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Social acceptance of geothermal technology on a global view: a systematic review

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Abstract

Background The role of geothermal technology in the context of global efforts toward carbon-free and clean energy production is becoming increasingly important. Social acceptance is a decisive factor in the successful implementation of geothermal projects.

Main text This systematic review summarizes the major aspects and evaluates the crucial outcomes of recent research on community acceptance as a dimension of social acceptance of geothermal technology since 2011, on a global scale. From the literature, we identified and grouped researched acceptance factors into five main acceptance categories, namely 'project organization and process', 'environment', 'municipality', 'technology', and 'governance'. Each category comprises a number of specific acceptance factors addressed by different survey methods (e.g., interviews, questionnaires, content analyses) in the relevant publications. The acceptance factor categories 'technology' and 'governance' are remarkably underrepresented, whereas the acceptance factors combined in the categories 'project organization' and 'municipality' are frequently mentioned in the literature. Acceptance factors combined within the category 'environment', 'trust in key actors', and 'information about the project' are expectedly the most dominant ones in the papers studied. Interestingly, acceptance categories and number of mentions of acceptance factors are comparable in all survey methods applied in the various studies. Besides the acceptance factors combined in the categories 'environment' and 'project organization and process', 'knowledge about geothermal technology' (an acceptance factor from the category 'municipality') represents the predominant acceptance factor of geothermal technology.

Conclusions Deeper knowledge, in particular about the technical aspects of geothermal energy generation, might enable a more comprehensive and holistic view on geothermal technology. Furthermore, the integration of all relevant groups of stakeholders in the process of implementation of geothermal projects strongly influences their social acceptance. Following the results of our systematic literature review, we propose these aspects should be addressed in more detail in future research on the community acceptance of geothermal technology and energy production.

Keywords Geothermal energy, Community acceptance, Induced seismicity, Renewable energy, Energy transition, Environmental impact

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Background

Due to the wide consensus about the correlation between increasing CO_2 concentration in the Earth's atmosphere and global warming, one of the biggest future challenges is the reduction of man-made CO_2 emissions. One step in managing this challenge is to replace energy extracted from fossil resources with energy gained from renewable, low-emission techniques [1]. The share of geothermal energy in the global energy mix is already growing and it has the potential to play a significant role in the renewable energy transition worldwide in the future [2–6]. The increased use of geothermal power may turn out to be a crucial factor to ensure the renewable energy source mix represents a sustainable, baseload-capable energy portfolio [7]. Besides the aspects of technical and economic feasibility, the social acceptance of energy-related infrastructure projects within the community is a crucial factor. It is important to note that a number of geothermal projects have already failed in the past because of the lack of social acceptance. For example, geothermal projects in Puchheim in Germany, Milos and Nisyros in Greece, and Mt. Lawu in Indonesia, were all unsuccessful because of concerns and fears about environmental pollution, operational safety, or for religious reasons, respectively [8–10].

There are various approaches to investigate the social acceptance of renewable energy sources. For instance, Gaede and Rowlands [11] identified in their bibliometric analysis of more than 800 articles, six different clusters of social acceptance within the renewable energy sector. The leading topics were wind energy, carbon capture and storage, bioenergy, and hydrogen vehicles. A frequently cited concept for social acceptance in this literature review is the three-perspective model of Wüstenhagen et al. ([12] cited in, e.g., [13–15]). The three perspectives are socio-political acceptance, market acceptance, and community acceptance (Fig. 1). For this literature review, we chose the perspective of community acceptance because, even though it is an essential factor when it comes to the realization of geothermal projects, there are currently no established standards or models (e.g., [16–18]).

Hence, the focus in our literature review is on publications regarding the influencing factors of social acceptance in society linked to geothermal projects, highlighting community acceptance and other aspects that influence the opinion of community citizens before and during the realization of geothermal projects [12, 13, 19, 20]. Our main goal is to provide an overview of the state of research over the past ten years from 2011 to 2021. We have chosen this period as 2011 is the time after the Fukushima-Daiichi nuclear disaster in in Japan, which greatly affected the public perception and acceptance of energy technologies globally and 2021 is the year before the Russia Ukraine conflict in Europe aggravated, which presumably affect public acceptance as well [21–23]. Furthermore, this review intends to identify focus patterns, analyze methods chosen for the research, and categorize acceptance factors in the context of geothermal projects that were primarily studied. These results can be used as fundament for future research on the application and implementation of new findings in geothermal projects, as well as the development of corresponding guidelines and standards.

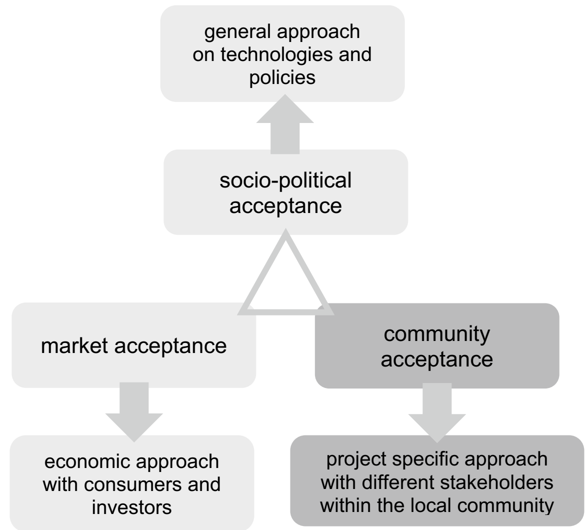

Fig. 1 Triangle of social acceptance of renewable energy innovation. Adapted from Wüstenhagen et al. [12]

Main text

Methods

All studies analyzed in this paper are peer-reviewed papers and were sourced via the search engines Web of Science and Scopus. In addition, a search was conducted using the database GeoRef by ProQuest to add a geo-specific database. To ensure the analysis reflects the most recent and relevant findings, the search was limited to the time period between the years 2011 and 2021. The search string in all three databases was 'geoth* AND accept*'. The search results yielded a representative number of matches in Web of Science (number (n) = 506), Scopus (n = 550), and GeoRef (n = 207), with a total number of 1263 papers retrieved (accessed 07th February, 2022). Duplicates within the three different databases (n = 332), publications with missing topic references in the published title or abstract (n = 873), and three papers overlapping with other papers were omitted; furthermore, five conference papers unavailable to the authors (despite repeated efforts to obtain them) were excluded. The systematic search yielded a total number of 36 studies published in academic journals, five conference contributions, and nine book contributions included in the literature review. The selected studies were all published as full text papers in English. To obtain a broad view on the topic, the review includes studies in all regions of the world.

Social acceptance in the context of geothermal projects

To address the social acceptance at the local level in this literature review, we use one dimension of the 'triangle of social acceptance of renewable energy innovation' developed by Wüstenhagen et al. [12]. The model consists of the levels of market acceptance, socio-political acceptance, and community acceptance (Fig. 1). Market acceptance is based on the economic dimension with consumers and investors. For socio-political acceptance, the relevant actors are the public, central decision-makers or stakeholders, and politicians. Community acceptance focuses on interests and opinions of different stakeholders within specified projects on a rather local scale. The stakeholders are part of the community and include, e.g., local society, politicians, and the community administration. It considers community-based aspects of regional acceptance in the context of renewable energy projects [12, 19, 20].

Upham et al. [13] also emphasized the importance of community acceptance with respect to regional energy projects. They emphasize social groups, e.g., regions or communities that are essential for acceptance and describe the three dimensions of Wüstenhagen et al. in more detail [12, 13]. Upham et al. point out that the local acceptance or community acceptance deals with specific physical energy infrastructure projects within a community [13]. For this reason, we deem socio-political and market acceptance less relevant for the purpose of this literature review. Linnerud et al. and Leiren et al. applied this approach to the wind energy sector and defined different acceptance categories and factors. Their approaches were adapted for this literature review [14, 15].

