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Social Aspects of Deep Geothermal Drilling in the ORCHYD Project

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ABSTRACT

The ORCHYD (Novel Drilling Technology Combining Hydro-Jet and Percussion For ROP Improvement in Deep Geothermal Drilling) is an ongoing Horizon 2020 project that endeavors to increase the drilling rate of penetration (ROP) of deep hard rocks from 1 to 2 meters per hour (m/h) to 4 to 10 m/h by combining two previously distinct, mature technologies: High Pressure Water Jetting (HPWJ) and Percussive Drilling. As a follow-up to recent work on the environmental impacts of deep geothermal drilling, this study addresses public understanding, public acceptance, and attitudes towards geothermal drilling. Despite the general acceptance of renewable energy, experience from some cases has demonstrated that public opposition, especially in the case of geothermal energy, can result in project termination. The purpose of this research is to explore the potential impact of an innovative drilling technique on the attitudes towards geothermal energy, with a focus on promoting social acceptance and facilitating the adoption of geothermal resources in countries heavily dependent on imported energy.The term acceptance refers to both sociopolitical and community acceptance. Examining the public awareness of a developing technology, such as deep geothermal drilling, is one method for determining the level of societal acceptance and minimizing the risk of opposition. Prior surveys have revealed that attitudes toward geothermal development frequently shift as the project progresses to the drilling stage and construction of the plant begins. Two major causes identified in the literature, which can negatively affect the public perception of geothermal energy, are induced seismicity and odors. Geothermal development and operation may have additional unfavorable environmental effects, which are also investigated in terms of social acceptance. These include negative impacts on ecosystems, human health, and the economy. To explore public acceptance towards deep geothermal drilling, an online questionnaire based on the findings of our previous research on the environmental impacts of deep geothermal drilling in the ORCHYD project has been designed. The questionnaire includes multiple-choice items for demographic information, and Likert-scaled ratings for NIMBY (not in my back yard) attitudes towards the technological, environmental, material, energy, socioeconomic, cultural, institutional and (geo)political aspects and impacts of geothermal energy and deep geothermal drilling. The survey is conducted among a diverse group of people in the five countries with partners that participate in the project: four European countries, France, the United Kingdom, Norway, and Greece and one Asian country, China. Some of the respondents are likely to have a background in engineering and/or geoscience subjects, or at the very least be familiar with those fields, which helped in a better comprehension of the survey. Multivariate statistical techniques such as Principal Component Analysis, Cluster Analysis, and multiple regression are used for the analysis of responses, with the aim of discovering similar societal attitude groups. The analysis endeavors to establish social perceptions resulting in environmental/geothermal energy societal tribes, and how they perceive the ORCHYD project and geothermal energy in general. Lastly, this research addresses a literature gap, by conducting one of the few surveys of the public acceptance of (deep) geothermal drilling.

1. INTRODUCTION

Several social science studies have shed light on why consumers reasonably oppose the widespread adoption of more efficient technology. This is due to various factors, including ambiguity in terminology, skepticism of corporate or government claims, and default purchase patterns. Integrating social science into energy research necessitates a concerted effort to implement three recommendations: collect social science data, focus energy research on challenges, and encourage a diverse range of viewpoints (Sovacool et al., 2015). Society is a significant consideration because of the relationship between technology and governance (Syivarulli, 2020). Changes in one of the three can affect the others. The interaction of both worlds profoundly impacts the rate of change and society's acceptance of new technologies (Dowd et al., 2011). The role of social acceptance is sometimes underestimated in debates about technology transfer and renewable energy adoption (Mallett, 2007).

Because of improvements in new technology and a desire for energy security, communities might shift from traditional to renewable resources such as geothermal energy. Participation and community involvement have evolved into technology evaluation research. They developed two viewpoints on the community due to their participation: acceptance and rejection (Syivarulli, 2020).

The development of conceptual frameworks and basic methodological standards for public engagement in the energy transition is still progressing. According to Im et al. (2021) and Poortinga, Aoyagi, and Pidgeon (2013), developing trust with local people is becoming an unavoidable goal for renewable energy transitions. The public's role in energy transition concerns is linked to the public's ability to accelerate or block the development of new energy technology (Demski et al., 2015). Incorporating the values of the public expands the authority's information base for energy transition decisions (Butler et al., 2015). Chavot et al. (2018) investigated how local governance may conflict with the state framework in the sphere of energy transition in their study. According to the findings, upstream information exchange and public participation are necessary for project social acceptance.

In recent years, public engagement and citizen participation have gained new traction in the mainstream political debate worldwide (Allansdottir, Pellizzone & Sciullo, 2019a). Due to social opposition, many technical projects, including carbon dioxide (CO_2) sequestration and geothermal energy production, have been postponed or canceled. Notable cases include opposition of local communities in the Greek Island of Milos during the late 1980s, and more recently in Central Oregon and Switzerland where the local government bodies Kantone stopped many geothermal projects after the 2006 Basel accident, as Kunze and Hertel (2017) note.

