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Short and long-term dominance of negative information in shaping public energy perceptions: The case of shallow geothermal systems

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ABSTRACT

Positive perception of renewable energy systems, including shallow geothermal systems, is essential for a sustainable energy transition. However, it is underexplored how citizens' feelings towards and evaluations of this technology change over time and consolidate into a stable, positive perception. In an online longitudinal experiment in Western Switzerland (Time 1: $N = 823$, Time 2: $N = 342$, Time 3: $N = 221$), we investigated i) how informing citizens about twenty positive or negative aspects of shallow geothermal systems change their affect towards and evaluations of the technology, ii) if such changes are stable over time, and iii) how individual differences influence these processes. Results of Time 1 (pre-information) indicate affect is positively associated with shallow geothermal systems' evaluations. At Time 2 (post-information, three weeks later), citizens significantly updated their affect and evaluations with the information provision. The effect was double for negative over positive information, and enhanced by citizens' biospheric values. At Time 3 (three months post-information) changes were partially retained only in the negative information condition. In informational campaigns, we thus recommend focusing on reducing the effects of negative messages while tailoring positive messages around citizens' values, to minimize the temporal decay and maximize the positivity of geothermal systems' image in the public's eye.

1. Introduction

1.1. Background

Net CO_2 emissions produced by human activities must approach zero to stabilize global mean temperature and limiting human-induced global warming to under 1.5 °C and 2 °C (Davis et al., 2018; IPCC, 2021). A successful global energy transition to net-zero emissions energy systems is likely to depend on vast amounts of inexpensive, emissions-free energy (Davis et al., 2018), and international plans have been introduced to reach net carbon neutrality, such as the European Green Deal (European Commission, July 2021). Among the energy systems with net-zero emission proposed as solutions, geothermal energy could account for 4–5% of global heat production by 2050, with further potential to provide electricity in up to 40 countries (Beerepoot, 2011; Bertani, 2016). In 2018, Switzerland has enacted the Swiss Energy Act with the aim to increase its renewable energy production (The Federal Council of Switzerland, 2016). Geothermal systems are to produce 7% of electricity and 20% of district heating supply by 2050 (Art. 33; Hirschberg et al., 2015; Panos et al., 2021). Development of geothermal systems also require public support, and recent studies have begun documenting citizens' perceptions of it (Cousse et al., 2021; Manzella et al., 2019; Volken et al., 2019). Although being a local energy source competitive to more known renewable energies in environmental terms, especially for heat production in shallow systems (Pratiwi and Trutnevyte, 2021), the induced seismicity risk inherent in deep geothermal operations and the public's low familiarity with the technology make its public acceptance ambivalent and volatile (Reith et al., 2013; Volken et al., 2018).

Social science research highlights how citizens' acceptance (i.e., support or opposition) and evaluations of energy technologies are not only based on rational cost/benefit analyses, but strongly influenced by affective reactions towards the implicated technologies (Finucane et al., 2000; Brosch et al., 2014; Jobin and Siegrist, 2018; Perlaviciute et al., 2018; Rinschied and Wüstenhagen, 2018; Truelove, 2012). Two recent reviews have argued that how citizens emotionally feel is an essential predictor of their climate and technology-related beliefs and behaviors, identifying affect and emotions as the most promising drivers motivating climate change mitigation and adaptation (Brosch, 2021;

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Schneider et al., 2021). Coupling this evidence with the urgency of transitioning towards renewable energy production, it is crucial to understand how citizens create affective associations with renewable energies, how citizens update these associations with new information, and how the associations remain stable or decay through time.

In this paper, we aim to contribute to the energy systems' acceptance literature by investigating how affect towards shallow geothermal energy in Western Switzerland is updated when being provided multiple pieces of positive or negative information, and if these information-induced affect changes are temporally stable three months later. The objective of this study is to provide policymakers with strategies on how to best communicate about renewable energy to promote long-term positive perception of energy projects foundational to sustainable energy transitions.

1.2. Perception of geothermal energy

Only a few studies have shed light on citizens' ambivalent perception of geothermal energy (e.g., Kubota et al., 2013; see Manzella et al., 2019). Icelandic citizens exemplify positive perception of geothermal systems, as these systems are integrated in everyday electricity and heating use in Iceland (Jónsson and Rastrick, 2017). In Australia, Chile, and Italy, geothermal energy is generally accepted and perceived to be low risk (Bronfman et al., 2012; Dowd et al., 2011; Pellizzone et al., 2017). German citizens show low levels of acceptance instead, with public protests springing up after geothermal systems-induced seismic events in Switzerland and Germany, and more than half of deep geothermal projects being cancelled between 2009 and 2015 (Knoblauch et al., 2018; Kunze and Hertel, 2017). French citizens echo such negative sentiments, as fear of geothermal systems-induced earthquakes and complaints mounted over time during the creation of a deep geothermal project (Duijn et al., 2013; cf. Manzella et al., 2019).

In Switzerland, awareness is low, with one Swiss citizen out of four reporting not having heard of geothermal systems (Cousse et al., 2021). Geothermal systems are generally perceived as positive when knowledge is low, whereas increases in knowledge are associated with lower acceptance and higher preference for siting geothermal systems away from populated areas (Blumer et al., 2018; Knoblauch et al., 2018, 2019; Volken et al., 2019). Two informed citizen panel studies have shown that Swiss citizens initially have positive affective associations with and favorable preference for deep geothermal systems, but that receiving information about different aspects of the technology (e.g., accidental impacts) decreases preference for developing the technology and leads to more negative affective evaluations (Dubois et al., 2019; Volken et al., 2019). Whether these changes are stable over time or not is not conclusive, as the two studies reported either a return to initial preference levels or more negative final affective evaluations three weeks post-intervention. The most negative perceptions of deep geothermal systems are generally linked to the seismicity risk inherent with this technology. Citizens report seismic risks to be the most important aspect use to evaluate geothermal systems and increases in seismic risks correspond to decreases in public acceptance, regardless of the technology's benefits (Knoblauch et al., 2019; Volken et al., 2019). However, seismic risks are not the only aspect for the evaluation of geothermal systems, as perceiving geothermal systems as local and natural increases support (Blumer et al., 2018). Overall, the perception of geothermal systems is initially positive, but largely depends on the integration of information regarding multiple aspects of the technology, seismic risk being the most salient.

Whereas acceptance of deep geothermal systems is researched, perception of its shallow depth counterpart is less studied. As the name implies, shallow geothermal systems broadly represent geothermal energy systems that do not operate at high depth. Their energy output is restricted to heating utilities, but their operations have close to zero likelihood of induced seismicity (Trutnevyte and Wiemer, 2017). Cousse et al. (2021) found that even citizens with low knowledge discriminate between the different types of geothermal systems. Providing information about the seismic risks associated with deep geothermal systems did not affect attitudes towards shallow geothermal systems (Cousse et al., 2021, Study 1). However, raising awareness of deep geothermal systems' seismic risk with affectively charged information spilled over to changes in emotions (i.e., higher worry, lower enthusiasm and pride) about and perceptions of risks and benefits of shallow geothermal systems, suggesting that information-induced spillovers across the two types of geothermal systems may occur.