We used the work of previous publications of Wüstenhagen et al. and Upham et al. as general foundation, and the work of Linnerud et al. and Leiren et al. as wind-specific basis to develop a new model of applied community acceptance with focus on geothermal projects (see Fig. 2 [12–15]) depicts a modified structure of applied community acceptance, in which two overarching categories are identified. The first main category consists of a general approach, with social acceptance factors relevant to different geothermal projects. We identified two overarching categories the first main category of which consists of a general approach, with social acceptance factors relevant to different geothermal projects. The second main category is rather project-specific and deals with social acceptance factors that have a direct connection to a specific geothermal project. The two main categories are further subdivided into six specific acceptance categories, which are focused on different aspects of social acceptance.

The main category 'general' consists of:

- the *technology category*, including social factors on a technological basis; and
- the *environment category*, which addresses environment-related acceptance factors.

The main category 'project specific' focuses directly on the specific geothermal project and is subdivided into:

- the *governance category*, which focuses on acceptance factors regarding political topics;
- the *project organization and process category*, which includes acceptance factors closely related to the geothermal project inherent characteristics; and
- the *municipality category*, which summarizes local based acceptance factors.

These categories help in organizing and structuring the numerous acceptance factors and are utilized in the

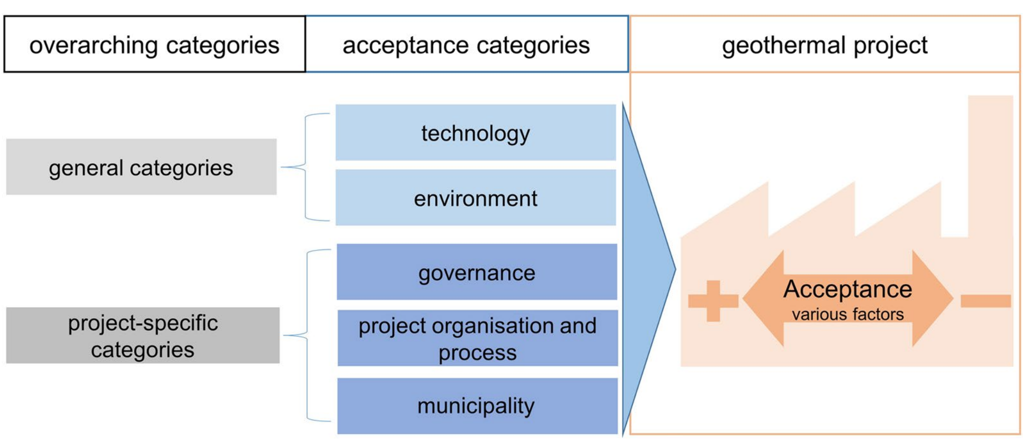

Fig. 2 Relation of social acceptance categories to geothermal project. Modified figure based on Leiren et al. [15]

results and discussion sections to provide a structured and systematic acceptance factor analysis.

Results of the studies

Literature database

The selected studies include geothermal projects in countries all over the world. Mentioned in seven studies, Switzerland is the most frequently addressed country in this review, followed by Japan with five studies. Australia, Indonesia, Chile, and Germany are represented four times each. Additionally, there are 14 countries with three or fewer mentions in the examined papers. Five studies are without a country-specific focus (Fig. 3). It is remarkable that for Iceland and New Zealand, two geologically active countries with a well-established geothermal infrastructure and a long-standing tradition in the usage of geothermal energy, no social acceptance studies were found that could be included in this literature review [22–26]. This may be an expression of minimum public concerns and disputes regarding geothermal energy in these countries.

Methodological approaches

Data collection and used methods are essential parts of research related to the use of geothermal energy. In order to deal with these important features, we examine the methodological facets of the publications in the following. From the 50 reviewed articles, 18 publications used more than one research method [8, 16, 24–39] and 32 papers utilized exclusively one method [10, 17, 18, 24, 32, 40–66]. Figure 4 summarizes the various methodological approaches found in the papers and depicts the sample sizes within questionnaires, interviews, and focus groups. Five additional methods, each used once in the reviewed papers, are not discussed in depth in this literature review (Fig. 4).

The most widely used method is the questionnaire. Within the 30 usages of this method, a certain variability in its utilization is observed. In the studies paper-based, telephone, or online surveys were used, utilizing multiple-choice, single-choice questions, as well as open-ended questions for the participants. Twelve publications used questionnaires in combination with at least one other research method [16, 25, 27–31, 33–35, 67, 68]. With this method, between 16 and 1353 people participated in the different studies and, overall, a median of 329 questionnaire respondents was reached (Fig. 5).

Interviews were carried out in nine studies, in which individuals were interviewed in a direct conversation either face to face, online, or via telephone. In semi-structured interviews, key topics and key questions were asked to gain information from the experience and/or expertise of the interviewees. Afterwards, full transcripts were prepared from recordings and subsequently