As a result, before implementing a given geothermal project, it is necessary to evaluate the status of social acceptance. The main problem with implementing renewable energy technology is that decisions on investment and location selection affect many other stakeholders rather than just one customer or investor. Consequently, the decision must be accepted by several stakeholders in addition to the investor (Wüstenhagen, Wolsink, & Bürer, 2007).

2. SIGNIFICANCE OF PUBLIC ACCEPTANCE OF RENEWABLE ENERGY TECHNOLOGIES

According to Pellizzone et al. (2017), geothermal technologies and their impact on society are particularly interesting because they address many issues. These issues include environmental (i.e., water usage, drilling and exploitation risk, gas emissions), socioeconomic-political (i.e., procedural and distributive justice, public engagement in science, carbon lock-in debate, costs), and innovation-related (smart grids, prosumer role, new geothermal technologies). The perception of technology and its risks is critical in determining whether or not it is accepted by society (Dowd et al., 2011; Manzella et al., 2018). Since the 1970s, new technologies have enabled capturing geothermal energy even at depths of a few thousand meters. Hot Dry rock geothermal operations were the first efforts towards geothermal development through hydraulic fracturing, as Meller et al., 2018 explain.

When utility-scale wind farms were built in many countries of the Global North in the 1980s, including the United States, Denmark, and Germany, it stimulated the research on the social aspects of renewable energy technologies (RET), which began to emerge with a broader worldwide scope and within a specific socio-geographical area, the Global North (Batel, 2020). During this time, studies focused on issues such as a lack of support among key stakeholders, policymakers' reluctance to devote themselves to consistent and effective policies, and a lack of understanding of the roots of public attitudes toward wind power schemes, particularly the underestimation of the critical importance of landscape issues in wind power scheme attitudes. As the public became more aware of environmental devastation, policymakers began to incorporate environmental considerations into models (Ribeiro, Ferreira, & Arajo, 2011). Concerns were also expressed about renewables' social foundations regarding the installations’ magnitude, as well as the possibilities for installation ownership and decentralized power supply (McDaniel, 1983; Wolsink, 1987). Nonetheless, due to widespread popular support for renewable energy technology in the 1990s, the issue of societal acceptance was largely ignored.

Public acceptance is generally defined as a positive attitude toward technology or a measure that leads to supporting behavior when needed or desired, as well as overcoming opposition from others. From a market-oriented to a socio-political standpoint, the definition of social acceptance has altered (Vargas Payera, 2018). Social acceptance is critical in developing any energy project (Cataldi, 1999). It has been identified as one of the most severe obstacles to adopting novel technologies in the worldwide renewable energy sector (Cataldi, 1999; Wüstenhagen et al., 2007). It is often utilized in traditional energy policy thinking (von Hippel et al., 2011). According to Ramirez et al. (2017), the most significant benefits of renewable energy development are reduced greenhouse gas emissions and enhanced energy independence through local production. Oluoch et al. (2020) point out that public opinion on renewable energy sources is critical for designing future energy portfolios. In this way, public acceptance will remarkably impact the evolution of energy policy and the operation of the energy market.

2.1 Review of Geothermal Energy Social Acceptance Studies

There needs to be an agreement in the literature on what defines acceptance. As a result, the sentence might be read in various ways. Social acceptability is complex and dynamic because it is a process (Wolsink, 2018). Wüstenhagen and Bilharz (2006) define societal acceptance as the intention to adopt technology, which they quantify using the willingness to pay. All actors involved in the decision-making process are concerned with acceptability. The scenario quickly becomes problematic when these actors include not only the surrounding inhabitants and local civil society organizations but also foreign investors, large energy companies, and higher-level government officials. The social implications of the new technology's application become critical almost immediately (Wüstenhagen, Wolsink, & Bürer, 2007).

Residents' involvement may help to avert future issues. Furthermore, it can help generate ideas for new and improved products and services, enhancing the openness and transparency of scientific and technological breakthroughs, which is the cornerstone for a trusting connection among various actors (Meller et al., 2018). According to Pellizzone et al. (2015), previous involvement of locals has demonstrated that they may be proactive and give interesting ideas, such as addressing energy and environmental issues in educational programs. Communication of environmental issues and energy technologies that form public opinion, change policies, and impact our society is one instrument that allows different actors involved in project development to connect (Dowd et al., 2011).

Finding consensus among key stakeholders such as public authorities, industrial organizations, citizens, and associations, as supported by Schmidle-Bloch, Heintz, and Moullet (2019), is also required for public acceptance. Stakeholder mapping is beneficial when investigating social acceptability since it aids in identifying similar or opposing interests and relationships between them, which can sometimes add to the complexity of a scenario.