In summary, evaluations of geothermal systems are ambivalent at best, with between-country differences in terms of acceptance but a shared overall low awareness of the systems (Dowd et al., 2011; Pellizzone et al., 2017). Shallow geothermal systems are perceived more positively, but there is a dearth of studies focusing on this particular geothermal type.

1.3. The influence of affect on technology perception

Citizens' perceptions of the benefits and risks of an energy technology are negatively associated, despite objective risks and benefits being positively correlated in reality (Slovic and Peters, 2006). This "illogical" relationship is explained by the influence of affect on evaluations: on the one hand, feeling positive about a technology increases the perceived benefits while decreasing the perceived risks; on the other hand, feeling negative about a technology increases the perceived risks while decreasing the perceived benefits (Finucane et al., 2000; Efendić et al., 2021). Illustrating that citizens' risk perception is affective in nature – and not solely driven by rational risk/benefit calculations – has led to the definition of the affect heuristic, which points out that affect provides quickly accessible information that pervasively influences technology evaluations and decision-making (Slovic and Peters, 2006). Emblematically, positive feelings towards renewable energies have been shown to be positively associated with Swiss citizens' preferences for searching additional information about and selecting a higher energy output from each energy systems in hypothetical future energy portfolios (Jobin and Siegrist, 2018; Jobin et al., 2019).

Only three studies have tracked how peoples' affect influences their evaluations through time. Burns et al. (2012) found, in a panel spanning the first year of the 2008 financial crisis, that harboring negative emotions about the crisis covaried with a heightened perception of its risks. In a Swiss sample, Visschers and Wallquist (2013) compared nuclear energy acceptance five months before and six months after the Fukushima nuclear accident. Highly ambivalent Swiss citizens (i.e., harboring both positive and negative sentiments towards nuclear energy) were less accepting of the energy source after the disaster, compared to less ambivalent participants. In another Swiss study, increases in positive affect towards nuclear energy during the month leading up to a national referendum about nuclear phaseout cascaded into changes in risk and benefit perceptions. These changes later explained fading voter support of the nuclear phaseout on voting day from intentions reported before the referendum, ultimately leading to the rejection of the phaseout proposal (Rinscheid and Wüstenhagen, 2018).

Although commendable for their ecological nature, Burns et al.'s (2012) and Rinscheid and Wüstenhagen's (2018) studies are correlational, measuring the evolving fluctuations in affect and perceived risks at different points of the 2008 economic crisis or the nuclear phaseout referendum without experimentally manipulating either variable. Visschers and Wallquist (2013) circumscribed themselves to the effects of a single event (and subsequent news coverage) they could not experimentally control. These studies furthermore lacked affect measures before and after (Burns et al., 2012; Rinscheid and Wüstenhagen, 2018), or during (Visschers and Wallquist, 2013) the event associated with the affective changes they measured. This limits the inferences that can be drawn regarding both how information accumulation causally influences affect and how stable over time affective associations are.

Here, we provided multiple relevant information items in an experimentally controlled manner, measuring affect before, during, and after the information provision. We can therefore contrast the accumulation of positive versus negative information more carefully than the previous studies, discern the effects of these two types of information, and assess the dynamic relationship between information accumulation and affective change. We are moreover in a position to systematically compare the long-term effects of the types of information in terms of the temporal stability of the affective changes they generate. This knowledge will be valuable for policymakers needing to decide whether to provide positive information or to combat negative information is a better strategy to foster a long-term positive perception of geothermal systems.

1.4. The role of values in technology evaluation and information processing

Evaluating energy technologies and processing related information are not acontextual processes, but are guided by citizens' prior beliefs and concerns (Schwartz, 1992). Biospheric values, a higher-order category of personal values associated with protecting nature and caring for the environment, are a prime candidate to influence the appraisal of energy projects. In a comprehensive review of psychological factors influencing energy acceptance, Perlaviciute and Steg (2014) recognized that values are protagonists in shaping technology evaluations, even at the initial stages. In addition, values can shape emotional responses towards these technologies (Brosch et al., 2014). These two perspectives translate in predicting that, on the one hand, citizens should support energy projects that are positively aligned with their personal values, predominantly with their biospheric values (Perlaviciute et al., 2018). On the other hand, citizens may appraise an energy technology negatively when they perceive it to be against their values (e.g., to be harming the environment), which can lead to strong negative reactions (e.g., for nuclear energy; Corner et al., 2011; de Groot et al., 2013). In this framework, shallow geothermal systems should be perceived positively by citizens with pronounced biospheric values, even when they possess low knowledge, because shallow geothermal systems are carbon-emissions-free, renewable energy systems, and therefore in line with the pro-environmental goals underlying biospheric values.

Additionally, values moderate the relationship between incoming information and the intensity of the affective reaction the information elicits (Brosch, 2013; Schwartz, 1992). Values can thus be conceptualized as lenses that weight the pertinence of new information and guide their appraisal at onset (Scherer, 2013; Schwartz and Bilsky, 1987). New information appraised as value-relevant directs attention in a noisy environment and elicits stronger emotional reactions than value-irrelevant information (Conte et al., 2022). Biospheric values in particular have been related to more intense emotional responses towards positive and negative information concerning nature and climate change (Conte et al., 2022), and to an individual disposition to experience emotions in an environmental context (Hahnel and Brosch, 2018). This suggests that biospheric values might enhance the updating of affective associations to energy technologies: in other words, accumulating information about a value-relevant energy technology should lead to more extreme affective reactions.

2. Research questions and hypotheses

The aim of the present study was to investigate i) how citizens update their affective associations with geothermal energy when accumulating positive or negative information, ii) whether these changes are stable through time, and iii) whether individual differences moderate these processes. We first measured citizens' affect towards shallow geothermal systems as well as their acceptance and evaluations of these systems to obtain baseline measures (Time 1). Three weeks later, we provided twenty sequential positive or negative information statements about shallow geothermal systems in order to measure the pattern of information-induced affect updating and evaluations change (Time 2). Three months later, we measured whether the observed changes were stable in time (Time 3). Based on previous findings on the affect heuristic, we predicted affect to be positively associated with acceptance and evaluations and negatively associated with perceived risk (H_1). We moreover expected the information provision at Time 2 to cause affect updating (H_2): receiving negative information would lead to more negative affect and overall acceptance and evaluations of shallow geothermal systems (H_{2A}); receiving positive information would lead to more positive affect and overall acceptance and evaluations (H_{2B}). We expected the affect and evaluation changes at Time 2 to remain stable at Time 3 (H_3). We finally expected that biospheric values would be positively related to affect towards and evaluations of geothermal energy at all time points (H_{4A}), and that they would moderate the updating process during the information provision at Time 2 (H_{4B}).

3. Methodology

Data, study-unique materials, and code can be retrieved at https://osf.io/bmtds/?view_only=513400fe48914bd4abbb575bf6f1ddf3. The ethical commission of the Faculty of Psychology and Educational Sciences of the University of Geneva approved the project.