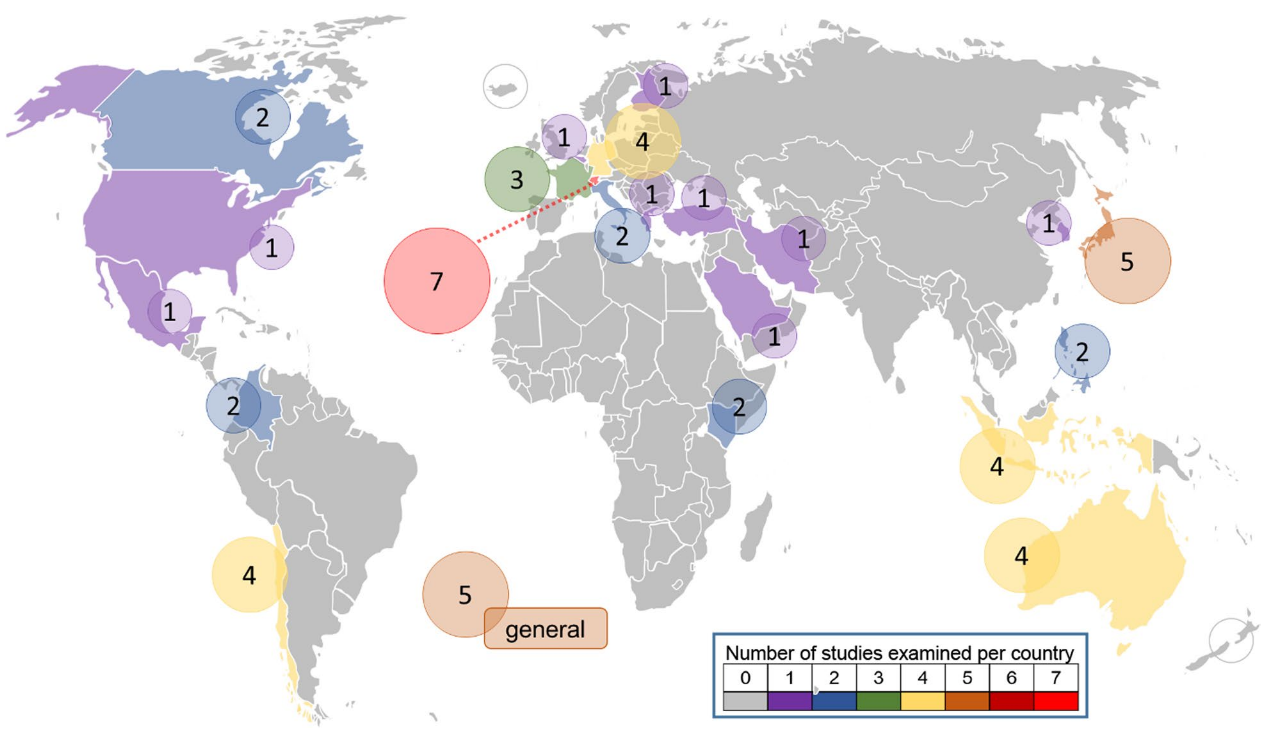

Fig. 3 Number of studies examined per country in the global context

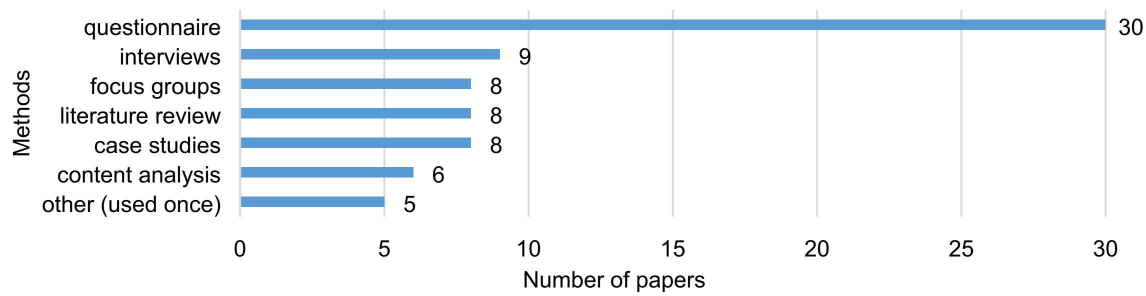

Fig. 4 Number of papers examined categorized by research methods used

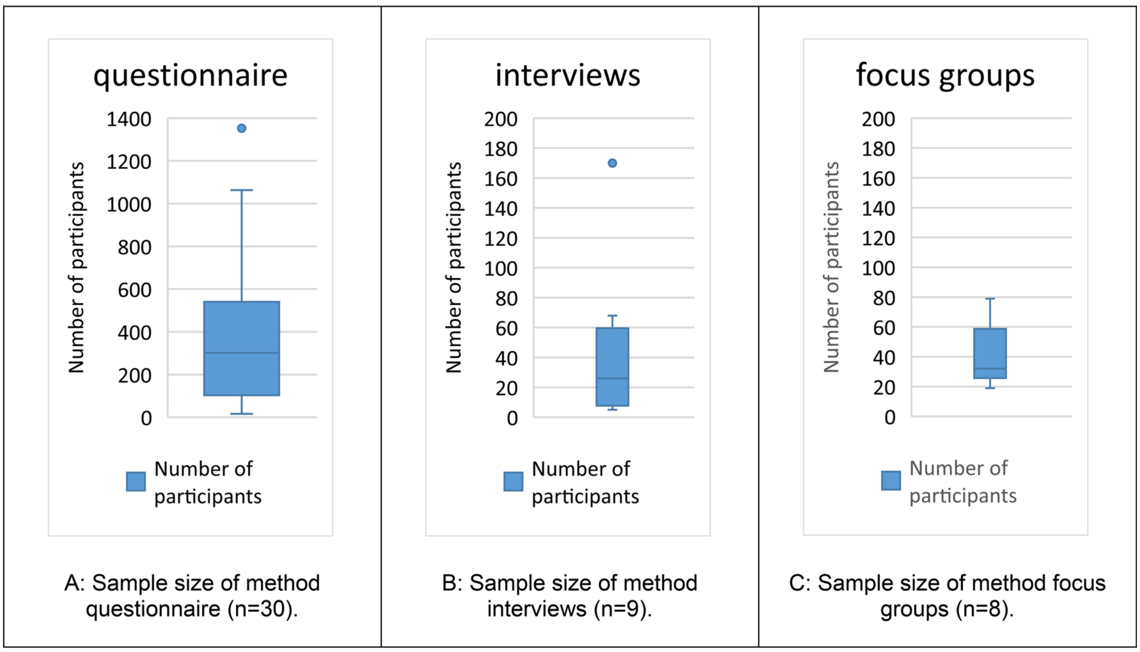

Fig. 5 Overview of box plots for the methods of questionnaire, interviews, and focus groups in this literature review

analyzed. Interview partners included stakeholders from politics, society, industry, or science, e.g., commissioners, representatives of residents' and environmental groups, scientists, and other officials. The duration of interviews ranged from 45 min to 2 h. As shown in Fig. 5, the median of interviews lies at 26 interviewed people. There are two papers with a minimum of five interviewees and one paper with as many as 170 participants [30, 38, 47]. One additional paper does not specify the number of interviewed people [28].

The semi-structured, qualitative focus group method was used in eight studies. In this method, the participants received impulses such as, e.g., factsheets, videos, articles, or verbal questions and then discussed in small groups with six to fourteen people. Afterwards, the results of the small discussions were summed up, for example, in collaborative key conclusions [16]. The duration of focus group sessions lasted about an hour and a half or longer, in multiple meetings [36, 68], either face to face or online. One publication gives no information about the number of participants [28]. Within the other 7 studies, a median of 32 people involved was reached (Fig. 5). The largest number of focus group participants was 329 people, while the minimum number was 119 [16, 38].

Another eight studies provide a literature review on defined countries or regions (e.g., France [44], Greece [10], the Philippines [66], Japan [62], other developing countries [29]) and/or specific aspects of geothermal projects (e.g., governance [56], corporate social responsibility [45], indigenous cultural communities [66], public engagement [65], and cultural aspects [62]). Those studies also take into account findings from other publications on the social acceptance of geothermal projects.

Case studies were used eight times in the reviewed papers. This method was used to examine one or multiple projects in a scientific manner with the aim to draw conclusions from the results of the case study [69–71]. The case studies in this literature review investigated either individual or multiple projects and set different focuses, e.g., the comparison of a geothermal project with other energy projects [46] or spotlight various aspects within a single geothermal project [8, 26, 35, 38].

The method of content analysis was used six times in publications in this literature review. In this method, different types of media content were analyzed. For example, national and local newspapers, local online news websites (articles, online comments), blogs, transcripts from radio and TV programs, communication documents, and the proceedings of public meetings in community groups were used in these papers within a time period from two months to six years [26, 37, 57, 59, 67]. The median of the studies using content analysis as a method is 1095 media content units, with a maximum at 31,351 units and a minimum at 415 units [37, 67]. One paper does not detail the number of media content units analyzed [44].

Geothermal technology

Regarding the type of energy generation in the papers examined, 16 papers focus on heat and electricity combined and 13 papers focus on electricity alone. Two papers focus on heat only and 19 papers do not specify the type of energy at all.

Twenty-six studies do not specify the geothermal technology used in deep or shallow settings and are summarized as 'general geothermal'. The geological and infrastructural contexts of these studies and the addressed acceptance factors strongly indicate the focus of these studies is on deep geothermal technology. The terminology of deep geothermal technology is used in 22 studies. One study also addresses shallow geothermal energy and another study focuses on low-temperature geothermal energy production. Both are summarized as 'other geothermal' technology.

Acceptance factors

In this literature review, a total of 221 mentions of acceptance factors within the five specified acceptance categories are identified.

The acceptance category of project organization and process is, with 77 mentions, the most prominent category. It is followed by the category of environmental characteristics with 55 mentions and the category of municipality with 51 mentions. Technological characteristics and impacts on governance, with 24 and 14 mentions, respectively, were featured less often (Fig. 6).

