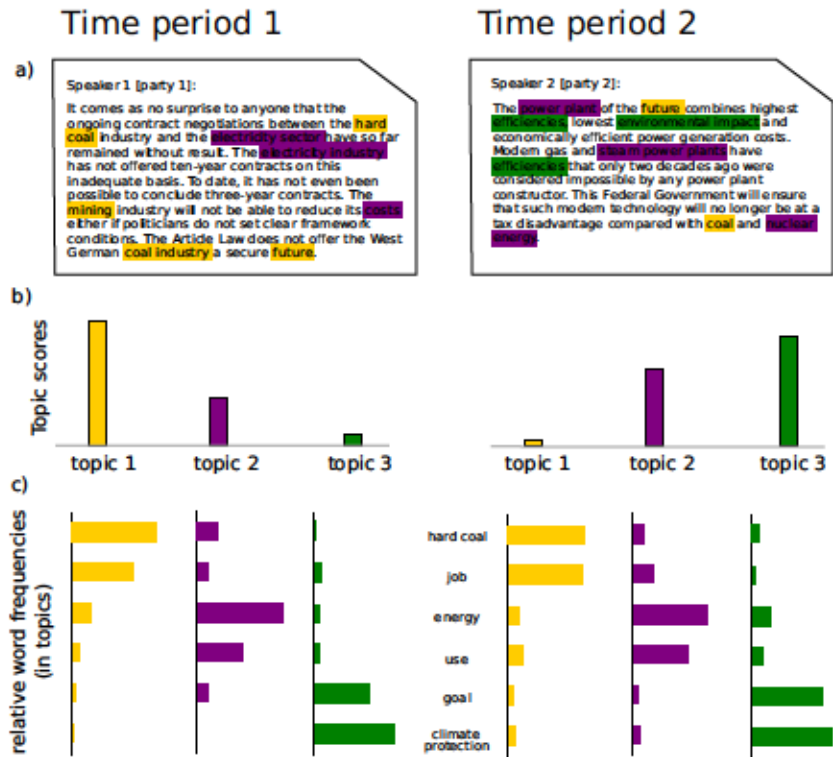
Figure 2: Illustration of the output of a dynamic topic model. The topic model relates the words occurring in speeches to topics that themselves are associated with lists of words. The figure shows two excerpts of speeches for two different time periods (a). The topic scores associated with the speeches indicate the relative importance of a topic for them as shown by the vertical bars (b). Each topic consists of a distribution of words, consisting of word scores as illustrated by the vertical bars (c). These word scores can change over time and show the relative importance of words for a topic in a time bin.

3.3. Evaluation and validation

Validation is fundamental to computational text analysis, especially for unsupervised machine learning methods like topic modeling. It requires the combination of internal and external validation procedures to ensure both a good model fit and interpretability of results [52, 47]. The dynamic topic model has several hyperparameters that need to be set by the modeler. To select the parameter settings, we run the model with different specifications and compare the performance and interpretability of results. For this we use on the one hand human judgment about how well the resulting topics could be interpreted as well as quantitative measures of model performance.

The most important hyperparameter in topic modeling is the overall number of topics K. The number of topics determines the granularity of the categories describing the content of the documents. As highlighted by Törnberg and Törnberg [51], this is a deeply qualitative exercise requiring expert judgement: one important aspect is striking a good trade-off between sufficient topic differentiation and avoiding overlap. We evaluate the interpretability of topics in models with 20 to 70 topics in steps of 5 topics. Additionally, we compare topic models pairwise, using matrices and graphs to visualize topic alignment (see Fig. S3 using methods from [99]).

We also investigate the effect of two other hyperparameters: the prior for the Dirichlet distributions that describe the words in topics α (using the values 0.005, 0.01, 0.05, 0.1, 0.5, 1.0) and the variance of topics over time σ (looking at settings for 0.001, 0.005, 0.01, 0.05). Lower values of the Dirichlet priors mean that the distributions tend to be more concentrated on a few words, while higher values correspond to more balanced distributions [100]. A very high value thus favors distributions with all words being almost equally likely.

To evaluate the model performance regarding these hyperparameters, we consider two aggregate measures proposed in the literature: exclusivity and coherence [101, 102, 103]. We further explore results manually if the models have a good trade-off between exclusivity and coherence (see Fig. S4). Using these procedures iteratively, we settle on the following parameters: $K = 35$, $\alpha = 0.01$ and $\sigma = 0.01$. In Sect. 4, we present the results of the topic model generated with this setting.

To make the results more accessible to readers, we label the topics identified by the dynamic topic model. The computer model associates words and documents with a certain topic but the content of a topic has to be interpreted by the researcher. To find adequate labels for the topics, we take into account the 20 words with the highest overall score, the temporal evolution of scores and the speeches with the highest document-topic scores. Two researchers label the topics independently before consolidating them. All labels are reviewed by the co-authors. Finally, we assign topics to five different categories that are devel-

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(max_iter) to 200, as recommended by Blei and Lafferty [68]. Tests for the dependence of results on initial seeds show that top words of topics vary slightly but topics do not change their primary focus.

oped inductively (for a similar procedure, see [51]). These five categories are *economy and budget*, *energy*, with topics focusing on energy technologies, *environment*, *international and regional*, which comprises topics on spatial aspects of energy politics, and *procedural and general politics*. In the following, we only discuss topics from the first four categories because the last is linked to general debates and procedural passages in the debates.

To make the interpretation of topic scores more accessible, we normalize them by the sum of scores in each time bin. The resulting topic shares indicate how much of the total scores were attributed to the specific topics.

We also study the highest scoring speeches of key topics to better understand their specific content. We identify meaningful quotations about coal by filtering highly scoring speeches for passages that contain the keyword 'Kohle' (coal). From these, we hand-select quotations that concisely capture ideas and arguments found in several high-scoring speeches. They are presented in Sect. 4.1 to give more context to specific topics. The document-topic scores from the model thus allow us to retrieve additional information from speeches that the model deems most important for a specific topic.

We further analyze how speakers from different parties and regions engage with the topics. To do so, we calculate the relative share of a topic with respect to all topics for a subgroup of speakers. The topic model links each topic to each speech with a score. Our relational database allows us to link these document-topic scores to speakers that are affiliated with a party and a constituency or party list from a state (Bundesland). By filtering for parties or regions, we can thus calculate aggregate topic scores for subgroups and normalize them by their sum. By calculating the share of a topic with respect to the total topic score of a party or region, we control for the different number of speeches that different subgroups have in parliament and the corresponding imbalance in topic scores. As a proxy for coal regions, we aggregate all speeches from speakers that are elected in a constituency or through a list in a state that is involved in coal mining. These are the five states of North Rhine-Westphalia, Saxony, Saxony-Anhalt, Brandenburg and Saarland. For the calculation, we only use speeches after 1990 to preclude biases due to the reunification of the divided Germany and the stronger differences in presence of parties in parliament before this date, although results for the entire period are similar (see Fig. S5).