3.1. Participants and sample size justification

We recruited citizens of West Switzerland through a panel provider. $N = 822$ ($n = 454$ females, mean $_{AGE} = 40 \pm 14$ years) responses were collected between September and November 2020 at Time 1; three weeks after, between November 2020 and January 2021, $N = 342$ (41% retention, $n = 213$ females) participants completed Time 2; another three months later, between January and April 2021, $N = 221$ (26% retention, $n = 131$ females) participants completed Time 3. A sample size of $N = 680$ for Time 1 and $N = 324$ for Time 2 was identified weighting the panel provider's pool size and a-priori sample size calculations with the online tool GLIMMPSE (Kreidler et al., 2013) and G*power (Version 3.0, Faul et al., 2007). For participant exclusions, sample size justification details, and sample differences due to longitudinal dropout, see Appendix (A), Section A1, and Table A3.1.2, respectively.

3.2. Design and procedure

The study a mixed longitudinal design, comprised of three different time points (within-subject factor, 3 levels): Time 1, Time 2, and Time 3. Clustered within Time 2, participants underwent the information provision (2 conditions, between-subjects factor, 20 repeated measures of affect towards shallow geothermal systems, within-factor).

Time 1 procedure. Participant accessed the survey through an anonymous link distributed by the panel provider. After registering their consent, they reported their age, gender, canton of residence, education, voting rights in Switzerland (dichotomous: yes/no). A short introduction to shallow geothermal systems followed the demographic section (see OSF link). Participants then reported their affect, acceptance and evaluations of shallow geothermal systems, in randomized order. Individual differences measures were subsequently presented. The survey concluded with a redirect to the Riskmeter website (see Measures section), where participants chose the proportion of electricity produced by different energy sources to meet Switzerland's 2035 electricity demand. Participants were redirected to the panel provider's website and compensated. The survey lasted approximately 25 minutes.

Time 2 procedure. Participants first reported their initial mood (manipulation check, see Appendix A3.1.3; 1-item visual analog scale; *How are you feeling right now?*, 0 = *very bad*, 7 = *very good*) and their baseline affect towards shallow geothermal systems. The information provision followed. Concluding that section, participants reported their mood again, and evaluated shallow geothermal systems – in terms of acceptance, perceived risks and benefits, and voting intentions. Participants completed the experiment with the Riskmeter. This survey lasted about 15 minutes.

Time 2 information provision. Participants were randomized into one of two information conditions: positive ($n = 171$) and negative ($n = 166$) information about geothermal energy. Participants received either 20 positive or 20 negative information statements, each depicting one aspect of shallow geothermal systems (see Table 1 for examples), sequentially: at each trial, participants were randomly presented one statement, after which they reported their affect towards shallow geothermal systems on a scale from 0 (*very negatively*) to 100 (*very positively*). The next trial would then begin, until the completion of twenty trials. The forty statements were crafted with factual information about geothermal systems, and were furthermore pretested for cross-condition differences in perceived valence and persuasiveness in two pilot studies ($N_{pilot\ 1} = 85$, $N_{pilot\ 2} = 50$, see Appendix, Section A6).

Time 3 procedure. At Time 3, participants' affect, perceived risks and benefits, voting intentions, and acceptance were assessed one final time, in 5 minutes. Finally, participants reported their subjective knowledge of shallow geothermal systems, and the study concluded.

3.3. Measures

All materials were presented in French.

Geothermal-specific variables: We measured affect towards and evaluations of shallow geothermal systems with visual analog scales, ranging from 0 to 100: affect towards shallow geothermal systems (single-item: *In general, how do you feel about shallow geothermal systems?*, 0 = *very negatively*, 50 = *neutral* anchor, 100 = *very positively*), perceived risks and benefits of shallow geothermal systems (*In general, how risky [beneficial] do you perceive shallow geothermal systems to be?*, 0 = *not risky [beneficial] at all*, 50 = *Moderately risky [beneficial]* anchor, 100 = *very risky [beneficial]*), voting intentions in favor of or against shallow geothermal systems in hypothetical referendums (2-items: *In case of a cantonal [general] referendum, would you be in favor or against heating production derived from shallow geothermal systems?*, 0 = *very much against*, 100 = *absolutely for*, anchored at 50; composite score, $\alpha = 0.96$), acceptance of the technology (Items: *Shallow geothermal systems are a promising technology*; *Shallow geothermal systems should be a part of the energy future of my country*; *Shallow geothermal systems should be a part of the energy future of my canton*; and *I want my house to be connected to the geothermal reservoir*. Question: *How confident are you that:*, 0 = *not at all*, 100 = *totally certain*, anchored at 50. Composite score, Cronbach's $\alpha = 0.95$). We also measured subjective (*How much do you think you know about shallow geothermal systems?* 1 = *nothing at all*, 9 = *a lot*), objective (5 true/false questions, available at the open data link) knowledge of shallow geothermal systems, and three additional shallow geothermal systems-specific variables not included in the present study (presented in the Appendix for completeness).

Individual differences: Personal values were collected with the 58-item version of the Schwartz Value Survey (Schwartz, 1992; de Groot and Steg, 2008). Although our study focused on the influence of biospheric values, previous research had highlighted how other value categories are positively (e.g., values related to altruism) or negatively (e.g., egoistic values, related to self-advancement) associated with pro-environmental actions. Ratings were within-participant centered and aggregated into biospheric, altruistic, hedonic, and egoistic values scores, and all value categories were added as predictors in the regression and multilevel models. Further individual differences are described, with related hypotheses, in the Appendix.

Riskmeter: The Riskmeter (Xexakis et al.) is a web-based interactive tool where participants build the Swiss electricity portfolio to meet the electricity demand in 2035 under technology and energy resource constraints. Participants interacted with the web-tool by varying the amount of TWh/year produced by seven technologies – hydropower, photovoltaics, wind, deep geothermal systems, waste incineration, biomass, and nuclear power plants – receiving continuous feedback on the energy demand met (Xexakis and Trutnevyte, 2019). Although our study measured perception of shallow geothermal systems for heating instead of electricity, the Riskmeter was still used to provide an alternative measure of energy choice behavior.

Table 1
Example of information statements delivered in the information provision at Time 2.

Aspect	Information Statements
Technology Status	***Positive*** *"For decades, geothermal heating has provided safe, reliable, environmentally benign heating used in a sustainable manner with mature technologies to provide direct heating services."* ***Negative*** *"Shallow geothermal technology is at present poorly known and under-developed at this stage. There is still a need for further geological data to improve the geothermal cost performance. The availability of local geothermal reserves is also poorly understood."*
Impacts on climate change	***Positive*** *"Shallow geothermal systems are greenhouse gases free during operation (which contribute to climate change). During the whole life cycle, climate impacts of these systems are lower or in the same range as those from renewable technologies considered in Switzerland for the future."* ***Negative*** *"The exploitation of geothermal heat has an impact on climate change because the exploration, drilling, and operation consume fossil fuels and electricity. This impact is higher than other renewable energy, like solar and wind. "*

Example of statements for two aspects of shallow geothermal systems. First row: information statements about the "technology status" aspect delivered to the Positive and Negative information conditions. **Second row**: information statements about the "impacts on climate change" aspect delivered to the Positive and Negative information conditions. Statements were delivered in French. For the full list of statements, see Appendix, Section A5.