A total of 33 different acceptance factors are identified over all studies within this literature review (Fig. 7). The acceptance factor of trust in key actors, such as stakeholders, project managers, decision-makers, or companies was encountered in 20 studies. Regarding the category of project organization and process, information about the project with 18 mentions, the distribution of benefits and costs between actors within the community with 14 mentions, and opportunities for participation and consultation in the planning and permitting process with 11 mentions seem to be relevant aspects. The importance of local profits and income also falls within this category with 11 mentions. With one mention each, trust in the process, validation from neutral institutions, and process length only play a minor role in the researched papers.

In the second largest category named environment, the general impact on environment and the risk of seismicity are the two essential acceptance factors, which were researched 17 and 16 times in the studied papers, respectively. The general impact on the environment includes effects on wildlife and biodiversity, but also the aspect of ecological friendliness. Hence, this acceptance factor can be distinguished from seismicity or the groundwater pollution factor,

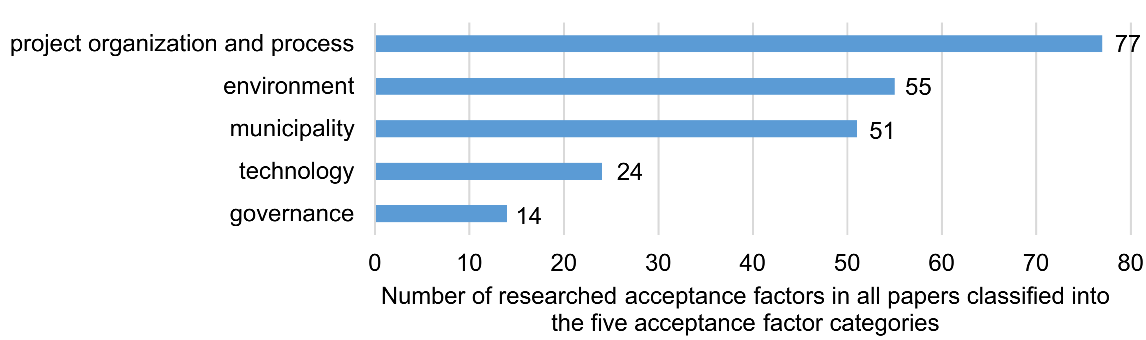

Fig. 6 Number of researched acceptance factors in all papers classified into the five acceptance factor categories

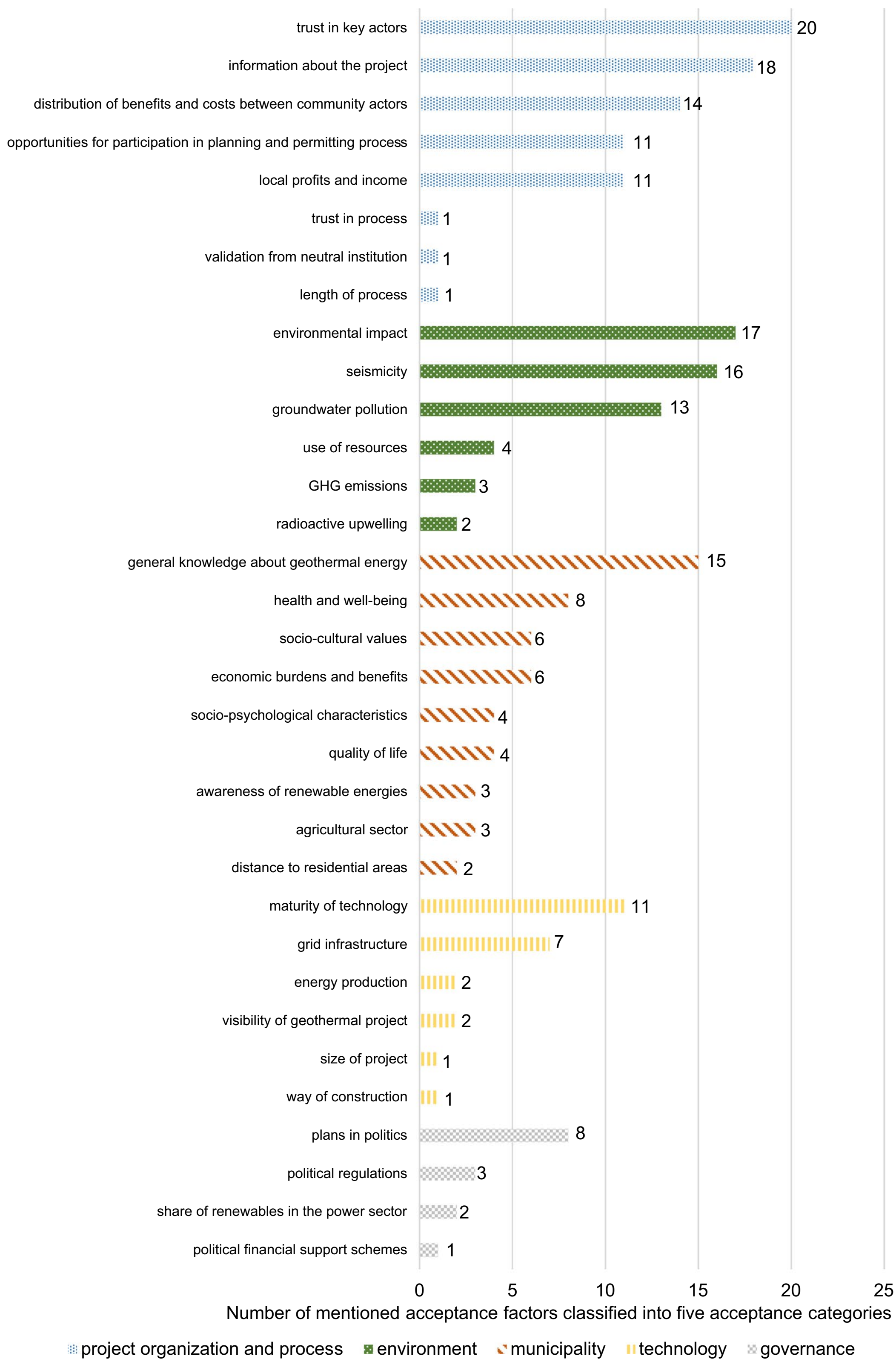

Fig. 7 Number of mentioned acceptance factors classified into five acceptance categories

which is addressed 13 times. The use of resources, addressed four times, is another acceptance factor in this category and deals with water and land use. Other acceptance factors in this category are greenhouse gas emissions with three mentions and radioactive upwelling with two mentions.

In the context of municipalities, general knowledge about geothermal energy is addressed in 15 studies. Health and well-being, dealing for instance with noise and hot water, is mentioned eight times. Sociocultural values and the economic burdens and benefits are mentioned six times each. The socio-psychological characteristics (experiences) are discussed in four papers. The factor quality of life, with aspects pertinent to the standard of living, was researched four times. The acceptance factors awareness of renewable energy and agricultural sector are mentioned three times each. The distance of geothermal power plants from residential areas is mentioned twice.

In the category of technology, the maturity of technology is addressed 11 times and the grid infrastructure improvement seven times. Two papers refer to energy production and visibility of geothermal projects as acceptance factors. The size of the project and the way of construction is discussed one time each.

Governance acceptance factors are plans in politics, which is discussed eight times, political regulations with three mentions, the regional or national share of renewables in the power sector with two mentions, and national and political financial support schemes with one mention.