3.4. Topic co-occurrence

Additionally, we construct topic co-occurrence networks to analyze how often topics appear together in speeches. In the network, nodes represent topics and links represent their joint occurrence. Stronger links indicate topics which co-occur more often in speeches than topics that are connected by weaker links or not at all. We construct the networks in the following way: First, we assign topics to documents based on a threshold that at least 10% of the total topic score needs to be attributed to the topic. This yields on average 3 topics per document. For each pair of topics, we then count the number of documents in which the topics co-occur, which gives us a matrix that measures co-occurrence. We opt for such a correlation measure because of high correlation values with the

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standard measures (Pearson and Spearman correlation coefficient) for samples with many zeros. We normalize the co-occurrence counts with the total number of documents making them comparable. To construct the topic correlation network from the co-occurrence matrix, we connect those topics with the 20% highest co-occurrence rates. Finally, we vary the thresholds for network creation to ensure robustness of results. We also check that the chosen normalization procedure do not introduce biases and find that other types of normalization does not change results. Apart from co-occurrence networks for all speeches, we also construct networks from subsets of speeches for parties and time periods. The periods are chosen to include at least four parliamentary periods each and such that the start and the end of each period either coincides with a change in government or Germany reunification (in 1990).

We use the topic co-occurrence analysis to infer information about the framing of coal policies in the debates. Traditional frame analysis focuses on the way (political) ideas are verbalized and which problem definitions, moral evaluations, and persuasiveness beyond rational argumentation this implies [26]. Language evokes cognitive patterns – so-called frames – that selectively highlight certain aspects of an issue while ignoring others [25, 27]. If frames resonate with the norms and experiences of an audience, they can be used to persuade people and mobilize their support [104]. The co-occurrence of topics shows which topics are systematically mentioned together in the context of coal and are thus a good proxy for learning about the framing of coal in the discussions. This approach is similar to corpus-based frame analysis methods that use word frequencies to identify dominant frames in large collections of texts [105].

3.5. Limitations of the method

While topic modeling approaches are widely used and can provide insightful results for the analysis of large text corpora, there are several limitations that need to be accounted for: First, the selection of adequate parameters for the model requires qualitative and quantitative judgment of model performance. This is why we extensively validate and evaluate our results.

Second, the process of interpreting the results of topic models is a potential source of subjective bias. We label and classify the topics independently by different people. But there remains room for different interpretations, which is why we report all steps for generating and checking results in as much detail as possible.

Third, topic models only consider a small part of the information contained in the text data, as they only take word frequencies into account. This means that much of the information from the text is discarded during preprocessing. Political speeches include much more information, which is difficult to analyze with computational methods: Subtleties in the language such as irony and sarcasm, incomplete references to previous speeches and implicitly stated policy positions, e.g. distancing from another party's position. Even though there have been some advances in identifying policy positions with other automated methods [106], their reliability and correlation with hand-coding varies [107]. Advanced natural language processing methods such as argument mining [108]

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may capture and represent more features of political texts than topic models, but need to improve to capture subtleties in political speech.

Finally, computational approaches to political text have the problem of confirmation bias [109]: If the results make sense in light of the knowledge that the researcher already has about a topic or finding in the literature, they can be interpreted as a confirmation. But if results suggest counter-intuitive conclusions, this is likely to be blamed on models supposedly not performing well. Such an imbalance calls for the further development of methodologies that integrate computer-assisted with hand-coding approaches to mitigate over- and under-interpretation of results. This could help to better validate whether surprising results are just a matter of badly calibrated models or whether they provide new insights that had been previously overlooked.

4. Results

4.1. From coal as an economic base to coal as an environmental problem

In this section, we discuss the temporal evolution in the debates on coal in the Bundestag as expressed in research question 1. Fig. 3 shows that coal has been discussed in the German Bundestag since 1949 with a slightly increasing trend over time. On average, it is mentioned in 482 speeches in each parliamentary period. The parties with the highest total number of speeches mentioning coal are the conservatives and social democrats, which is due to their presence in all parliamentary periods and their high share of parliamentary seats which gives them more speaking time.

The framing of coal debates in the German Parliament (Bundestag) has changed multiple times over the last 70 years. The overview in Figure 4 reveals two overarching macro-trends: economics and budgetary questions have been dominant issues in coal discussions in the German Bundestag. With declining coal production and consumption, this has partly made way for environmental and energy technology topics.

The temporal evolution of individual topics in Figure 5 provides details for this overarching trend. The shift did not occur abruptly, but gradually across a series of smaller changes that can be associated with energy policy debates and events (see Sect. 4.3).

Individual topics identified by the DTM are only prevalent over shorter time periods of at most a few decades. On the one hand, this indicates the topical nature of the political process that focuses on particular political issues at particular periods of time. On the other hand, it indicates that even for topics that have been present over longer periods of time, the language and word composition changes so much that the model fits similar issues with different topics as most obvious for the two economic policy topics or the two budgetary topics. Hence, most topics become time specific themselves in our long-term analysis.

In the following, we discuss the dominant topics for specific time periods in their political context and illustrate some of them with quotes from speeches with high scores in the respective topic (see Sect. 3.3). The temporal patterns we observe are driven by political processes and events highlighted in Fig. 5.