3.4. Data analysis

Data were analyzed with R (Version 4.1.1, R Core Team, 2021) and packages lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), TOSTER (Lakens, 2017), and cocor (Diedenhofen and Musch, 2015). Gender, age, and education were added as covariates in all models; $n = 2$ participants were removed as their gender was not specified in the binary category.

We tested the relationship between affect, perceived benefits and risks at each time point with correlations. Information-induced changes at Time 2 in the correlation between these factors were statistically compared with R package cocor (Diedenhofen and Musch, 2015). Alpha levels were Bonferroni corrected to $\alpha = 0.016$.

Time 1 data analysis involved four linear stepwise regressions with affect, acceptance, chosen share of deep geothermal energy production (normalized) in the Riskmeter, and voting intentions, as dependent variables, respectively. Predictors for the first step comprised: biospheric, altruistic, hedonic, egoistic values, and objective and subjective knowledge. Affect was added in the second step for all models but the affect regression. Alpha levels were corrected to $\alpha = .005$.

At Time 2, we first compared baseline affect across the two conditions with independent-sample t-test and equivalence testing (Lakens, 2017). This allowed us to test whether baseline affect significantly differed between the two conditions, or the two conditions were statistically equivalent to zero.[1] Similarly, we compared mood ratings before and after the information provision with dependent-sample t-test and equivalence testing (see Appendix A3.1.3).

[1] To select smallest effect sizes of interest for equivalence testing (Lakens, 2017), we chose effect sizes that we had 80% power to detect, given our sample size. The smallest effect size of interest differed across equivalence tests is explicitly stated.

We then analyzed affect ratings reported during the information provision with a multilevel model. We specified three random effects: intercept for participant, intercept for the initial affective response at Time 2 to take into account the variance associated with individual differences in initial affect toward shallow geothermal systems before the information provision, and intercept for information statement presented in the information statement, to take into account the variance associated with each aspect of shallow geothermal systems (Judd et al., 2012). Akaike Information Criterion (AIC) weighing model comparison confirmed this structure fit the data best. Fixed effects comprised: condition (factor), trial, biospheric, altruistic, hedonic, and egoistic values. We added the hypothesized three-way interactions between condition, trial, and biospheric values to the model. Upon visual inspection of affect updating through trials, we conducted an exploratory multilevel model with a dummy variable dividing trials into four groups of five, to compare slopes across trial groups (see Appendix, Fig. A3.3.1). This was conducted to test whether participants' affect updating differed in size and direction between first, mid, and last groups of information provision. We conducted three multilevel model with a similar fixed-effects structure to predict acceptance, voting intentions, and Riskmeter choice of geothermal electricity production across Time 1 and Time 2 - replacing the predictor trial with Time.

We conducted the analyses of the longitudinal data across the three time points with a multilevel model. We specified three random effects: intercept for participant, slope for time, and slope for the exact period of days elapsed across time points within participants. AIC weighing model comparison rejected the random slopes in favor of the single random intercept for participant. Fixed effects comprised: condition (factor), Time, biospheric, altruistic, hedonic, and egoistic values. We added the three-way interaction between condition, Time, and biospheric values to the model.

4. Results

We first present the correlational evidence obtained at Time 1, followed by the results of the information intervention at Time 2, and conclude with the long-term effects of the information intervention at Time 3. Unless otherwise specified, all p-values are <.001.

4.1. Time 1

Overall, citizens felt positively towards shallow geothermal systems (mean $_{affect}$ = 68.43 ± 20.84; see Fig. 1). They were accepting of the technology (mean $_{acceptance}$ = 69.18 ± 21.50) and perceived it as beneficial (mean $_{benefits}$ = 67.05 ± 20.43) and moderately risky (mean $_{risks}$ = 44.04 ± 22.57), that they intend to support in referendums (mean $_{voting}$ = 72.12 ± 23.00), despite reporting not knowing much about the technology (mean $_{subjective\ knowledge}$ = 3.95 ± 2.00). Congruently with the affect heuristic, citizens feeling more positive towards shallow geothermal systems also perceived the technology as more beneficial (r = 0.71, 95% CI[0.68, 0.75]) and less risky (r = −0.46, 95% CI[-0.52, −0.41]); perceived benefits and risks were moderately and negatively correlated (r = −0.34, 95% CI[-0.40, −0.28]).

Moving to the regressions, the overall affect model was significant (see Table 2). Citizens with higher objective knowledge or who subjectively considered themselves to be more knowledgeable about the technology also felt more positively towards shallow geothermal systems (t(816) = 4.946, β = 3.03, 95% 95% CI[1.829, 4.237], and t(816) = 6.981, β = 2.63, 95% CI[1.889, 3.367], respectively). Similar to affect, the overall acceptance model was significant (see Appendix, Table A2.2.1): citizens with higher objective and subjective knowledge were also more accepting of shallow geothermal systems (t(816) = 4.947, β = 3.13, 95% CI[1.874, 4.369], and t(816) = 6.792, β = 2.63, 95% CI[1.887, 3.398], respectively). How citizens felt about shallow geothermal systems explained half of their acceptance's variance (ΔR^2= 0.50) when affect was added to the model, becoming the only significant predictor associated with acceptance (t(816) = 36.164, β = 0.81, 95% CI [0.766, 0.854]). Results were similar for voting intentions and Riskmeter choice, in that citizens' affect was the only significant predictor associated with them (t(816) = 39.795, β = 0.92, 95% CI[0.872, 0.963], and t(618) = 8.722, β = 0.57, 95% CI[0.443, 0.698, respectively; see Appendix A2.2.2–3). These results were independent from citizens' biospheric values.