Literature observations

In recent years, the social acceptance of geothermal technology has gained increasing attention internationally. Figure 8 depicts an overall increase of research on social acceptance regarding geothermal technology within the time period 2011 to 2021. In 2015, the first peak of publications might be connected with the United Nations Climate Change Conference in Paris. The topic of renewable energy, including geothermal energy, was also addressed at that conference and the Global Geothermal Alliance was founded during the event. Furthermore, the capacity of geothermal energy was steadily growing over the last 10 years [72]. The peak number of publications is shown in 2019, when the largest number of acceptance factors were investigated, followed by a sharp drop in 2020. One reason for this drop of publications is likely the Covid-19 pandemic, which led to a longer manuscript processing time and, therefore, delayed publication. It is also shown that, except for 2011 and 2014, the category of project organization and process is the most prominent acceptance category. The categories of community and environmental characteristics follow as the second and third most researched acceptance categories. Technological characteristics also tend to play a growing role in research. Governance, in contrast, plays a subordinate role with only a few papers focusing on this category.

The number of methods applied in each acceptance category is shown in Fig. 9. The questionnaire method is clearly dominant across all five acceptance categories. It is followed by interviews and focus groups. Except for the acceptance category of governance, which is not using focus groups as a method, all categories are represented in all methods. It can be concluded that there is currently

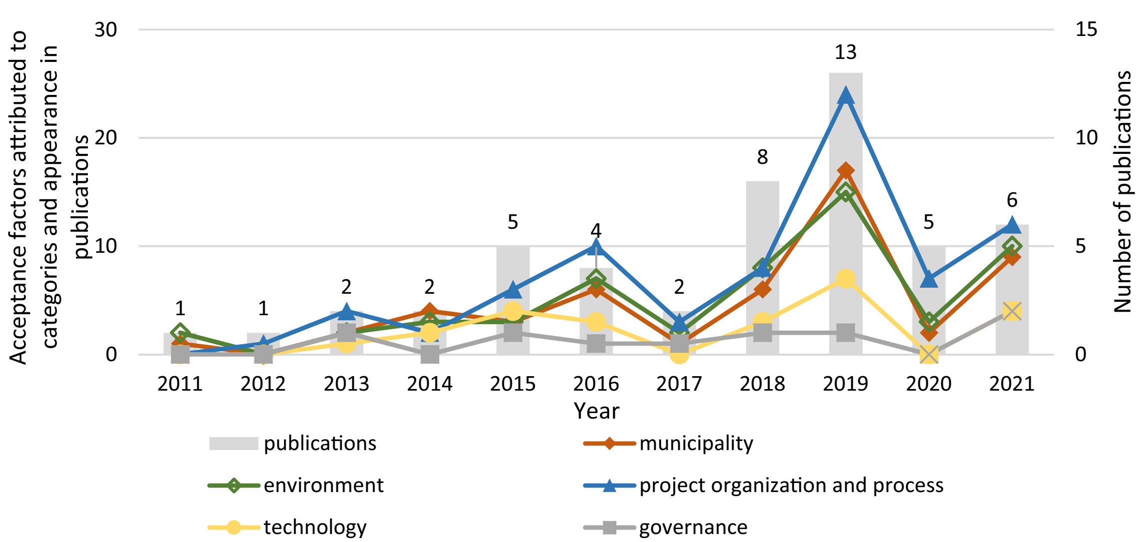

Fig. 8 Number of mentions of acceptance factors attributed to categories and number of publications from 2011 to 2021

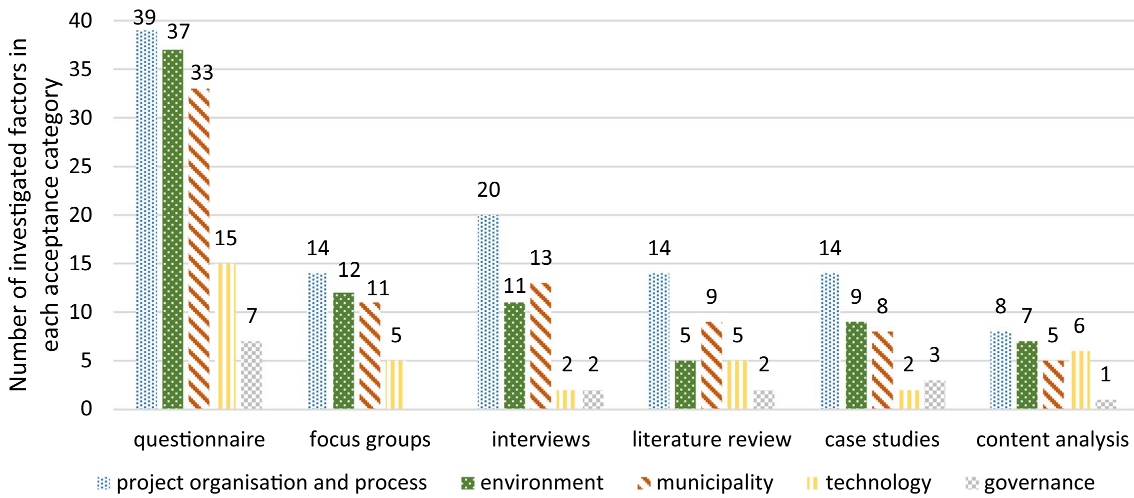

Fig. 9 Used methods with the number of investigated factors in each acceptance category

no single tailored method to fully characterize a specific acceptance category. Chiefly, questionnaires seem to be the preferred method when it comes to obtaining quantitative data. Interviews and focus groups are more appropriate when acquiring qualitative data. In 18 publications, a combination of two or more of the different methods was used [8, 16, 24–39]. The combination of qualitative and quantitative methods helps reveal the most crucial criteria of social acceptance in the context of geothermal projects, within a holistic approach.

The results show that there are various methods and aspects that together form a complex system when researching social acceptance as a whole (Table 1). The following discussion puts the acceptance factors into context with the scientific methods and provides suggestions for prioritization of the acceptance categories and factors.

Discussion of the studies

Limitations

During our research, we recognized certain limitations of the present study. First, we would like to emphasize that our literature review shows the state of research from 2011 to 2021. Because of this, our research is a view back in time and the results do not include the most recent and current developments as of 2022 and 2023. The cause of this limitation is especially the continuous change of parameters either from the technical perspective or the sociological perspective. Society and social structures are continuously developing and, therefore, new perspectives of acceptance keep emerging. Furthermore, geothermal technology develops constantly which may lead to different and new technological aspects. The dynamics within and between those two perspectives, moreover, cannot be fully characterized and depicted within the scope of this literature review. Another limitation is that the selected papers only cover specific geographic regions on Earth. Therefore, generic statements for an entire country or geothermal technology cannot be made.

Many of the papers analyzed do not specifically distinguish between shallow and deep geothermal projects.

Central acceptance factors

As Fig. 7 shows, there are numerous acceptance factors addressed by the 50 papers in this literature review. For the sake of simplicity and to keep the focus, we will analyze acceptance factors with a share of more than one percent of the quantity of all identified acceptance factors in the following (i.e., less prominent acceptance factors will not be discussed in detail).

Within the most researched acceptance category, project organization and process, the factor of *trust in key actors* is dominant. There appears to be a lack of trust in decision-makers [10, 33, 46, 64], the government [8, 16, 48], and companies [18, 44], which overall seem to affect the social acceptance of geothermal projects. One consequence is the lack of belief in information provided by some of the stakeholders [33]. Honesty is a central aspect, which can strengthen or weaken the trust in stakeholders [47]. Recently founded companies, unknown ones, and companies that are not based locally are often times associated with a deficit of experience, which in turn affects trust within the local community [44]. Zaunbrecher et al. considered confidence in stakeholders and common values with the actors of the geothermal project as essential factors for social acceptance [64]. To increase or rebuilt trust in stakeholders, regular citizen involvement in the projects can be used as a supportive measure [33, 66, 68].