Geothermal energy projects face similar opposition to other energy-related infrastructure projects (Cousse, Trutnevyte, & Hahnel, 2021). Nevertheless, according to Hosseini et al. (2018), geothermal energy has less public acceptance than other renewable energy sources such as wind and solar. Geothermal energy is one of the least understood renewable and clean energy sources by non-expert communities, making it more susceptible to community skepticism. Because of its subsurface nature, public perception of it is frequently skewed, especially in the absence or lack of communication and awareness efforts, inconsistency with local policies, and a lack of alignment with the project’s aim (Barich et al., 2022). The social acceptance of renewable energy technology is crucial for an effective implementation. This acceptability involves both social and political acceptance. Although “social acceptance” frequently appears in policy literature, exact definitions are rarely supplied.

The process nature of social acceptance has been utilized to distinguish between the three major acceptance dimensions: sociopolitical, community, and market acceptance (Wolsink, 2018). Wüstenhagen, Wolsink, and Bürer (2007) characterized social acceptance as a combination of three different dimensions.

First, there is socio-political acceptance, which is acceptance at the broadest, most general level and is tied to technology, public perception, key stakeholders, and policymakers. Acceptance of this type is linked to broad public opinion and important stakeholder and policymaker perspectives (Toke, Breukers & Wolsing, 2008). According to Wolsink (2017), redefining market choice sets or effectively empowering citizens for renewable energy co-production is mainly an issue of socio-political acceptance.

Second, community acceptance is tied to procedural justice, distributive justice, and trust, and is related to specific site decisions. The context for NIMBY (Not In My Back Yard) debates is community acceptance (Bell, Gray & Haggett, 2007). NIMBY exemplifies the "social and cultural" concerns that must be addressed in policy agendas (von Hippel et al., 2011). As a party involved in developing geothermal energy technology, community acceptance plays a critical role in supporting stakeholders in overcoming challenges and concerns (Syivarulli, 2020).

Third, market acceptance is concerned primarily with customers, investors, and intra-firm relationships. According to Wolsink (2018), the objective of this definition was a conceptual differentiation rather than absolute separation. It was developed to enhance empirical study by comprehending and formulating research questions concerning the existence and significance of distinct paths in overlapping parts of society where acceptance processes occur.

The numerous geothermal energy projects that have been developed highlight the geothermal industry's need to find an appropriate solution to challenges caused by a lack of social acceptance. According to Karytsas et al. (2019b), popular practices for increasing social acceptance of geothermal projects include the engagement of local people, prevention and mitigation of undesirable consequences, and production of advantages for local communities. Future geothermal energy difficulties will increasingly rely on social sustainability. That means that development must be linked with the perspectives, values, and needs of society and local communities, as well as other forms of stakeholder and societal engagement exercises and practices (Allansdottir, Pellizzone & Sciullo, 2019b).

2.2 Social Acceptance Issues Related to Geothermal Energy

Geothermal energy is not widely used, according to the literature review, necessitating the resolution of social, political, and market challenges (Soltani et al., 2021). The public, industry, stakeholders, and the media are all working together to increase public acceptance, engagement, and understanding of geothermal energy. Each party is essential to developing geothermal energy (Syivarulli, 2020). Nisbet (2009) points out that the media plays a significant impact on public perceptions of emerging energy technology. According to the research, even people who are generally favorable of renewables do not support them without conditions, resulting in a disparity in approval between the general and so-called local levels (Joe et al., 2016).

The availability factor of geothermal energy is the highest among renewable energy sources reaching 80%, compared to 63% for solar PV, 38% for wind, and 30% for biomass, as Kumar et al. (2022) suggest. These comparative statistics confirm the reliability of geothermal energy. Cousse et al. (2020) and Jobin et al. (2019) argue, based on previous experience with wind and solar energy technologies, that a good understanding of the public's emotive reactions to energy technologies is critical for anticipating indicators of public concern and, thus, reducing the risk of opposition. Because of the nature of the source, fear contributes to the lack of social acceptance of geothermal energy. Benefits are only sometimes visible in the early stages of development and appear balanced by negative environmental changes.

Geothermal projects that use drilling technology to gain deeper access to the earth's crust are commonly carried out in public areas and are subject to deep underground use regulations (Ryef & Ejderjan, 2021). As the project progresses to the drilling stage and construction on the plant begins, attitudes toward geothermal development often shift. These activities may have a negative impact on ecosystems, human health, and the economy. Most research on geothermal power plant risk perception has lately increased. However, social science approaches remain limited (Im et al., 2021).

Concerns about the environment may impact public acceptance of geothermal energy. Early research has shown that public opinion can be influenced by a lack of public awareness of the technology, insufficient media coverage, and concerns about drinkable water and detectable seismicity during reservoir creation and operation (Dowd et al., 2011; Meller et al., 2018). As Benighaus and Bleicher (2019) point out, public opposition can significantly delay or even prohibit the deployment of energy projects, particularly deep geothermal energy. According to Vargas Payera (2018) and Ibrohim, Prasetyo, and Rekinagara (2019), low levels of comprehension and knowledge of the technologies and processes involved in geothermal energy exploitation are associated with low levels of social acceptance. People have no preconceptions about deep geothermal energy because it is still a relatively unknown technology (Blumer et al., 2018). Respondents' desire for deep geothermal energy decreases considerably when they are educated about the technology's potential repercussions (Volken, Xexakis, & Trutnevyte, 2018). As Meller et al. (2018) and Pelizzone et al. (2017) point out, environmental, economic, and political concerns are prevalent in public debates about deep geothermal energy.