In summary, Time 1 hypotheses were partially supported. Congruent with our expectations, citizens' feelings about shallow geothermal energy were positively associated with their benefit evaluations and negatively associated with perceived risks of shallow geothermal systems (H_1 supported). Furthermore, how citizens felt about shallow geothermal systems was positively associated with acceptance (H_1 supported), and was associated with their subjective and objective knowledge of shallow geothermal systems, even if the majority of citizens reported low initial levels of subjective knowledge. Contrary to our

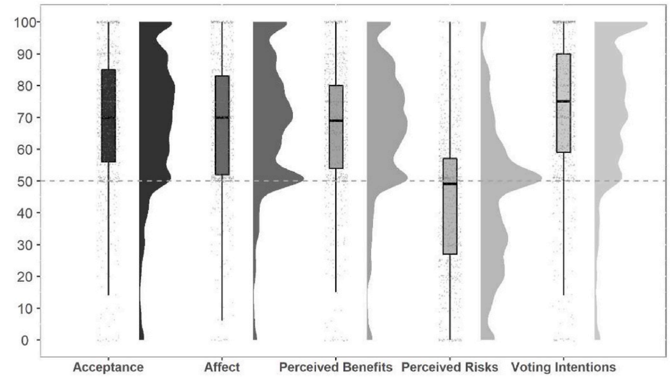

Fig. 1. ***Box and raincloud plots for the distribution of main geothermal-specific variables at Time 1 – Affect towards and evaluations of shallow geothermal systems.*** From left to right: Acceptance of shallow geothermal systems, affect towards shallow geothermal systems, perceived benefits of shallow geothermal systems, perceived risks of shallow geothermal systems, and intentions to vote in favor or against shallow geothermal systems. The values increasing from 50 in the y axis related to being more accepting of, feeling more positive towards, perceiving more beneficial and riskier, and expressing intention to vote in favor of heating production through shallow geothermal systems. Values decreasing from 50 related being less accepting of, feeling more negative towards, perceiving less beneficial and less risky, and expressing intention to vote against shallow geothermal systems. The dashed line represents the neutral anchor point for each visual analog scale.

Table 2
Regression model for affect towards shallow geothermal systems.

				95% Confidence Intervals		
Predictor	Estimate	SE	t-value	Lower	Upper	*p*
Intercept	50.18	3.25	15.543	43.809	56.558	<.001
Education	0.24	0.42	0.577	−0.587	1.077	.56
Age	−0.10	0.05	−1.881	−0.200	0.004	.06
Gender	−0.01	0.01	−0.360	−0.032	0.022	.72
Biospheric values	0.07	0.50	0.148	−0.900	1.047	.88
Altruistic values	0.71	0.49	1.449	−0.253	1.677	.15
Egoistic values	−0.09	0.37	−0.239	−0.809	0.633	.81
Hedonic values	−0.61	0.53	−1.136	−1.653	0.441	.26
Objective knowledge	**3.03**	**0.61**	**4.946**	**1.829**	**4.237**	**<.001**
Subjective knowledge	**2.63**	**0.36**	**6.981**	**1.889**	**3.367**	**<.001**

Note: $F(9, 813) = 13.55$, $p < .001$, $R^2 = 0.13$, $R^2_{adj} = 0.12$. Objective knowledge = Objective knowledge of shallow geothermal systems; Subjective knowledge = Subjective knowledge of shallow geothermal systems. Significance level adjusted, with Bonferroni correction, at p = .005. Significant predictors in bold.

hypotheses, biospheric values were not associated with any of our geothermal-specific dependent variables (H_{4A} not supported).

4.2. Time 2

At the beginning of the information provision, citizens across conditions felt similarly towards shallow geothermal systems, as the difference of affect towards shallow geothermal systems across conditions was not statistically different from zero or, if present, significantly smaller than $\delta = 0.20$ (Mean $_{diff}$ = 0.62, *t*-test $t(394.92) = -0.337$, $p = .74$; equivalence test $t(394.92) = 1.657$, $p = .049$). Only $n = 28$ participants initially reported negative affect towards shallow geothermal systems (i.e., affect<50): due to randomization failure, all were assigned to the Negative information condition. This did not affect our results (see Appendix, Table A3.3.1).

In line with findings on Time 1, citizens feeling more positive towards shallow geothermal systems also perceived the technology as more beneficial ($r = 0.80$, 95% CI[0.75, 0.83]) and less risky ($r = -0.56$, 95% CI[-0.63, −0.49]); the relationship between affect and these evaluations was stronger after the information provision ($\Delta r = 0.06$, z = 2.1049, $p = .035$, and $\Delta r = -0.15$, z = -2.7271, $p = .006$, respectively). In parallel, perceived benefits and risks were moderately and negatively correlated ($r = -0.57$, 95% CI[-0.64, −0.49]; $\Delta r = -0.24$, z = -4.1402, between Time 1 and Time 2).

The information provision was successful in causing affect updating in the Positive and Negative information conditions, and the multilevel model explained a moderate-to-high amount of variance of the affect updating after each trial of the information provision ($R^2_{marginal} = 0.44$, $R^2_{conditional} = 0.85$, see Table 3). Citizens receiving positive information felt more positively towards shallow geothermal systems (mean $_{Positive\ total\ update} = 14.43$, $t(173) = 11.897$, $\delta = 0.90$) compared to Time 1. The opposite was true for citizens receiving negative information (mean $_{Negative\ total\ update} = -30.98$, $t(165) = -16.347$, $\delta = -1.27$). Affect updating

Table 3
Multilevel model for affect towards shallow geothermal systems updating across trials in the information provision.

Predictor	Estimate	SE	t-value	95% Confidence Intervals Lower	Upper	p
Intercept	56.20	4.54	12.384	47.307	65.097	<.001
Age	−0.02	0.06	−0.279	−0.145	0.109	.78
Education	0.50	0.54	0.935	−0.549	1.550	.35
Gender	**−2.91**	**0.94**	**−3.078**	**−4.763**	**−1.057**	**<.001**
Condition Positive	**17.41**	**2.07**	**8.406**	**13.351**	**21.47**	**<.001**
Trial	**−1.12**	**0.04**	**−26.573**	**−1.204**	**−1.039**	**<.001**
Condition Positive * Trial	**1.48**	**0.06**	**25.482**	**1.363**	**1.590**	**<.001**
Altruistic values	0.66	0.65	1.019	−0.613	1.940	.31
Hedonic values	0.51	0.64	0.794	−0.748	1.768	.43
Egoistic values	1.09	0.47	2.325	0.171	2.007	.02
Biospheric values	−0.26	0.87	−0.294	−1.960	1.449	.77
Trial * Biospheric values	**−0.08**	**0.02**	**−3.561**	**−0.130**	**−0.038**	**<.001**
Condition * Biospheric values	2.18	1.20	1.823	−0.164	4.525	.06
Trial * Condition Positive * Biospheric values	**0.12**	**0.03**	**3.571**	**0.054**	**0.185**	**<.001**

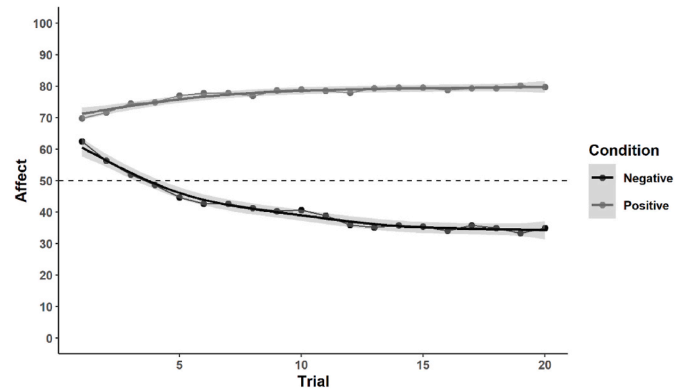

Fig. 2. Shape of affect updating curve across conditions in the information provision at Time 2. The y axis represents the affect towards shallow geothermal systems, with values increasing from 50 related to feeling more positively towards shallow geothermal systems, and values decreasing below 50 related to feeling more negatively towards shallow geothermal systems. The x axis represents the trial number, the number of information statements received. Participants in the Positive information condition are represented by the dark grey line, while the black line represents participants in the Negative information condition. Light grey bands represent the standard errors produced by model fitting with a GAM function. The dashed line represents the “neutral” anchor point (Affect = 50) in the visual analog scale.