Table 1 Overview of studies considered in this literature review

Author	Year	Title	Country	Type of method	Type of energy produced (e = electricity; h = heat; N/A = no information available)	Type of geothermal technology (dg = deep geothermal technology; gg = geothermal technology in general; o = other)	Social acceptance categories				
							Project organization and process	Environment	Municipality	Technology	Governance
Allansdottir et al	2019	[65]	General	Literature review	N/A	dg	2				
Baek et al	2021	[67]	South Korea	Content analysis Questionnaire	e	dg	1		1		
Balzan-Alzate et al	2021	[40]	Canada Colombia Chile Belgium France	Questionnaire	e	dg	3	4			
Blumer et al	2018	[41]	Switzerland	Questionnaire	e	dg			1	1	1
Bronfman et al	2012	[42]	Chile	Questionnaire	e	gg	1				
Carr-Cornish et al	2014	[25]	Australia	Focus groups Questionnaire	h, e	gg	1	3	3	1	
Çetiner et al	2016	[43]	Turkey	Questionnaire	h, e	gg	1	2	3	1	
Chavot et al	2018	[26]	France	Interviews Case studies Content analysis	h, e	dg		2		1	
Chavot et al	2019	[44]	France	Literature review	h, e	gg	1	4	1	3	
Contini et al	2019	[45]	General	Literature review	N/A	gg	3		1		
Cousse et al	2021	[27]	Switzerland	Questionnaire Questionnaire	h, e	gg	1	3		2	
Cuppen et al	2020	[46]	Switzerland	Case studies	h, e	dg	1	3			
Dowd et al	2011	[16]	Australia	Questionnaire Focus groups	N/A	gg		2	1		
Ejderyan et al	2019	[24]	Switzerland	Case studies	h, e	dg	1				
González Acevedo et al	2021	[39]	Mexico	Case studies Interviews Questionnaire	e	gg	2	2	3		
Hall et al	2015	[47]	Australia	Interviews	N/A	dg	2				
Hariyadi et al	2019	[48]	Indonesia	Questionnaire	N/A	gg	3		2		1

Table 1 (continued)

Author	Year	Title	Country	Type of method	Type of energy produced (e = electricity; h = heat; N/A = no information available)	Type of geothermal technology (dg = deep geothermal technology; gg = geothermal technology in general; o = other)	Social acceptance categories				
							Project organization and process	Environment	Municipality	Technology	Governance
Higgins et al	2017	[28]	USA	Questionnaire	e	o	2	1	1		
				Focus groups							
				Interviews							
Hosseini et al	2018	[29]	Iran	Questionnaire	N/A	gg			1		1
				Literature review							
Hymans et al	2021	[49]	Japan	Case studies	N/A	gg	1		1		1
Hymans	2021	[50]	Japan	Case studies	e	gg	2				2
Ibrohim et al	2019	[8]	Indonesia	Case studies	e	gg	3	2	3	1	
				Interviews							
Jung et al	2016	[51]	Finland	Questionnaire	h	o					1
Karytsas et al	2019	[10]	Greece	Literature review	e	dg	1	1	2	1	
Kluge et al	2016	[30]	General	Interviews	N/A	dg	4	2	2		
				Questionnaire							
				Conjoint analysis							
Knoblauch et al	2018	[52]	General	Online experiment	N/A	dg		1			
Knoblauch et al	2019	[31]	Switzerland	Questionnaire	h, e	dg		1	1		
			Germany	Questionnaire							
Kubota et al	2013	[53]	Japan	Interviews	e	dg	2	1	1		2
Kunze et al	2017	[17]	Germany	Online review	N/A	dg	1	1			1
Malo et al	2019	[54]	Canada	Questionnaire	h, e	dg	4	5	2	2	
Mosly et al	2018	[55]	Saudi Arabia	Questionnaire	h, e	gg		1			
Oluoch et al	2020	[32]	Kenya	Questionnaire	e	dg	1		1		
Pellizzone et al	2015	[68]	Italy	Questionnaire	h, e	gg			1	1	
				Focus groups							
Pellizzone et al	2016	[33]	Italy	Questionnaire	h, e	gg	5	3	1	2	
				Focus groups							
Qorizki et al	2021	[34]	Indonesia	Questionnaire	h, e	gg	2	1	4	2	1
				Questionnaire							

Table 1 (continued)

Author	Year	Title	Country	Type of method	Type of energy produced (e = electricity; h = heat; N/A = no information available)	Type of geothermal technology (dg = deep geothermal technology; gg = geothermal technology in general; o = other)	Social acceptance categories				
							Project organization and process	Environment	Municipality	Technology	Governance
Radzi et al	2014	[56]	General	Literature review	N/A	gg	1		1	1	
Ratio et al	2020	[35]	Philippines	Case studies Questionnaire Focus groups	N/A	gg	3				
Ratio et al	2019	[66]	Philippines	Literature review	e	gg	3		2		
Romanach et al	2015	[57]	Australia	Content analysis	e	gg	1	3	2	2	
Rosso-Cerón et al	2015	[58]	Colombia	Questionnaire	N/A	dg	1				1
Ruef et al	2020	[36]	Switzerland	Focus groups Observation	N/A	gg	1				
Stauffacher et al	2015	[59]	Switzerland	Content analysis	h, e	dg	2			1	1
Trevisan et al	2013	[37]	Germany	Content analysis Content analysis	N/A	dg	2	1	1	1	
van der Zwaan et al	2019	[60]	Kenya	Questionnaire	N/A	gg		1	1		
Vargas-Payera	2018	[18]	Chile	Interviews	h, e	gg	4	1	2		
Vargas-Payera et al	2020	[38]	Chile	Interviews Focus groups Case studies	N/A	dg	1		1		
Wahyudi et al	2019	[61]	Indonesia	Questionnaire	N/A	gg		1	1		
Yasukawa	2019	[62]	Japan	Literature review	h, e	gg	3		1		1
Yasukawa et al	2018	[63]	Japan	Questionnaire	N/A	gg	1	3			
Zaunbrecher et al	2018	[64]	Germany	Exploratory study	h	dg	3		2	1	

Relationships and personal experiences can also boost the trust among stakeholders [49].

The characteristics of the acceptance factor *information about the project* are openness and transparency [35, 47, 62], information asymmetry [45], and the amount and type of information distribution [18, 24, 28, 54]. For the flow of information, time is an important aspect. Information about the project should be delivered to the stakeholders as soon as possible [24, 28]. A communication strategy is also recommended to avoid or minimize suspicion about the project due to poor communication of the project development [35, 38]. According to Kluge et al. local newspapers, direct mail, and websites are the preferred information channels [30].

Environmental impact addresses the social acceptance from an ecological perspective. This acceptance factor summarizes a number of environmental aspects. Seismicity and groundwater pollution are excluded and addressed in separate acceptance factors due to their prominence (i.e., numerous mentions) in the literature. The acceptance factor of environmental impact deals with specific risks, e.g., environmental pollution [10, 34, 44], soil contamination [33, 54], or the irreversibility of environmental damage [40, 53]. Furthermore, uncertainty about the effects of geothermal projects on the environment [18, 37] and positive associations with this type of energy generation [27, 28, 43, 55, 61] are included in this factor. Although fracking was also mentioned and fits within this factor, it does not seem to play a central role [46].