Landscape changes and the alteration of natural features of cultural or religious significance caused by civil and industrial works, as well as changes in the use of public areas as a result of project activities, frequently elicit public outrage. As a result, an increasing number of people believe geothermal energy is expensive, polluting, and potentially hazardous to people's health. As Vargas-Payera, Martnez-Reyes, and Ejderyan (2020) describe, visual contact in the construction of drilling platforms for geothermal project development has been highlighted as a factor that causes public concern and anxiety. Furthermore, access roads through naturally preserved regions have been identified as a socially criticized aspect of geothermal drilling activities.

Acceptance concerns of geothermal energy are predominantly documented in Europe (Benighaus & Bleicher, 2019; Dowd et al., 2011; Chavot et al., 2016; Pellizone et al., 2015) and on a smaller scale in Asia, as well (Grigoli et al., 2015). Promising initiatives in the Greek islands of Milos and Nisyros were abandoned due to social opposition (Karytsas, Polyzou & Karytsas, 2019a). In the United States, the AltaRock geothermal power project north of San Francisco was similarly halted due to public opposition (Liu et al., 2018). As Stauffacher et al. (2015) describe, these issues inspired research into public perceptions of geothermal energy development.

2.2.1 Induced Seismicity

Liu et al. (2018) cite several case studies of man-made seismicity related to deep geothermal applications in their study, including the hot dry rock tests at Fenton Hill in New Mexico (Pearson, 1981; Ferrazzini et al., 1990), Geysers in California (Majer & Peterson, 2007), and Cooper Basin (Zang et al., 2014).

Near-surface usage of subsurface heat by heat pumps is widespread in Swiss private installations (Lund & Toth, 2021). According to a recent study (Ryef & Ejderjan, 2021), deep geothermal sources have never produced electricity in Switzerland by 2021. Edwards et al. (2015) and Trutnevyte and Wiemer (2017) evaluated two deep geothermal pilot projects in the Swiss cities of Basel and St. Gallen, which resulted in earthquakes, minor building damage, and USD 9 million in damage (Knoblauch, Trutnevytea & Stauffacher, 2019). These occurrences, according to Ejderyan, Ruef, and Stauffacher (2019), marked a turning point in the media's debate on geothermal energy in terms of danger in Switzerland and posed additional challenges in terms of public and political acceptance of an ongoing Swiss deep geothermal project in Haute-Sorne, Jura (Cousse, Trutnevyte & Hahnel (2021). Kunze and Hertel (2017) revealed that the majority significantly impact people's perceptions of geothermal power plants from positive to negative.

The Basel deep geothermal project was canceled due to public concern caused by induced seismicity associated with reservoir stimulation (Majer et al., 2007). Cousse, Trutnevyte, and Hahnel's (2021) studies indicate that knowledge, even if supplied negatively (e.g., the costs and injuries connected with seismic risk), may positively influence people's attitudes about geothermal energy (i.e., pre-information). Furthermore, their research shows that negatively portraying seismic risk in the media or through oppositional party-led movements negatively impacts public perceptions of the technology. This may result in a spillover of seismic risk perception from risky deep geothermal projects to less risky shallow geothermal projects. Although these accidents impacted geothermal expansion in Switzerland, they did not lead to the technology's demise (Ryef & Ejderjan, 2021). According to Knoblauch, Trutnevytea, and Stauffacher (2019), public protest and opposition might lead to the abandonment of deep geothermal energy projects. In Germany, induced seismic occurrences associated with the Landau (Mw = 2.7) deep geothermal energy project triggered widespread outrage and the formation of citizen initiatives (Kunze & Hertel, 2017; Breede et al., 2013; Knoblauch, Trutnevytea & Stauffacher, 2019).

Im et al. (2021) used social representation theory and a mixed-method approach combining qualitative and quantitative research to analyze how residents of Pohang, Korea, perceive geothermal plants following the 2017 Pohang earthquake (Mw = 5.5) (Ellsworth et al., 2019). The review investigated whether the geothermal power plant system, which was previously unknown to the public but has subsequently earned universal acceptability, has become a source of public anxiety as a result of the unanticipated occurrence of the 2017 earthquake. According to the study results, regardless of safety, climate change mitigation, or economic concerns, Pohang residents expressed a significantly negative view toward geothermal plants. The findings statistically confirm that Pohang residents associate geothermal power plants with nuclear power plant risk discussion. In a previous study, Zaunbrecher, Kluge, and Ziefle (2018) projected that public attitudes regarding geothermal and nuclear power would be comparable.