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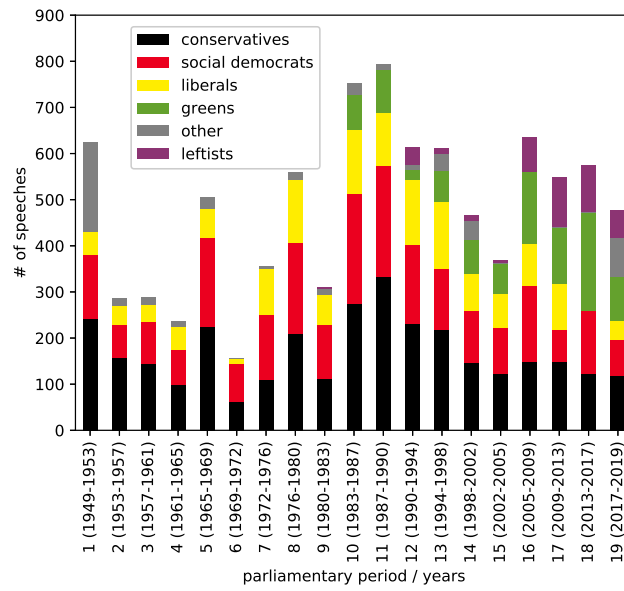
Figure 3: Number of speeches mentioning coal by parliamentary period and political party. 'Other' comprises speeches of parliamentarians with affiliations to parties that have not been present in the Bundestag for more than 3 periods and of speakers without party affiliation.
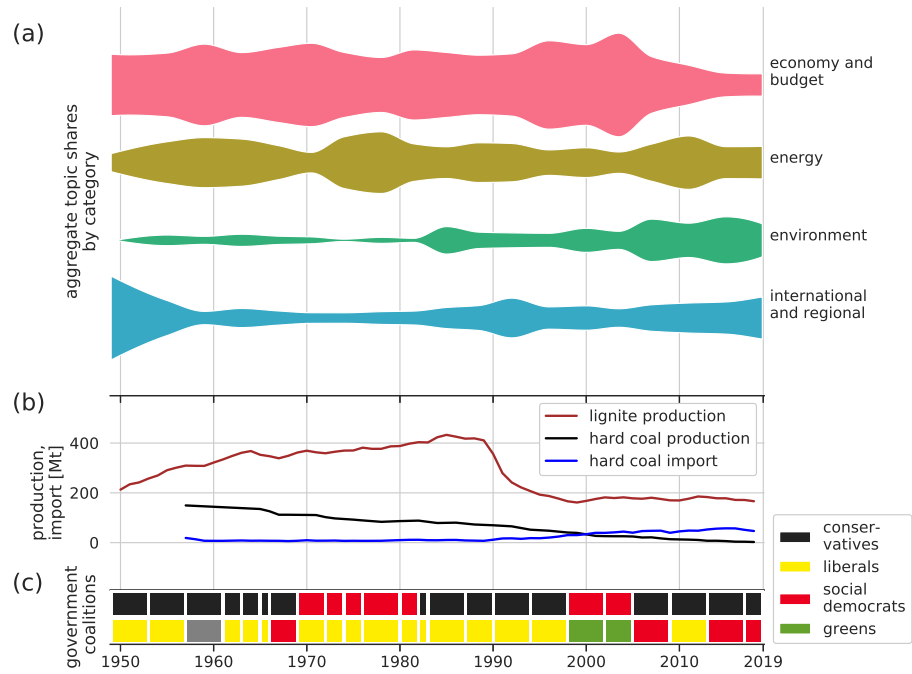
Figure 4: Overview of the evolution of coal discourse in the German parliament in context: (a) development of topic shares (i.e., percentages of a single topic score with respect to the sum of all topic scores) aggregated by topic category (see Sect. 3.3), (b) indices of coal industry development over time (lignite production, hard coal production and hard coal import in Mt) and (c) ruling government coalitions with the senior coalition partner on the top row. The curves showing topic shares were smoothed using PCHIP interpolation [110].
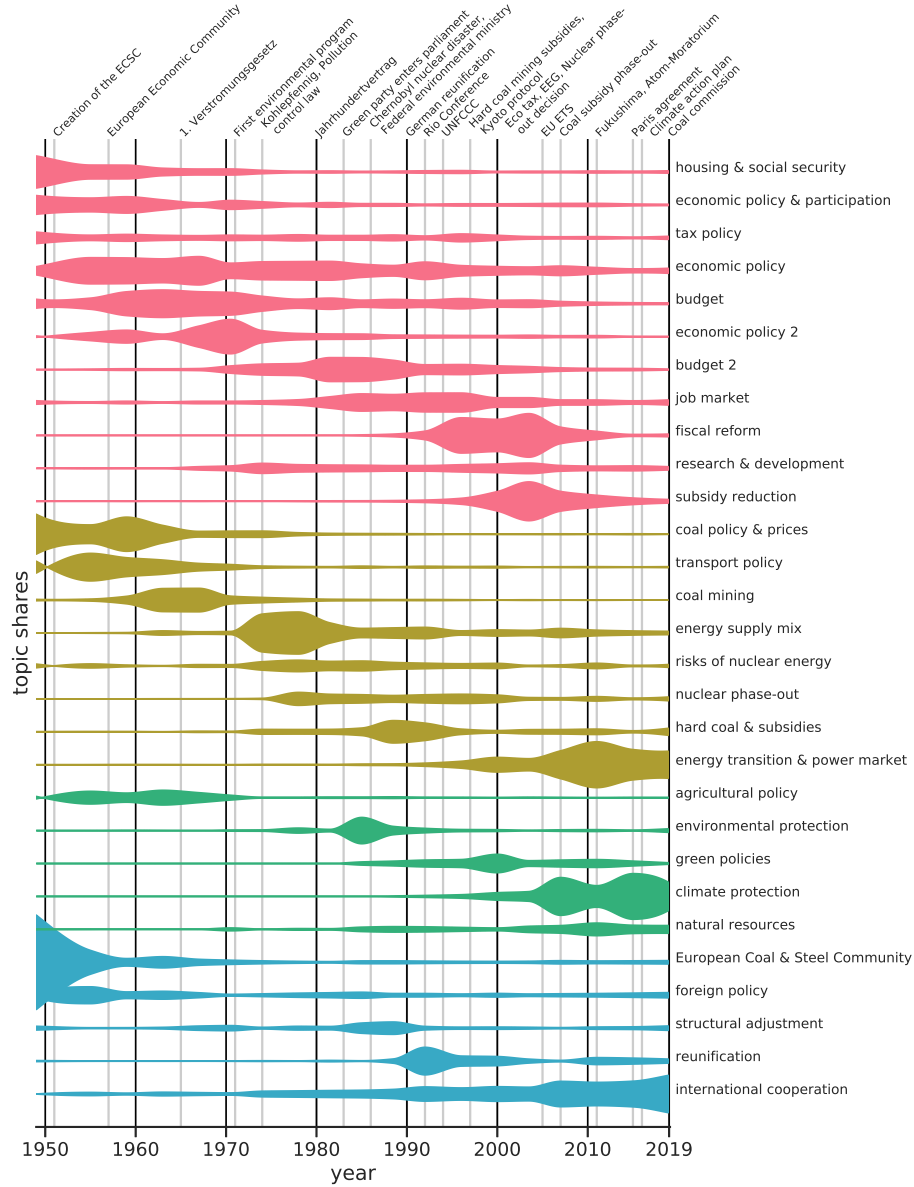
Figure 5: Evolution of topics in coal debates over 70 years. The topics are grouped by category (marked with color) and ordered by year of the peak in their topic shares. Topics are juxtaposed with important events related to energy and coal policy (Table S1 provides further information on the specific policy events). The curves showing topic shares were smoothed using PCHIP interpolation [110]. Topics classified as procedural and general politics are not shown. Table A.1 provides a list of all topics, including category, topic label, top words and the share of topic scores.

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In the first parliamentary periods of the Bundestag, 1949 until the mid-1960s, coal was strongly interlinked with international relations in Europe, in which access to coal and steel played an important role (topic *European Coal & Steel Community*). Furthermore, *housing & social security* was discussed in relation with coal as there were shortages in coal for heating and coal prices soared. Subsequently, policies were applied to better control coal prices, as reflected in the topic *coal policy & prices*.

The coal debates in the 1960s and 1970s mainly revolved around questions around the economic and fiscal viability of coal policies (topics *budget* and *economic policy*) as well as the diversification of the *energy supply mix*, which included the expansion of nuclear energy. In the context of the oil crises, for example, coal was discussed as an alternative to oil for a broader energy mix and to make energy demand less import dependent:

> Dr.-Ing. Laermann (FDP): It is therefore necessary not only to save oil but to substitute it as quickly as possible. At present, coal – hard coal as well as lignite – is the most suitable option.[11] (protocol 8/167, 1979-07-04)

Interestingly, as early as in the late 1970s, the consequences for the climate were already mentioned.