was significantly less pronounced after receiving positive compared to negative information ($t(165) = 8.295$, $\delta = 0.90$; see Fig. 2) [2]. Citizens also differed across condition in the affect updating after each trial ($t(6443) = -25.482$, $\beta = 1.477$, 95% CI[1.363, 1.590]): simple effect analysis show that citizens in the Negative condition felt approximatively two times more negatively after each information statement ($t(3136) = -21.926$, $\beta = -1.112$, 95% CI[-1.211, −1.012]) compared to how more positive citizens felt in the Positive condition after each information statement ($t(3290) = 12.862$, $\beta = 0.361$, 95% CI[0.306, 0.416]); the exploratory multilevel model suggested that participants updated their affect the most when receiving the first five information statements (see Fig. 3 and Appendix, Fig. A3.3.1). As illustrated in Fig. 3, this relationship was exacerbated by biospheric values: although biospheric values did not significantly predict affect ($t(351) = -0.294$, $\beta = -2.554$, 95% CI[-1.960, 1.449], $p = .77$), the hypothesized three-way interaction with condition and trial was significant ($t(6443) = -26.573$, $\beta = -1.122$, 95% CI[0.054, 0.185]). The more strongly citizens endorsed biospheric values, the more positively or more negatively they felt about shallow geothermal systems after each trial, when receiving positive and negative information, respectively (Positive condition: $t(3292) = 2.134$, $\beta = 0.036$, 95% CI[0.003, 0.069], $p = .03$; Negative condition: $t(3137) = -3.186$, $\beta = -0.090$, 95% CI[-0.146, −0.034]), leading to overall more extreme final affect ratings (Fig. 3). Finally, female citizens felt less positive overall towards shallow geothermal systems ($t(309) = 6.852$, $\beta = 2.910$, 95% CI[-4.762, −1.057], $p = .002$). No other predictor was significant, and adding subjective knowledge at Time 1 as a potential moderator of the information provision did not increase the model’s explanatory power ($t(6780) = -1.483$, $\beta = -0.019$, 95% CI[-0.043, 0.006], p = .14).

We further analyzed how the citizens changed their acceptance, voting intentions, and Riskmeter choice in light of the information provision with multilevel models replacing the trial variable with Time factor. This model moderately explained variance in acceptance ($R^2_{marginal} = 0.32$, $R^2_{conditional} = 0.68$). The interaction between Time and condition was significant: compared to Time 1, citizens in the Positive information condition were more accepting of shallow geothermal

[2] $n = 32$ participants (9%) did not update their affect throughout the information provision.

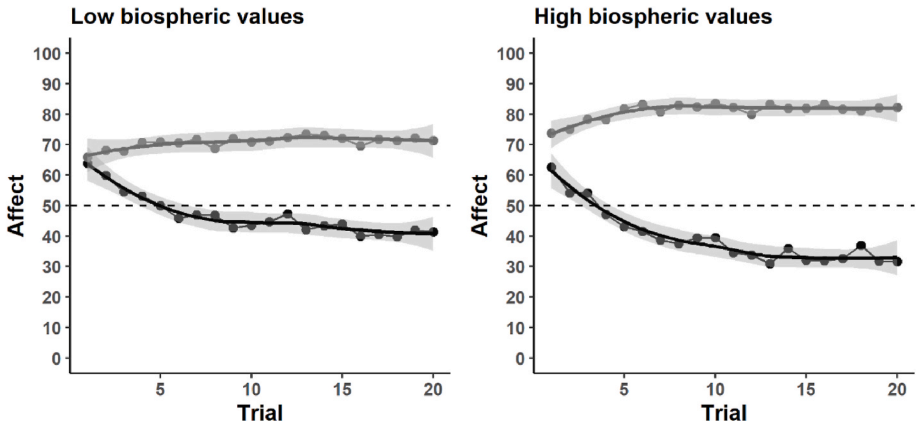

Fig. 3. Influence of information provision for participants with high and low biospheric values at Time 2. The y axis represents the affect towards shallow geothermal systems, with values increasing from 50 related to feeling more positively towards shallow geothermal systems, and values decreasing below 50 related to feeling more negatively towards shallow geothermal systems. The x axis represents the trial number, the number of information statements received. Participants in the positive information condition are represented in dark grey, participants in the negative information condition in black. **Left:** Affect updating curve for participants in the lowest quantile of personal importance of biospheric values. **Right:** Affect updating curve for participants in the upmost quantile of personal importance of biospheric values. Light grey bands represent the standard errors produced by model fitting with a GAM function. The dashed line represents the "neutral" anchor point (Affect = 50) in the visual analog scale.

systems ($t(174) = 3.776$, $\beta = 6.035$, 95% CI[2.902, 9.169]), as citizens in the Negative information condition were less accepting ($t(340.2) =$ -14.930, $\beta = -19.095$, 95% CI[-23.260, −14.930]) at Time 2. We also found a three-way interaction between Time, condition, and biospheric values ($t(340) = 2.704$, $\beta = 4.529$, 95% CI[1.247, 7.811], $p = .007$), which highlighted the changes in acceptance of shallow geothermal systems as a result of the information provision were magnified by biospheric values. We could not conclude that citizens in the Positive condition who bestowed more importance to biospheric values were more accepting of shallow geothermal systems ($t(174) = 1.066$, $\beta =$ 1.021, 95% CI[-0.856, 2.897], $p = .29$). Instead, increased importance to biospheric values was associated to citizens' being increasingly less accepting of shallow geothermal systems in the Negative condition ($t(340) =$ -2.542, $\beta = -3.508$, 95% CI[-6.212, −0.804], $p = .012$). Participants' voting intentions in favor of shallow geothermal energy production and their choice of proportion of deep geothermal electricity production for the Swiss 2035 electricity portfolio as measured by the Riskmeter were significantly predicted by Time, condition, their interaction, and their three-way with biospheric values, with the effects of biospheric values circumscribed to the Negative condition (see Appendix, Table A3.2.2–3). Finally, female citizens exhibited lower acceptance, lower intentions to vote in favor of shallow geothermal systems, and they chose a lower proportion of deep geothermal electricity for the Swiss 2035 portfolio (see Appendix A3.2).

In summary, citizens updated their affect, evaluations, and behavior in light of incoming information about shallow geothermal systems ($H_{2A\text{-}B}$ supported). Citizens felt two-to-three times more negatively and less accepting when processing negative information compared to how positive and more accepting citizens felt after receiving positive information, both overall and after each information statement they received.[3] Given that the mean baseline affect was positive, a ceiling effect for the positive condition may contribute to this asymmetry. However, the fact that we observed highly similar results for the Riskmeter choices (which were uniformly distributed at baseline) speaks against ceiling effects as the main driver of information effects.

