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A comprehensive approach to reviewing latent topics addressed by literature across multiple disciplines

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HIGHLIGHTS

- An approach to review the literature addressing similar latent topics is proposed.
- This approach relies on the use of probabilistic topic models and semantic fields.
- Latent topics are addressed differently across multiple disciplines.
- We support the identification of new areas of research.
- It can be used for a wide range of latent topics, in particular moral values.

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ABSTRACT

This paper proposes an approach to capturing and reviewing scientific literature addressing latent topics across multiple scientific fields. As latent topics like moral values are affected by word polysemy and synonymy, a traditional keyword-based approach is often ineffective and therefore inappropriate. As a result, scientific literature addressing latent topics tends to be fragmented thereby constraining efforts to address similar and complementary research challenges. A novel approach to reviewing the literature by utilizing both semantic fields and probabilistic topic models has therefore been developed. We illustrate this approach by reviewing the literature addressing the value justice in the energy sector and compare this with a regular keyword-based approach. The new approach results in a more complete overview of the relevance of energy justice as compared to the traditional keyword-based approach. This novel approach can be applied to other latent topics including other values or phenomena such as societal resistance to technologies, thereby leading to an increased understanding of existing relevant literature and the identification of new areas of research.

1. Introduction

Scientific literature addressing the consideration of moral values in the deployment of technologies is growing. Friedman [1] defines moral values as what a person or group of people consider important in life. Examples are privacy, safety, trust and justice. Key scientific fields, including ethics of technology, institutional design, sociology and social psychology address moral values explicitly. In ethics of technology, scholars aim at pro-actively embedding the moral values of stakeholders into the design of technologies [2]. By doing so, their ethical acceptability can be increased, eventually decreasing the risk of future societal opposition [3]. The field of institutional design researches and proposes governmental interventions in the form of institutional arrangements [4]. In sociology and social psychology, moral values, beliefs and norms are considered to influence how individuals perceive and hence respond to the deployment and operation of technologies [5–7]. By addressing moral values, they aim to evaluate and improve the societal contribution of technologies and regulations for the wide range of stakeholders they affect.

However, literature addressing moral values is largely fragmented. Moral values are discussed in a wide range of scientific fields as well, including very technical ones. For example, privacy issues and potential solutions are often addressed in the fields of electrical and computer engineering [8,9]. Safety is largely considered within the field of material sciences [10,11]. While the identification of potential sources of concern tends to be performed by social scientists, technical fields may provide very pragmatic and detailed solutions to the lack of value fulfillment. Hence, the fragmentation of the literature constrains the

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design of technologies that better fulfill moral values. Without adequate technical solutions, identified ethical concerns may remain unsolved. And without an understanding of the potential societal concerns of technologies, proposed technologies may be rejected by the public, whereas they may have other strong societal benefits as well.

One important reason for the fragmentation of this literature is that it is difficult to capture scientific articles addressing similar moral values by means of traditional literatures searches. Researchers using forward and backward citation analyses rely dangerously on past scientific work already bridging scientific fields of interest [12]. By using keyword searches in indexed databases they may force a focus on highly cited articles, thereby omitting potentially relevant contributions of smaller fields. This is particularly problematic given the current exponential growth of scientific publications. Moral values are often addressed in a latent manner within scientific articles and their denomination is domain specific, thereby making them more difficult to capture using a limited number of search terms.

The challenge addressed in this paper is how to review literature that (1) bridges scientific fields and (2), where the reviewed topic is latent. In accordance with the field of text-mining, latent topics are described as polysemous and synonymous [13]. In these cases, no single word is unanimously used for a topic. Contrary to this, a wide range of words may be used to refer to elements of it. These same words may also refer to notions other than the topic of interest. For example, authors may use the word just to refer to the idea of justice, although it may also be used to refer to the notion of simplicity. In literature reviews, latent topics often relate to complex concepts like societal phenomena (such as societal resistances), specific societal expectation of technologies (such as moral values) or technological concepts (such as the smart electricity grid). In cases like these, literature searches that rely less on the enumeration of a set of specific words are required.

This paper proposes an approach to address this challenge by answering the research question: *How can multidisciplinary literature addressing similar latent topics be captured?* The proposed approach starts with a traditional keyword search and adds two distinct methods. Using probabilities topic models, we are able to identify topics addressed by a large set of potentially relevant articles less dependent on their scientific fields or very specific word use. As topics related to social phenomena or societal expectations of technologies tend to be smaller topics in the literature, probabilities topic models are less helpful. In these cases, articles addressing these smaller topics are captured using semantic fields created in multidisciplinary teams. The proposed approach leads to a greater visualization and understanding of how similar (latent) topics are addressed across multiple scientific fields, thereby leading to the identification of new areas of research.

This paper is structured as follows. First, the limitations of traditional literature searches in capturing the literature addressing latent topics across different fields are introduced in Section 2. This section also provides an introduction to probabilistic topic models and their limits in identifying latent scientific topics. Second, an approach to capture latent topics addressed by multiple scientific domains is proposed in Section 3. Third, an illustration of this approach is presented in Section 4. This illustration shows new types of research and design insights that can be gained by capturing the range of literature addressing the value justice in the energy sector. Finally, Section 5 discusses research results and gives some practical implications for multidisciplinary research and future research steps.

2. Theory

2.1. Traditional literature searches and limitations

Two main types of systematic literature searches are usually used to perform a review of the literature, viz. keyword searches, and forward/backward citation searches [14]. Both types of searches have limitations when reviewing latent topics addressed by multiple scientific fields. These limitations are explained below.

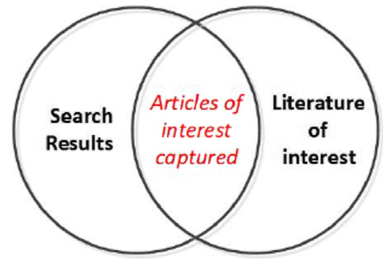

Fig. 1. Targeted literature in a keyword search.

2.1.1. Keyword searches

A keyword search starts with the identification of a list of search terms which is believed to adequately represent words that authors may use to address a topic of interest. A query is then used in an indexed database such as Web of Science or Scopus to retrieve the set of articles of interest for further analysis. The success of a keyword search is measured by the extent to which search results match the set of articles of interest (see Fig. 1). Typically, a keyword search is performed iteratively, as a learning process is required to ensure a better match.

An adequate match between search results and the set of articles of interest becomes more difficult if the topic researched is more latent. In these cases, search results tend to include many irrelevant articles, and an important number of potentially relevant articles may not be captured either. To cope with this, one strategy could be to use search terms that refer to a wider notion of the topic of interest. For example, the search term energy could be used to capture a wider range of articles addressing electric batteries. This however could lead to capturing a larger range of irrelevant articles and thereby making the isolation of relevant articles within the set of articles retrieved more difficult. Inversely, the use of more narrow words could exclude a large set of articles of interest. To illustrate this, we take the example of three topics with a high degree of latency. The first refers to a technological concept (the smart electricity grid), the second to a social phenomenon (societal resistance to infrastructures) and the third to a design consideration for technologies (privacy).

The smart electricity grid embraces a wide range of technologies designed to control imbalances between electricity supply and demand, as well as to support the integration of consumers as active participants in the electricity supply chain [15]. The latency associated with the concept of the smart grids is explained by the fact that it relies on a wide range of diverse technologies: smart meters, batteries, solar panels, etc. The search term smart grid when used in an indexed database could result in the exclusion of a large number of articles addressing technologies of use, or potential use, in the smart grid. An alternative would be to specifically mention the names of all technologies, but this would require knowledge of all relevant terms in advances. Also, these same technologies may be used in other technological contexts. Although not relevant for the review, these articles will be included in the search results.

The introduction of large scale infrastructure projects is often met by societal resistance and opposition [16–19]. The latency of societal resistance as a topic is illustrated by the wide range of terms authors use when referring to it. Examples include social protests, societal protests, public resistance, public protests, public mobilization, technology acceptance, technology acceptability. This long list suggests that there may be a wider range of words authors can choose from when addressing societal resistance. Some authors directly address specific sources of societal concern like a lack of privacy, safety or fairness of technologies, without mentioning the notion of societal resistance as such. In cases like this, searching for articles discussing societal resistance to large scale infrastructures by using a traditional keyword-based approach would run the risk of omitting a large number of articles that may be of relevance but which might be published in other scientific fields.