> Helmut Schmidt (Hamburg) [SPD]: In addition, the burning of coal and gas has led to an increase in the overall environmental impact. In the last three decades, carbon dioxide emissions have tripled worldwide. The possible consequences for the climate all over the world [...] cannot yet be estimated with certainty, but they will have to be taken into account in long-term energy policy decisions. (protocol 8/167, 1979-07-04)

During the 1970s and 80s, coal has been mainly discussed in relation to nuclear energy and jobs in the coal industry (topic *job market*). Environmental topics received more traction when the green party first entered the Bundestag in 1983, with discussions especially related to air pollution (topic *environmental protection*):

> Dr. Friedrich Zimmermann (München) [CDU/CSU]: After flue gas desulphurisation, we need new technologies against nitrogen oxides in particular. This is necessary for the further development of environmentally friendly power plant technologies, so that domestic coal remains environmentally sound and can maintain its important role in energy supply in the future. (protocol 10/22, 1983-09-15)

The abrupt decline of lignite production induced by the German reunification in 1990 was accompanied by a last increase of economic topics, mainly on *subsidy reduction* and *fiscal reform*. From the highest ranking speeches in the latter topic, it can be concluded that fiscal reform is not directly linked to coal

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[11]The translations from the original in German are our own with assistance from `deepl.com`.

policy but coal subsidies are often mentioned in this context. *Hard coal subsidies* and *reunification* were dominant topics in many coal speeches as well as accompanying topics like *structural adjustment*.

> Dr. Helmut Kohl [CDU/CSU]: Economy and environmental compatibility as well as security of supply and economic efficiency are cornerstones of the overall energy policy concept [...]. For the German government one thing is clear: domestic coal must be a central component of this concept. Hard coal and lignite must contribute to a secure energy supply also in a united Germany, albeit at a lower level than before. (protocol 12/5, 1991-01-30)

In the last two decades, economic topics became less dominant while environmental topics became more prevalent, mainly due to a strong increase in the *climate protection* topic. It is particularly interesting that this increase is noticeable only after the coalition government of social democrats and greens left office. This could be related to the fact that the Green Party prioritized a nuclear phase-out and at least did not strongly oppose the building of new coal-fired power plants at the time. Furthermore, more efficient coal-fired power plants are often presented as a contribution to mitigate climate change.

> Sigmar Gabriel [SPD]: We cannot, for the time being, do without coal to generate electricity. [...] The replacement of the inefficient plants will bring massive relief for climate protection. The new power plants are so much more efficient that up to 42 million tons of carbon dioxide per year can be saved for the atmosphere. (protocol 16/94, 2007-04-26)

Apart from a topic on *international cooperation*, the third dominant topic in the last two decades was *energy transition & power markets*, which is strongly related to the discussion on the German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG).

> Angela Merkel [CDU/CSU]: Renewable energy sources are to become the central pillar of future energy supply. We want to reach the age of renewable energy. [...] The share of renewable energy in energy consumption is to increase to 60 percent by 2050 and their share in electricity consumption to 80 percent. (protocol 17/114, 2011-06-09)

It is surprising though that the topic model does not identify more economic topics in coal debates of recent years. Even though economic topics presumably were discussed strongly during the economic crisis, they were apparently not linked to coal. But the prominent discussion about the phase-out of coal-fired power plants in 2018 and 2019 also saw many arguments being made about job losses and economic effects.

> Michael Theurer (FDP): Instead of relying on emissions certificate trading and letting the market economy take effect, we are now intervening with regulations in individual sectors and would prefer to dictate how much
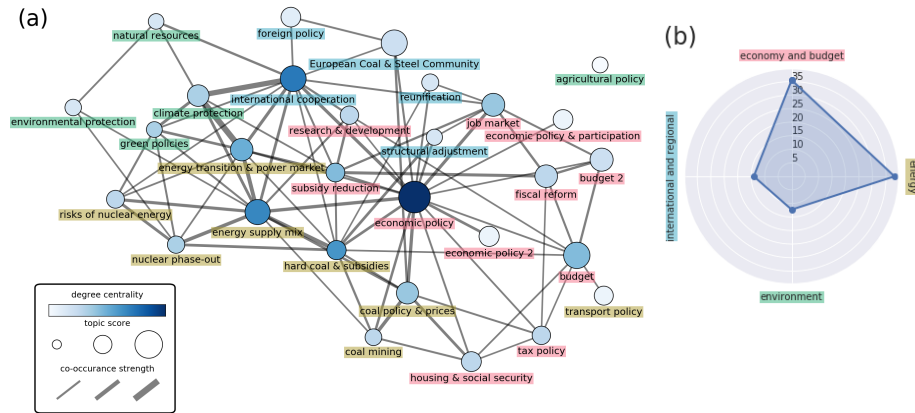
Figure 6: Topics occurring often together in coal speeches. (a) Co-occurrence network with topics as nodes and frequent co-occurrence as stronger links. We show the strongest 20% of co-occurrences. The node size marks the topic share and the node color the degree centrality (the number of links attached to each node). The colors highlighting the labels indicate topic categories (procedural topics are not shown). Panel (b) shows the aggregate degree of these categories relative to the total degree of the network.

₆₃₀ energy individual companies use and how much CO2 they emit. Ladies and gentlemen, this planned economy will not help you to protect the climate – which cannot be achieved by a single country on its own anyway – nor will it secure jobs and prosperity. (protocol 19/77, 2019-01-31)

This signal in the speeches seems to be so weak (see the minor increase e.g. in the *job market* topic) that it does not counter the general trend of the declining ₆₃₅ importance of economic topics.

Overall, the analysis of shifts in the topics suggests that coal is no longer discussed as an economic factor of national importance. At most, it remains relevant at the local or regional scale. Instead, it is increasingly discussed as an environmental threat.

₆₄₀ *4.2. Shifts in topic co-occurrence*

To further support our point about the shift in the framing of coal policies, we now look at information on how often a topic or group of topics are jointly present in speeches. Figure 6 shows a co-occurrence network (see Sect. 3.4) in which the nodes represent topics and the strength of links indicates the fre- ₆₄₅ quency with which topics appear together in speeches. Across our corpus of parliamentary speeches, we find that topics like *economic policy*, *international cooperation* and *energy supply mix* are not only the most prominent (high average topic score), but do also most often appear together with other topics. We measure this by their degree centrality, i.e. how many links they have in ₆₅₀ the network. Economic and energy topics co-occur on average more often than environmental and regional/international topics.
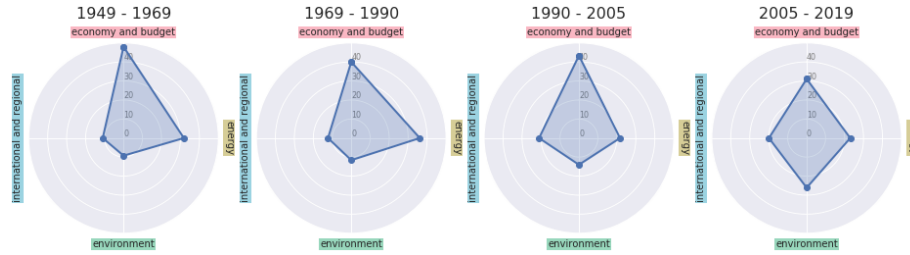
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Figure 7: Evolution of the centrality of topic categories. The figure shows the aggregate degree of topics by category in topic co-occurrence networks constructed for different time periods. The degree measures the increased co-occurrence of topics in the coal speeches.