As predicted, citizens updated their affect more after each information statement the more important they regarded biospheric values (H_{4B} supported). This moderating effect was also present in geothermal systems' evaluations (i.e., acceptance and voting intentions) and the Riskmeter choice, but limited to the negative information condition.

[3] These effects were robust against the previously mentioned randomization failure: removing the participants who started feeling negatively towards shallow geothermal systems did not affect these results, see Appendix Table A3.3.1.

Contrary to our hypotheses, biospheric values were again not associated with any of our geothermal-specific dependent variables ((H_{4A} not supported).

4.3. Time 3

Comparing baseline subjective knowledge (Time 1) to three months after the information provision (Time 3), citizens did not consider themselves more knowledgeable than before, or the change was smaller than $\delta = 0.22$ (Mean $_{difference}$ = 0.18, t-test $t(220) = 1.484$, $p = .14$; equivalence test $t(220) = 1.786$, $p = .038$).

Citizens feeling more positive towards shallow geothermal systems also perceived the technology as more beneficial and less risky ($r = 0.73$, 95% CI[0.66, 0.79], and $r = -0.49$, 95% CI[-0.58, −0.38], respectively). Again, perceived benefits and risks were moderately and negatively correlated ($r = -0.34$, 95% CI[-0.45, −0.22]).

The multilevel model to analyze the longitudinal effects of the information provision moderately explained variance in affect ($R^2_{marginal} =$ 0.36, $R^2_{conditional} = 0.69$, see Table 4). Compared to Time 1, citizens in the Positive information condition felt more positively towards shallow geothermal systems at Time 2 (Mean$_{diffTime1\text{-}Time2}$ = 10.31 ± 18.83, $t(234) = 5.510$, $\beta = 9.726$, 95% CI[6.266, 13.186], $p = .003$, see Fig. 4), but the difference disappeared at Time 3 (Mean $_{difference\ Time1\text{-}Time3}$ = 0.52 ± 14.88, $t(234) =$ -0.390, $\beta = -0.688$, 95% CI[-4.147, 2.772], $p =$ .70, $\delta = -0.03$). Compared to Time 1, citizens in the Negative condition felt more negatively at Time 2 (Mean $_{difference\ Time1\text{-}Time2}$ = −34.08 ± 27.73, $t(208) =$ -12.264, $\beta = -34.041$, 95% CI[-39.349, −28.570]). They returned to feeling positively towards shallow geothermal systems, but their feelings were significantly less positive at Time 3 compared to Time 1 (Mean $_{difference\ Time1\text{-}Time3}$ = −10.32 ± 22.64, $t(208) =$ -3.978, $\beta = -11.029$, 95% CI[-14.439, −5.594], $\delta = -0.28$). These results were independent from citizens' biospheric values ($t(442) = 0.356$, $\beta = 0.210$, 95% CI[-0.945, 1.365], $p = .72$), and female citizens felt more negative about the technology ($t(221) =$ -4.472, $\beta = 5.75$, 95% CI[-8.130, −3.375]). Citizens' acceptance and voting intentions followed the same trajectory, in that changes at Time 2 were partially retained at Time 3 for citizens in the Negative condition (see Appendix A4).

All in all, citizens in the Positive condition returned to pre-information levels of affect towards shallow geothermal systems. Citizens in the Negative condition at Time 3 still felt significantly less positive towards shallow geothermal systems compared to Time 1, so the effect of the negative information provision was partially maintained, albeit reduced by a half-to-two-thirds and with a return to feeling positive about shallow geothermal systems on average (H_3 partially supported). These longitudinal results were independent how important biospheric values were to citizens (H_{4A} not supported). Citizens'

Table 4
Multilevel model for affect towards shallow geothermal systems across Time.

				95% Confidence Intervals		
Predictor	Estimate	SE	t-value	Lower	Upper	*p*
Intercept	68.89	5.87	11.732	57.381	8.398	<.001
Time 2	**−34.00**	**2.41**	**−14.132**	**−38.720**	**−29.288**	**<.001**
Time 3	**−11.03**	**2.41**	**−4.584**	**−15.745**	**−6.313**	**<.001**
Condition Positive	−0.74	3.27	−0.226	−7.140	5.666	.82
Time 2 * Condition Positive	**43.73**	**3.91**	**13.701**	**37.474**	**49.986**	**<.001**
Time 3 * Condition Positive	**10.34**	**3.91**	**3.240**	**4.085**	**16.597**	**.001**
Gender	**−5.75**	**1.21**	**−4.742**	**−8.130**	**−3.375**	**<.001**
Education	0.71	0.70	1.016	−0.661	2.086	.31
Age	−0.004	0.09	−0.050	−0.176	0.168	.96
Altruistic values	1.31	0.82	1.597	−0.299	2.929	.11
Hedonic values	0.11	0.87	0.121	−1.608	1.820	.90
Egoistic values	0.70	0.61	1.142	−0.499	1.894	.25
Biospheric values	−0.63	1.37	−0.460	−3.318	2.056	.65
Time 2 * Biospheric values	−0.07	1.29	−0.052	−2.606	2.470	.96
Time 3 * Biospheric values	0.66	1.29	0.510	−1.878	3.198	.61
Condition Positive * Biospheric values	1.16	1.81	0.639	−2.697	4.288	.52
Time 2 * Condition Positive * Biospheric values	0.80	1.78	0.446	−2.697	4.288	.66
Time 3 * Condition Positive * Biospheric values	−0.45	1.78	−0.255	−3.947	3.037	.80

reporting small-to-no difference in subjective knowledge between Time 1 and Time 3 suggests that these results might be partially due to information forgetting.

5. Discussion

The aim of the current study was to investigate how Western Swiss citizens update their affective associations with geothermal energy, in the short and long-term, after receiving positive or negative factual information about shallow geothermal systems, and to identify individual differences which moderate these changes. We find that giving citizens information about the energy source causes large changes in their affect towards and evaluations of shallow geothermal systems. Citizens receiving negative information felt two times more negatively about and less accepting of shallow geothermal systems compared to how positive and more accepting citizens receiving positive information felt. Three months later, citizens receiving positive information returned to baseline levels of affect towards shallow geothermal systems, whereas citizens receiving negative information felt significantly less positive towards shallow geothermal systems. As predicted, citizens bestowing high importance to biospheric values updated their affect the most with each information statement. We discuss these results and study limitations next.