The notion of privacy is becoming increasingly important in the energy sector due to the progressive introduction of information technologies to improve grid management. The latency of the word privacy comes from the fact that it is addressed differently in multiple scientific fields. Social sciences tend to address the issue of privacy from a human perspective, describing ethical and societal issues at stake for individuals [20,21]. The fields of computer science and electrical engineering tend to tackle the issue of privacy from a technical perspective and frequently use terms such as cyber-attack, hacking and data leak without necessarily mentioning the word privacy [22,23]. It would be difficult to capture literature of interest here without knowing this set of words in advance. They would all need to be included in the search query before the technical literature addressing potential privacy problems could be included in the set of articles finally retrieved. This would, however, inevitably lead to capturing irrelevant literature on cybersecurity issues that may not pose a privacy problem but would be pertinent to protect electricity grid equipment.

2.1.2. Forward and backward citation searches

In a citation search, a limited number of articles that are considered to be central to the literature of interest are initially selected. Forward and backward searches are then performed, by examining scientific articles citing and cited by articles of the initial reference set. Additional iterations can be performed depending on the research scope, and to review second and third generation articles (i.e. articles cited by the references of the initial articles).

The use of forward and backward citation searches is advantageous when reviewing latent topics as it does not rely on specific keywords that might be used differently across multiple scientific fields. However, forward and backward citation searches rely on previous work that has already bridged multiple disciplines [12]. This carries the risk that potentially relevant citation networks that are less connected to other fields are excluded from search results. One way to address this limitation would be to use a larger set of articles as a starting point. This however implies knowing the set of potentially relevant fields in advance.

2.2. The promises of probabilistic topic models

There are several ways to capture a wider set of scientific articles across multiple scientific fields. One is proposed by Chappin and Ligtvoet [24] in the form of a more systematic forward and backward citation analysis. The starting point of the analysis involves collecting articles from an indexed database using key terms and linking them by author and reference similarity. This allows the creation of co-author networks (i.e. showing which authors have worked together on specific articles [25]) and citation networks (i.e. which articles cite each other [26]). As the starting point of the analysis is a large set of articles captured using keywords, the analysis is less dependent on a limited number of articles as a starting point. Neither is it dependent on articles having previously bridged multiple scientific fields of interest. However, it remains dependent on the specific keywords used to capture the initial set of articles. Additionally, this approach aims primarily at understanding the citation structure of the literature and provides little information about its content. This is a strong limitation when attempting to understand how a topic is addressed in different scientific fields. A more promising approach to reviewing latent topics across multiple scientific fields would be to use probabilistic topic models.

A probabilistic topic model is a text-mining tool originating from the field of scientometrics [27,28]. Computational tools are used to enable topic models to identify topics addressed by a large set of documents by means of an algorithm. For example, if a large set of documents addressing wind and solar energy is provided to a model as an input, it would be able to retrieve these topics by identifying which words are frequently used within a single article while passing through the text of the articles.

Latent Dirichlet Allocation (LDA) is the most commonly used type of probabilistic topic model [29] and is an unsupervised method. This means that except for the digital copies of the set of articles of interest and a few model parameters (such as the number of topics to be found by the model), no other information such as topic titles or words relating to topics needs to be provided as an input for the identification of topics. Hence topics are identified by the model in an autonomous way. A topic model may discover multiple topics addressed within one single article. For example, if an article addresses both wind and solar energy, one possible outcome of the model would be that the article discusses the topic of wind energy for 70% and solar energy for 30%.

An interesting property of a topic model is that it is less dependent on the use of very specific words to identify topics. Instead, the model relies on a larger set of words that authors use to address a specific topic. For example, articles addressing the topic of batteries may use the word battery but also lithium-ion, discharge and capacity. As a topic model identifies topics not based on individual words but on a range of words that are used within articles to address this topic, the model may find that two articles both address the topic of batteries, even if one article does not mention the term battery. This property is highly relevant for capturing latent topics addressed by a wide range of scientific communities. If two scientific communities frequently address privacy issues, one using the word privacy and the other cyber-attacks, but both using terms like information, consumption data and sensitive, the model would be able to conclude that the same topic was addressed.

A second interesting property is that the accuracy of topic identification increases with the number of documents provided as an input to the model. The higher the number of documents, the better the autonomous training of the model. As a result of this, the large number of potentially relevant scientific articles addressing a latent topic of interest is no longer a challenge but has become an advantage.

2.3. Related work

Topic models, and in particular LDA models, have been applied to various types of documents including emails, scientific articles and newspaper archives [29] or to classify images [27]. In Griffiths and Steyvers [28], the authors demonstrate the use of topic models for reviews of the literature. A set of abstracts of papers published in the Proceedings of the National Academy of Sciences is used to explore the topics addressed by these articles. By doing so, they demonstrate the consistency between topics extracted by the model and the topics that were initially selected by the authors of the papers.

Although a large number of scientific articles from the field of computer sciences address probabilistic topic models as a methodology, actual applications to literature reviews are limited. From these we were able to identify two reasons for authors to use topics model. The first is an exploration of the relative size of topics within a broader field of research. By applying topic models to perennial crop literature, Kane [30] discovered the dominance of rice and wheat publications over articles addressing soil biology and carbon dynamics, thereby suggesting a bias in the literature. In the hydropower development literature, Jiang [31] found that most articles discuss post construction issues rather than construction technology. The second reason is the identification of emerging topics addressed by a scientific community. Wei [32] used a topic model to identify emerging subjects of patents in the area of shale gas technology. Grubert [33] used a topic model to show that life cycle assessment literature tends to concentrate increasingly on climate change issues rather than on health and pollution problems.

2.4. Intermediary conclusions

While several articles have already attempted to demonstrate the relevance of probabilistic topic models to support more systematic and comprehensive literature reviews, in particular when multidisciplinary research is of interest (see [34,35] for a discussion), its application is still relatively low. We attribute this lack of application to the minimum level of programming skills required to apply topics models, but also to their limited ability to isolate a very specific topic of interest. As most types of topic models are unsupervised, topics generally found are merely the large ones. Hence, insights provided by the use of topics models are limited to overall observations about the composition of the literature and its trends. This is sufficient to get a general understanding of the literature, but not to target a specific (latent) topic of interest. For these cases, an adjusted approach is necessary.

3. Proposed approach

This section presents an approach to identify and review articles addressing latent topics. Examples of latent topics are privacy matters, societal resistance or the smart electricity grid. Often, we are interested in the consideration of latent topics within a larger context, for example, within the energy sector. This larger context may be latent as well. The proposed approach relies on the use of probabilistic topic models and semantic fields. The probabilistic topic models were introduced in Section 2.2, and the semantic fields will be discussed in Section 3.1. The approach is presented in Section 3.2.

3.1. Semantic fields

A semantic field is composed of a set of words referring to a common idea [36]. For example, words such as fairness, neutrality and legitimacy all refer to the idea of justice and are therefore part of its semantic field. Hence, if these words are observed in a scientific article, we can deduce with a reasonable amount of certainty that the article addresses the value justice, whether the article actually mentions the word ‘justice’ or not. To create the semantic field of a word, the following sources of information can be used: speakers’ judgments, corpus-based studies, thesauruses and dictionaries, computational models of lexical knowledge, psycholinguistic experimentation, naturally occurring and experimental data and discourse analysis [36].

The use of semantic fields presents two challenges. First, there are no strict rules to define the semantic relationship between words in a semantic field. According to Murphy [36], most authors agree that “antonymy, synonymy, hyponymy and the like” are valid relationships. Second, some words are synonymous. Hence, a certain word might only point to the topic of interest if it is used in a specific context. An example of this would be the word ‘private’. It could refer to privacy but could also indicates something entirely unrelated like a non-publicly owned company. When faced with these two challenges, semantic fields should be created with care and should preferably involve sector experts.