Over time, the framing in the parliamentary debate on coal shifted from economic growth and prosperity towards environmental issues around climate change and the energy transition. In line with patterns of growth and decline in aggregate topics (Figure 4), we find matching evidence of topic co-occurrence as shown in Fig. 7. As for our previous analysis, we aggregate the topics into four major categories and show changes in the normalized sums of the degree centrality of nodes for different periods. The economic topics have the highest centrality in all periods except for the most recent period. Environmental topics were not mentioned frequently alongside other topics in the periods until 1990, their importance grew until they reached the highest share in the period 2005 - 2019. This suggests that they became a major frame and partly replaced the previously dominant economic frame. These results are robust with respect to threshold choice (see Fig. S6) and are qualitatively the same as the total sums over all co-occurrences in a certain topic category (see Fig. S7).

4.3. Topic development and policy events

The special feature of the dynamic topic model employed in this study is that we cannot only observe the growth and decline of the various topics, but also how the words and their weights that constitute a topic change over time. The weights and their development indicate how the language changed with which a particular topic was discussed. This provides both an opportunity to evaluate the results of the topic model and to learn about shifts in the debates about coal that occur on the level of single topics (research question 2). In general, changes in word scores and thus word order in top words reflect shifting foci within a topic. Even though the time periods used in our analysis comprise usually three to four years, changes in top words between periods can be related to policy events within different periods.

Fig. 8 shows the top words of two selected topics and how they evolve over time. In the topic *climate protection*, we can observe that words related to meeting targets grow in importance in recent periods as the discussion of Germany not reaching its self-imposed 2020 targets becomes stronger. In parliamentary periods 15 and 16, emissions trading is more prominent, coinciding with the introduction of the EU ETS. The emergence of coal power stations as important

top words reflects debates about the incompatibility of climate protection and German coal power use beginning in parliamentary period 15. In the current period (19), coal phase-out is the most important policy related term. This clearly coincides with the debates around policies targeting coal in the context of the 2016 Climate Action Plan and the coal commission.

The *energy transition & power market* topic took off as a discussion on renewable power triggered by the renewable energy legislation in parliamentary period 14. The costs of the policy are of concern from the beginning. Energy transition and renewables are the most important words of the topic in the two most recent parliamentary periods. Slow progress in the expansion of the high-voltage grid that aims to bring the electricity produced by large-scale wind farms in the North to industry hot spots in the South becomes increasingly salient and more important than pure cost concerns in recent periods. Similar analyses can be made with other topics, and we provide interesting additional examples of changes in topics in the SM (Figs. S9 and S10).

These results highlight how policy events and processes directly or indirectly appear in the topics' top word lists. The plausibility of the shifts is a good indication of the functioning of the method in the context of policy analysis and can thus be seen as a procedure for topic validation. The examples indicate that many changes can indeed be linked to developments in coal politics as reflected in the debates.

4.4. Party and regional differences in topics

Discourses of coal in parliament do not only change across time: we also find substantial differences across parties and regions (research question 3). Because our database contains all plenary speeches, we can compare the number of speeches mentioning coal to the total number of speeches. Figure 9 shows that parties mention coal in 0.8 to 2.5% of all speeches. The greens and the left parties[12] mention coal more often (1.6% and 1.1% of speeches) than conservatives, social democrats and liberals (0.8% to 1.0%). The share is highest for the residual group 'other', which is mainly driven by debates on coal in the 1950s, in which small parties strongly participated that do not exist anymore (e.g. communists, national conservatives and centrists).

Parties also differ with respect to the relative frequency with which they engage with specific topics. Fig. 10 presents the deviations of relative topic scores for parties and coal regions from the average (for details see Sect. 3.3). On average, the speeches from different parties are characterized by choice, combination and frequencies of words, thereby marking substantial differences in the language used. Fig. 10 shows that the leftists and greens are more active than other parties in the climate protection and energy transition topics. The liberals, on the contrary, engage more with the *subsidy reduction*, *economic policy* and *job market* topics. Speakers from the greens engage less in the *economic policy*

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[12]For better comparability, we merged the Left Party with its predecessors PDS and WASG.

climate protection

14 (1998-2002)	15 (2002-2005)	16 (2005-2009)	17 (2009-2013)	18 (2013-2017)	19 (2017-2019)
2.7%	3.4%	13.4%	7.7%	16.2%	12.9%
prozent [percentage]	prozent [percentage]	klimaschutz [climate protection]	klimaschutz [climate protection]	klimaschutz [climate protection]	klimaschutz [climate protection]
klimaschutz [climate protection]	klimaschutz [climate protection]	prozent [percentage]	prozent [percentage]	prozent [percentage]	ziel [goal]
coemission [CO2 emission]	emissionshandel [emission trading]	emissionshandel [emission trading]	ziel [goal]	ziel [goal]	deutschland [Germany]
deutschland [Germany]	deutschland [Germany]	deutschland [Germany]	deutschland [Germany]	deutschland [Germany]	prozent [percentage]
ziel [goal]	ziel [goal]	ziel [goal]	emissionshandel [emission trading]	erreich [reach]	erreich [reach]
emissionshandel [emission trading]	erreich [reach]	kohlekraftwerk [coal power plant]	kohlekraftwerk [coal power plant]	bundesregier [federal government]	bundesregier [federal government]
erreich [reach]	bundesregier [federal government]	bundesregier [federal government]	bundesregier [federal government]	emissionshandel [emission trading]	kohleausstieg [coal phase-out]
bundesregier [federal government]	coemission [CO2 emission]	erreich [reach]	erreich [reach]	kohlekraftwerk [coal power plant]	klimawandel [climate change]
international [international]	kohlekraftwerk [coal power plant]	international [international]	international [international]	klimawandel [climate change]	emissionshandel [emission trading]
emission [emission]	instrument [instrument]	beim [with]	beim [with]	paris [Paris]	klimapolit [climate policy]

energy transition & power market

14 (1998-2002)	15 (2002-2005)	16 (2005-2009)	17 (2009-2013)	18 (2013-2017)	19 (2017-2019)
5.2%	4.3%	9.9%	16.3%	10.8%	9.5%
strom [electricity]	strom [electricity]	strom [electricity]	energi [energy]	energiew [energy transition]	energiew [energy transition]
wettbewerb [competition]	energi [energy]	energi [energy]	erneuerbar [renewable]	erneuerbar [renewable]	erneuerbar [renewable]
energi [energy]	prozent [percentage]	prozent [percentage]	strom [electricity]	energi [energy]	strom [electricity]
prozent [percentage]	wettbewerb [competition]	erneuerbar [renewable]	energiew [energy transition]	strom [electricity]	energi [energy]
kost [cost]	kost [cost]	netz [net]	prozent [percentage]	prozent [percentage]	prozent [percentage]
kraftwarmekoppl [cogeneration]	erneuerbar [renewable]	kost [cost]	netz [net]	ausbau [buildup]	netz [net]
anlag [facility]	verbrauch [consumption]	wettbewerb [competition]	ausbau [buildup]	netz [net]	ausbau [buildup]
deutschland [Germany]	netz [net]	verbrauch [consumption]	deutschland [Germany]	deutschland [Germany]	deutschland [Germany]
erneuerbar [renewable]	deutschland [Germany]	kraftwerk [power plant]	kost [cost]	kost [cost]	kost [cost]
kraftwerk [power plant]	kraftwerk [power plant]	deutschland [Germany]	kraftwerk [power plant]	eeg [EEG]	strompreis [electricity price]

