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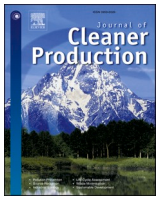

Analyzing public discourse on photovoltaic (PV) adoption in Indonesia: A topic-based sentiment analysis of news articles and social media

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ABSTRACT

The importance of integrating renewable energy, such as solar PV, in the global energy mix for mitigating carbon emissions is increasing. Despite the global drive towards renewable energy, the limited uptake of solar PV particularly in developing nations, such as Indonesia, poses significant challenges for transition to sustainable energy. This study analyses public discourse to comprehend the obstacles for widespread adoption of solar PV technologies. This study employs topic modelling and sentiment analysis of mainstream and social media data to comprehensively capture public discourse and perceptions concerning PV and residential PV adoption in Indonesia. The findings reveal shared thematic areas in both mainstream and social media. Nonetheless, the two media types diverge significantly in their focal points. Our findings support previous survey-based research while introducing three new topics found in both media channels. These topics are: (1) knowledge, misconceptions, and skepticism, (2) economically viable alternative PV technologies; and (3) government regulations and policies. Social and visual impressions such as aesthetics, hedonic motivation, and social influence are notably absent. Public perception varies, with mainstream media portraying PV technology more positively than social media. From both media, the public generally holds favorable views of PV, particularly in terms of its practicality, installation, safety, and information accessibility. Nevertheless, negative perceptions arise regarding investment costs, regulations, governmental policies, and the adequacy of government support.

1. Introduction

In the face of global challenges, addressing issues related to renewable energy technologies (RET) and carbon emissions has garnered significant attention. Greenhouse gas (GHG) emissions represent a substantial contributor to global warming, with the transportation sector standing out as one of its primary sources. According to the International Energy Agency (IEA), global CO_2 emissions reached 35,153.3 million tons in 2018, marking a nearly 31% increase over the past nine years (Haryadi et al., 2023). The principal contributors to these emissions are fossil fuels, namely coal and petroleum, which accounted for 42% and 32% of the total global CO_2 emissions in 2018, respectively. The urgent need to mitigate carbon emissions has necessitated exploring innovative approaches to cleaner energy production. One significant avenue through which carbon emissions can be reduced is the widespread adoption of renewable energy (RE) in electricity generation, such as photovoltaic (PV) solar energy.

The electricity generation sector significantly contributes to carbon emissions, prompting a critical examination of alternatives. In this context, solar PV has emerged as a viable solution to curtailing carbon emissions from electricity generation. Photovoltaic (PV) systems, as renewable energy harvesters, promote sustainability, environmental awareness, and carbon reduction. These systems generate electrical energy primarily from sunlight, making the electricity production process accessible even in remote areas. Furthermore, Photovoltaic systems are versatile, and constructed with simplicity, speed, and scalable power

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capacity, ensuring equal opportunities for individuals to build and use PV systems according to their specific needs, ranging from small-scale (watt) to large-scale (Megawatt). Based on clean energy progress tracking (IEA, 2023a,b), solar PV annual growth usage reached 26% in 2022, which aligns with achieving the Net Zero by 2050.

Table 1 shows the usage of solar PV as an electricity source in selected countries categorized based on their economic development (IMF, 2023). However, until now, solar PV adoption is still below its full potential particularly in the context of developing nations. Table 1 shows that solar PV adoption in developing countries significantly lags behind that of developed nations, both in terms of the total gigawatt hours (GWh) generated and contribution to electricity generation. Specifically, Indonesia exhibits an exceptionally low adoption rate, when compared to its neighboring countries in the ASEAN region. Indonesia, positioned geographically along the equator and characterized by a tropical climate, harbors a substantial solar energy resources that has not been utilized, potentially exceeding 3000 Gigawatts (IRENA, 2022). This disparity underscores the urgency of examining the underlying factors contributing to the low adoption rate. To shed light on this subject, there is a need for a study that focuses on Indonesia, which represents a dynamic setting in which residential solar PV encounters unique challenges.

Indonesia is undergoing a significant energy transition to diversify its energy mix. While fossil energy currently dominates with around 90% of national production, the government aims for a 29% reduction in greenhouse gas emissions by 2030 and net zero emissions by 2060 (IRENA, 2022). Haber et al. (2021) emphasized that successful implementation of RE requires a thorough understanding of economic, environmental, behavioral, and societal considerations. Indonesia, endowed with diverse RE potentials, must assess these variables to achieve its net zero targets. The government supports this shift, targeting a 23% contribution from renewable sources by 2025 (KESDM, 2023), and the trajectory of adoption is shaped by the viability of systems, resource access, and public reception.

While text mining has been extensively employed to gauge public perceptions across various energy domains, the application of this technique remains relatively untapped within the realm of solar PV. Despite the limited application, text mining offers a suitable method for investigating individuals' reactions to different posts, news, and how it spread around (Talib et al., 2016). Notably, individuals using social media platforms are well-positioned to articulate their experiences with and observations of solar PV. Currently, public perceptions concerning residential PV are predominantly elicited using survey methods. Moreover, text mining also provides methodological triangulation of research findings obtained through surveys or interviews (McCaig et al., 2018). This means that text mining approaches in solar PV could be beneficial in providing confirmation of findings, and more comprehensive data, and enhanced understanding.

Text-mining applications in social media are mainly oriented toward text-based platforms such as Twitter and Facebook. However, in this research, we utilize different data sources, including video-based platforms such as YouTube and TikTok. Social video content (SVC), ranging in duration from a few seconds to several minutes, has emerged as a highly popular video format on contemporary social media platforms (Wang, 2020). This medium enables users to disseminate compelling experiences and useful insights while fostering interactive engagement with online communities (Xiao et al., 2023). By venturing into these dynamic, video-centric spaces, we aim to provide a more comprehensive understanding of public sentiment toward residential PV systems in developing countries. This shift is driven by the recognition that users of such platforms can offer in-depth insights and perspectives.

Social media platforms offer the capacity to glean comprehensive insights and public perspectives concerning residential photovoltaics (PV). However, these platforms may be insufficient in capturing a holistic public perception of PV implementation from a macroscopic perspective. This study aims to address these gaps by describing the topic coverage and sentiment polarity regarding solar residential PV in Indonesia both from mainstream as well as from social media. Additionally, it compares public discourse in SVC with the topics presented by mass media, thereby providing insights into the congruence or divergence between the public sentiments and media narratives. Moreover, this study also analyzes PV-related word sentiment to provide deep understanding of public perceptions, encompassing both the general PV implementation covered in mainstream media and residential PV as discussed in social media. Moreover, learning about public sentiment from social media platforms offers a comprehensive understanding beyond previous studies using surveys. Social Media analytics (SMA) could be effective in capturing reactions to posts, exploring new data sources, and incorporating video-based platforms like YouTube and TikTok for in-depth perspectives on residential PV systems in developing countries. Analyzing user-generated content using SMA is exploratory research, hence it could capture several factors that have not been theoretically addressed but are discussed in society and overcome challenges such as manual data collection. Additionally, understanding the contrasting presentations of PV technology in mainstream and social media is crucial for policymakers, as it fosters a more comprehensive public engagement and helps policymakers gauge the acceptability of new technologies. By pursuing these objectives, this study contributes to a nuanced understanding of the challenges and opportunities associated with PV technology implementation in Indonesia.

This paper is organized as follows: Section 2 presents the literature review undertaken to identify relevant articles on RE acceptance, solar PV adoption, and text-mining approaches. Section 3 describes the methods of analysis, including detailed steps on extracting the SVC and media article dataset, and constructing the topics and sentiment of PV public discourse. Subsequently, further analysis and discussion are presented in Section 4. In Section 5, conclusions, limitations, and practical implications are explained.

Table 1
Breakdown and comparison of electricity generation (IEA, 2023a,b).

Developed countries	Solar PV electricity generation (GWh)	PV proportion of overall electricity generation (%)
Australia	27,713	10.44
Germany	49,992	8.40
United States	146,249	3.35
Japan	88,701	8.94
Developing countries	**Solar PV electricity generation (GWh)**	**PV proportion of overall electricity generation (%)**
Indonesia	171	0.06
Thailand	5031	2.80
Brazil	10,750	1.73
Argentina	1345	0.94

2. Literature review

2.1. Public acceptance of renewable energy

The emerging concern about RE has arisen in response to attempts to reduce the impact of climate change and the greenhouse effect (Dehler-Holland et al., 2022). Based on the National Academies of Sciences (2001), public acceptance can be defined as the result of a process that involves identifying interested or affected stakeholders, clarifying issues, and putting in place mechanisms to facilitate reaching an agreement. This terminology is often associated with 'social acceptance' (Butkowski et al., 2020; Hai, 2019; Jung et al., 2016; Nuortimo et al., 2017; Solangi et al., 2015; Yuan et al., 2011). The 'social acceptance' terminology refers to individual tolerance, whereas public acceptance concerns about agreement between stakeholders. Recent literature examining the readiness of RE highlights three levels of public acceptance (Corbett and Savarimuthu, 2022): 1) socio-political acceptance,

which involves the way that policy actors and the public perceive RE implementations; 2) community acceptance, which refers to the acceptance of RE projects by local (rural and urban) stakeholders; and 3) renewable projects and market acceptance, which is related to a diffusion process when a policy or RE innovation starts to spread in the population. Table 2 summarizes the relevant literature regarding public discourse toward RE based on the previously mentioned scope.

Public acceptance of RE also vary depending on the subject under investigation. For biomass, there is a contrasting sentiment between social media discourse and editorial publications i.e., public sentiment is more positive in editorial publications than in social media (Nuortimo et al., 2017). Meanwhile, the awareness of RE manufacturers specifically shows positive feedback (Haber et al., 2021).

The public discourse regarding RET is not only limited to its implementation but also based on technology development. For instance, spent nuclear fuel, defined as a high-level radioactive material, is a critical subject in public opinion (Roh and Kim, 2022). This indicates that the establishment of nuclear power plants is not solely a compelling factor in public acceptance but is also linked to waste management, especially in developed countries such as South Korea. However, the public is more concerned with the nuclear policy rather than the used fuel because it directly impacts their electricity use. In different energy sources, such as genetic modification in bioenergy, farmers and corporate actors are considered important actors in the acceptance of novel technologies (Butkowski et al., 2020). This is because statements and actions from corporate actors have an indirect influence on consumer decisions, based on their social trust. Higher social trust indicates that a person is fully committed to an institution or a person that uses genetic modification in bioenergy.

2.2. Public acceptance of solar PV

The current trend in solar PV adoption has been predominantly positive, as described in Table 3. Nevertheless, it is important to acknowledge that various challenges exist, and they vary across different countries. These challenges have different characteristics from country to country. In this section, we categorize the level of PV social acceptance in developed countries and developing countries. In developed countries such as Spain, the public discourse in news media could potentially exert an influence on the public and improve social acceptance. Still, policymakers in Spain believe that public acceptance of PV is not an issue (Heras-Saizarbitoria et al., 2011). Moreover, public

Table 2
Research on the acceptance of RE.