Seismicity is a geothermal-specific acceptance factor. Studies found that induced seismicity is an essential point of concern for citizens regarding geothermal projects [16, 17, 25, 26, 30, 31, 33, 40, 43, 52, 54, 63]. According to several studies, the general notion within communities is that seismicity seriously affects both the community and the environment [16, 17, 44]. In a study by Cousse et al. seismic risk is seen by the participants as a critical risk in the light of geothermal project planning, an effect that can be reduced with more detailed information about the controllability of those risks [27]. Cuppen et al. described a "spill over" effect of induced seismicity from other technologies, such as shale gas exploitation, which can decrease the social acceptance of geothermal energy significantly [46]. According to Knoblauch et al., there is "a statement of uncertainty and limited expert confidence" regarding the seismic potential in geothermal technology that also reduces social acceptance [52]. However, information about geothermal technology and on how to control potential seismic activity can mitigate the negative impact on social acceptance [16, 27, 44]. Another approach to reduce the risk of seismicity is to focus on geologically stable regions [17] (e.g., cratons). The study of Romanach et al. shows that the risk of seismicity is not the central point of concern in Australian media [57].

This leads to the acceptance factor *general knowledge about geothermal energy*, which also influences social acceptance. Overall, the general knowledge about geothermal energy and technology appears to be low [16, 18, 28, 29, 45, 54, 64, 68]. That lack of knowledge often creates reservations about, or even the rejection of, geothermal projects [8, 18, 25, 30, 61, 68]. In some of the investigated groups there was very little knowledge about whether geothermal energy and technologies could have a positive or negative impact on the environment [43]. Contini et al., therefore, recommend to increase the social acceptance of geothermal projects by deepening that knowledge [44], which tends to improve the social acceptance along the way [28]. An important goal is to raise awareness and to avoid a lack of information and knowledge before and during geothermal projects [16, 29]. The transfer of knowledge can be achieved, for example, by workshops that bring together citizens and scientific specialists, or by topic-related meetings and conferences [16, 29].

The *distribution of benefits and costs between actors within the community* addresses the cost–benefit ratio and allocation of costs and benefits to the different stakeholders. Allansdottir et al. point out that the perception of risks has a bigger impact on social acceptance than benefits [65]. In several countries such as Canada, Colombia, Belgium, and France this aspect seems to be highly relevant for the acceptance of geothermal projects [40]. Both the financial and the legal dimension play an important role in the cost–benefit ratio in the communities [17, 18]. For instance, an earthquake insurance for local citizens can, to some extent, alleviate their uncertainty [17]. Furthermore, the local stakeholders and especially the local communities can be won over with financial benefits, as in the promulgation of the Department of Energy Act in the Philippines 1992 [66]. The potential of geothermal energy as a personal cost reducer is perceived as a positive aspect [37]. Another aspect of this acceptance factor is the high upfront expenditure seen as a major investment risk [50, 53, 56, 64]. One suggested solution is an amendment of the national policy framework to balance out the different energy forms and, at the same time, lower the risks for the implementation of geothermal projects [50]. A boost for regional economic development and national and social welfare provided by geothermal energy is generally seen as a positive effect [34].

Another important environmental acceptance factor is *groundwater pollution*. The main concern is the contamination of groundwater when geothermal technology is installed and used, this concern is seen by study participants across different countries [25, 26, 44, 54]. The concern is mainly rooted in the possibility of water contamination during the drilling process [8, 27, 57, 63]. Another reason can be a technology spill-over, perhaps as a consequence of bad experience with other subsurface technologies in the past [46]. The negative aspect of groundwater pollution is predominantly relevant to agriculture, which can be seriously hampered by soil and subsurface contamination [8]. However, there were also responses that see no negative effects [25]. An environmental management program can help prevent environmental damage and demonstrate ecologic responsibility [8]. Again, a possible reason for the wide concerns is the lack of knowledge about geothermal energy and technology [54].

The social acceptance factor labeled *opportunities for participation and consultation in planning and permitting process* describes the possibility of involving local citizens in a geothermal project. The opportunity to be involved in decisions and to be an equal participant within a project is of high interest and relevance to the local communities [30, 62]. Carr-Cornish et al. found that many citizens think they are not involved deeply enough in Australian geothermal projects while Vargas-Payera indicated that local communities in Chile were not sufficiently included in decision-making processes [18, 25]. It is shown that active and frequent involvement of citizens in geothermal projects increases the social acceptance of those projects [33, 35, 45, 54, 66]. Therefore, public consultation and community empowerment during the geothermal project is recommended [8, 54] and, according to Pellizzone et al., public participation should be increased [33]. Yasukawa suggests a council of local stakeholders as a forum to discuss and share relevant information [62]. Practical implementation of participation can, e.g., be a telephone hotline for the public, open house days, tours of operating geothermal facilities, roundtable discussions with project managers, or other information events [30].

The next acceptance factor focuses on the perception of the *maturity of the geothermal technology*. According to a survey carried out in France, geothermal technology and the companies working in this field are deemed rather immature [44]. Blumer et al. suggested the personal opinion about geothermal energy and technology strongly depends on personal experiences and familiarity with the topic [41]. According to Cousse et al., the notion of an immature state of geothermal technology also seems to be linked to a certain fear of triggered seismicity. In that study, the concerns seem to be more pronounced in the context of deep geothermal projects rather than shallow geothermal projects and can be reduced with increasing information about the geothermal technology. Furthermore, information and knowledge about controlling seismic risk leads to a more positive view on the maturity of geothermal technology [27]. In a study carried out in Canada, operational safety for employees and nearby communities are identified as a necessary condition to support geothermal projects [54]. Although a history of geothermal-related technical failures in Indonesia weakens the social acceptance [8], Qorizki et al. show in their study a positive attitude towards technological development [34]. In the study of Pellizzone et al., the distrust in geothermal projects is about as high as the distrust in stakeholders [68]. In Germany, geothermal technology is widely perceived as relatively prone to failure compared to other technologies [37]. However, concerns about technology uncertainty are also prominent in Australian media, where they are among the top two points of concern [57]. In Switzerland, the maturity of the geothermal technology is one of the four most critical topics discussed in the media [59].

The economic dimension is expressed by the acceptance factor *local profits and income*. Local profits can be realized through cost savings for energy and an increase of the economic efficiency that benefits the communities [27, 37, 63]. In two studies the communities see geothermal as a potential threat to their local industry, such as farming or fishing, mainly because of the perceived risk of water pollution or shortage [8, 48]. Ibrohim et al. described the fears of the local people in Indonesia, according to whom employment within geothermal projects may only last until the infrastructure has been built and they have been replaced by professional workers [8]. In contrast, studies in Canada and Australia suggest the local communities see geothermal projects as a good opportunity to create jobs [54, 57]. Overall, financial benefits to the local communities tend to support social acceptance [66]. Pellizzone et al. note, however, that geothermal projects and infrastructure in Italy may give way to financial speculation, in turn compromising social acceptance [33]. In summary, geothermal energy and technology are mostly associated with a positive impact regarding local benefits, profit, and income.

The acceptance factor of *health and well-being* deals with aspects that directly affect the local community. Aspects supporting acceptance are, e.g., the linkage of geothermal plants with water treatment and new ways to access hot water supplies [43]. A disadvantage associated with this acceptance factor is the fear of adverse effects on citizens' health [10]. Furthermore, the fear of noise and air pollution with smelly emissions tends to lower the acceptance [33, 34, 54, 57, 66].

Grid infrastructure deals with energy security [25, 56, 57] and possible effects [33, 43, 44] on the grid infrastructure due to geothermal projects. It can affect local businesses and their energy supply [44]. There is a wide notion that the usage of geothermal energy within in the power infrastructure can cause some degree of independence as the energy is commonly produced in close proximity [27]. The anticipated potential of a geothermal project within the local grid can lead to a positive change of social acceptance within the community [44].