Despite an optimistic national atmosphere for renewable energy, local attitudes are typically significantly less favorable (Baek, Chung, & Yun, 2021). Following the Pohang earthquake in 2017, the previously positive media framing based on environment and technology shifted dramatically to a negative framing based on risk, according to the study. This is because the Enhanced Geothermal System (EGS), which has enabled the use of geothermal resources in deeper geological layers (Spada, Sutra, & Burgherr, 2021), may have triggered the earthquake despite not being the primary cause.

3. METHODOLOGY

The objective of the empirical survey was to determine social attitudes toward geothermal energy drilling and how the project's technological improvements could serve social needs. The final 100 responses to the survey responses were analyzed to identify social perceptions that result in environmental/geothermal energy societal “tribes” and how they perceive the ORCHYD project. The concept of energy tribes identifies different groups in the public which are categorized according to their distinct perceptions of uncertainties surrounding energy supply and demand. This approach gives rise to three distinct Energy Tribes, each characterized by their contradictory scenarios: "Business as Usual," "Middle of the Road," and "Radical Change Now." These scenarios establish diverse parameters for what is considered credible or incredible, possible or impossible, sensible or foolish, rational or irrational, as explained by Thompson (1984).

The survey was composed of 60 questions, 34 of which require the respondent to declare the level of agreement on a 6-point Likert scale regarding attitudes towards the technological, environmental, material, energy, socioeconomic, cultural, institutional, and (geo)political aspects and impacts of geothermal energy and deep geothermal drilling. The goal was for the questions to be written clearly and simply so that technical details or words did not influence the respondents' responses.

Among the participants, there were 72 male and 28 female respondents. Their age range spanned from 24 to 65 years, with an average age of 40.88 years. Within the sample, various occupations were represented, including 27 researchers, 13 private employees, 12 university faculty members, 11 students, 5 state employees, and others. In terms of educational background, the participants had varying levels of attainment, with 31 having completed university degrees, 28 holding doctoral degrees, 18 having completed postgraduate studies, 18 holding postdoctoral qualifications, and smaller numbers having vocational or secondary education. The majority of respondents (40) lived in France, followed by 22 in Greece, 12 in Norway, 9 in China, 5 in the United Kingdom, and 10 from other countries of the world, reflecting a diverse geographic representation within the sample.

3.1 Structure of the Questionnaire

Section 1 contained background information. The remaining sections are organized as follows. Section 2 was created using the findings on the environmental impacts of geothermal energy and drilling of a previous study. Sections 3-5 were designed based on the triangle of social acceptance, as proposed by Wüstenhagen, Wolsink, and Bürer (2007).

Section 1 consisted of 20 anonymous questions collecting sociodemographic data, including gender, age, education, income, residence, energy consumer type, and familiarity with geothermal. The data was analyzed by aggregating and clustering responses based on factors like age, income, education, residence, population density, and energy consumer type, which impact individual energy procurement behavior.

Section 2 of the survey focused on environmental concerns and incorporates questions derived from Papakostas et al. (2023). This section examined impacts on lithosphere, hydrosphere, atmosphere, and biosphere, addressing issues related to land use, water quality, air pollution, ecosystems, and socioeconomic impacts. This section also included six questions on the urgency of specific environmental concerns and their impact on the existing energy production model, addressing issues like pollution, aesthetics, and water resources in relation to geothermal development in respondents' areas.

Section 3 of the survey focused on sociopolitical aspects of geothermal development. It included 15 questions covering topics such as respondents' perspectives on global issues, the importance of environmental regulations, knowledge of sustainable energy initiatives, decision-making authority in geothermal exploration, trust in energy sources, and acceptance factors for geothermal projects. The questions also addressed factors like public safety, environmental protection, employment, community awareness, consultation, compensation, media coverage, and opinions on utilizing geothermal energy for electricity and heat generation. Additionally, respondents were asked about their thoughts on the development of pilot energy projects in their countries.

Section 4 of the survey explored community acceptance of renewable energy projects, focusing on geothermal energy. It consisted of 15 questions covering various topics. These included respondents' knowledge of geothermal energy, the role of local communities in exploration, concerns about drilling near properties, factors influencing the decision to switch to geothermal energy, trust in selected factors, concerns about energy plants, willingness to accept drilling with safety measures and benefits, factors contributing to public concern about drilling, seismicity-related questions, and active opposition to geothermal drilling operations.

Finally, section 5 of the survey focused on market acceptance of renewable energy, specifically in relation to geothermal energy. The questions inquired about public incentives or measures available in respondents' countries to support the transition to geothermal energy and the perceived quantity of such incentives. Additionally, respondents were asked to rank the importance of factors like economic benefits, social benefits, community awareness, and environmental benefits when considering a switch to a geothermal-only energy provider. The impact of geothermal energy being less expensive than traditional energy sources on respondents' perspectives regarding geothermal drilling was also explored.

3.2 Survey Distribution

3.2.1 Focus Group

The questionnaire was distributed to the University of Piraeus research team during this first phase, in order to clarify and test whether the survey accounted for the findings of the literature review. Issues related to the length of the questionnaire and the simpler wording of some questions also were identified Once the resulting concerns were addressed, the pilot survey commenced.