Reference	Subject of Investigation	Energy Source	Country	Data Source	Key Findings
Nuortimo et al. (2017)	The recent increase in biomass power technology market deployment	Biomass	European countries, China, India, Japan, USA, Australia	Editorial publications and social media	Public sentiment toward biomass power is more favorable in editorial publications than in social media.
Haber et al. (2021)	Renewable energy discussions, especially on its manufacturers	General	Hungary	Social media	Future technologies of renewable energy sources can replace carbon-based technologies.
Vespa et al. (2022)	Renewable energy technology in Instagram posts, especially advanced inventions	General	Globally (based on tags)	Social media	Solar and wind energies elicit more positive emotions than other RETs.
Corbett and Savarimuthu (2022)	Emotional discourse toward sustainable energy for policy actors' decision-making	General	United States	Social media	Utilities with negative polarity over time are in the minority, whereas pride, cheerfulness, and optimism are the primary positive emotions in the discourse.
Roh and Kim (2022)	The usage of nuclear fuel reuse	Nuclear	South Korea	Social media	The public is more interested in nuclear energy policy than used fuel because it is an issue that directly impacts their electricity use.
Liu et al. (2021)	China's policy of carbon capture, utilization, and storage	General	China (Mainland)	On-site questionnaire	Although people were concerned about the risks, they were willing to accept Carbon capture, Utilization and Storage (CCUS) considering that CCUS can reduce carbon emissions and positively impact national industry and public welfare.
Butkowski et al. (2020)	Implementation of genetically modified bioenergy crops (biogas or biofuel)	Biogas or biofuel	Germany	Role-play simulation	In order to cultivate stakeholder support using genetic modification bioenergy, energy companies act as the center of the bioenergy supply chain.
Titov et al. (2021)	Biomass energy utilization in a rural region	Biomass	Hungary	On-site questionnaire	Local concerns include awareness, economic participation, and trust in local authorities for biomass development. Convincing the younger generation is crucial for promoting the benefits of biomass.
Xiang et al. (2021)	Public sentiment on China's carbon policy	General	China (Mainland)	Social media	Western media often holds a negative and biased view of China, which may influence its perception of China's carbon policy due to its rapid economic growth.
Jeong et al. (2021)	Data analysis framework to identify renewable energy concern	General	South Korea	Social media	The public's primary interest lies in solar panel installation, particularly its cost. Formulating effective RE policy strategies is essential to meet public needs.
Loureiro and Alló, 2020	Climate change and energy issues based on social media opinion	General	United Kingdom and Spain	Social media	Spain's public perception of climate change is more negative than the UK's, with fear being a dominant emotion. Spain faces greater vulnerability to climate change, evident in frequent wildfires and droughts.
Dehler-Holland et al. (2022)	Assessing technology legitimacy with topic models and sentiment analysis - the case of wind power in Germany	Wind turbine	Germany	German newspapers	The legitimacy of wind energy in Germany has faced increasing concerns due to its negative impacts on people, wildlife, and the environment. Policymakers can address issues related to practical acceptance, such as involving the community in decision-making and ensuring that local communities benefit financially.

Table 3
Social acceptance of solar PV technology.

Reference	Country	Data Source	Methods	Findings
Abdullah et al. (2017)	Pakistan	Survey	Descriptive statistics	The public has a high interest in residential PV. However, there are obstructions such as high cost, and less trust from panel providers.
Heras-Saizarbitoria et al. (2011)	Spain	Interviews and written press media	Qualitative analysis	Media analysis reveals negative views on the PV sector, while policymakers remain optimistic about public feedback on PV implementation.
Hu et al., 2019	Finland	Interviews	Qualitative analysis	The state of willingness is analyzed to establish five segments of customers, ranging from non-WTA, conditional WTA, unconditional WTA, and positive WTA.
Malik and Ayop (2020)	Malaysia	Survey	Descriptive statistics	The public largely accepts the government's PV initiative, despite having only average awareness of solar energy.
Alsabbagh (2019)	Bahrain	Survey	Descriptive statistics	Although the respondents' interest is high, there are several challenges in buying and installing PV. The government needs to ensure the successful engagement of the public.
Peñaloza et al., 2022	European Union	Literature review and survey	Inferential statistics	The investment cost of PV is identified as the main barrier for adoption in all European countries. Other challenges vary such as (1) legal and organizational; (2) economic; and (3) technology.
Woo et al. (2022)	South Korea	Survey	Mixed logit model	Consumer acceptance is influenced more by aesthetic factors than by generation efficiency, although both factors are significant. The economic value of installing PV also influence the adoption more than generation efficiency.

acceptance depend on the willingness to adopt (WTA), which could behave differently depending on the pre-adoption conditions (Hu et al., 2019). Therefore, understanding the WTA of PV could be useful in PV customer segmentation. Conversely, in developing countries such as Pakistan, public discourse reflects substantial enthusiasm among potential users, particularly for residential PV. However, the government needs to show a proactive stance in leading the development of residential PV, encompassing initiatives such as incentives, increased installation rates, and the establishment of new power plants (Abdullah et al., 2017).

The positive perception toward solar panels is also supported by findings from different countries. A positive perception in developing countries is found in Malaysia (Malik and Ayop, 2020), and is also supported for developed countries such as Bahrain (Alsabbagh, 2019), South Korea (Woo et al., 2022), and countries in the European Union (Peñaloza et al., 2022). In Malaysia, the Government has been planning and implementing PV project initiatives to increase the income of low income households (Malik and Ayop, 2020). In order to achieve this, additional efforts are needed to increase public awareness whose knowledge can be considered basic. Similarly, Peñaloza et al. (2022) highlight the importance of information availability about these technologies to stakeholders, in addition to investment concern in European countries. This information should include the recoupment of the investment cost, payback time, and suitable business models. These findings indicate that detailed information about solar PV technology plays a significant role in increasing public awareness. From this review it can be concluded that studies from developing countries focus on investigating the government's and community's readiness to adopt solar PV (Abdullah et al., 2017; Malik and Ayop, 2020), while studies from developed countries mainly focus on the operational and economical concerns, particularly the investment and installation (Peñaloza et al., 2022; Woo et al., 2022). The present study will further analyze the public discourse in developing countries specifically, with Indonesia as a case study.

Topics related to public acceptance of PV can be classified (Hai, 2019) based on the stages of readiness of potential customers (i.e., willingness to adopt) and based on willingness to pay (Alsabbagh, 2019). These two aspects are crucial for ensuring successful adoption and are mainly studied in developed countries. Therefore, further analysis is needed in the context of developing countries, as the assessment in developed countries is mostly focused on the ex-post assessment of installing residential solar PV (Alsabbagh, 2019).

During the public acceptance assessment process, there are various challenges faced in different countries. Although most European countries consider investment cost as a barrier to adoption, the specific problems vary by country (Peñaloza et al., 2022). For instance, legal and organizational issues are considered as barriers in Spain. This is supported by the high amount of negative sentiment related to climate change and energy issues in social media opinion (Loureiro and Alló, 2020). By contrast, public acceptance in Asian countries such as South Korea is concerned with aesthetic factors rather than power generation (Woo et al., 2022), even though the public is also interested in the government's implementation strategies for PV (Jeong et al., 2021).

2.3. Social media analytics

Social media analytics (SMA) is used to transform data collected from social media into actionable information. In recent years, there has been a surge in studies pertaining to text mining within the RE domain. There are two predominant analytical methodologies, namely direct experimental approaches and those utilizing indirect datasets. The former encompasses on-site questionnaires for example Liu et al. (2021) and Titov et al. (2021), and simulation experiments, for example Butkowski et al. (2020). Conversely, the latter entails data extraction from specific platforms hosting public discourse. Prominent platforms for text analysis include X (formerly Twitter) (Corbett and Savarimuthu, 2022; Xiang et al., 2021), Facebook (Nuortimo et al., 2017), TikTok (Haber et al., 2021), Instagram (Nuortimo et al., 2017; Vespa et al., 2022), as well as news media sources (Dehler-Holland et al., 2022).

In text analysis, the most common objectives are to assess the perceived legitimacy of the newly implemented technology by looking at public sentiment and the most discussed topics (Dehler-Holland et al., 2022). Public sentiment can be defined as a thought, opinion, or idea based on a feeling about a situation, or a way of thinking (Tan et al., 2013). In the context of renewable energy, text related to the RE topics and the compiled data are analyzed using text-mining analytics. For example, topic modelling has been used to identify key themes discussed related to wind power technology (Dehler-Holland et al., 2022). This is done using a corpus of texts drawn from media sources, online discussions, and official documents. Data extraction was done using a program that is connected to a social media application programming interface (API). Furthermore, the selected comments are filtered using a list of environment-related keywords to classify the topics (Corbett and Savarimuthu, 2022). For a specific context, several main keywords are typically used as a baseline in web crawling (Jeong, et al., 2021). Besides topic modelling, frequency analysis can also be applied to identify the most frequent words. This approach is different to survey-based analysis where a questionnaire is given to a respondent consisting of pre-specified items. These items explain the effect between independent variables and dependent variables in a population (Titov et al., 2021). The questionnaire result will be modelled via multinomial logistic regression using outcome variables of accepting, not accepting, or

unsure about renewable energy technologies adoption.

Topic modelling and sentiment analysis in SMA are used to identify issues described in user-generated content, ideas and opportunities, and important discussions (Abbasi et al., 2018). To undertake sentiment analysis, different subjects of investigation require adjustments in the natural language toolkit. Sentiment analysis tools can use data from software, such as M-adaptive media monitoring (Nuortimo et al., 2017). Moreover, most packages are accessible in an open-source library such as Valence Aware Dictionary and Sentiment Reasoner (VADER) (Xiang et al., 2021), EmoLex (Loureiro and Alló, 2020), and Bidirectional Representation for Transformer (BERT) (Bedi and Toshniwal, 2022). The analysis can be done based on lexicon or dictionary, which are used to identify word and phrase structure.

There are several advantages of analyzing user-generated content such as social media posts over survey-based experiments. Most surveys ask pre-specified questions to the respondents based on a theoretical hypothesis, while SMA, because of its explorative nature, can highlight unprompted responses that are predominantly not part of a survey's pre-determined structure. Moreover, challenges in questionnaire design such as manual data collection, geographic reach, and confined scope of respondents' answers, present additional difficulties comprehending the voice of customers (Wang et al., 2023). This study focuses on the application of topic modelling and sentiment analysis for public discourse around solar PV in Indonesia. The analysis is conducted because there is currently a lack of applications of text-mining for understanding public perceptions concerning residential PV systems in developing countries, and behavioral patterns in the use of social media within developing countries may potentially differ from those observed in developed countries.

3. Method

This section discusses the analysis methods applied in this study. Fig. 1 shows the media analysis framework applied to both mainstream media and social media datasets. The framework consists of three stages: (1) data collection and preprocessing; (2) topic modelling; and 3) sentiment analysis. These will be explained in detail in the following subsections.

3.1. Data gathering and preprocessing

This study incorporates two distinct datasets, comprising information sourced from news portals and prominent SVC, i.e., YouTube and TikTok. Both SVCs were selected due to their substantial user bases within Indonesia i.e., YouTube with 139 million users and TikTok with 109.9 million users in 2023 (Kemp, 2023). YouTube and Tiktok videos are retrieved through the utilization of search keywords such as "solar panel Indonesia" and "PV Indonesia." The content of these videos is crafted by diverse entities, including governmental institutions, mass media outlets, and individual content creators. These entities actively engage in promoting the adoption and implementation of photovoltaic (PV) technology. Comments from those selected videos were scraped. The prevailing commenting culture among Indonesians on online news is notably limited. Consequently, this study focuses primarily on the news content alone. The data compilation involved the aggregation of news articles and public commentary from PV-related videos, facilitating the identification of prevalent themes and topics currently being discussed across social media platforms. For the extraction process, web data extraction software was used and the data exported to.csv format.

To ensure the integrity and accuracy of the ensuing analytical process, a series of preprocessing measures were applied to the collected data prior to the application of topic modelling. Initial steps involved the removal of user mentions, denoted by the "@username" format, followed by the conversion of all text into lowercase format. The elimination of extraneous numerical expressions, code sentences, and special characters further streamlined the dataset. Additionally, text normalization techniques were employed to eliminate any misspellings or out-of-vocabulary terms. Furthermore, the elimination of irrelevant terms, using the Python Sastrawi library and a researcher-curated list, contributed to enhancing the data quality. Notably, the data refinement process emphasized the retention of nouns, while excluding non-relevant lexical components. Lastly, stemming and tokenization procedures were implemented to mitigate the issue of data sparseness and reduce the overall vocabulary dimension.