3.2. Approach

This section presents an approach for identifying and reviewing the literature addressing latent topics. A flowchart of the proposed approach is presented in Fig. 2. In step 1, a large set of articles is extracted from an online database using a broad keyword to ensure the inclusion of a maximum number of potentially relevant articles. In step 2, probabilistic topic models are used iteratively to progressively reduce the dataset towards the desired set of articles addressing the latent topic of interest. If the latent topic is small, the topic model will, in most cases, not reduce the dataset to exclusively relevant articles. A semantic field of the latent topic is therefore created within a multidisciplinary team in step 3. This semantic field is used to capture articles addressing the latent topic within the dataset that was previously reduced using the topic model in step 4. This dataset refers to the context of consideration of the latent topic of interest, for example the energy sector. Finally, the literature is analyzed in step 5. The description of the proposed approach is followed by an illustration in Section 4 in which articles addressing the latent topic justice in the energy sector are captured and reviewed.

3.2.1. Step 1: Data extraction in an online database

First, a database containing an initial set of articles needs to be created. To do this, articles are downloaded from an online database using a search term that is broad enough to ensure that the maximum number of potentially relevant articles is included. For example, if a latent topic within the energy sector is of interest, then an adequate search term would be ‘energy’. The trade-off here is between the inclusion of a maximum number of potentially relevant articles and the time required to download this large set of articles from indexed databases. Most databases have download limits to the number of articles that can be downloaded simultaneously, thereby requiring articles to be downloaded in successive batches.

3.2.2. Step 2: Iterative creation of a topic model

After data has been extracted, topic models are created iteratively, excluding a set of irrelevant articles at each iteration. The Gensim package [37] is used for this. ‘Jupyter’ and ‘Ipython’ are used for data analysis and ‘pyLDAvis’ for visualizations of the topic model created [38]. Creating a topic model requires providing an initial number of topics to be found by the algorithm. This is an important step as the initial number of topics set by the modeler greatly influences the outcome. Measures of model quality can be used to guide this decision; these include the perplexity measure [39] or topic coherence [40]. Measures are only indicators of model quality and human judgment of the topics generated by the model is mandatory.

Articles can be excluded at each iteration by using thresholds. As a topic model indicates how much of each of the topics it addresses in each article (for example 30% for topic 1, 40% for topic 2, etc.), articles in which the topic of interest is not sufficiently addressed can be removed from the dataset. A new topic model is than created based on the reduced dataset. The iterative creation of topic models ends when the latent topic of interest is found in one or more of the topics identified by the model. If this topic cannot be found, the topic model that relates to the wider context of interest is used (for example the energy sector). A semantic field of this topic is created to identify articles addressing the latent topic in step 3.

3.2.3. Step 3: Creation of semantic fields

If the latent topic of interest is small (represents a limited number of articles within a broad context), the topic model will, in most cases, be unable to find this topic autonomously. A semantic field of words that relate to this latent topic then needs to be created.

As different scientific communities may address this topic using different words, this diversity should be reflected in the semantic fields created. This can be done by means of a workshop, grouping experts from the different scientific communities that might address this topic. These experts should have a background in the larger context of consideration of the latent topic as well.

These semantic fields can be created by the following process. First, an initial list of words referring to the topic can be drawn up using online thesauruses. Examples of suitable thesauruses are the English Oxford Living Dictionaries [41], the Rogets International Thesaurus [42], the Merriam-Wester Dictionary of Synonyms and Antonyms [43], and the Collins Online Thesaurus [44]. The antonyms, synonyms and ‘related words’ suggested by online thesauruses are extracted from them. Next, workshop participants are asked to remove words from this initial list that do not match the following two conditions: (1) it is highly probable that a scientific author would use this specific word to refer to this topic and (2) when seen in scientific articles, it is highly probable that this word refers to only this topic. Participants are also asked to add words they feel are missing. A voting system can be used to guide decision-making on word additional and removal.

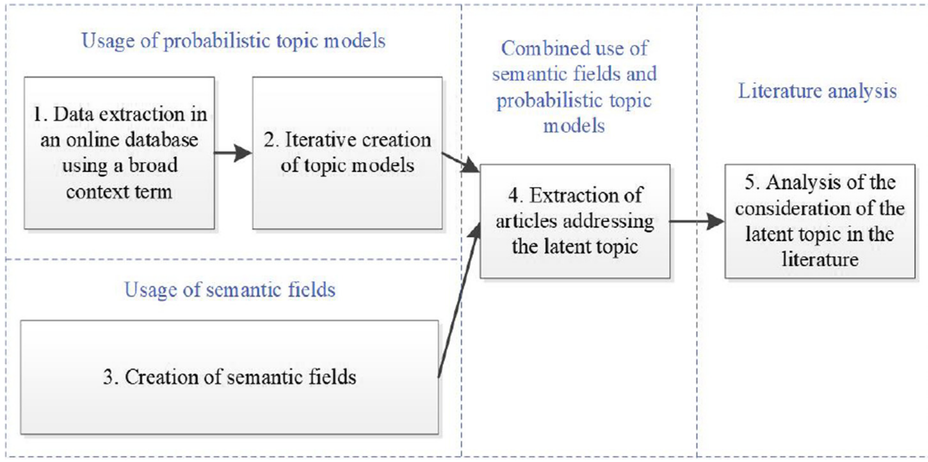

Fig. 2. Flowchart of the proposed approach.

3.2.4. Step 4: Extraction of articles addressing the latent topic

Following step 3, articles in the reduced dataset that mention at least one of the words of the semantic field are isolated. It is possible to gain insight into the contexts in which this latent topic is frequently discussed (for example in relation to certain technologies) by looking at the topics to which they were assigned by the topic model.

3.2.5. Step 5: Analysis of the consideration of the latent topic in the literature

The analysis of the latent topic in the literature is performed in step 5. This analysis can be performed manually or by using other computation tools, such as the co-citation analyses as proposed by Chappin [24].

The application of the approach introduced in this section is demonstrated by an illustration of the way in which the latent topic justice is addressed in the energy sector in Section 4.

4. Illustration: justice in the energy literature

This section provides an illustration of the proposed approach presented in Section 3. It illustrates an analysis of the consideration of the value justice by scientific literature in the energy sector. It identifies which justice issues are addressed within the energy sector, by which community and by which means. The illustration demonstrates the additional insights found using the proposed approach and the relevance of outcomes in performing reviews of the literature. This example from the energy sector covers all activities related to energy extraction, production, transport and consumption, and related policies.

An overview of the experimental configurations is provided in Section 4.1. After this, the topic models and semantic fields are presented in Section 4.2. The issue of justice in the energy sector is analyzed in Section 4.3, showing how research outcomes are instrumental for multiple scientific fields. Finally, search results are compared with outcomes of traditional keyword searches in Section 4.4. An overview of the application of the proposed approach to the value justice in the energy sector is provided in Fig. 3.

4.1. Experimental setup

4.1.1. Data extraction

An initial set of articles was downloaded from Scopus, using the query AUTHKEY(energy). The search, performed in March 2018, led to the retrieval of 380,760 articles. Articles were extracted by exporting titles, abstracts and keywords of each article into a CSV file and grouped into a single string using Python. This resulting set of words (the string) was then considered as the text corresponding to an article, which was later used to build the topic model. Text-mining packages such as 'stop-word' and 'nltk' were then used to further process the data (i.e. removing words that did not add any meaning and conversion of strings into substrings).

4.1.2. Iterative creation of topic models

To create topic models, the number of passes (i.e. the number of times the algorithm passes through the set of documents provided as an input) was set to 5, as topics did not appear to change later on. Coherence analyses and manual investigations were performed to evaluate the number of topics found in the model. Topics that were considered relevant to the consideration of the value justice in the energy sector were isolated and articles that were assigned to these topics by the topic model by at least 33% were extracted and placed into a new dataset. In each case, samples were performed to verify the proper extraction of articles. The new dataset was then used to create the next topic model.