In the governance acceptance category, the acceptance factor *plans in politics* is the most discussed one. Political conditions in a region [49, 50, 59] and political influence on geothermal projects [34, 53, 58, 62] both affect social acceptance. Political strategies can either support or weaken the framework and conditions for successful geothermal projects [53, 58].

Social-cultural values influence social acceptance in different ways. The implementation of a new geothermal project always means some level of change. Hence, conservative values and the suspicion of innovation can affect social acceptance in a subjective way [30, 53]. Religious aspects rooted in the local culture and tradition can also affect the acceptance of geothermal projects [8, 18, 34]. A study in Indonesia at Mount Lawu highlighted that social acceptance and community support was very low because a geothermal project had been planned at a sacred site [8].

The social acceptance factor *economic burdens and benefits* focuses on monetary aspects. The costs and yield for energy are one issue [44, 60], particularly when there is the concern of low amounts of produced electricity [44]. Moreover, the expectation of lower prices compared to fossil energy can affect the acceptance of geothermal projects [60], as do energy costs and affordability on an individual scale [37]. However, economic prospect, e.g., the potential impact of geothermal energy and technology on employment [34, 62], is also a relevant aspect of this acceptance factor.

Another social acceptance factor in the category of municipality are the *socio-psychological characteristics*. This acceptance factor focuses on individual experiences with geothermal energy and technology, although there is also some overlap with other acceptance factors (e.g., of socio-cultural nature). Negative experiences, such as earthquakes or accidents at geothermal sites, individually affect social acceptance [10, 41, 67]. Conversely, negative experiences with other energy projects can also support the social acceptance of the geothermal approach [64].

Water use is a key aspect of the acceptance factor *use of resources* [16, 40, 54, 60]. Resource considerations within the society have been researched during a number of surveys in different countries including Canada, Colombia, Belgium, Australia, and Kenya [16, 40, 54, 60]. In Kenya, land use turned out to be an additional important aspect regarding the social acceptance of geothermal projects [60].

Quality of life is another acceptance factor in the category of municipality. It includes the aspect of benefits for future generations, which can work in favor of a running geothermal project [25]. Another example for this acceptance factor is the availability and usage of energy through geothermal activities and the connected improvement of the standard of living [39], in addition to the monetary or job prospect (compare acceptance factor economic burdens and benefits). In a study focusing on indigenous communities in the Philippines, the dislocation of rural settlements is an additional relevant aspect [66].

The outline of the 18 most researched acceptance factors shows that 13 of these factors occur within the "project specific" overarching category. Because of this, we suggest these factors can characterize most aspects of social acceptance on a project-focused level. The acceptance category of project organization and process and the category environment are two categories studied in great detail. Hence, these two categories are of particular importance when it comes to research into the social acceptance of geothermal energy and technology.

As the result of several studies in this literature review, the most researched aspect for generating and utilizing social acceptance is trust in key actors, as is the case in other energy projects [73–76]. The same holds true for the social acceptance factors of information about the project, distribution of benefits and costs, and opportunities to participate and consult in planning and permitting processes [74–76].

In contrast to these analogies there are also differences, which demonstrate the special role of geothermal projects with respect to social acceptance. Some of these aspects depend more on the technology. Whereas locality and distance can be important factors at wind farms or biogas sites [75–77], the actual location of geothermal energy plants only seems to play a minor role in the researched papers. A number of social acceptance factors are unrelated to other renewable energy technologies, such as seismicity, groundwater pollution, and the knowledge about geothermal energy (compare Fig. 9). These aspects also show the social complexity, particularity, and unique selling point of geothermal projects.

In addition to the aforementioned aspects, there are subtle but fundamental conditions that cannot be negotiated easily. In some regions, religious and cultural reservations are historically rooted in society and have to be taken into account carefully when planning a geothermal infrastructure. Otherwise, these aspects can impact the support within the local community negatively and could even bring developing projects to complete halt. Showing awareness about the specific cultural or religious facets and considering the local concerns in the project planning can prevent protests and counteract poor of acceptance [8, 50, 56]. Furthermore, larger-scale international changes can heavily affect social acceptance, such as the geopolitical developments with the conflict between Russia and Ukraine in early 2022. The latter apparently caused a boost of geothermal energy and energy independence in many European countries [78]. Although sometimes hard to predict, the impact of such global-scale events should be kept in mind when researching into the social acceptance of geothermal energy and other energy sources and technologies.

Conclusions

Due to an increasing focus on the acceptance of the geothermal technology in the scientific community and literature during the past decade, we carried out an up-to-date literature review. In doing so, we considered a large number of publications that contain numerous different aspects of the social acceptance of geothermal energy and technology all over the world.

The different aspects of social acceptance of geothermal technology collated and categorized from the literature are clustered in five categories. Figure 5 gives a schematic overview of the context of these categories, which essentially build upon the previous work by Wüstenhagen et al., Upham et al., Linnerud et al., and Leiren et al. [12–15]. Important acceptance factors such as trust, information, participation, and distribution of benefits and costs are combined within the category 'project organization and process'. The category 'environment' includes several acceptance factors, however, seismicity and groundwater pollution turned out to represent two key factors in the papers studied. The general knowledge about geothermal energy and the factors of health and well-being are in the spotlight of the category 'municipality'. In the category 'technology', the main social acceptance factors are the maturity level of the technology and the improvement of grid infrastructure. Somewhat surprisingly, the category 'governance' only seems to play a subordinate role and, thus, provides an open field for future endeavor of political decision-makers worldwide. This overview of the most critical social acceptance categories and factors can provide a baseline and orientation tool for local, regional, and national governments, local communities, and the geothermal industry when facing questions and developing strategies in accordance with social acceptance.

There is a large variety of aspects that affect community acceptance in different ways, and the matter is too complex to establish a simplistic, one-fits-it-all scheme of prioritization of acceptance factors in the worldwide context; each geothermal project and site has its own specific requirements depending on various factors. Therefore, we see much potential for further research with different foci. However, as an outlook from the results of this literature review, two promising methods are identified, based on which further work on acceptance factors of geothermal technology can be carried out. First, we recommend investigating the social acceptance qualitatively focusing on one specific, widely relevant acceptance factor (e.g., knowledge about geothermal technology or environmental impacts) in order to identify any potential information deficit or fundamental lack of knowledge in the regional or local population. Second, a more quantitative approach can include a much larger number of possible acceptance factors through extensive targeted surveys in a specific region to establish a detailed profile of geothermal technology acceptance for that particular region. A combination of such studies from different regions of a continent or even worldwide, in consecutive steps, will provide a meaningful overview and help identify, understand, and address relevant social acceptance factors within the population.

An additional promising tool for future analyses of acceptance factors regarding geothermal technology is a survey of acceptance factors targeting different social groups (e.g., people with variable levels of education or income). The studies analyzed in the present literature review mostly focused on students, managers, and scientists, but only contained little representative results from other groups of the society. As a further result of our literature review, different groups of stakeholders (e.g., citizens, the local administration, industry), by their nature, tend to prioritize different acceptance factors and, therefore, need to be approached in a different, customized way tailored to their interests. To achieve an improved understanding of social acceptance within the greater community, new concepts of communication and participation should be developed, tested, and verified.

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Author contributions

RR designed the literature review, prepared the results and figures, and led the paper preparation. EB, MS, and MD co-designed the paper. RR, EB, MS, MD, MK, and MP interpreted the results and approved the final manuscript.

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Declarations

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