3.2. Topic modelling

Topic modelling using Latent Dirichlet Allocation (LDA) requires three essential inputs *i.e.,* a corpus, a word dictionary, and the specified number of topics. Topic modelling consists of the following steps. First, data pre-processing is required, which includes case folding, punctuation removal, misspelled handling, part-of-speech tagging, keeping only nouns, removal of stopwords, stemming, normalization, and tokenization. Second, the corpus is transformed to Term Frequency-Inverse Document Frequency (TF-IDF). Third, the hyperparameter in LDA is fine-tuned. The hyperparameter selection in LDA was based on the best outcome obtained from an experimental evaluation. Fourth, the number of topics generated in LDA is evaluated using quantitative and qualitative measures. Topics are categorized based on the most frequently appearing words ('top keywords') and subsequently verified through examination of the most representative review documents related to each topic. After determining the optimal number of topics, the topics are labelled according to the top words and then validated by the most representative review documents on the topic. The degree of importance of topics can be calculated by how frequently the topic is discussed. Therefore, the total of the contribution probability of each topic to all comments indicates the importance of each topic in the dataset as illustrated in Fig. 2. Then, the contribution stock (CS) was normalized using Equation (1) to make data more comparable and easier to analyze. Hence, the established topics will be used further for sentiment analysis.

For the quantitative measurement we use coherence score and Jaccard similarity index. Coherence score produces topics that are easier for humans to interpret because the words in each topic have high relevance (Hu et al., 2019). Topics with higher coherence scores are more likely to contain words that appear together frequently. Meanwhile, the Jaccard similarity method aims to measure the similarity of one topic to another (Tran et al., 2013). The lower the Jaccard similarity value, the greater the indication that one topic and another discuss different things. Meanwhile, the qualitative measurement is based on topic separation, which is visualized using LDAvis. A good model occurs when the proportions between topics are almost equal and the number of overlapping topics is small (Sievert and Shirley, 2014).

$$\begin{aligned} Contribution\ Stock_t &= \sum_{i=0}^{j} TD\ Matrix_{t,i}, \\ Contribution\ Stock_{t\ normalized} &= 10 \times \frac{CS_t}{\sum_{1}^{t} CS_t} \end{aligned} \tag{1}$$

where,

$\sum_{i=0}^{j} TD\ Matrix_{t,i}$ is value on the topic-document matrix on the topic t and document i;
CS_t is contribution stock on the topic t;
$\sum_{1}^{t} CS_t$ is total contribution stock.

3.3. Sentiment analysis

The objective of this phase is to evaluate the extent of public sentiment associated with each identified topic. Sentiment analysis is a valuable tool to comprehend human emotions and opinions (Luo et al.,

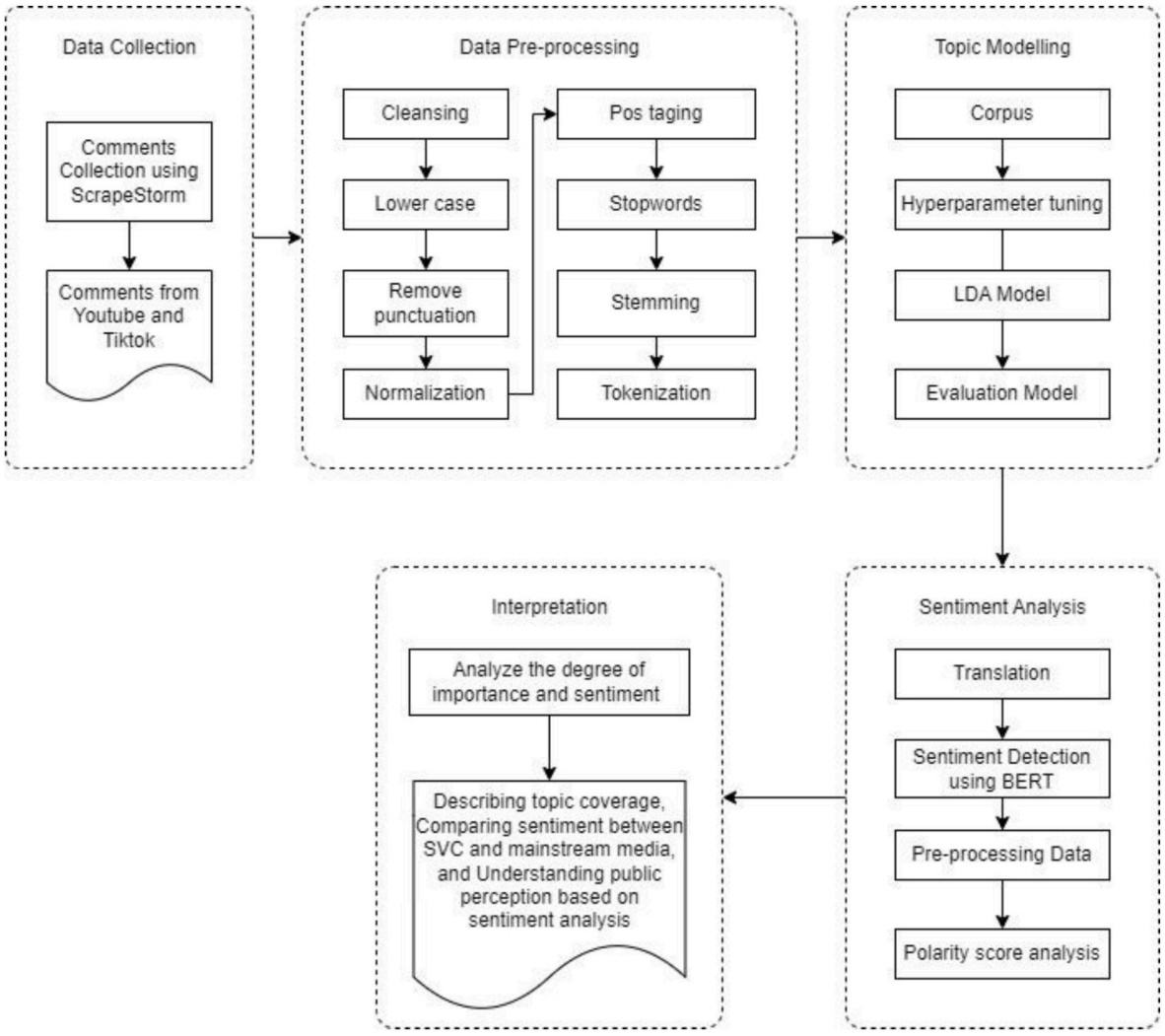

Fig. 1. Media analysis framework used in this study.

$$\begin{bmatrix} & D_1 & D_2 & D_3 & \cdots & D_n \\ Topic_1 & 0.010 & 0.051 & 0.001 & & \\ Topic_2 & 0.112 & 0.508 & 0.023 & & \\ Topic_3 & 0 & 0.020 & 0.614 & & \vdots \\ \vdots & & & & & \\ Topic_n & & \ldots & & & \ddots \end{bmatrix} \qquad \begin{bmatrix} & TK \\ Topic_1 & 182.8 \\ Topic_2 & 92.57 \\ Topic_3 & 124.6 \\ \vdots & \\ Topic_n & 247.3 \end{bmatrix}$$

Topics-Documents Matrix — Contribution stock for topics

Fig. 2. Topic significance calculation (Jeong et al., 2019).

2020). We run this analysis using the Bidirectional Encoder Representations from Transformers (BERT) technique, which operates based on deep learning principles. BERT holds a distinct advantage over other methodologies owing to its bidirectional text-processing capability, enabling the analysis of text in both left-to-right and right-to-left directions, in contrast to other approaches that process text from left to right only (Devlin et al., 2018). By using BERT, the model gains the capacity to grasp the context and intricate relationships between words within the text, thereby enhancing the precision of sentiment analysis.

All documents that contained Indonesian language were translated into English using Google Translate. For the mainstream media dataset, each article written in paragraphs was split into sentences, with the aim of identifying more specific sentiments for each sentence. The social media comments consisted of relatively short texts; thus the dataset could be analyzed directly using BERT. For both datasets, BERT was then applied to obtain sentiment polarity (using https://huggingface.co/nlptown/bert-base-multilingual-uncased-sentiment). After obtaining the polarity value which is ranging from 1 to 5, certain words that were

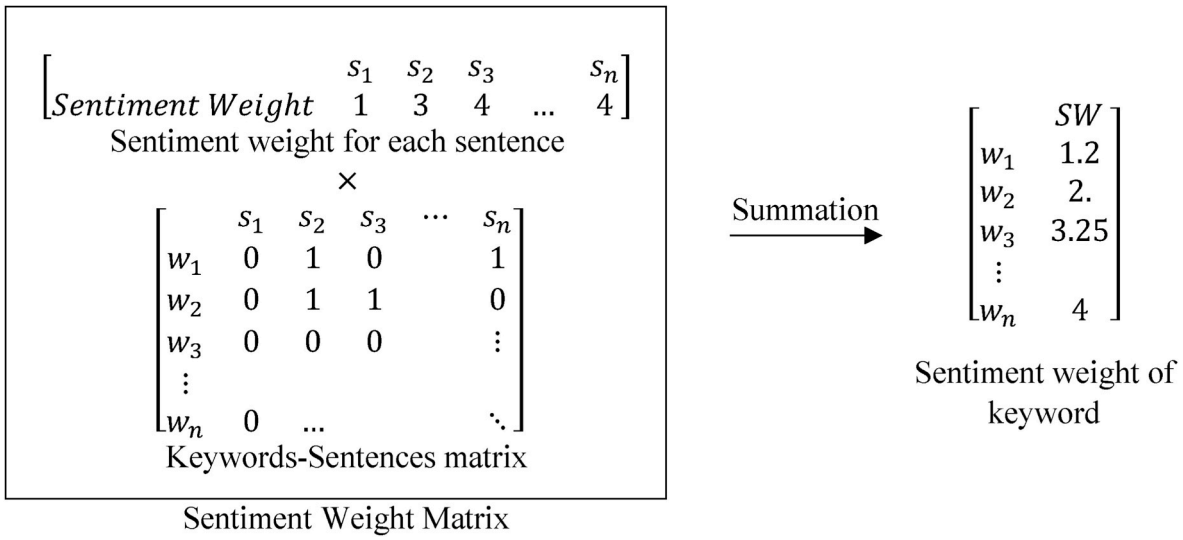

Fig. 3. Concept of computing the average sentiment score for each keyword.