Figure 8: Change of language associated with the two exemplary topics *climate protection* and *energy transition & power market*. For each topic and time bin, the topic model assigns a score to the topic's associated words. The figure shows the change in the composition and order of the ten highest scoring words. The boxes represent time bins and accommodate highest scoring words at the top. The bold numbers indicate parliamentary periods associated with the time bins, the percentages show the topic's share in the respective period. Words have been stemmed, which is why their ending is missing. For readability of changes between periods, the words within a topic are colored with a random scheme. Stronger frames indicate higher shares of topics in the respective periods.
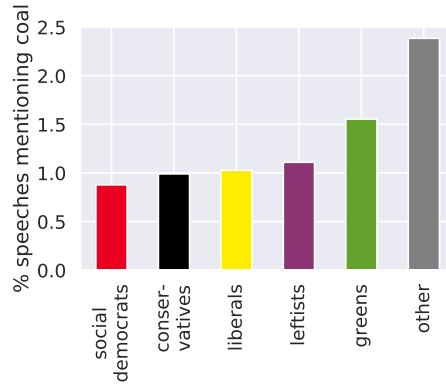
25

Figure 9: Share of speeches mentioning coal relative to all speeches in the German Bundestag by party. The high share in 'other' is mainly driven by small parties from the 1950s.

and *job market* topic in speeches related to coal, while the two major parties remain close to the average with respect to these topics.

The picture is less clear for the analysis of differences between parliamentarians from coal and non-coal regions. Parliamentarians from coal regions speak more about reunification, which is probably related to the fact that three out of five coal regions are states from the former German Democratic Republic. They also talk more about *hard coal & subsidies* and slightly more about climate protection. With respect to the *subsidy reduction* and *economic policy* topics, there are no discernible differences between coal and non-coal regions. The two topics that are less connected to parliamentarians from coal regions are *fiscal reform* and *international cooperation*. Additional analyses show that these regional deviations cannot be explained by differences in party shares in the regions (see Fig. S8).

Integrating information on topic co-occurrence, we find small, but characteristic differences that point to different framing of coal across parties. Similar to Fig. 7, Fig. 11 shows aggregate degree centrality of co-occurrence networks of all documents after 1990 associated with one party. Apart from mentioning specific topics more often, parties also differ in the topics they discuss together. The liberals most strongly frame parliamentary discussions on coal around economic topics, while environmental topics provide the strongest framing for the greens and the leftists. The two major parties (social democrats and conservatives) sit in between with an emphasis on frames around economic and energy issues.
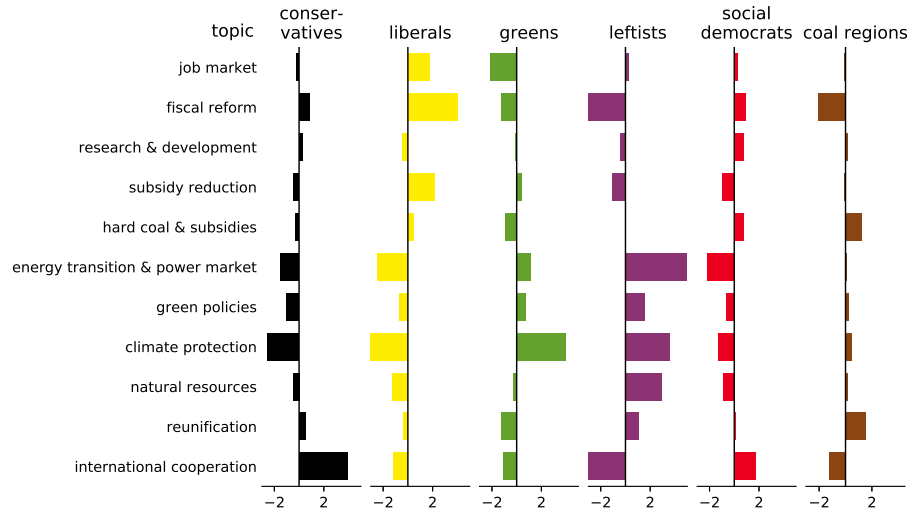
26

Figure 10: Variation of topic incidence by party and region. The figure indicates how much more or less parliamentarians from parties or regions engage with topics compared to the average. It shows the deviation of the topic share per party or region from the mean over these topic shares (in percentage points of topic shares). This measure is not biased by higher total number of speeches by the major parties. Note that the deviations for non-coal regions are the ones for coal regions multiplied by -1. The figure uses only the shares of speeches after 1990 to exclude biases from reunification and strong differences in presence of parties in the Bundestag. All topics with relevant shares after 1990 are shown.
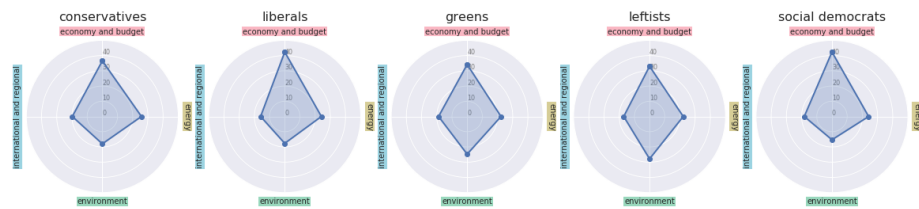
Figure 11: Centrality of topic categories by party. The figure shows the aggregate degree of topics by category in topic co-occurrence networks constructed for different parties. Networks were constructed using only speeches after 1990.

5. Discussion and conclusion

This paper explores the application of dynamic topic modeling to study the development of the debate on coal in the German Bundestag over 70 years. It thereby provides a comprehensive overview of the different issues discussed in relation to coal.

To answer our first research question on the temporal evolution of topics and framing of coal in debates, we analyze how both topic scores and topic co-occurrence developed (Sects. 4.1 and 4.2). Our final model features 35 topics, which highlight four major thematic areas related to coal: economic policy, energy policy, environmental policy as well as international and regional policy. We find that economic topics have been dominating the debate for most of the time, yet in recent years their relative importance declined. Environmental and energy topics, especially climate protection and the energy transition, became more prominently linked to coal. This indicates a shift in the framing of coal from a driver of national wealth to coal as a problem for climate protection. This is based on several major shifts in the debate: Starting with coal framed as a major economic driver of national progress in the 1950s and 1960s, the discussions subsequently shifted to political economy issues around coal mining and coal prices. Environmental concerns played a larger role beginning in the 1980s with air pollution. Later, discussions of environmental concerns and coal shifted to problems of nuclear energy and natural resources and finally to climate change and the energy transition. Our analysis of the topical shifts over time largely reflect the accounts of German energy and coal policy as discussed in Section 2. Our findings suggest that topics directly related to coal policy lose importance but coal still appears as a relevant sideline and constraint in the more dominant debates about energy transition, power markets, climate policy and international cooperation. We further substantiate such an interpretation by showing in an analysis of topic co-occurrence over time that environmental topics became more central over time and economic topics' centrality declined, albeit from a high level.