4.1.3. Creation of semantic fields

A semantic field of the value justice was created based on online thesauruses. The list of words was then reviewed with researchers representing a variety of backgrounds: (institutional) economics, system engineering, standardization and ethics. All researchers had a solid background in the energy sector and were well acquainted with the concept of values. The definition of justice provided to researchers was the following "The system is just, impartial, or fair". The final semantic field created can be found in Fig. 3.

4.2. Results

4.2.1. Topic models

The outcomes of the first topic model are presented in Fig. 4. The ten words most frequently used by authors to address each topic are given. The figure shows that only the first topic relates to the energy sector, while the others refer to body metabolism, sensor networks and material science. The presence of the later three topics is not totally surprising as the use of the word energy is obviously not exclusive to the energy sector. As we are only interested the consideration of justice in the energy sector, articles that were sufficiently assigned to topic 1 were extracted to a new dataset.

The second topic model contains 100 topics. The overview of topics can be found in Table 4 in Appendix B. As a topic model is only able to present words most frequently used by authors to address a topic, we have provided our own titles to topics. An interactive visualization of the 100 topics identified by the model can be found online as well as in

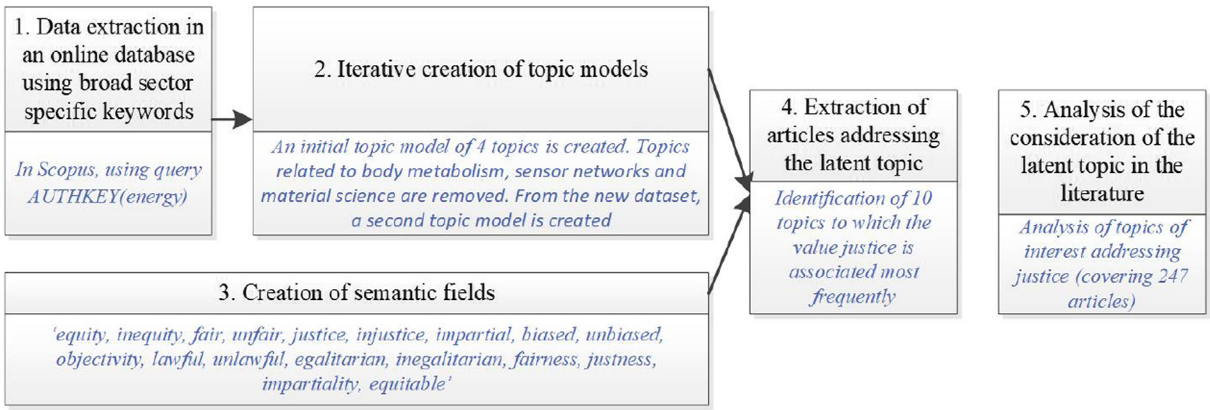

Fig. 3. Flowchart of the proposed approach applied to the latent topic 'justice'.

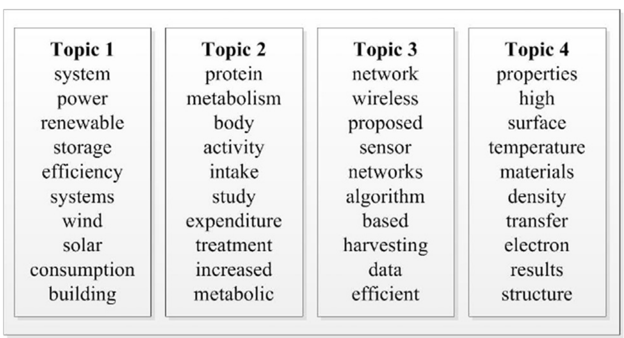

Fig. 4. Topics identified in the first topic model.

(*https://github.com/tristandewildt/Latent_Topics_Energy_Sector*). It shows the thirty most frequently used words for each of the 100 topics. The python code used to perform the analyses can be found using the same link. An overview of the relative size of each topic (the marginal distribution of topics) can be found in Fig. 5 in Appendix C.

The topics found by the topic model can be put in five categories. The first, a large set of topics, relates to specific technologies or infrastructures like smart energy management systems, inverters and wind turbines. The second category refers to energy sources and (undesired) products like carbon emissions, biomass and hydrogen production and fossil fuels. The third includes references to energy governance like energy policy and economic development. The fourth set of topics relates to geographical areas such as cities and communities. The final category comprises topics that refer to specific methods like scheduling algorithms and spatial optimization.

We found that the articles in the category containing the technological topics generally tended to propose technological innovations and describe control and management methods like new scheduling algorithms. The category containing the energy sources, products, governance and geographical topics mostly included articles containing evaluations related, for example, to the environmental impact of effectiveness of policies. Most of the articles in the final category, proposed simulation models, algorithms and optimization methods, for example, for the integration and scheduling of different energy system components.

As no topic related to justice issues was found in the new topic model while the new dataset still related to the broader context of interest (i.e. the energy sector), we used a semantic field to capture articles of interest.

4.2.2. *Semantic field created*

A semantic field of justice was created containing 18 words that can be found in Fig. 3.

4.2.3. *Topics frequently addressing justice*

We found 1297 articles containing a word of the semantic field of justice from the dataset adjusted after the first topic model (hence only creating articles addressing the energy sector). In this illustration, we focus our analysis on the ten topics that most frequently addressed the topics of justice (see Table 1). Topic numbers and titles are provided in the first two columns. The third column shows the number of articles addressing the value justice found per topic. The fourth column gives the five highest cited articles addressing the value justice per topic. When creating this table, we assumed that an article belonged to a topic if at least 15% of the words in the article were assigned to this topic by the topic model.

Table 1
Ten topics most frequently associated to the value justice.

Topic #	Topic titles	Counts	Five highest cited articles
17	Load management	44	Bai et al. [45], Zhao et al. [46], Negash et al. [47], Tian et al. [48], Huang et al. [49]
6	Energy policies	36	Pandey [50]; Sawangphol and Pharino [51], Lauber and Jacobsson [52], Cherni and Hill [53], Balta-Ozkan et al. [54]
1	Carbon emissions	35	Raupach et al. [55]; Davis and Caldeira [56]; Capros et al. [57]; Chapman et al. [58]; Hyder [59]
24	Communities	29	Cowell et al. [60], Aitken [61], Miller et al. [62], Bilgili et al. [63], Sovacool and Scarpaci [64]
15	Fossil fuels	27	Sagar and Kartha [65], Aitken [66]; Miller et al. [67], Bilgili et al. [68], Sovacool and Scarpaci [69]
2	Smart energy management systems	23	Zhang et al. [70], Wang and Huang [71]; Paul and Aisu [72]; Mhanna et al. [73], Aswantara et al. [74]
42	Nuclear energy	12	Steinbach and Brückmann [75]; Löfquist [76]; Kilb [77]; Kim [78]
10	Energy and economic development	9	Huijts et al. [7]; Wang et al. [79]; Sovacool [80]; Toklu et al. [81]; Jenkins et al. [82]
69	Energy Poverty	9	Heffron and McCauley [83], Zhang [84], Walker et al. [85], Stretesky and Lynch [86], Reames [87]
8	Micro-grids	6	Hong et al. [88], Nordman and Christensen [89], Xin et al. [90]; Parisio et al. [91], Lamberti et al. [92]

Table 1 shows that the value justice is frequently associated with all five types of topics identified in Section 4.1. Justice is addressed together with energy production inputs and outputs ('carbon emissions' and 'fossil fuels'), energy governance ('energy policies', 'energy poverty' and 'energy and economic development'), geographical areas ('communities'), technologies ('smart energy management systems', 'microgrids', 'nuclear energy') and methods ('load management').

4.3. Analysis

The analysis shows how the new approach adds additional insight into the consideration of justice in the energy sector, in the form of ranges of potential injustices covered by the literature and the approaches used to address them. We also show that some ranges of injustice are insufficiently covered in different scientific domains leading to the identification of new opportunities for (multidisciplinary) research.

4.3.1. Justice issues addressed and approaches

Table 5 in Appendix D provides an overview of justice issues addressed within the articles mentioned in Table 1. Information on the stakeholders affected by these issues and the different approaches used to address them are also provided.