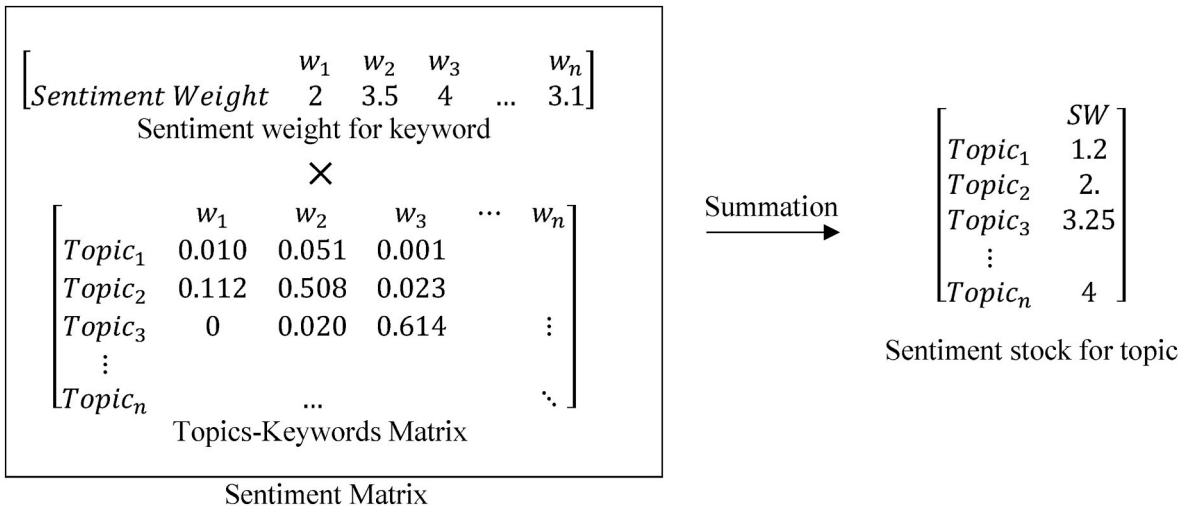

Fig. 4. Concept of computing satisfaction degree of topics.

not included in the list of unique tokens were then eliminated from the topic modelling. Subsequently, the sentiment weight of each word was calculated using Equation (2) and illustrated in Fig. 3. Furthermore, the topic sentiment was calculated using Equation (3) and illustrated in Fig. 4. In the latter part, sentiment weight was then normalized on a scale of −1 to 1, to yield the sentiment value (Corbett and Savarimuthu, 2022).

$$Sentiment\ Stock_{Wn} = \frac{\sum_{i=0}^{j} Sentiment\ Weight\ Matrix_{w,s}}{\sum_{i=0}^{j} Keyword\ Sentiment\ Vector_{w,s}} \tag{2}$$

$$Sentiment\ Stock_t = \sum_{i=0}^{j} Sentiment\ Matrix_{t,i}$$

$$SS_{t\ normalized} = \frac{SS_t - SS_{min}}{SS_{max} - SS_{min}} - (SS_{new\ max} - SS_{new\ min}) + SS_{new\ min} \tag{3}$$

where,

$Sentiment\ Stock_{Wn}$ is sentiment weight of keyword *n;*

$\sum_{i=0}^{j} Sentiment\ Weight\ Matrix_{w,s}$ is sum of product of sentiment weight for each sentence and keywords-Sentences matrix;

$\sum_{i=0}^{j} Keyword\ Sentiment\ Vector_{w,s}$ is number of occurrences of keyword in sentences.

4. Data and results

For a comprehensive overview of PV implementation in Indonesia, articles from online portals spanning from January 1, 2010 to March 7, 2023 were scraped, using search keywords such as 'PV,' solar panel', 'rooftop', and 'plts'.[1] This process resulted in the collection of 719 articles. Additionally, to capture public discourse on PV, comments on and replies to PV-related videos on platforms such as YouTube and TikTok were collected from April 2022 to January 2023. This source yielded 5792 comments and replies that exceeded 15 words in length. These datasets underwent comprehensive analysis, including topic modelling and sentiment analysis, providing insights into public discourse and perception from both mainstream media outlets and social media.

[1] PLTS is an abbreviation of *Pembangkit Listrik Tenaga Surya* written in Bahasa, meaning solar power plant.

4.1. Holistic view of PV implementation in Indonesia based on mainstream media

The dataset comprises 719 articles. For the LDA analysis, values for the alpha and beta parameters were set to 'auto' allowing the algorithm to learn from the data. Initial word filtering was conducted by removing terms that occurred in less than five documents and those that were excessively common, appearing in more than 3% of all documents. This process reduced the initial 10,162 unique tokens to a refined set of 1166 tokens. Additionally, LDA hyperparameters were fine-tuned.

Fig. 5 shows that the optimal number of topics, determined by the largest gap between Jaccard similarity and coherence score, is six. Fig. 6 demonstrates a satisfactory degree of separation between these topics, though with a slight overlap between topics 2 and 3. The model achieved a coherence score of 0.636 and a Jaccard similarity score of 0.043.

Topic labelling was based on the 20 articles that represented the highest contribution (by percentage) within each respective topic. Table 4 provides insights into normalized topic contribution stocks, sentiments, and summaries. In summary, the media coverage encompasses a range of topics, including:

a) The introduction of PV technology in facilities and infrastructures owned by Indonesian state-owned enterprises (Topic A3).
b) Public education (Topics A2 and A6) regarding PV and government initiatives.
c) Media scrutiny of key stakeholders in PV implementation (Topic A5).
d) Critiques of PV implementation in Indonesia, encompassing regulatory concerns, financial aspects (Topic A1), and discussions about other government programs (Topic A4).

Normalized contribution stocks quantify how frequently a topic is discussed in articles relative to other topics. In this context, it becomes evident that topic A1 (20.84%) garners the most attention in articles revolving around PV capacities, financial support through loans, and the regulatory prerequisites to increase the competitiveness of RE against other conventional energy sources. Conversely, topic A2, focusing on public education regarding PV and government initiatives at the household level, has the lowest contribution, at 11.86%. Education related to PV, particularly when compared to other energy sources, occupies the second-lowest position, representing 13.39%.

When reviewing the sentiment associated with each topic, it becomes apparent that all topics display a relatively consistent sentiment polarity, falling within the range of 0.296 to .317. Media articles are considered to have a positive sentiment when their polarity exceeds .20. Table 5 illustrates the sentiment associated with individual keywords. Table 5 shows that several terms (indicated with bold font) exhibit sufficiently high positive sentiment (>0.50). For example, words such as 'toll_gate', 'stadium', 'railway', 'solaruv', and 'PNRE' that are closely related to the installation of PV in public infrastructure. Conversely, a few keywords show a neutral sentiment (<0.20), namely 'loan' and 'allocation'. These keywords demonstrate how the mainstream media highlights the challenges associated with implementing PV in Indonesia. These challenges revolve around securing investment loans for PV installations and distributing resources effectively in an archipelagic state country, where each island possessing its own unique characteristics.

4.2. Public discourse about residential PV on video-based social media

Text data consisting of 5792 comments on and replies to social media videos were analyzed. Rare words that occurred in fewer than five documents, and overly common words appearing in more than 1% of all documents, were excluded. After this, out of the initial 2204 distinct tokens, 692 tokens remained. Some other hyperparameters of LDA were fine-tuned, e.g., passes = 100 and iterations = 200.

A similar procedure was employed for the comment data as was applied to the article data, encompassing topic labelling and sentiment analysis for both topics and keywords. At the initial stage, the optimal number of topics was determined based on maximizing the gap between the coherence score and the Jaccard similarity index; this process resulted in 26 topics. However, this model is very complex due to many overlapping topics, as shown in Fig. 7. Therefore, the number of topics must be reduced. Fig. 8 shows the relationship between the number of topics and the Jaccard index. The elbow point in Fig. 8 shows that nine is the optimal number of topic. As shown in Fig. 9 this reduction resulting in a better model with good separation, a coherence score of 0.628 and a Jaccard index of 0.058. This model was then retained for further analysis.

Table 6 explains the nine topics, alongside their contribution stock, sentiment polarities, and list of the top keywords in each topic. Table 6 shows the topics covered in public discussions *i.e.,*: (a) raising public

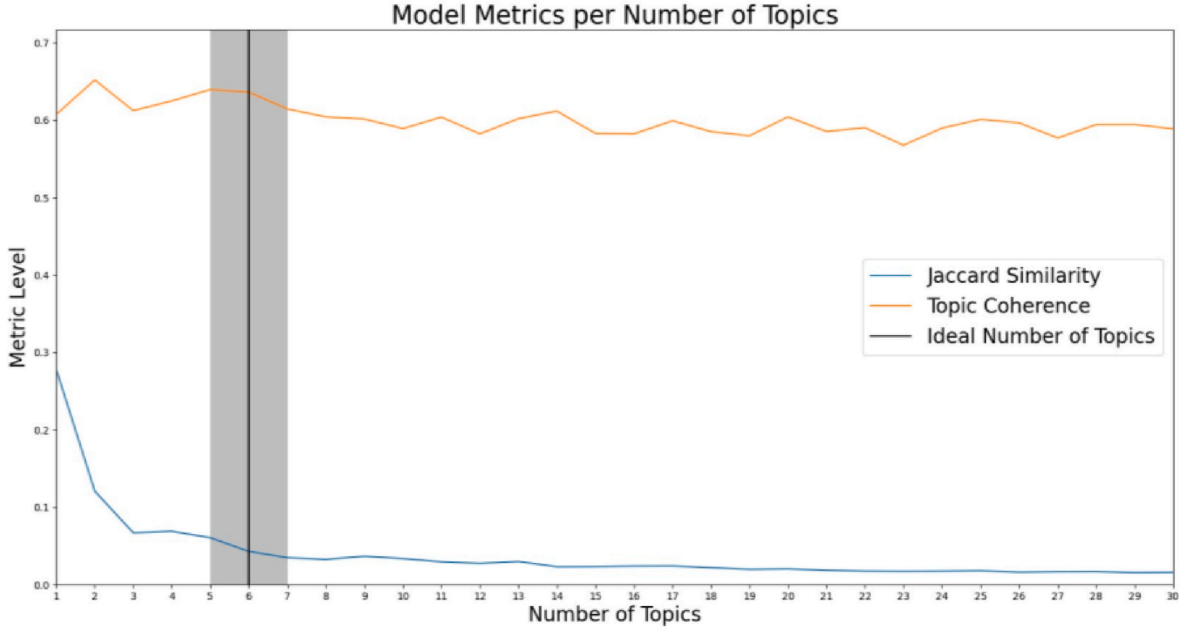

Fig. 5. Selecting the optimal number of topics for articles based on coherence score and Jaccard index.

Fig. 6. Intertopic distance map for six article topics.

awareness about PV as a green energy source (C2) and addressing misunderstandings related to PV (C8); (b) addressing facilitating conditions and technical aspects, such as equipment specifications complying with regulatory standards (C1), more-economical self-assembled PV systems (C6), equipment setup (C7), and the long-term viability of PV systems (C5); (c) comparing the advantages of on-grid and off-grid systems from a financial perspective (C3 and C9); and (d) addressing public skepticism, where people doubt the financial benefits of PV and question whether government programs will effectively implement PV (C4). Table 6 also shows the distribution of contributions across topics, where topic C4 – 'public skepticism', has the largest portion of comments (13.34%), while topic C7 – 'equipment setup for PV', has the smallest portion (8.39%). However, the sizes of the topics presented by contribution stocks are fairly comparable, implying that the significance level of each topic is approximately equivalent.

In contrast to the polarity of sentiment in articles from the mainstream media, the sentiment expressed by the public in the comment data tends to lean toward the neutral to moderately negative range, from −0.120 to −0.241. Several topics exhibit moderately negative sentiment, including topic C1: 'technical aspects' (−0.202), topic C3: Off-grid systems and economic aspects' (−0.216), topic C9: 'financial benefits of PV and on-grid systems' (−0.241), topic C8: 'Misconceptions about PV' (−0.206), and topic C4: 'public skepticism' (−0.202).

Looking at sentiment by keyword as seen in Table 7, it is worth noting that among the top keywords, only 'assemble' (topic C7) carries a positive sentiment score, of 0.273. This keyword signifies that the public is interested in the idea of self-assembly to achieve more economically viable PV systems. This notion is additionally corroborated by the pessimistic sentiment attached to the term 'year' (−0.236), indicating a long-term return on investment. This illustrates public doubt concerning the profitability of the present PV system with its high investment cost.