Our analysis of changes in topics' highly scoring words shows that they can be related to specific policy events in energy and climate policy (research question 2). The change in top word compositions of the *climate protection* and *energy transition* topic highlight how discussions gradually shifted towards a discussion on the end of coal as well as the urgency of expanding renewable energy and dealing with the related bottlenecks. The specific feature of dynamic word scores in the dynamic topic model also allows the validation of the plausibility of topics and the evaluation of the impact of policy events on shifts inside topics. While many shifts in top words can be linked to policy events, some of the patterns need further investigation to be explained in detail.

Regarding our third research question concerning differences between groups by region and party affiliation, we show that the dynamic topic model can indeed quantify how parliamentary groups engage with topics differently. Based on the linkage of the parliamentary speeches to additional metadata on individual parliamentarians, we find differences in relative party attention to different

topics related to coal as a trade-off between economic, energy, environmental as well as regional/international policy issues and their centrality in topic co-occurrence networks (Sect. 4.4). We identify distinct party profiles with the Green and Left Party emphasising environmental topics and the remaining parties focusing primarily on energy and economic concerns.

The analysis of regional differences suggests that interests from regions are either not strongly expressed in the Bundestag in discussions around coal or these differences are not captured by the topic model. The latter could be the case if representatives from different regions express different positions but use similar vocabulary to do so, such that the co-occurrence of words and thus topics are similar. Furthermore, we group coal and non-coal regions at the federal state level even though usually only relatively few constituencies have larger employment shares in coal production.

The topic model results allow us to infer how much certain combinations of keywords occur in speeches. These results can be interpreted as an indication on how salient issues are within the parliament. But inferences about a specific group's salience towards a policy have to be treated with care. The discussion of a certain topic by one group in the Bundestag may force others to comment on it. Once a policy is raised by a party to the agenda, other parties have to deal with it as well, even if it has low priority for them. This can make the proportion of mentions of a topic an unreliable measure of an issue's salience for a group. Furthermore, policy makers' reactions will depend on their positions on an issue. This suggests that the dimensions of salience and position are not independent in a policy space such as the Bundestag, where actors constantly react to each other.

Our findings reflect other types of analysis that investigate the framing of energy policies in various countries. Frames often align with energy policy goals identified in the literature like access, cost efficiency and competitiveness, environmental sustainability and supply security [111, 112, 37]. They thus convey trade-offs and lines of conflict in energy policy making. These frames are prominent across countries in different discussions around energy policy and show similar trends that we also found in our analysis. For example, the studies by Edberg and Tarasova [113], Hess [114] and Sanderink [115] focus on frames and actor coalitions in debates around nuclear energy in Sweden, international renewable energy institutions and community energy policies in California, respectively. These studies all identify climate or transition and change frames to be most prominent in recent years, even though these frames are challenged by incumbent actor coalitions. For the recent discussion about the future of coal in Germany, Leipprand and Flachsland [44] have spelled out such frames and narratives of actor coalitions in detail.

The method used in this paper can be applied to study the framing of coal and energy policies in other countries. Future research can build similar analyses of parliamentary speeches to contribute to comparative research and assess the different events and actors that shift the focus of coal and energy policies from mainly economic frames to transition and climate topics. This could also include looking at changes of party-specific topics over time. The advantage

of using computational methods for such analyses is that they are easier to compare and reproduce than traditional frame analyses. Therefore, they are especially suitable to add to comparative studies such as the one by Osička et al. [46], which focuses on the discourse in the press about the future of coal in different European countries. Compared to traditional frame analysis, the applied methods have the shortcoming that infrequent keyword combinations are less likely to be detected. Thus, uncommon frames might be missed.

Our research provides important information on the strength and limitations of dynamic topic modeling for the study of parliamentary debates over long time periods (research question 4). Previous analysis of political and public debates using topic modeling often apply static LDA approaches that do not take time explicitly into account. Overall, our analysis highlights the strengths of the DTM methodology for longitudinal studies, i.e. with a strong emphasis on the development over time. In the dynamic model, change cannot only occur as a shift in the relative prominence across different topics, but also in the list of words that describe a particular topic. We find that topics are very time sensitive with substantial topic scores being limited to discrete time windows (Sect. 4.1). Policy instruments discussed in different time periods introduce specific jargon, which is reflected in the change of top words in the model (see Sect. 4.3). This provides more nuance to the computational analysis of political speeches than simple LDA approaches.

Like other topic models, DTM only uses information on word frequencies while discarding all other information. Topic scores therefore show how much a topic is discussed but do not provide direct information on the policy positions with respect to different issues. However, the analysis of co-occurring topics by actors gives at least partial information about positions of parties. Co-occurring topics, as identified by our topic network analysis, can shed light on how actors frame certain issues, which can be linked to coarse differences in positions. While such assessments need to be further validated and triangulated by other computational approaches, the difference between parties' co-occurrence networks are a first indication that such an interpretation is valid.

Our application of DTM furthermore highlights some constraints of the DTM method: First, it is computationally much more expensive than normal LDA which makes it hard to apply to very large document collections without high-performance computing infrastructure. Second, the changing word scores for the topics make standard evaluation methods more difficult to apply. This limits on the one hand comprehensive validation but on the other hand provides the possibility for external validation by linking the changes in top words to expected political events. Third, the finding that many topics are only dominant in several periods, which is robust for various model specifications, raises the question about differences in interpretation between shifts inside and between topics. Finding a good balance between changes of weights inside and between topics, as mediated by the parameter σ, thus becomes an important question for model calibration. This further suggests that the number of topics should depend on the change parameter σ to produce models with comparable results, which should be taken into account in procedures for DTM calibration.

Our use of computational methods results in an analysis that is more coarse grained than traditional frame and discourse analysis methods. However, there are similarities: Traditional frame analysis identifies which words and topics are mentioned in the context of a specific issue and thus how its problems are expounded [27]. Topic co-occurrence analysis gives hints to commonly used frames because it systematically identifies linked topics and thus their underlying words as identified by the topic model. Another similarity applies to discourse network analysis, which connects actors uttering similar statements in the context under investigation but also takes into account the position with respect to statements and arguments [28]. Here, we used a similar approach regarding actors from different parties but with respect to broader topics rather than specific statements.

Many limitations of topic modeling methods have already been discussed in the literature (see Sect. 3). Here, we only want to highlight some aspects of our longitudinal approach that should be addressed in future research. First, the dynamic topic model cannot quantify or infer how significant differences in time and between different groups of speakers are. For such questions, the structural topic model could be applied in a way that uses time or time periods as metadata that influence topic distributions [59].

Second, the combination of topic modeling with classification tasks such as sentiment analysis and stance detection could be used to better detect political positions with respect to specific issues [116]. Including this dimension could enable automatic analyses similar to discourse network analysis.

Third, the qualitative evaluation of speeches with high topic scores indicates the potential of combining quantitative computational approaches with qualitative methods. But further research is needed that draws on the strengths of NLP techniques and systematically integrates them with qualitative discourse analysis methods [47]. To operationalize this, specific methodological guidelines, protocols and procedures need to be developed, for example for the iterative design of codebooks for manual coding and topic model specification.