A first type of injustice addressed is the disparity between the CO_2 emissions of different countries which can influence their contribution to climate change. While developed countries have historically largely contributed to CO_2 emissions, populations of developing countries are the ones that appear to suffer most [81]. Several environmental policies to limit CO_2 emissions have been introduced. These include carbon taxes but they may hinder economic development in poorer countries. It is unfair to expect developing countries to bear the brunt of these measures as their economic growth has now become more limited by environmental measures than developed countries were in the past [55,84,59].

A second type of injustice addressed is the inequality in access to newer, cleaner energy technology and sources, mostly due to their higher costs. As a result of this, poorer countries, regions and citizens are sometimes deprived of access to newer, cleaner energy and suffer more frequently from ill health and the safety risks related to unsustainable energy production and consumption [79,65,68,63]. A third and related type of injustice entails inequalities in faculties to support the costs of environmental measures. Energy efficiency measures may, for example, increase the living costs of households and it may be difficult for underprivileged sections of the population to bear these additional costs [54].

A fourth type of injustice arises from the health and safety risks of energy production. While the availability of energy can provide benefits to an entire economic area, smaller, local communities are often adversely impacted by pollution and safety incidents [76]. A fifth type of injustice is related to the deployment of (cleaner) energy infrastructure due to cultural and aesthetic considerations. This is similar to the fourth type of injustice. Although an entire country can benefit from cleaner energy production, communities located close to the production plants are often adversely impacted by their presence.

We noted some injustices that are direction-related to the smart electricity grid. An increasing number of appliances owned by individuals are often connected to a single grid, creating unjust distribution issues. The sixth type of injustice originates from inequalities in conditions of access to the grid. The number of vehicles powered by electricity is increasing and as many of them are connected to the same system of charging stations, the distribution of electricity needs to be fair for all users, especially in locations where there are energy shortages [72,74]. A seventh type of injustice arises when multiple users make energy harvesting devices available to the electricity grid. Here, injustices may arise from inequalities in the usage of devices and revenues attributed to users [89–91,88]. An eighth type of injustice can be seen in the establishment of local energy communities. Individuals of these communities may, for example, invest different amounts in the local energy network and thereby create unjust issues of distribution of revenues [71]. Finally, a ninth type of injustice is related to fair competition between market participants [47,45].

Table 5 also shows ways to remediate injustices by both revealing and reducing them. Authors rely on data analysis to reveal injustices, for example, to identify historical disparities in CO_2 emissions [55]. Others simply review the scientific literature [58,70] or perform case studies, for example through surveys [61].

We noted other ways to reduce injustices. These include contractual arrangements like the design of improved market rules [45]. We also noted a frequent discussion on redesigning algorithms to lead to a fairer distribution of energy and revenues [72]. Finally, some authors simply advocate sustainable development as this is considered to inherently reduce injustices [81], while others aim to both reveal and reduce injustices, such as energy injustice [82,93].

4.3.2. Relevance of results for scientific fields addressing justice issues

These results first point to new areas of research. The illustration shows that a wide range of injustices are addressed in the literature. However, several injustices have not yet been addressed, leaving potential for more research. For example, the literature explicitly addressing justice in the energy sector tends to be embedded in justice frameworks such as energy justice and environmental justice. We, however, find that this merely concentrates on a limited set of injustices, while these frameworks do not explicitly claim to limit themselves in that. We also found that articles addressing energy justice tend to concentrate on the protection of the underprivileged, whether citizens, regions or countries and are mostly related to climate change, environmental policies and the deployment of renewables. However, Jenkins et al. [82] explain that energy justice seeks to "apply justice principles to energy policy, energy production and systems, energy consumption, energy activism, energy security and climate change". Hence, injustices that emerge from the deployment of the smart grid are within the scope of energy justice and therefore also need to be addressed. This is especially important when considering the fast roll-out of smart grid technologies, their importance for achieving sustainability goals and societal concerns related to their deployment [54,20,94,95].

A second finding relates to the potential concerns certain sectors of the population might have about specific technologies. This is particularly relevant for engineers since these concerns could hinder the successful deployment of new technologies. Engineers may be forced to adjust technological designs to prevent deployment issues. We found that the issue of the location of traditional power plants is important as it affects sectors of the population differently. This, however, does not apply to renewable energy sources, as can be seen by the large number of wind energy projects [96]. When looking at smart grid developments, it is clear that community characteristics also appear to play an important role in the success of technological deployment. Algorithms that distribute electricity and revenues between participants may (unintentionally) prioritize some households over others. This could lead to issues of fairness and trust resulting in the progressive rejection of the technologies proposed.

A third finding relates to the types of approaches used to address justice issues. It appeared that it would be easier to introduce new technologies if local characteristics were considered more carefully. The use of the Community Knowledge Networks proposed by Catney et al. [97] could, for example, provide a better understanding of community knowledge and practices in relation to consumption. This could be useful when proposing technological solutions in terms of complexity and priorities that individuals in the community have. An improved overview of existing types of approaches may show that a range of potentially relevant technical solutions to address justice issues already exist for social science related fields. This is crucial to ensure that discourse on justice is not limited to the mere identification of issues but is followed by actual adjustments of technological and regulatory designs.

4.4. Comparison with traditional keyword searches

We compared the results of our proposed approach with the ones of a traditional keyword search by performing two searches without the use of a topic model. In the first case, we only retrieved articles from the initial set of articles that mention the search term ‘justice’. This is equivalent to using the query AUTHKEY(energy) AND TITLE-ABS-KEY (justice) in the Scopus database at the time of the search. As it is doubtful that a researcher would only use the word ‘justice’ when trying to find articles addressing justice, we performed another search using all the words in the semantic field of justice created in Section 4.1. We analyzed the 50 highest cited articles in both searches and identified the different types of injustices, the affected stakeholders and the proposed approach to remediation. Articles that did not address justice as defined in this research were passed over, even though some of them contained a word in the semantic field of justice. Extended outcomes can be found in Table 6 in Appendix E and in Table 7 in Appendix F. We compare the results based on the number of articles addressing one type of injustice in Table 2. The differences between types of stakeholders affected and approaches for remediation are discussed in the text.

We made four observations from the comparison presented in Table 2. First, the proposed approach enabled us to find a wider set of injustices related to the energy sector. When we compared this to the literature found using keyword searches without a topic model, we noted that the latter concentrated primarily on types of injustice related to the environment (injustices 1–5). Injustices related to the smart grid and energy markets (6–9) were not addressed when the keyword ‘justice’ was used and were negligible when the semantic field of justice was used. We also noted that no additional types of injustice were found when using the simple keyword searches. Hence, the proposed approach enabled us to find more types of injustice in the energy sector without omitting other types that would have been found using a simple keyword search.

Second, as we found more types of injustice, we also found a wider range of affected stakeholders. While the simple keyword search mainly addressed local communities, poorer populations and future generations, the proposed approach revealed injustices to citizens as consumers, economic actors and economic regions.

Third, the proposed approach enabled us to find more processes for remediation. As the literature addressing injustices related to the smart grid and the design of the market tends to be more technical, we were able to find a wider range of processes aimed at reducing injustices, for example through the redesign of algorithms and market rules.

Fourth, Table 2 shows that the types of words used to refer to the value justice vary strongly depending on the scientific field addressing this value. The word ‘justice’ tends to be used in articles that rely on well-defined justice frameworks, such as energy justice (see [95]). Other articles do not appear to be embedded in justice frameworks. The words ‘equity’ and ‘inequity’ are frequently used in the context of energy policy to describe inequalities between countries or citizens. The words ‘fair’ and ‘fairness’ are frequently used to assess injustices in the context of the smart grid and inequality of access to markets or market revenues.

5. Discussions and conclusion

This paper proposes an approach to reviewing latent topics addressed by multiple scientific communities. Starting from a (very) large set of potentially relevant articles, we use probabilistic topic models iteratively to progressively reduce the dataset to one containing articles addressing the latent topic of interest. As topic models are limited in finding smaller latent topics, semantic fields are used to identify relevant articles. This approach enables us to visualize and compare how a specific latent topic, for example justice, is considered in multiple scientific fields and the types of technologies it is frequently associated with.