Furthermore, there are several keywords with negative sentiment polarities approaching −0.50, including competition (−0.466), corruption (−0.500), rolling blackout (−0.444), supply (−0.467), and export-import (−0.426). In this context, 'rolling blackout' and 'supply' suggest a perceived disconnect between claims of electricity oversupply and the reality of ongoing power disruptions and electricity supply challenges in remote areas. This disconnect is believed to contribute to a negative public perception of environmentally friendly energy, as evidenced by terms such as 'friendly' (−0.278) and 'environmentally friendly' (−0.295), showing negative sentiment. Additionally, 'corruption' plays a pivotal role in shaping public skepticism within topic C4. This skepticism is also assumed to influence public perceptions of government initiatives (with a sentiment of −0.347) and the export-import (exim) system applied to residential PV in Indonesia, where the sentiment is most pronounced at −0.426.

4.3. Comparing topic coverage and sentiment polarity: mainstream media vs. social media

In general, there are five key areas covered by both mainstream and social media. These facets encompass financial benefits, technology,

Table 4
Topic contribution stock, sentiment, and summary for selected articles.

No.	Topic	Normalized contribution stock (%)	Sentiment value	Summary based on top keywords
A1	Establishing regulations and financial backing to ensure the effective adoption of PV	20.84	.304	a) The need for regulations to enable renewable energy (e.g., PV) to compete effectively with fossil fuels. b) PV capacities on both industrial and household scales c) Securing long-term financial support for PV plant investment through loans d) Installing PV for toll-gate operations
A2	Public education about PV and government initiatives at various level	11.86	.300	a) Public education on the principles behind PV operation, such as electrons and photovoltaic cells b) Utilizing PV systems in sport stadiums c) Government initiatives at the household level, such as LTSHE d) Floating PV along coastlines
A3	The application of PV in public infrastructure	16.84	.301	a) Installing PV at airports, ports, and large industrial facilities. b) Executing government (PUPR's) PV-related programmes such as integrating PV into newly constructed homes. c) Encouraging domestic PV providers to dominate the domestic market
A4	Public apprehensions regarding the export-import system and more economical alternatives for PV implementation	17.84	.317	a) Installing PV systems at railway stations b) The buzz of PV discussion in the public recently c) Developing solar panels made from recycled plastic materials d) Ensuring that the import-export system accounts for energy generated by residential PV as household energy savings
A5	Stakeholder engagement in PV implementation and PV at the crossroads	19.23	.301	a) Implementing PV at gas stations b) Engaging various stakeholders, including state-owned enterprises (e.g., PNRE PERTAMINA Indonesia), and provincial and municipal governments c) Reporting electricity outputs in terms of gigawatt hours (GWh)
A6	Evaluating PV against other power-generation options and the allocation of resources for PV deployment	13.39	.296	a) Introducing semi-transparent solar roofing solutions for electric cars b) Comparing the performance of solar plants with other types of power generation facilities (i.e., PLT), such as PLTD c) Allocating resources for main road solar street lighting and repurposing used batteries from electric motorcycles as alternative energy storage solutions

Note: the underlined words are the main keywords that represent the respective topic; LTSHE stands for. *Lampu Tenaga Surya Hemat Energi* in Bahasa or energy-saving solar-powered lamp; PUPR is the Ministry of Public Works and Public Housing; PNRE stands for Power and New Renewable Energy Sub-holding PERTAMINA Indonesia; PLTD is *Pembangkit Listrik Tenaga Diesel* in Bahasa, or diesel power plants; PLT stands for *Pembangkit Listrik Tenaga* in Bahasa, or power generation facilities.

government policies and regulations, challenges and criticism, and also information reach, public awareness, and perception, as summarized in Table 8. There is a distinction between the two types of media, in that mainstream media explores macro-level topics, such as comparing the advantages of solar power generation against other energy sources, while social media emphasizes the financial gains experienced by adopters, the total investment involved, and the return on investment. This is also reflected in regard to government policies and regulations. Mainstream media primarily highlights how the government is implementing PV technology in Indonesia, along with regulations and policies at the macro level. By contrast, social media can capture the policies that seek to promote the adoption of residential PV among the public, including technology standardization and the regulation of spare parts in the market.

This contrast is also discernible through the varying levels of emphasis on different subjects. Mainstream media primarily focuses on the exposure of government policies and regulations, while concurrently shedding light on the challenges and criticisms associated with the current PV implementation. By contrast, social media discussions among the public frequently revolve around technical and technological aspects, including installation procedures, alternative technologies, equipment durability, assurance of spare parts, facilitating conditions, and the uninterrupted availability of energy.

The contrasting presentations of photovoltaic (PV) in mainstream media and social media can be caused to several factors. The first factor is the nature of the platform. Social media platforms are known for their wide range of voices and opinions. This diversity includes concerned citizens, activists, and experts who may emphasize potential drawbacks or challenges associated with PV technology. Their discussions often reflect a grassroots perspective that mainstream media might not capture. This phenomenon is supported by research indicating that social media platforms enable a broader spectrum of viewpoints, often highlighting issues not covered by traditional media (Bruns and Burgess, 2015).

The second factor is editorial policies of mainstream media. Mainstream media outlets often operate under established editorial guidelines. These guidelines may lead them to prioritize content that aligns with the interests or commercial objectives of their perceived audience. Positive stories about PV, for instance, may be favored to promote a narrative of innovation and progress, reflecting a more optimistic viewpoint often seen in mainstream narratives (McCombs and Shaw, 1972).

The third factor is audience engagement strategies. Mainstream media may focus on positive aspects of PV to attract a broader audience and maintain positive public sentiment. This approach contrasts with the nature of social media, where debate and controversy often thrive, leading to more nuanced and critical discussions. The dynamic nature of social media encourages diverse opinions, which can challenge the one-dimensional narratives sometimes found in mainstream media (Papacharissi, 2015).

The last factor is the sources of information. Mainstream media sources often rely on official reports and industry sources, which may present a more optimistic view of PV. In contrast, social media tends to amplify individual experiences and grassroots perspectives, which can provide a more critical or concerned viewpoint. This difference in sourcing can lead to a variation in the portrayal of PV, with mainstream media possibly underreporting challenges faced in the industry (Hermida, 2010).

Despite discrepancies in how photovoltaic (PV) is portrayed in mainstream and social media, this divergence is actually beneficial for

Table 5
Top five keywords, occurrences (O), and sentiment value (SV) per keyword for articles.

Topic A1	O	SV	Topic A2	O	SV	Topic A3	O	SV
Competition	2.643%	.321 [a)]	Stadium	.834%	**.565** [a)]	Airport	2.782%	.424 [a)]
Capacity_MWp	2.782%	.340 [a)]	Electron	2.086%	.327 [a)]	Port	2.921%	.339 [a)]
Loan	2.921%	.121	LTSHE	.974%	.240 [a)]	PUPR	2.643%	.292 [a)]
Toll_gate	.974%	**.662** [a)]	Coastline	2.086%	.238 [a)]	Dominate	2.364%	.254 [a)]
Gate	1.252%	**.657** [a)]	Photovoltaic_cell	1.947%	.240 [a)]	Cement	.974%	.331 [a)]
Topic A4	O	SV	Topic A5	O	SV	Topic A6	O	SV
Railway	2.086%	**.522** [a)]	Gas_station	2.225%	.338 [a)]	IKN	1.808%	.377 [a)]
Buzz	1.530%	.335 [a)]	PNRE	1.113%	**.512** [a)]	Roof	1.391%	.372 [a)]
Plastic	1.947%	.410 [a)]	Provincial_gov	2.364%	.284 [a)]	PLTD	2.364%	.388 [a)]
Saving	1.808%	.209 [a)]	Municipal_gov	1.669%	.215 [a)]	PLT	1.530%	.307 [a)]
Solaruv	1.252%	**.680** [a)]	GWh	2.643%	.456 [a)]	Allocation	2.921%	.165

Notes:b) negative sentiment (<-0.20), and otherwise, neutral.
[a]) positive sentiment (>.20).

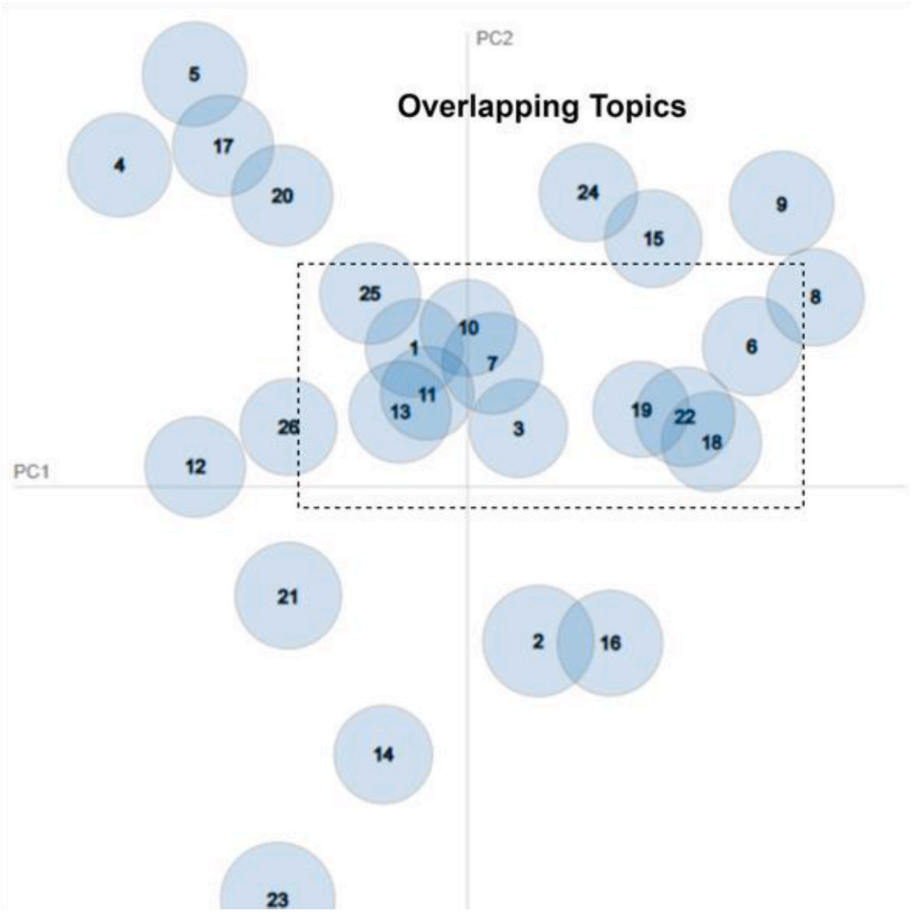

Fig. 7. An example of overlapping topics.

public engagement and policy formulation. The portrayal of PV significantly impacts public opinion: positive representations in mainstream media encourage public acceptance and support, while social media's critical views can lead to skepticism and calls for more thorough evaluation. This contrast between media platforms fosters a more comprehensive public debate, enabling individuals to form more informed decisions based on a broader spectrum of information. Additionally, policymakers often use public sentiment and these varied media portrayals as a barometer for gauging the acceptability of new technologies. Thus, a balanced understanding that incorporates both positive and critical perspectives is crucial in developing well-informed and robust policies surrounding PV.

The sentiment polarity presented in Fig. 10 is derived from an analysis of all documents, encompassing both articles and social media, without regard to the specific topics within each dataset. As depicted in Fig. 10, mainstream media reflects a notably more positive sentiment (60%), while social media, conversely, tends to exhibit a tendency toward neutrality (34%) and negativity (42%). These findings align with the observations made by Nuortimo et al. (2017) in their study on biomass energy.