3.2.2 Pilot Survey

The questionnaire that resulted from the focus group was tested with a pilot group of 21 respondents to see whether it could be simplified, improved regarding its structure and readability, so that its coherence and consistency would improve.During the pilot phase, the questionnaire, which was originally designed in English, was also translated into French to ensure that as many French-speaking respondents as possible participated. In addition, the questionnaire was created in Google Forms and then copied to Microsoft Forms to allow respondents in the People's Republic of China, where Google is blocked (at the time of conducting the survey and writing this paper), to access it. Following the aforementioned improvements, the final version of the questionnaire was made available to ORCHYD partners.

3.2.3 Final Survey

The ORCHYD partners were asked to distribute the final survey (incorporating any changes resulting from the pilot phase), which targeted different groups of people in the selected countries, to determine whether and how their perspectives differed from the overall group of respondents. Some of the respondents are likely to have a background or be familiar with engineering and/or geoscience subjects, which will aid comprehension of the survey. The survey was administered to a diverse group of people in the five countries where the project's partners are located: Association pour la Recherche et le Developpement des Methodes et Processus Industriels (France), Imperial College London (United Kingdom), SINTEF AS (Norway), Drillstar Industries (France), University of Piraeus Research Center (Greece), and China University of Petroleum (East China) (China).

3.3 Internal consistency of questionnaire

In order to confirm the reliability or internal consistency of the questions of an instrument (such as a questionnaire), Cronbach's alpha was used. Cronbach's alpha is calculated for all variables together and also when omitting a single variable at a time. It has been recommended that Cronbach's alpha be at least 0.7 for an instrument (e.g., a questionnaire) to be considered reliable.

In reliability testing, a sample is recommended to contain several hundred observations (i.e. responses), while an empirical rule of thumb recommends a minimum of 10 observations per item. This means that in the case of the 100 responses that were collected, testing more than ten items (variables) is not advisable. Furthermore, with many items (such as in the case of a long questionnaire like the ORCHYD one), Cronbach's alpha may increase (even over 0.95) without this meaning that the questionnaire items are internally consistent; in fact, such high values of Cronbach's alpha oftentimes imply that some items are redundant, and the questionnaire could be shortened without losing reliability (Mooi & Sarstedt, 2011; Tavakol & Dennick, (2011).

Although it is not recommended that Cronbach's alpha be used with the total questionnaire items, it may be used with the subset of multimodal variables that were used for extracting principal components (PCs). Excluding a few items that were found to be linearly dependent (and prevented calculations), Cronbach's alpha for the variables with multimodal histograms was found to be 0.863, with a 95% lower confidence bound of 0.823, indicating high reliability for this set of variables.

Cronbach's alpha may also be used with the quantitative variables of the five sections of the questionnaire to test their internal consistency: Cronbach's alpha for Section 1 (Background data) items was 0.53, indicating mediocre internal consistency. Section 2 (Environmental concerns) items had a Cronbach's alpha of 0.906; Section 3 (Socio-Political issues) items had 0.938; and Section 4 (Community acceptance) items had 0.953 (excluding some that were found to be linearly dependent). Finally, Cronbach's alpha for section 5 (Market acceptance) items was 0.594, indicating mediocre internal consistency, partly due to some heterogeneous items (e.g., mixing opinions on incentives with attitudes for economic, social, and environmental benefits).

4. RESULTS

4.1 Principal Component Analysis

Principal Component Analysis (PCA) was performed to extract a small number of PCs, which would subsequently be used for Cluster Analysis (and any other analyses). The purpose of PCA was to obtain a few linear combinations of the ranking variables, which account for most of the variability in the data. Two alternative PCAs were run: (1) on selected variables that exhibited multimodality in their distribution and (2) on subjectively selected groups of conceptually related ranking variables (dissemination, economic, environmental, geopolitical NIMBY, and public acceptance). Missing cases were excluded listwise in both cases.

For the first method, the KMO statistic for the questionnaire exceeded the recommended threshold of 0.6, indicating that extracting principal components (PCs) will likely yield valuable information. Similarly, Bartlett's test for sphericity resulted in the rejection of the null hypothesis, suggesting that the variables have common variance and justifying the extraction of PCs. Consequently, the extracted PCs accurately capture the data's variability and can be utilized for cluster analysis. The PC variable coefficients are not displayed as they were not extracted for interpretation but specifically for cluster analysis purposes.

For the second alternative of extracting PCs from each variable group is followed, a total of 38 PCs would be available for cluster analysis: 4 PCs for dissemination, 4 PCs for economics, 6 PCs for the environment, 6 PCs for geopolitics, 8 PCs for NIMBY, and 10 PCs for public acceptance. However, it should be noted that, for a sample size of 100 observations, it is recommended by Formann (1984) to have only 6 to 7 clustering variables as quoted by Mooi and Sarstedt (2011). Therefore, utilizing all 38 extracted PCs from this section is not feasible.

For these reasons, the first method, i.e., extracting 10 PCs from multimodal variables, was preferred.