The approach presented in this paper provides a more valuable use of probabilistic topic models. While the potential contribution of topic models to review latent topics in the literature is clear, a limited number of applications have been found. We argue that this is explained by the fact that the simple application of topic models only

Table 2
Comparison between sources of injustices found.

Sources of injustices	Proposed approach	Keyword search: ‘justice’	Keyword search: semantic field of justice
1. Historical disparities between countries in carbon emissions and impacts of climate change	5	9	8
2. Inequality of access to newer and cleaner energy technology and sources	11	12	15
3. Inequalities in faculties to support the costs of environmental measures	8	6	13
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	5	7	4
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	4	16	5
6. Inequalities between users in conditions of access to the grid	3	0	1
7. Inequalities in usage of devices and revenues attributed to smart grid users	10	0	4
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)	1	0	0
9. Lack of fairness between competitors in electricity markets	2	0	0

provides high levels insights about a set of articles, such as topic trends or the relative importance of different topics, with limited possibilities to guide the search to a more precise dataset of interest. The proposed approach aims to fill this gap, thereby increasing the value of probabilistic topic models to reviews of the scientific literature.

Our work offers three main contributions. First, the proposed approach makes it easier to cope with the exponential growth of scientific articles and publications. As the amount of literature is growing, it is becoming increasingly difficult for researchers to keep track of recent scientific developments that may be of interest for their own research. The use of topic models allows for the execution of more comprehensive and complete reviews thereby supporting quality research. Second, the proposed approach supports research that bridges multiple scientific fields. Certain scientific communities may, for example, have answers to problems that others lack. Also, research from multiple fields may have strong potential for complementarity. For example, Manders-Huits [2] and Correljé et al. [4] explain that value sensitive design lacks clear methodologies to systematically include values in designs and cope with value trade-offs. The literature on value sensitive design could benefit from the socio-technical systems literature, as it is more equipped to engage stakeholders and make value trade-offs visible [98]. Certain scientific research may raise concerns that require the design or adjustment of technical solutions. As the illustration demonstrates, a large range of sources of injustice can be identified in the energy supply chain, but technical and regulatory solutions are not always clear. Ultimately, a better visualization of affiliations and an understanding of complementary or conflicting findings by multiple scientific fields addressing similar moral values may point to new research opportunities. Third, we support computer science research by showing the added-value but also the shortcomings that probabilistic topic models have when used to review scientific literature. The difficulty to identify small latent topics within a larger set of scientific articles is a strong limitation here, which in our approach, requires the creation of semantic fields.

Our work is particularly relevant for research addressing the design and deployment of technologies. Essentially, all topics are latent, but some more than others. This is particularly true for topics that do not relate to very specific technologies but to vaguer societal phenomena or societal expectations of technologies. As these concepts are more complex and therefore more difficult to grasp, understand and explain, society employs a wide range of terms when referring to them. Different societal groups may use different words to refer to similar ideas, but also understand similar words differently. Technologies are often deployed within a large societal context and different societal groups can be positively or negatively affected by them and may react accordingly, for example, by opposing the installation of new infrastructure. In order to support the deployment of technologies and propose adequate solutions, it is necessary to gain a better understanding of these latent topics. It would be advantageous to consider these latent topics across a range of scientific domains as this would both increase awareness of potential societal concerns (typically identified by fields of social sciences) and would be instrumental in proposing adequate technological and regulatory solutions (typically proposed engineering and policy related fields).

The range of potential applications of the proposed approach is large. We take the value justice as an example in the illustration and show how our approach leads to a better overview and an improved understanding of potential sources of injustice, the different scientific fields that do (or do not) address certain types of justice issues and the existing approaches that may be used to address these issues. The proposed approach can be applied to other values like privacy, safety and security of supply and within narrower contexts, such as the smart electricity grid or nuclear energy, or different economic domains, like transport and ICT. It may be appropriate to apply the Q-methodology if key relevant values at stake are not known in advance [99,100]. Extending to the use of expert interviews and discourse analysis methods, the Q-methodology enables improved visualization of the variety of perspectives that a range of stakeholders have on a particular issue. Other potential applications of our approach include specific societal phenomena, such as public protests against infrastructures, other design considerations for technologies, such as the identification of multiple approaches to address energy efficiency (for example Geng et al. [101] and Cui et al. [102]) or technological concepts encompassing a wide range of technologies (for example Li and Zheng [103]).

A number of limitations should be taken into account when using the approach proposed in this article. First, this approach makes it possible to identify a wide range of articles addressing latent topics but is not equipped to find all leading articles in each of the fields addressing the topic in question nor the most recent. Even if the approach starts with a very large set of scientific articles, it is still a subset of all potentially relevant articles. Second, creating semantic fields is an effective way to cope with the difficulty topic models have in finding smaller topics, but is still limited in coping with the challenges of word polysemy and synonymy as, although created more robustly, we still rely on an enumeration of specific search terms to identify relevant articles. Third, there are methodological limitations to the use of topic models. Using topic models requires setting input parameters such as the number of topics to be identified by the algorithm and the number of times the algorithms pass through the input text. Although we have verified the impact of experimental settings, these choices are always debatable. Finally, the proposed approach makes it possible to identify relevant articles addressing latent topics in a more automated way but does not replace expert judgement. A thorough inspection of results throughout the stages of the search process is recommended.

A key area for future research relates to the use of semi-supervised topic models for literature reviews. Contrary to unsupervised models, semi-supervised topic models allow the user to participate and guide the model learning procedure [104]. This is particularly relevant for smaller topics that are hard to identify by unsupervised models, for example those related to specific phenomena or to societal expectations of technologies. Usable software implementations are currently, however, still lacking.

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Appendix A

Table 3

Table 3
Sample of excluded and remaining articles.

Title	Authors	Journal/Conference/Book
Remaining articles		
"Flexible control for small power generation employing renewable energy source used in isolated communities"	Barara et al. [105]	56th International Scientific Conference on Power and Electrical Engineering of Riga Technical University, RTUCON 2015
"Profiling energy profilers"	Jagroep et al. [106]	Proceedings of the ACM Symposium on Applied Computing
"Marginal abatement cost curves for policy recommendation - A method for energy system analysis"	Tomaschek [107]	Energy Policy
"Can you take the heat? - Geothermal energy in mining"	Preene and Younger [108]	Transactions of the Institutions of Mining and Metallurgy, Section A: Mining Technology
"The energy-saving potential and countermeasures of the medium and large cities in Jilin Province"	Li and Zhao [109]	Applied Mechanics and Materials
"Dissemination of nuclear energy applications"	de Siqueira et al. [110]	22nd International Conference on Production Research, ICPR 2013
"The integrated solid waste management system: its implementation and impacts towards the environment"	Norazli et al. [111]	Causes, Impacts and Solutions to Global Warming
"Containerless Solidification of Magnetic Materials Using the ISAS/JAXA 26-Meter Drop Tube"	Ozawa [112]	Solidification of Containerless Undercooled Melts
"Analysis of energy strategies to halve CO2 emissions by the year 2050 with a regionally disaggregated world energy model"	Hosoya and Fujii [113]	Energy Procedia
"Modeling of water spray evaporation: Application to passive cooling of buildings"	Belarbi et al. [114]	Solar Energy
Excluded articles		
"Linking recovery and recrystallization through triple junction motion in aluminum cold rolled to a large strain"	Yu et al. [115]	Acta Materialia
"Color control in coaxial two-luminophore nanowires"	Garreau et al. [116]	ACS Nano
"Near-infrared emission and energy transfer mechanism of Tm 3+/Yb 3 + codoped tellurite glasses"	Xu et al. [117]	Guangzi Xuebao/Acta Photonica Sinica
"Drying kinetics of olive pomace in a fluidized bed dryer"	Meziane [118]	Energy Conversion and Management
"Two-photon absorption coefficient in relation to the typical pulse models of laser"	Zhao et al. [119]	Optics Communications
"An energy-balancing unequal clustering protocol for wireless sensor network"s	Yang and Zhang [120]	Information Technology Journal
"The integrated Sachs-Wolfe effect in unified dark matter scalar field cosmologies: An analytical approach"	Bertacca and Bartolo [121]	Journal of Cosmology and Astroparticle Physics
"Energy efficiency evaluation of wireless LAN over bursty error channel"	Yin et al. [122]	GLOBECOM - IEEE Global Telecommunications Conference
"Measurement of linear energy transfer distribution at CERN-EU high-energy reference field facility with real-time radiation monitoring device III and its comparison with dosimetric telescope"	Doke et al. [123]	Japanese Journal of Applied Physics, Part 1: Regular Papers and Short Notes and Review Papers
"Multicompartment model for mechanics and energetics of fibrillating ventricle"	Yaku et al. [124]	American Journal of Physiology - Heart and Circulatory Physiology

Appendix B

Table 4

Table 4
List of topics found by the second topic model.