Additionally, for a more nuanced exploration of public perceptions regarding PV, this section presents a word-level sentiment analysis across both datasets: mainstream and social media. This approach does not overlook the topics previously identified; instead, it seeks to

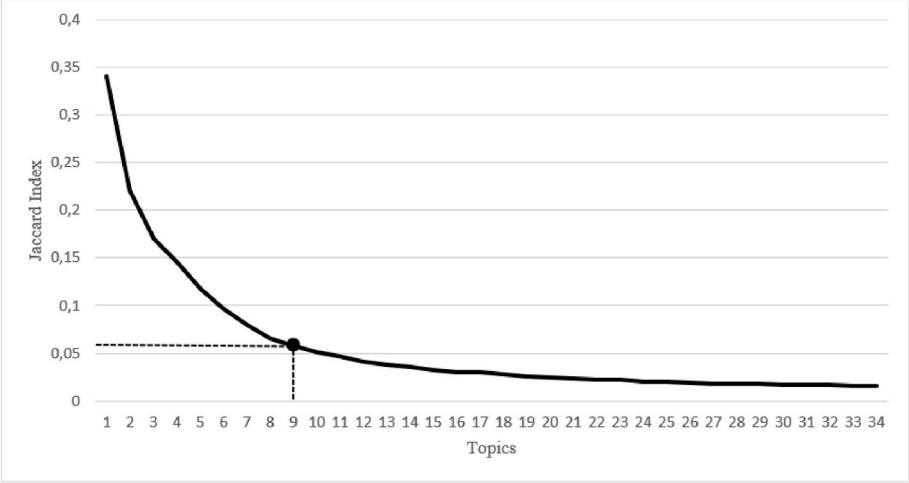

Fig. 8. The selection of the optimal number of topics based on Jaccard index.

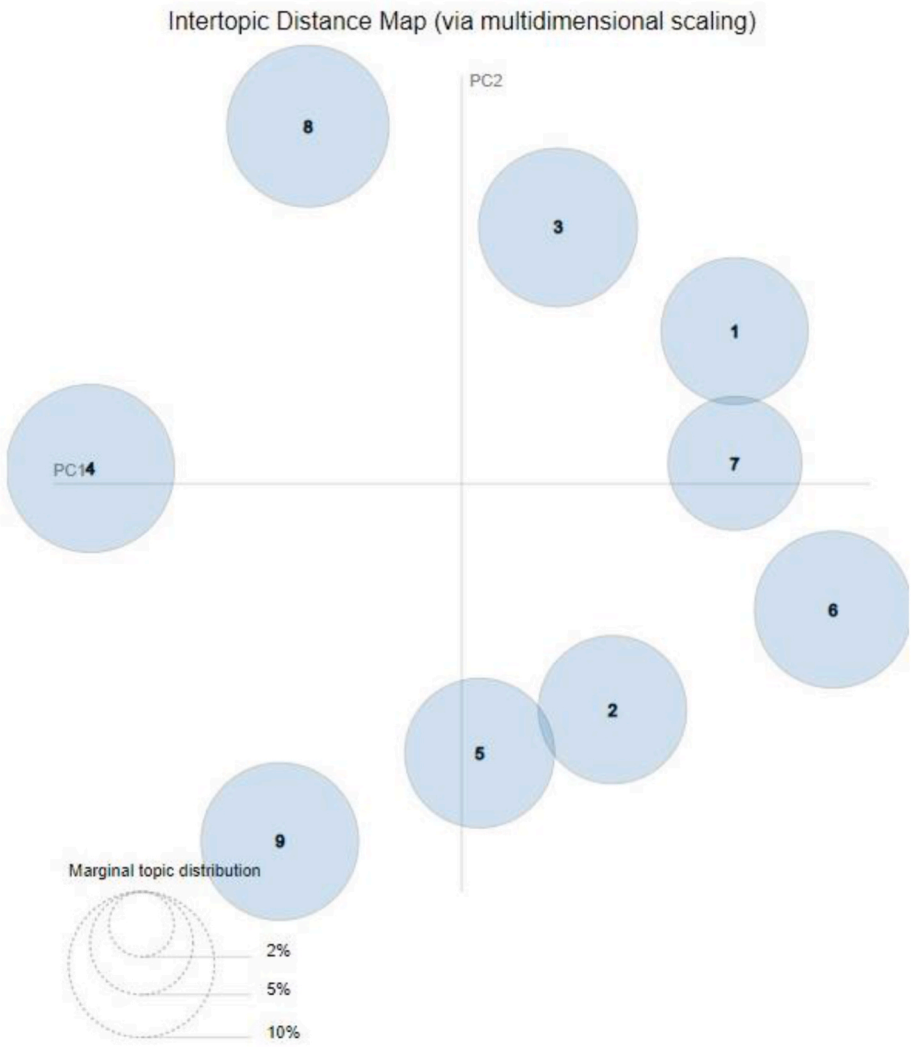

Fig. 9. Intertopic distance map and topic proportions for social media data.

comprehensively assess the sentiment associated with each word across all available documents. By contrast, the sentiment analysis in Sections 4.1 and 4.2 is topic-specific, focusing on the sentiment within documents related to those particular topics. It is worth noting that the sentiment analysis method employed in this section is similar to the approach used in the topic-based sentiment analysis discussed in Tables 5 and 6

Table 6
Topic contribution stock, sentiment, and summary for residential PV.

No.	Topic	Contribution stock (%)	Sentiment value	Summary based on top keywords
C1	Facilitating conditions and technical aspects	10.35	−.202[b)]	a) Electric voltage stability b) After-sales service c) Self-managed oversupply from PV (sharing excess power with neighbors) d) Compatibility specifications that must comply with regulations e) Affordable energy storage alternatives (car batteries)
C2	Public awareness	10.21	−.176	a) Public awareness that PV is environmentally friendly/green energy b) Gradual enlargement of residential PV systems (from a smaller scale and subsequently expanding) c) More competitively priced options
C3	PV regulations, off-grid systems, and economic aspects	11.83	−.216 [b)]	a) Economic aspects of PV – break-even point in years b) Off-grid systems and the necessity of lithium battery manufacturing facilities/factories and the corresponding supportive regulations
C4	Public skepticism	13.34	−.202 [b)]	a) Public disbelief about the advantages of PV (export-import meter) compared to the existing system (electric token) b) Public distrust in the challenges of PV implementation: human resource quality, the potential for corruption
C5	Sustainability of PV systems	10.36	−.120	a) Durability of PV system (PV lifespan) b) Continuity of energy availability (e.g., during the nighttime – when there is no sunlight, cloudy weather, rainy season, etc.) c) Assurance of spare parts (including type, affordability, and availability)
C6	Energy accessibility and self-assembled PV systems	11.52	−.174	a) Comparison of PV brands b) Discrepancies in energy accessibility within rural areas (e.g., rolling blackouts, frequent electricity disruption) c) Public doubts about the durability of PV components, prompting a necessity for self-assembled PV systems using recycled/used materials
C7	Equipment setup for PV	8.39	−.184	a) Equipment setup for assembled PV systems b) The advantages of using renewable energy, such as PV for induction stoves due to a gas shortage
C8	Misconceptions about PV	12.30	−.206 [b)]	a) Misunderstandings regarding PV restricted to daytime use and its inability to provide electricity during the night b) The necessity of spreading information and communicating about the innovation (PV) with the general public c) PV installation outside of the electricity provider's network/path
C9	Financial benefits of PV and on-grid systems	11.69	−.241 [b)]	a) PV is perceived as suitable for high-wattage electronic devices (e.g., air conditioners/AC, water pumps), reducing electricity expenses b) Potential damage to PV equipment and electronic devices due to voltage instability c) The export-import system (on-grid) is more economically advantageous than off-grid systems for utilizing surplus energy (supply) generated by residential PV

Notes:
a) positive sentiment (>0.20).
[b]) negative sentiment (<-.20), and otherwise, neutral.

The occurrence frequency of words varies, signifying their significance within public discourse. Therefore, this analysis incorporates the consideration of importance levels, as indicated by relative occurrences, employing min-max normalization. In this context, a word with the highest frequency is assigned a score of 10, whereas a word with the lowest frequency is given a score of 0. Sentiment values range between

Table 7
Top five keywords, occurrences (O), and sentiment value (SV) per keyword for residential PV.

Topic C1	O	SV	Topic C2	O	SV	Topic C3	O	SV
Volt	7.80%	−.111	Green	7.08%	−.020	Off_grid	7.95%	−.149
Service	6.50%	−.144	Scale	6.50%	−.033	Factory	7.37%	−.225 [b]
Neighbor	5.92%	−.390[b]	Friendly	6.50%	−.278 [b]	Lithium	5.35%	−.216 [b]
Specification	4.05%	.054	Competition	4.19%	−.466 [b]	Regulation	5.49%	−.197
Car battery	3.61%	.160	Environmentally friendly	5.64%	−.295 [b]	Year	3.47%	−.236 [b]
Topic C4	O	**SV**	**Topic C5**	O	**SV**	**Topic C6**	O	**SV**
Challenges	8.09%	−.170	Lifespan	8.09%	−.036	Durable	6.65%	−.011
Token	7.66%	−.236 [b]	Type	6.65%	−.087	Brand	6.50%	.078
Quality	7.08%	−.136	Spare_part	5.64%	−.090	Used	5.92%	−.049
Corruption	6.94%	−.500 [b]	Sunlight	5.06%	−.057	Rural	5.78%	−.075
Exim	4.62%	−.281 [b]	Rainy_season	4.34%	−.083	Rolling_blackout	4.34%	−.444 [b]
Topic C7	O	**SV**	**Topic C8**	O	**SV**	**Topic C9**	O	**SV**
Initiative	5.20%	−.347 [b]	Phone	7.95%	.018	Supply	6.36%	−.467 [b]
Minister	4.48%	−.226 [b]	Path	7.66%	−.274 [b]	Water_pump	6.21%	.093
Renewable_energy	4.48%	−.210 [b]	Day_night	4.91%	.176	AC	5.35%	.027
Stove	3.90%	−.019	Innovation	5.49%	−.221 [b]	Damaged	5.20%	−.236 [b]
Assemble	3.18%	.273 [a]	General_public	4.62%	.016	Export_import	3.90%	−.426 [b]

Note:
[a]) positive sentiment (>.20).
[b]) negative sentiment (<-.20); otherwise, neutral.

Table 8
Map of topic coverage in the mainstream media and social media.

No	Area	Topic coverage	
		Mainstream media	Social media
1	Financial benefits	Topic A6: Eliciting financial benefits of PV compared to other power generation facilities at the macro level	Topic C3: Financial benefits – return on investment at the residential level
2	Information reach, public awareness and perception	Topic A2: Information reach about PV and its technology	Topic C2: Public awareness about green or environmentally friendly energy Topic C4: Public skepticism about and trust in PV-related stakeholders Topic C8: Misconceptions about PV
3	Technology	Topic A4: More economical alternative technology for PV	Topic C7: Equipment setup or installation Topic C1: Facilitating conditions Topic C1: Technical aspects such as stability and standard specifications Topic C5: PV sustainability, specifically regarding durability, assurance of spare parts, and continuity of energy availability Topic C6: more economical alternative technology for PV
4	Government policies and regulations	Topic A5: Key stakeholders in PV implementation Topic A1: Regulations and the need for financial incentives Topic A2: Information reach about government initiatives Topic A3: The implementation of PV in public infrastructure as one of the government policies	Topic C3: Government regulations specifically related to residential PV, such as standardized PV components and spare part availability in the market
5	Challenges and criticisms	Topic A4: Public apprehensions about the export-import system and more economical alternatives for PV Topic A6: Eliciting challenges in implementing PV, such as resource allocation	Topic C6: Energy accessibility, specifically related to rolling blackouts and electricity access in rural areas

−1 and 1. A word that is both most frequently discussed and associated with the most negative sentiment will be attributed a score of −10, while conversely, it would receive a score of 10 for the most positive sentiment. Table 10 demonstrates the calculation of weighted sentiment values. This procedure was applied to both mainstream media and social media datasets.