4.2 Cluster Analysis

This section aimed to identify any geothermal energy "tribes" present in the sample and, presumably, in the population. Their existence would allow for more targeted and practical efforts to increase public acceptance of geothermal energy. On the issue of sample size, Formann (1984), as quoted by Mooi and Sarstedt (2011), recommends a sample of at least 2m cases, where m equals the number of clustering variables. Although these are just recommendations, it follows that it would be good to not exceed 6 (2^6=64) to 7 (2^7=128) variables to cluster and analyze the available 100 complete cases of ranking variables.

Using Ward's linkage method with the squared Euclidean as the preferred distance metric should create larger and more distinct clusters (Hair et al., 2009). Based on the observations made during the inspection of the histograms, only two and three cluster solutions were considered.

Two different variable configurations were used for cluster analysis: (1) All 32 PCs extracted from all ranking variables, and (2) Only the first 7 PCs extracted from all ranking variables. Cluster analysis was run on the 10 PCs extracted from the variables (with multimodal histograms) that did not have any missing data. Two equally plausible solutions were obtained: one with two clusters and a second one with three clusters. In total, 88 out of 146 variables (60.3%) showed a significant ANOVA F-test, indicating the presence of three clusters in the sample of responses.

The three-cluster approach is favored to the two-cluster solution due to the greater number of variables with a statistically significant difference among cluster centroids (50 versus 88, respectively), allowing for a more meaningful differentiation between the clusters. Selected quantitative background information of the clusters are summarized in Table 1.

Table 1: Background information of clusters

	Cluster 1	*Cluster 2*	*Cluster 3*
Size (respondents)	22	59	19
Age (years)	40.6	41.6	39.1
Annual income (thousand euros)	43.333	46.111	50.000
Familiarity with geothermal (scale 1 to 6)	4.546	3.967	2.737

The character of clusters is further characterized in Table 2.

Table 2: Cluster characterization

Cluster 1 “lower income, most familiar with geothermal, skeptical, distrustful”	Cluster 2 “concerned, trustful, community oriented”	Cluster 3 “upper income, least familiar with geothermal, focused concern, science-minded”
● Least concerned about urgency of GHG emissions, environmental issues, environmental impacts of geothermal, and environmental regulations ● Preferring national and regional authorities to the EU ● Consistent (via 2 questions) lowest rating of the necessity to produce renewable energy ● Considering solar, wind and geothermal to be the least impactful on the way of life ● Least concerned about economic and community issues ● Least exposed to geothermal in the news ● Least trustful of various authorities (media etc.), with research journals and expert publications being relative more trusted ● No active opposition to geothermal drilling	● Most concerned about environmental issues and aesthetics ● Most concerned about socioeconomic, institutional, and community issues ● Preferring national, EU and local authorities to producers and suppliers ● Consistent (via 2 questions) intermediate rating regarding the necessity of producing renewable energy ● Considering solar, wind geothermal and biomass to be the most impactful on the way of life ● Considering the role of scientists and researchers in energy selection less important ● Underestimating the importance of energy independence ● Most concerned about nearby nuclear energy installations ● Least concerned about induced seismicity changing people's perspective about geothermal energy ● Most trustful of the media, NGOs, environmental associations, colleagues, and friends	● Highest concern for climate change effects and biodiversity, moderate concern about other environmental issues ● Preferring national, EU and regional authorities to producers and suppliers ● Consistent (via 2 questions) highest rating regarding the necessity of producing renewable energy, and considering oil most impactful of the way of life ● Considering scientists and researchers in energy selection very important ● Trusting the EU and national governments, but not the media ● Most concerned about nearby geothermal installations ● Most concerned about groundwater/soil contamination, water use, air pollution, noise, and geothermal induced seismicity ● Prioritize academic/research/expert publications ● Highest active opposition to geothermal drilling

4.3 Discussion

4.3.1 NIMBY Attitudes

Cluster 1 respondents appeared to be the least worried about the environmental consequences of geothermal drilling or other energy sources near their property. Furthermore, they valued the social acceptance of geothermal energy the lowest among the three clusters. An example is the worry about GHG emissions from geothermal drilling, which is the lowest of the three groups. It is worth noting that Cluster 1 respondents thought that they were the most familiar with geothermal energy and understood better how it works. Furthermore, they had the least faith in environmental organizations. However, the worry was higher in the case of wind or PV installations than in the other two Clusters. There were no Cluster 1 respondents who would actively oppose geothermal drilling activities in their region. Cluster 1 respondents may have adopted a somewhat dispassionate stance concerning geothermal drilling activities. The reactionary attitude characterizing Cluster 1, considering their low trust in organizations and media and their low esteem of environmental issues, is probably countered by their better impression of academic researchers and experts.