Topic#	Topic titles	Distr.
	Technologies	
Topic#	*Topic titles*	*Distr.*
2	Smart energy management systems	3
5	Inverters	25
7	Wind turbines	2
8	Micro-ends	1.9
9	Heat storage	1.9
11	Heat pump systems	1.5
13	Solar energy systems	1.5
19	Combustion engines	1.3
20	Hydraulic systems	1.3
23	DC converters	1.2
76	Mobile systems and appliances	0.6
77	Urban sustainable infrastructures	0.6
78	Magnetic energy systems	0.6
79	Traffic	0.6
80	Deployment of decentralized systems	0.6
89	Sodium reactors	0.5
91	Air conditioning	0.5
93	Macrotidal ecosystems	0.5
97	Energy appliances in buildings	0.4
99	Flyback converters	0.4
100	Carbon capture and storage	0.4
	Energy inputs and outputs	
72	Humans and the environment	0.7
75	Economic growth	0.6
87	Agriculture	0.5
92	Russian energy policy	0.5
94	Energy regulation	0.5
95	Environmental protection	0.4
96	Degradation of energy systems	0.4
	Geographical area's	
Topic #	*Topic titles*	*Distr.*
22	Cities	1.3
24	Communities	1.2
38	Districts	1

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Table 4 (*continued*)

25	Combined heal and power	1.2	*Topic #*	*Topic titles*	*Distr.*	64	Geographical locations of energy systems	0.8
26	Hydro and wave energy	1.1	1	Carbon emissions	3.7			
27	Flywheels	1.1	4	Energy consumption of buildings	2.7		***Methods***	
28	Smart grids	1.1	12	Riomass and hydrogen production	1.5	*Topic #*	*Topic titles*	*Distr.*
30	Desalination plants	1.1	15	Fossil fuels	1.4	3	Scheduling algorithms	2.7
32	Cooling systems	1	16	Combustion exhausts	1.4	14	Spatial optimization	1.4
37	Geothermal energy	1	21	Energy wastes	1.3	17	Load management	1.4
42	Nuclear energy	0.9	29	Energy for food production	1.1	31	(fuzzy) multi-objective decision-making	1.1
44	Digital control of technologies	0.9	39	Modeling of networks	0.9			
45	Transmission grids	0.9	52	Clean energy	0.9	39	Modeling of networks	0.9
47	(wireless) sensors	0.9	65	Residential energy consumption	0.8	46	Short term scheduling of energy systems	0.9
49	Phase Change Materials	0.9	83	Waste water treatment	0.6			
51	Wave energy	0.9	84	Biofuels	0.5	53	Exergy analysis	0.9
54	Electrical power technologies	0.8	98	Voltages	0.4	56	Grid stability assessments	0.8
55	Lithium batteries	0.8		***Energy Governance***		60	Algorithms in smart energy systems	0.8
57	Tidal power	0.8	*Topic #*	*Topic titles*	*Distr.*	63	Energy and exergy analyses	0.8
58	Smart homes	0.8	6	Energy policies	2.1	67	Building energy systems evaluations	0.7
59	Compressed air energy storage	0.8	10	Energy and economic development	1.6	70	Energy management and safety of vehicles	0.7
61	Micro safety systems	0.8	33	Energy policy options	1			
62	Energy system failures	0.8	34	Energy education	1	81	Building refurbishment	0.6
66	Lighting	0.7	35	Energy economics	1	82	Pricing and markets	0.6
68	Energy storage capacitors	0.7	41	Financial and security assessments	0.9	85	Energy physics	0.5
71	Monitoring and communication platforms	0.7	43	ETJ energy policy	0.9	86	Retrofitting	0.5
			48	UK energy industry	0.9	88	Sparse transition estimations	0.5
73	Solar cell efficiency	0.7	50	(wind) Potential and investments	0.9	90	Energy saving mechanisms	0.5
74	Doubly led induction machines	0.7	69	Energy poverty	0.7			

Appendix C

Fig. 5

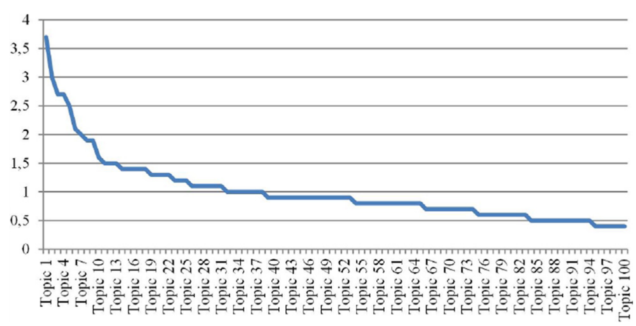

Fig. 5. Marginal distribution of topics found by the LDA model.

Appendix D

Table 5

Table 5
Summary of sources of injustices, affected stakeholders and approaches for remediation identified based on the search approach proposed in this paper.

Sources of injustices	Affected stakeholders	Approaches for remediation
1. Historical disparities between countries in carbon emissions and impacts of climate change	Developing countries, Socio-economic groups	Measurement of historical inequalities in CO_2 emissions [55]; Support of sustainable development [81]; Usage of Energy Justice Metric for energy policy decision-making [125]; Investigation of disparities between countries of the ratio CO_2 emitted/consumed [56]
2. Inequality of access to newer and cleaner energy technology and sources	Economic regions, poorer citizens	Empirical study to evaluate inequalities between regions based using the concept of meta-frontier [79]; Usage of the concept of energy justice [82]; Review of challenges of biofuel deployment [65]; Performance of a SWOT analysis [126], Environmental Kuznets Curve approach [63], Single-Resource-Separate-Production-Reference (SRSPR) allocation method [69], Increase of bioenergy competitiveness [68], Investigation of energy poverty Nothern Ireland [85]

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Table 5 (*continued*)

Sources of injustices	Affected stakeholders	Approaches for remediation
3. Inequalities in faculties to support the costs of environmental measures	Low income households, economic regions, developing countries	Evaluation of conditions when (carbon) taxes lead to more inequity [66]; Identification of necessary changes to energy policy models to take specificities of developing countries into account [50]; Usage of the concept of polycentrism for energy governance [80]; Usage of the concept of energy justice [82,83]
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	Local communities, future generations	Deployment of renewables and energy efficiency measures [76]; Proposal for an improved design framework for local production systems [127]; Review of the EURATOM legal framework [77], Usage of the concept of energy justice [64], Concept of environmental justice [86]
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	Local communities	Performance of a case study evaluating equity perceptions of wind farms [61]; Usage of the concept of energy justice [82]; Evaluation of more effective and just approaches to resolving inequities [60]; Proposal for a comprehensive framework of energy technology acceptance allowing to understand reasons for renewable technology acceptance or rejection [7], Usage of the concept of energy justice [87]
6. Inequalities between users in conditions of access to the grid	Electric vehicle users	Proposal for a fair Use Policy-based Offered Energy Calculation [72]; Proposal for a satisfaction metric of EV user [74]
7. Inequalities in usage of devices and revenues attributed to smart grid users	Users of energy harvesting devices, Wholesale energy market participants, electricity consumers	Proposal for improvements to nanogrids power distribution rules [89]; Proposal for improved scheduling algorithms for utilization of dispersed energy storage systems [90]; Proposal for a cost allocation method based on LMP sensitivity [47]; Proposal for a two-stage mechanism for electricity cost sharing [73]; Proposal for a load allocation approach [88], Nash bargaining framework [46], Multiagent minority-game (MG)-based demand-response management [49]
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)	Energy communities	Proposal for a fair cost sharing methods which is based on Nash bargaining [?]
9. Lack of fairness between competitors in electricity markets	Market participants	Institutional redesign of the Chinese retail electricity market [45]

Appendix E

Table 6

Table 6
Summary of sources of injustices, affected stakeholders and approaches for remediation identified based on a keyword-based search using the word 'energy'.