Figs. 11 and 12 present the sentiment spectrum of words distinguished by weighted sentiment values surpassing the 95th percentile, classifying them as notably favorable. Roughly 50% of these terms are categorized as neutral, while fewer than 5% fall within the least favorable category in their respective datasets. The findings extrapolated from Figs. 11 and 12 reveal a distinct inclination towards a positive sentiment bias prevalent within mainstream media. Even when scrutinizing the weighted sentiment values below the 5th percentile, they consistently maintain a position within the neutrality spectrum. Nonetheless, it is essential to acknowledge that specific terms, such as 'ministerial decree,' 'module manufacture,' and 'consequences', persistently emerge as the most unfavorable within this context. This discernible pattern extends to datasets associated with social media, which predominantly exhibit a sentiment spectrum ranging from neutrality to negativity. Upon closer examination of the weighted sentiment values surpassing the 5th percentile, they do not conform to the category of

Table 9
Top five words expressing highly negative sentiments (95% percentile) from the social media dataset.

No	Word	Relative occurrences (min-max normalization)	Sentiment value per word	Weighted sentiment value
1	blackout	9.804	−0.564	−5.526
2	excuses	9.020	−0.480	−4.333
3	corruption	8.431	−0.500	−4.216
4	contract	6.863	−0.600	−4.118
5	right	7.255	−0.560	−4.059

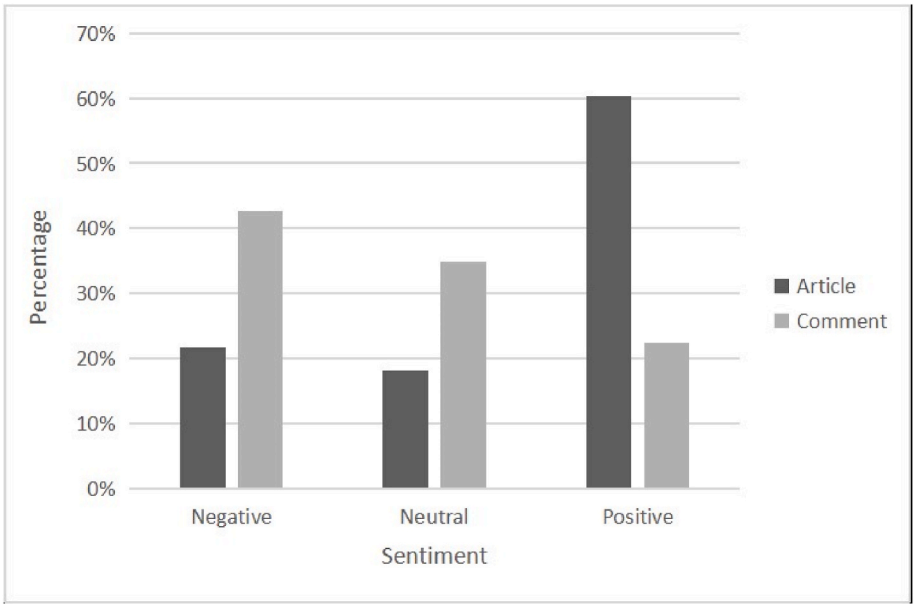

Fig. 10. Sentiment polarity from mainstream media and social media.

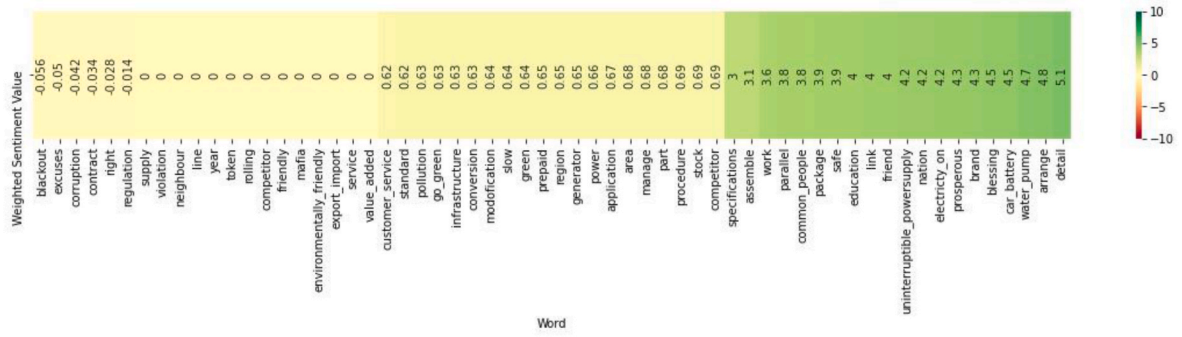

Fig. 11. Sentiment spectrum from the mainstream media dataset.

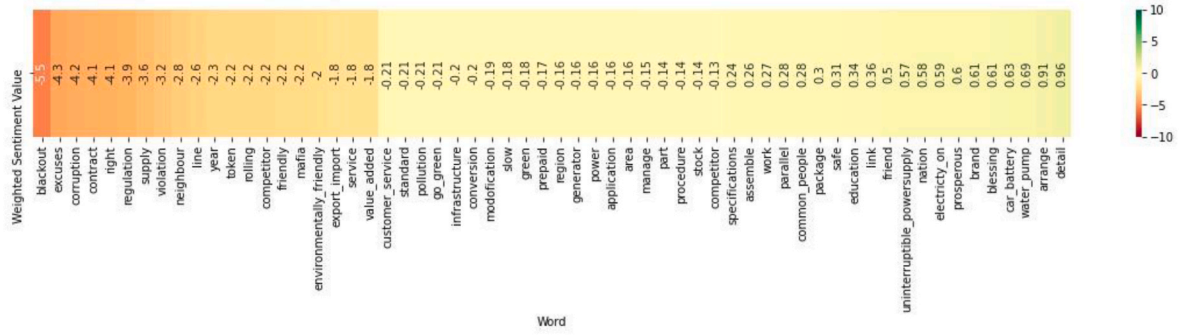

Fig. 12. Sentiment spectrum from the social media dataset.

positive sentiment. Nevertheless, within this specific dataset, words such as 'detail' and 'car battery' consistently assert themselves as the most unfavorable. Consequently, this data analysis culminates in the formulation of Table 10, offering comprehensive insights into the polarity of public sentiment concerning PV in both datasets.

From Tables 10 and it can be inferred that specific aspects are perceived as positive in both datasets. Notable among these are the applicability, installation and safety, and the reach of information dissemination. Moreover, several aspects are perceived as ranging from neutral to moderately negative in both datasets. These include capital costs, sustainability of PV, government policies and regulations, and governmental support. An intriguing observation pertains to the distinct role of mainstream media as a source of information and education. This role is evident from the positive perceptions related to green energy technology (GET) awareness and environmental benefits. However, within the social media dataset, the perception of GET awareness is negative, while the perception of environmental benefits remains neutral. On the other hand, a set of aspects is found to have the most negative perceptions, particularly within the context of the social media dataset. These negative perceptions are directed toward access to affordable and uninterrupted electricity supply, trust in stakeholders, and financial benefits. This recurring pattern underscores as paramount three concerns held by the public regarding the implementation of PV.

Table 10
Public perception: The most positive (favorable) and the most negative (unfavorable) perceptions of PV.

No.	Factor	Associated Words	Mainstream Media	Social Media
1	Financial benefits	Year, value_added	N/A	Unfavorable
2	Capital cost	Capital_expenditure*	Neutral	N/A
3	Green energy technology awareness	Friendly, environmentally_friendly, green, go_green	Favorable	Unfavorable
4	Information reach	Friend, link, education, common_people, knowledge*, community*	Favorable	Favorable
5	Environmental (non-financial) benefits	Environmental_sustainability*, environment*, dioxide*, greenhouse_gas*, pollution	Favorable	Neutral
6	Applicability, installation, and safety	Safe, specifications, water_pump	Favorable	Favorable
7	Facilitating conditions	Service**	Favorable	Unfavorable
8	PV performances	Mwh*, gwh*, airport*, maritime*	Favorable	N/A
9	Sustainability of PV	Part, stock, durable*	Neutral	Neutral
10	More economical alternative technology	Car_battery, assemble(self)	N/A	Favorable
11	Trust in PV-related stakeholders	Excuses, corruption, mafia	N/A	Unfavorable
12	Government support	Infrastructure**, support*, resources*, module_manufacture*	Unfavorable	Neutral
13	Government policies and regulation	Ministerial_decree*, governance_esg*, standard, procedure	Unfavorable	Neutral
14	Access to affordable and uninterrupted electricity supply	Blackout, rolling, right, supply, line, token	N/A	Unfavorable

Notes: N/A stands for not applicable.
* Found only in mainstream media dataset.
** Found in both dataset; otherwise, found in social media dataset.

Table 11
Summary of literature review results on PV and findings from this research.

Aspect			Financial		Knowledge and awareness				
No	Author	Country	Financial benefits	Capital cost and/or ROI	GET awareness	Information reach	Non-financial benefits of PV	Environmental concern	Knowledge, misconceptions, and Skepticm
1	Claudy et al. (2011)	Ireland					✓		
2	Murphy and Westphal (2011)	US		✓					
3	Rai and Beck (2015)	US	✓		✓				
4	Hampton and Eckermann (2013)	Australia	✓	✓					
5	Enserink et al. (2023)	Netherlands							
6	Jager (2006)	Netherlands			✓				
7	Hai (2019)	Finland						✓	
8	Jung et al. (2016)	Finland							
9	Schaffer and Brun (2015)	Germany					✓		
10	Faiers and Neame (2006)	England	✓				✓		
11	Mbzibain et al. (2015)	England							
12	Li et al. (2018)	UK	✓						
13	Mukai et al. (2011)	Japan	✓						
14	Reeves et al. (2017)	Japan			✓				
15	Doedt and Maruyama (2023)	Japan						✓	
16	Sardianou and Genoudi (2013)	Greece							
17	Alrashed and Asif (2015)	Saudi Arabia		✓		✓			
18	Alsabbagh (2019)	Bahrain		✓	✓	✓			
19	D'Agostino et al. (2011)	China	✓		✓				
20	Yuan et al. (2011)	China		✓		✓			
21	Malik and Ayop (2020)	Malaysia				✓			
22	Solangi et al. (2013)	Malaysia			✓				
23	Wadi et al. (2014)	Malaysia			✓				
24	Goh et al. (2017)	Malaysia	✓	✓		✓			
25	Lau et al. (2020)	Malaysia	✓		✓				
26	Nurwidiana et al. (2021)	Indonesia	✓	✓				✓	
27	Setyawati (2020)	Indonesia	✓	✓		✓			
28	Aggarwal et al. (2019)	India			✓				
29	Zeng et al. (2022)	Pakistan		✓	✓		✓	✓	
30	Abdullah et al. (2017)	Pakistan		✓					
31	**This research**	**Indonesia**	✓	✓	✓	✓	✓		✓
Total			**11**	**11**	**11**	**7**	**5**	**4**	**1**

5. Discussion

5.1. Topic coverage on public discourse about PV implementation in Indonesia

Topic modelling was conducted separately for both datasets, with the interpreted results of the generated topics compiled and presented in Table 9. In Table 9, the topic coverage within both the mainstream media and social media datasets is plotted and compared with findings from other relevant studies, as shown in Table 11. The mapping in Table 11 is derived from prior research on PV, with checkmarks (✓) signifying factors that have been found to significantly influence PV adoption. Nevertheless, one notable factor that did not feature prominently in the formation of topics in Sections 4.2 and 4.3 but emerged in the comprehensive document analysis, as evidenced in Tables 10 and is the non-financial benefit, particularly pertaining to environmental advantages. This attribute was observed in both datasets.