Cluster 2 respondents placed greater emphasis on technological, commercial, social, and economic aspects associated with geothermal energy development. In most environmental concern items, they assigned the highest responses among the three clusters. They were also the most concerned about the impacts of energy systems on the environment and attributed high importance to organizations and institutions in the energy selection process. However, given that they appear to be the most receptive cluster towards geothermal energy development in their area and given specific incentives and benefits, one could argue that their attitude could change. Their responses suggest that a well-established legal and social framework would also change their opinions about geothermal drilling. Cluster 2 respondents are, therefore, quite responsive to geothermal energy, and any NIMBYism existing in the cluster might be mitigated with the proper public approach plan.

Cluster 3 was the only Cluster where females comprised the majority of respondents (52.63%) and believed they had the lowest understanding of geothermal energy. They considered public acceptance of geothermal energy the most significant among the three clusters and prioritized environmental, public health, legal, and safety considerations. They trusted the EU and valued the importance of energy independence, efficiency, and availability. Cluster 3 respondents had the most negative sentiments toward geothermal installation expansion in their region and hydraulic stimulation for geothermal drilling. On the contrary, they were not very concerned about their region's wind, PVs, and hydroelectric plants. Given that these three renewable energy sources are among the most prevalent in the EU, it is reasonable to conclude that Cluster 3 respondents could be easily persuaded by EU-planned ads touting the advantages of geothermal energy. Cluster 3 respondents were also very concerned about induced seismicity and water aquifer issues related to geothermal energy development in their area. Finally, Cluster 3 contained the largest number of respondents (15.79%) who would actively oppose geothermal drilling in their area. This shows a more pervasive NIMBY mentality in Cluster 3, which might be addressed if European-level incentives and a public education campaign were established.

4.3.2 Energy Tribe Approach

It appears that all four energy tribes defined by Caputo (2008) coexist in the sample of questionnaire respondents. Some can be found in two or all three clusters. The strong faith of all three groups in science and research is the key shared attribute that would lead to the construction of an effective strategy that would encourage the use of deep geothermal energy and make it socially acceptable. The leadership institution or organization seems to be the distinctive characteristic of any far-reaching program for these energy tribes. Core ecologists, for example, are mostly found in Cluster 3 and are the most willing to actively oppose geothermal projects in their region, despite their high faith in the EU and scientists and researchers. Thus, an EU-led effort to convey and promote the environmental advantages of projects like ORCHYD will positively influence this group's image of geothermal energy.

On the other hand, people who live in a hierarchical or individualistic social structure would be most likely to improve their opinion of geothermal drilling if national government-led or industry-led regulations were implemented, based on scientific study findings. Finally, persons who have adopted the fatalistic societal context may only be reached by independent and free access to scientific findings. All of this leads to the conclusion that scientific research is essential for developing cutting-edge renewable and sustainable energy technologies and their social acceptance. This indicates that the scientific, environmental, and economic research findings of any cutting-edge technology, such as the one ORCHYD intends to build, must be effectively conveyed to the public to deepen comprehension of the operating principles and increase societal acceptability.

5. CONCLUSIONS AND RECOMMENDATIONS

The PCA and Cluster Analysis of the questionnaire produced three groups with varied traits and preferences. Cluster 1 respondents can be characterized as lower income, most familiar with geothermal, skeptical and distrustful. Cluster 2 respondents can be characterized as concerned, trustful and community oriented. Finally, Cluster 3 respondents can be characterized as upper income, least familiar with geothermal, exhibiting focused concern, and being science-minded.

For the decision-making process regarding the energy production plan, all clusters place faith in their national governments over any other sort of institution or group. A national government policy, information campaign, or law would most effectively influence public awareness of geothermal energy. Furthermore, respondents in all clusters trusted scientists and researchers in the energy selection process, but trust in NGOs, environmental groups, and grassroots movements were relatively low, particularly in Clusters 1 ("lower income, most familiar with geothermal, skeptical, distrustful") and 3 ("upper income, least familiar with geothermal, focused concern, science-minded"). This demonstrates that dissemination operations undertaken by academics and scientists have a much more significant influence on public perception than activism and other types of communication used by NGOs, environmental groups, and grassroots movements.

Respondents from all clusters valued energy independence, efficiency, affordability, availability, and energy source diversification. This implies that geothermal energy's political, economic, and geopolitical worth should be investigated further and disseminated to the public to improve its public image. Environmental protection, community awareness, and consultation were critical for all clusters, mainly the second. Public health and environmental issues were significant concerns for all groups, but induced seismicity and water aquifer threats appear to be a focus of emphasis for Cluster 3. Furthermore, economic gains were relevant to responders from all three groupings. This implies that the public should be informed about geothermal energy's environmental benefits, particularly in projects such as ORCHYD, which improve the environmental profile of drilling operations.

Finally, in all clusters, the frequency of hearing about geothermal energy issues is small. This indicates that dissemination and communication activities should be strengthened, primarily by national governments, scientists, and researchers, who appeared to be the most reliable sources of information, as previously indicated. The significance of scientists and researchers in shaping the public's perception of energy sources should be emphasized since all three groupings acknowledge it. However, distinct approach tactics should be used for each cluster.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare. all co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report.

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