Sources of injustices	Affected stakeholders	Processes for remediation
1. Historical disparities between countries in carbon emissions and impacts of climate change	Population of developing countries, future generations	Review of the EU's external governance [128]; Review of guidelines of sustainable development [129]; Proposal for an Energy Justice Metric to be used for energy policy decision-making [125]; Evaluation of the perception of climate change by citizens [130]; Review of the role of cities in climate change inequities [131]; Evaluation of the potential and limits of renewable energy [132]; Introduction of the SCORE index allowing the evaluation of environmental prudence [133]; Support of sustainable development [134]; Proposal for an 'equal burden' formula for CO2 emissions [135]
2. Inequality of access to newer and cleaner energy technology and sources	Poorer populations	Review of sources of inequalities in access to energy [136]; Usage of the concept of energy justice [95,82,83]; Review and comparison of the concepts of energy justice and ethical consumption [137]; Review of equity aspects of energy poverty [138]; Review of the Warm Front Program aiming at reducing fuel poverty [139]; Identification of energy uses critical to households from a perspective of energy justice [140]; Evaluation of differences in energy consumption practices between generations [141]; Performance of a regional study to identify market potential of pelletised wood fuel [142]; Evaluation of the effects of energy infrastructures in terms of fuel poverty [143]; Evaluation of the relationship between fuel poverty, disabled people, and policy changes in England [144]
3. Inequalities in faculties to support the costs of environmental measures	Low income households, economic regions, developing countries	Usage of concept of energy justice [95,82]; Review of the social dimension of the energy transition [62]; Review of procedural and distributional aspects of the energy transition [145]; Performance of case studies to understand how stakeholders frame justice [146]; Evaluation of success factors of energy efficiency measures [147]

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Table 6 (*continued*)

Sources of injustices	Affected stakeholders	Processes for remediation
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	Local communities	Proposal for an environmental justice framework allowing the evaluation of the health impact of oil production and use [148]; Evaluation of disparities using the concept of environmental justice [86]; Review of cases where environmental justice was successfully applied [149]; Review of justice claims of business, government and civil society related to energy infrastructural development in the Arctic [150]; Exploration of novel approaches supporting the achievement of justice in nuclear energy policy [151]; Review of a failed initiative to 'strand' petrolium assets to improve policy advice [64]; Development of a three-level framework supporting morally responsible risk communication [152]
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	Local communities	Evaluation of more effective and just approaches to resolving inequities [60]; Usage of the concept of energy justice [95,82]; Usage of the concept of environmental justice [153]; Proposal for a community knowledge networks approach allowing the recognition of cultural characteristics of social groups [97]; Performance of a survey describing how general attitudes and project characteristics of wind energy projects are influencing local acceptance [154]; Identification of value clusters for energy system change [155]; Performance of a case study to evaluate project success factors [156]; Performance of case studies of failures to take procedural justice into account [157,158]; Proposal for a conceptual framework for social sustainability which is based on a process of community group priorization and visioning [159]; Survey on project perception by stakeholders [160]; Review of the local impacts of solar energy deployment [161]; Analysis of wind energy projects in terms of procedural justice [162]; Identification of the contribution of legislation on climate policy to sustainable development [163]; Evaluation of the potential of shared ownership of renewable energy projects [164]
6. Inequalities between users in conditions of access to the grid		
7. Inequalities in usage of devices and revenues attributed to smart grid users		
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)		
9. Lack of fairness between competitors in electricity markets		

Appendix F

Table 7

Table 7
Summary of sources of injustices, affected stakeholders and approaches for remediation identified based on a keyword-based search using the semantic field of justice.

Sources of injustices	Affected stakeholders	Processes for remediation
1. Historical disparities between countries in carbon emissions and impacts of climate change	Developing countries, population of developing countries, future generations	Measurement of historical inequalities in CO2 emissions [55]; Identification of disparities between countries of the ratio CO2 emitted and CO2 consumed [56]; Review of vulnerabilities of urban populations in developing countries in terms of health [165]; Empirical evaluation of the impacts of carbon taxes on competitiveness and distribution of income [166]; Support of sustainable development [167,81,168]; Review of guidelines of sustainable development [129]

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Table 7 (*continued*)

Sources of injustices	Affected stakeholders	Processes for remediation
2. Inequality of access to newer and cleaner energy technology and sources	Poorer populations, economic regions	Evaluation of the usefulness of energy poverty indicators [169]; Introduction of a MARKAL optimization model allowing the evaluation of preferable local energy systems [170]; Performance of a multi-part, split-sample contingent valuation method and fair share survey, which allows to research the willingness to pay for renewable energy sources [171]; Review of challenges of biofuel deployment [65]; Empirical study to evaluate inequalities between regions using the concept of meta-frontier [79]; Review of competitive fairness aspects of heat markets [172]; Performance of case studies allowing the evaluation of fuel choices of households in Zimbabwe [173]; Proposal for remote sensing-based indicators that evaluates equity issues in access to water [174]; Review of sources of energy for pumping groundwater [175]; Usage of the concept of energy justice [95,82]; Review of current distribution of energy consumption [176]; Introduction of the concept of 'just' grids [177]; Usage of the water-energy-food nexus [178]; Performance of a SWOT analysis [126]
3. Inequalities in faculties to support the costs of environmental measures	Low income households, economic regions, developing countries	Usage of the concept of polycentrism for energy governance [80]; Identification of how energy policy models should be changed to take specificities of developing countries into account [50]; Usage of Lorenz curves of cumulative electricity consumption and Gini coefficients to be used as metrics of energy distribution and equity [179]; Evaluation of conditions when (carbon) taxes lead to more inequity [66]; Analysis of the conventional energy efficiency rating system for existing residential buildings [180]; Reviews of the social dimension of the energy transition [62]; Support of stakeholder engagement, the fair distribution of costs and benefits of mitigation policies, as well as interregional agreements [181]; Evaluation of renewable electricity policy mechanisms [182]; Review of procedural and distributional aspects of the energy transition [145]; Proposal for public–Private Partnership to share investments risks [183]; Proposal for a dynamical multicriterion method for fair allocation of emission rights [184]; Evaluation of the impact of carbon taxes [185]
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	Local communities	Review of the literature that discusses equity issues of biofuels [186]; Usage of the environmental justice framework allowing the evaluation of the health impact of oil production and use [148]; Performance of empirical research to identify public attitudes related to biofuels technologies and policy [187]; Review of experts perspectives on managing climate change [188]
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	Local communities	Usage of a comprehensive framework of energy technology acceptance allowing to understand reasons for renewable technology acceptance or rejection [7]; Review of the social dimensions of biomass power plants [189]; Evaluation of more effective and just approaches to resolving inequities [60]; Performance of a case study to evaluate equity perception of wind farms [61]; Usage of an explanatory framework for addressing public responses to the deployment of wind energy [190]
6. Inequalities between users in conditions of access to the grid	Local communities	Identification of success factors of renewable energy deployment, including fair access to the grid [191]
7. Inequalities in usage of devices and revenues attributed to smart grid users	Users of energy harvesting devices, Wholesale energy market participants, electricity consumers	Proposal for an improved allocation algorithms [192,193]; Identification of equity issues by reviewing the demand response literature [194]; Usage of reciprocal fair energy management schemes [195]
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)		
9. Lack of fairness between competitors in electricity markets		

Appendix G. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.apenergy.2018.06.082.

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