Combining the strengths of qualitative and qualitative methods would help to better understand the discursive dimensions of socio-technical transitions and could inform how obstacles to a rapid energy transition can be circumvented. Research in this direction can draw on political speeches and many other texts containing political communication, such as articles and transcripts from traditional media, social media content, documents from science-policy consultations, and texts from public relations. With the ever increasing quantity of political communication available for computational analysis, techniques such as topic modeling can help to advance our understanding of how political discourses evolve and to accelerate energy transitions making them consistent with ambitious climate protection.

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Data and code availability

The data used for this project is freely available from the sources referenced in Sect. 3.1. The code to reproduce the topic models and figures is available at `https://github.com/mcc-apsis/coal-discourse` and `https://github.com/mcallaghan/tmv`.

Appendix A. Topic and top word list

Table A.1 shows the list of topics identified by the dynamic topic model grouped by the 5 categories to which we attribute them. The 10 top words in the table have been weighted by the topic scores in a particular period. To calculate the weights for each words in a topic, we weighted the topic-word scores for a time period by the sum of scores the topic represented in this period. By this, we ensure that the top words represent those periods more in which the topic is stronger in the corpus. The ten words with the highest scores are displayed in the table in descending order of their weighted word scores. The table also displays the topic score of a topic in percentage points of the total topic scores of all topics.

Table A.1: List of topics grouped by category with labels, top words and topic scores (in percent of total score).

category	label	weighted top words	score pct
economy and budget	economic policy	wirtschaft, unternehm, entwickl, deutsch, markt, deutschland, wirtschaftspolit, staat, stark, marktwirtschaft	5.49
	budget	milliard, million, bund, haushalt, hoh, rund, ausgab, bundeshaushalt, bundesregier, offent	3.78
	budget 2	haushalt, milliard, bundesfinanzminist, investition, regier, finanzpolit, finanzminist, schuld, offent, hoh	2.87
	job market	arbeit, arbeitslos, arbeitsplatz, sozial, arbeitnehm, arbeitsmarkt, unternehm, beschaft, zahl, wirtschaft	2.83
	fiscal reform	spd, prozent, deutschland, euro, koalition, steu, haushalt, milliard, hoh, reform	2.75
	economic policy 2	wachstum, wirtschaft, bundesregier, wirtschaftspolit, offent, stabilitat, seit, bundeswirtschaftsminist, konjunkturpolit, aufschwung	2.17
	housing & social security	sozial, gesetz, wohnung, wohnungsbau, rent, hoh, fall, arbeit, mittel, alt	2.09

Table A.1: List of topics grouped by category with labels, top words and topic scores (in percent of total score).

category	label	weighted top words	score pct
	economic policy & participation	gesetz, unternehm, gesetzentwurf, entwurf, betrieb, mitbestimm, offent, arbeitnehm, wirtschaft, gewerkschaft	2.07
	subsidy reduction	euro, subvention, milliard, prozent, mittelstand, deutschland, geld, wirtschaft, handwerk, unternehm	1.85
	tax policy	steu, belast, kommun, erhoh, hoh, gemeind, entlast, gesetz, bundesrat, vorschlag	1.78
	research & development	forschung, million, bereich, haushalt, mittel, forder, programm, technologi, entwickl, wissenschaft	1.77
energy	energy supply mix	energi, erneuerbar, energiepolit, kohl, bundesregier, energietrag, energieversorg, kernenergi, nutzung, fossil	3.42
	energy transition & power market	strom, energi, erneuerbar, wettbewerb, prozent, energiew, kost, netz, kraftwerk, deutschland	2.73
	coal policy & prices	million, tonn, kohl, bundeswirtschaftsminist, deutsch, preis, bundesregier, hoh, etwa, staatssekretar	2.59
	hard coal & subsidies	steinkohl, deutsch, bundesregier, saar, kohl, saarland, arbeitsplatz, heimisch, jahrhundertvertrag, kohlepolit	1.95
	transport policy	bundesbahn, deutsch, verkehr, strass, bahn, verkehrspolit, bundesregier, wirtschaft, million, rechnungsjahr	1.90
	risks of nuclear energy	kernenergi, kernkraftwerk, technik, anlag, technisch, bundesregier, nutzung, brut, schnell, betrieb	1.67
	nuclear phase-out	kernenergi, energiepolit, deutschland, grun, kernkraftwerk, spd, ausstieg, kohl, entscheid, ministerprasident	1.56

Table A.1: List of topics grouped by category with labels, top words and topic scores (in percent of total score).

category	label	weighted top words	score pct
	coal mining	bergbau, bundesregier, bergleut, steinkohlenbergbau, deutsch, energiepolit, kohl, ruhr, gesetz, bergmann	1.45
environment	climate protection	klimaschutz, prozent, deutschland, ziel, emissionshandel, erreich, bundesregier, kohlekraftwerk, international, coemission	2.50
	environmental protection	umweltschutz, umweltpolit, umwelt, bundesregier, kraftwerk, luft, buschhaus, kohlekraftwerk, naturschutz, technik	1.40
	agricultural policy	landwirtschaft, bau, betrieb, deutsch, agrarpolit, preis, grun, ewg, letzt, landwirt	1.29
	green policies	okolog, grun, bundesregier, atomenergi, okosteu, minist, umweltpolit, topf, atomkraftwerk, deutlich	1.28
	natural resources	rohstoff, wald, schutz, natur, umwelt, beispiel, okolog, schad, bergrecht, wass	1.25
international and regional	European Coal & Steel Community	europa, deutsch, vertrag, franzos, frankreich, deutschland, gemeinschaft, schumanplan, hoh, union	3.69
	international cooperation	europa, gemeinsam, international, deutschland, wichtig, entwickl, staat, wirtschaft, zusammenarbeit, bundesrepubl	3.63
	foreign policy	deutsch, deutschland, staat, bundesrepubl, militar, sowjetunion, bundesregier, krieg, ost, aussenpolit	2.05
	reunification	berlin, ddr, bundesland, ost, ostdeutsch, west, ostdeutschland, alt, einheit, braunkohl	1.50
	structural adjustment	nordrheinwestfal, region, bundesregier, gebiet, bund, regional, stadt, bay, strukturpolit, arbeitsplatz	1.34

Continued on next page

Table A.1: List of topics grouped by category with labels, top words and topic scores (in percent of total score).

category	label	weighted top words	score pct
procedural and general politics	common terms	tun, wirklich, wiss, red, gar, darub, natur, richtig, eigent, namlich	10.67
	procedural	darauf, haus, darub, darf, bereich, punkt, bundesregier, entscheid, debatt, zusammenhang	9.35
	federal government	bundeskanzl, partei, regier, deutsch, sozialdemokrat, deutschland, wort, demokrat, recht, red	4.04
	policy statements	deutsch, volk, bundesregier, freiheit, wirtschaft, gemeinsam, deutschland, staat, europa, sozial	3.99
	procedural 2	gesetz, wirtschaft, bundesregier, entwurf, bundesminist, ewg, punkt, zweit, gesetzentwurf, haushaltsausschuss	3.16
	debate government policy	endlich, kolleginn, regier, generation, merkel, zukunft, wirklich, deutschland, schul, geld	2.12

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