The topic coverage across both datasets encompasses several salient aspects. First, financial considerations, encompassing financial benefits, capital costs, and return on investment (ROI), emerge as pivotal factors in PV adoption. This is substantiated by the fact that 30% of the listed publications emphasize the significance of these factors in their research.

Second, the aspect of knowledge and awareness, including GET awareness, information reach, and non-financial benefits, are highlighted. In addition, this study introduces a novel factor related to knowledge, misconceptions, and skepticism, which may impede the adoption process. In the context of misconceptions, here are some example comments: 'these solar panels are believed to be highly susceptible to lightning, with concerns that a charging battery can be completely destroyed. ' Unfortunately, such misconceptions contribute to public hesitancy in adopting PV, despite the availability of technology to address these concerns. Regarding skepticism, some example comments include 'self-generated power is prohibited and made difficult,' and 'pv installations nowadays are challenging, and if you want it to be easy, you have to use a middleman for quick installation.' This skepticism is rooted in the public's perception that the government may not guarantee seamless implementation for residents. Consequently, there is a compelling need for a comprehensive information dissemination strategy to strengthen knowledge, to shape positive perceptions, and to foster public acceptance of PV technologies.

Third, technological facets and supporting facilities, spanning from

Technological aspects and supporting facilities					Trust and government support			Visual and social impression		
Applicability, installment, and safety	Facilitating conditions	PV performance	Sustainability of PV	More economical alternative technology	Trust in providers and/or other stakeholders	Government support in incentives/ subsidies	Government policies and regulation	Visual impact and/ or aesthetics	Hedonic motivation	Social influence
✓										
		✓								
								✓		
						✓				
						✓				
	✓									
✓					✓					
						✓				
✓								✓		
	✓	✓				✓		✓		
✓		✓			✓					
						✓				
						✓				
	✓	✓				✓				
	✓									✓
	✓									
✓	✓	✓							✓	✓
✓										
✓					✓	✓				
✓	✓	✓	✓	✓	✓	✓	✓			
8	**7**	**6**	1	**1**	**4**	**9**	**1**	**3**	**1**	**2**

the installation to facilitating conditions, play a pivotal role. This research introduces a salient theme concerning the sustainability of PV, which consistently surfaces through topic-based sentiment analysis in the social media dataset within Section 4.2 and via sentiment analysis at the word level throughout the mainstream media dataset, as documented in Table 10. The sustainability dimension encompasses considerations such as durability, the assurance of long-term spare part availability, and the continuity of energy supply. Additionally, this study unveils another crucial theme linked to alternative technologies that are more cost-effective, thereby affording consumers a wider array of choices in accordance with their financial constraints. Some example comments expressing the need for more affordable technology are as follows: 'can't Indonesia produce batteries at a lower cost?', 'the cost of batteries or accumulators significantly depletes funds and needs to be recycled or replaced at least once a year,' 'the inverter is expensive,' and 'I added a dry cell to my motorcycle; I assembled it using a used laptop lithium battery.'

Finally, trust in stakeholders and the provision of financial support by government entities have been the subject of extensive discussion. This research unearths factors linked to government policies and regulations that exert a propitious impact on PV adoption. Furthermore, it was found that these regulatory issues are confined to macro-level discussions in mainstream media and extend to individual-level discourse on social media platforms, where deliberations accentuate the influence of policies on the adoption of PV systems at the individual or residential level. Some examples of comments on social media related to government regulations and policies are: 'laws and regulations should be made for the people to make purchasing more accessible and affordable,' 'the regulations are created without a regulation impact analysis,' and 'our gov law allows private electricity providers to build power plants, leading to an over-supply situation.'

In contrast to the findings of prior studies by Alrashed and Asif (2015) and Alsabbagh (2019), which identified the visual impact and aesthetics as factors contributing to PV adoption, the current research did not ascertain the salience of such attributes, either at the topic or comprehensive data level. This omission may be attributed to the prevailing focus in developing countries on meeting fundamental needs, particularly the imperative to secure continuous and affordable electricity access. This is substantiated by the sentiments expressed in Table 10, wherein the public exhibits a negative outlook regarding this particular concern. Moreover, it is worth noting that certain factors, such as social influence (Lau et al., 2020) and hedonic motivation (Aggarwal et al., 2019), were not found in this research, possibly because of the difficulties in capturing individual motivations from social media data.

5.2. Indonesian public perception of PV

Sentiment polarity, which reflects public perception, was derived from the sentiment analysis of all documents in both datasets. The sentiment analysis was performed in two stages: first, at the document level, to provide an overview of polarity within both datasets; and second, at the word level, to investigate public perception more specifically. Subsequently, the sentiment analysis results at these two levels were compared to discern public perception from the vantage points of mainstream media and social media.

In general, mainstream media presents a more positive outlook in regard to PV technology compared to what is seen on social media, a

pattern that corresponds with the conclusions reached by Nuortimo et al. (2017). The public generally holds a positive view of various aspects of PV technology, such as its practicality, installation, safety, and the extent to which information is disseminated. This optimistic viewpoint is echoed by the research of Peñaloza et al. (2022), who emphasize the significance of sharing information related to technology to enhance public awareness.

However, negative perceptions arise when it comes to economic considerations, particularly in terms of investment costs. This finding is in line with the research conducted by Peñaloza et al. (2022) and Woo et al. (2022), especially in regard to developing countries. Furthermore, the public's attention is drawn to concerns regarding regulations, government policies, and the adequacy of government support, with moderately negative sentiments. This is consistent with the findings of Abdullah et al. (2017), which emphasize the necessity of proactive government measures, including incentives, to promote PV adoption.

5.3. Theoretical and practical implications

This empirical study demonstrates the significance of utilizing mainstream and social media data to capture public discussions and perceptions, encompassing both general viewpoints and detailed insights. Mainstream media is adept at providing a comprehensive perspective on the implementation of GET, while social media is useful in offering a more intricate and profound understanding of its application at the residential or individual level.

The findings from this research support the results of previous studies, particularly those based on surveys that focus on specific aspects such as financial considerations, knowledge and awareness levels, technology and supporting infrastructure, as well as the role of trust and government support. It is noteworthy that some elements related to visual and social impressions were not identified, potentially due to their limited relevance in the context of developing countries. Whereas visual and social impressions consisted of visual impact or aesthetics, hedonic motivation, and social influence are significant factors in the adoption of PV. Visual appeal and aesthetics play a crucial role, as the design and appearance of PV installations can impact perceptions of property value and neighborhood aesthetics (Rai et al., 2016). People are more likely to adopt technologies they find visually appealing or that they believe will enhance their property's value. Hedonic motivation, which involves the pleasure or satisfaction derived from using technology, also influences PV adoption. Individuals may derive personal satisfaction from using innovative and environmentally friendly technology, contributing to a positive self-image (Sundar et al., 2014). Finally, social influence is a significant factor. The decisions and opinions of peers and the community can strongly sway individual choices. The concept of social proof, where individuals look to others' behavior to guide their own decisions, is particularly relevant in the adoption of sustainable technologies like PV systems (Baiocchi et al., 2010). These factors combine to shape the overall perception of PV, influencing consumer decisions towards adoption.

Nevertheless, given the exploratory nature of this study, it unveiled several pertinent aspects, including: (1) issues pertaining to knowledge, misconceptions, and skepticism; (2) more cost-effective alternative technologies; and (3) the role of government regulations and policies. These findings underscore the need for further research to investigate the significance of these three variables in the context of PV adoption.

The findings are also very important for people making policies, those in the solar PV industry, and communicators. It shows that to get the public involved and make good policies, it's important to understand how solar PV is shown differently in mainstream media and on social media. Policymakers can use these different views to make policies that people will like, combining the positive views from mainstream media with the more critical ones from social media. The study points out important areas like financial benefits, new technology, government policies, and raising public awareness. These are key for making good policies and communication plans. For people in the solar PV industry, it's important to know about these areas to meet public needs and interests.

To overcome challenges, the study suggests several actions. First, improve public education and awareness, especially by using mainstream media to show the good sides of solar PV, like its environmental benefits and how easy it is to use. Also, it's important to address money concerns by offering financial help or new ways of paying to make solar PV more affordable. Making government policies better to help more people use solar PV is another important step, like making installation easier and providing strong support and rules. Lastly, it's crucial to create strategies that fit each type of media: mainstream media should focus on big educational campaigns, while social media should deal with technical issues, clear up misunderstandings, and encourage community involvement. These well-thought-out strategies, based on a good understanding of public opinion and how solar PV is shown in the media, are key to building trust, clearing up misconceptions, and quickly increasing the use of solar PV technologies.

6. Conclusion

Prior research has highlighted the importance of a comprehensive understanding of public discourse and perceptions pertaining to PV technology. Consequently, this study employed topic modelling and sentiment analysis of mainstream and social media datasets to holistically capture public discourse and perceptions, encompassing both general perspectives and specific considerations related to PV and residential PV adoption in Indonesia.

The findings from this study reveal that both mainstream and social media address similar topic areas, including: (1) financial benefits and technology; (2) government policies and regulations; (3) challenges and criticisms; and (4) information reach, public awareness, and perceptions related to PV. However, there are notable differences in the focuses of the two media channel types. Mainstream media predominantly emphasizes macro-level discussions, while social media is primarily characterized by micro-level interactions where individuals feel personally engaged with the issues. Mainstream media also places a particular emphasis on regulatory and government policy aspects and sheds light on challenges and criticisms concerning the implementation of PV. The findings of this study substantiate the outcomes of the previous survey-based research. Notably, it also introduces three novel topics, discussed in both forms of media, which have not been addressed in earlier survey-based research: (1) knowledge, misconceptions, and skepticism; (2) more economically viable alternative PV technologies; and (3) government regulations and policies. Remarkably, neither social nor visual impressions were evident in either type of media.

Regarding public perception, mainstream media tends to portray PV technology more positively than social media. The public generally views PV technology favorably, especially in terms of its practicality, installation ease, safety, and information reach. However, negative perceptions often arise concerning investment costs, regulations, government policies, and the sufficiency of government support.

The limitations and recommendations for future research are as follows. First, it is important to note that this study does not capture the demographics of social media users, which limits the consideration of user demographics when interpreting the results. Second, this study does not encompass comments on news articles, which also hold significant value. Third, the research employs text-mining techniques, specifically topic modeling and sentiment analysis. The insights derived from this analysis are exploratory in nature and highly beneficial for uncovering contextual issues within the field. However, the significance of the newly identified factors in this study regarding PV adoption remains unconfirmed. Consequently, further research is required to ascertain whether these new factors can indeed contribute to fostering

PV adoption. To ascertain the impact of three crucial factors—namely, (1) knowledge, misconceptions, and skepticism; (2) economically viable alternative PV technologies; and (3) government regulations and policies—on individuals' decisions regarding PV adoption, it is essential to employ survey-based methodologies.

CRediT authorship contribution statement

Yun Prihantina Mulyani: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Anas Saifurrahman:** Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Hilya Mudrika Arini:** Conceptualization, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Supervision. **Arwindra Rizqiawan:** Formal analysis, Investigation, Supervision, Writing – original draft. **Budi Hartono:** Conceptualization, Supervision, Writing – original draft. **Dhanan Sarwo Utomo:** Supervision, Writing – original draft, Writing – review & editing. **Agnessa Spanellis:** Conceptualization, Supervision, Writing – original draft. **Macarena Beltran:** Conceptualization, Supervision, Writing – original draft. **Kevin Marojahan Banjar Nahor:** Conceptualization, Formal analysis, Writing – original draft. **Dhyana Paramita:** Resources, Writing – original draft. **Wira Dranata Harefa:** Formal analysis, Writing – original draft.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to improve readability and language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Hilya Mudrika Arini reports financial support was provided by the UK - Indonesia Consortium for Interdisciplinary Sciences (UKICIS). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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