5.1 Accumulating information influences affect towards and

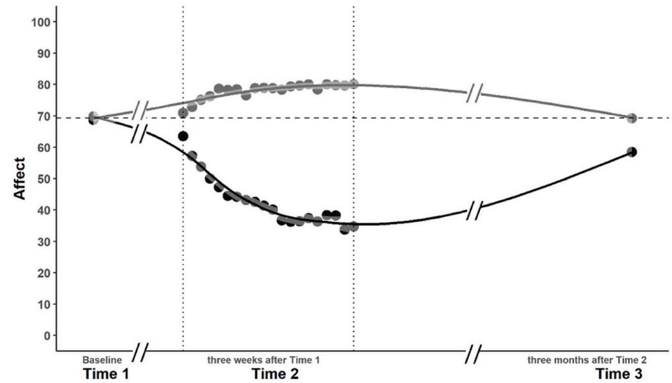

Fig. 4. Affect ratings through Time. The y axis represents the affect towards shallow geothermal systems, with values increasing from 50 related to feeling more positively towards shallow geothermal systems, and values decreasing below 50 related to feeling more negatively towards shallow geothermal systems. The x axis represents Time: the first dot represents the single affect measurement at Time 1, the following twenty time points represent the twenty affect measurements collected during the information provision at Time 2, and the last point represents affect towards shallow geothermal systems measured at Time 3. Participants in the Positive information condition are represented by the dark grey line, while the black line represents participants in the Negative information condition. The grey and dark lines are produced by model fitting with a GAM function. The dotted vertical lines represent the starting and ending points of the information provision at Time 2. The dashed line represents the "baseline" affect point at Time 1, as a visual aid to observe the long-term effects of the information provision.

evaluations of shallow geothermal systems: short and long-term dominance of negative information over positive.

The short and long-term asymmetrical dominance of negative information reflects the established finding in the social sciences that negative stimuli are more salient than positive ones (e.g., Rozin and Royzman, 2001; Smith et al., 2003), and that negative information are a better candidate for persuasive purposes (Brader, 2006; Soroka, 2006; Soroka et al., 2019). It also aligns with evidence that risk information has more impact on technology evaluations (Efendić et al., 2021; Knoblauch et al., 2018).

At the same time, our findings go beyond previous theoretical accounts by showing that positive information did not generate temporally stable affective associations, only negative information did. This entails that newly formed affective associations can expire if too much time elapses between creation and use, and that their consolidation partially depends on the positive or negative nature of the information processed. Since Finucane et al.'s (2000) studies, affect heuristic theorizing and research have both focused on the immediate effects of information provision and bestowed equal weight on positive and negative information in changing affect: our findings highlight the stronger influence of negative information on short-term changes and the long-term stability of newly forged affective associations with an energy technology. Both these aspects are underexplored and undertheorized but hold important implications for energy technology evaluations, and therefore represent a promising future research direction.

On an applied level, this entails that negative information is likely to engender bigger and more lasting changes in citizens' affective associations with shallow geothermal systems. Negative information causing longitudinal changes in affective reactions has also been reported in citizen panel studies, for geothermal systems, natural gas plants, and biogas, whereas information about other energy sources (e.g., solar panels, nuclear power) affected energy perceptions only in the short-term (Dubois et al., 2019; Volken et al., 2018). This discrepancy, Dubois et al. (2019) speculate, can be due to differences in initial knowledge and affective associations: for energy technologies that citizens have weak affective associations with and little knowledge about (e.g., geothermal systems, natural gas), providing information can induce longitudinal changes in energy perception; for energy technologies that citizens have strong affective associations with and more knowledge about (e.g., solar panels, nuclear power), information-induced changes are short lived instead. The low subjective knowledge expressed by West Swiss citizens at Time 1 might have therefore been fertile ground upon which new negative affective associations were formed and consolidated, influencing shallow geothermal systems' perception in the long-term. Future studies could test this hypothesis by measuring long-term information-induced change in public perception of different energy technologies involved in energy transitions, comparing energy technologies with strong affective associations (e.g., nuclear energy) with less known and more initially neutral ones (e.g., direct air carbon capture and storage; Federal Office for the Environment, 2019).

As we did not consider a time delay longer than three months for the Time 3 measurement, the decay curve of the effects of negative information on shallow geothermal systems' perception remains to be investigated. Aforementioned evidence by Visschers and Wallquist (2013) suggests that newly formed negative affective associations can be maintained up to six months when accidents occur. This is particularly poignant for geothermal system in general, as coverage of geothermal-induced seismic accidents is very present in Swiss media (Stauffacher et al., 2015): news about seismic events induced by deep geothermal systems (e.g., in Basel and in St. Gallen, Switzerland, and in Pohang, South Korea; Cousse et al., 2021; Stauffacher et al., 2015) increases the amount of negative information citizens accumulate, which may then create lasting negative affective associations for deep and shallow geothermal systems alike (Cousse et al., 2021). This long-lasting influence of negative information can thus explain ambiguous perception of geothermal systems by different publics (Duijn et al., 2013; Kunze and Hertel, 2017; Manzella et al., 2019).

The observed short and long-term dominance of negative information suggest it is important to reduce the damage negative information does to the public perception of geothermal energy. Psychological research offers useful techniques that can be implemented to address this issue, such as psychological inoculations (Lewandowski and van der Linden, 2021). This technique consists in pre-emptively providing counterarguments to rebut negative information before such information is shared with the public, rather than dealing with their aftermath (McGuire, 1961). Psychological inoculations have for instance been able to successfully reduce the influence of climate change misinformation on public perception of climate change consensus (van der Linden et al., 2017). The same approach can be implemented to protect citizens' positive perception of shallow geothermal systems against negative information before they enter public discourse and before they create strong and lasting negative affective associations.

5.1. *The enhancing effect of biospheric values on information accumulation*

Consistently throughout the study, citizens' perception of the renewable energy was unrelated to biospheric values per se (cf. Perlaviciute and Steg, 2014), nor were biospheric values related to subjective knowledge or long-term changes in perception of shallow geothermal systems: their role was selective to enhancing the short-term changes induced by information processing. Congruent with appraisal theory (Conte et al., 2022; Scherer, 2013), citizens who bestowed higher importance upon biospheric values updated their affect to a greater extent after each information statement than citizens who consider these values unimportant. Biospheric values also accentuated changes in evaluations of shallow geothermal systems and for the chosen deep geothermal electricity output for the Swiss 2035 energy mix, circumscribed to citizens who received negative information. As a consequence, citizens with high biospheric values who received negative information held the most negative feelings towards shallow geothermal systems at the end of the information provision. This was unexpected of pro-environmental citizens, stereotypical supporters of renewable energies (Perlaviciute and Steg, 2014).

This circumscribed effect of biospheric values on information processing about an unknown technology – shallow geothermal systems – suggests that biospheric values act as lenses through which information is processed (Conte et al., 2022; Schwartz, 1992). When enough information has been accumulated, the relationship between the technology and biospheric values is consolidated, biospheric values can directly color energy perception – as it is the case for well-known energy sources such as nuclear energy (de Groot et al., 2013; Perlaviciute et al., 2018). Once again, comparing information accumulation about well-known energy technologies against less known ones could provide some evidence as to whether this speculation is correct: for example, we would expect biospheric values to directly influence perception and information processing of well-known nuclear energy, and to be limited to information processing for less known direct air carbon capture and storage.

This enhancing effect of biospheric values on information processing could be used to good advantage to better engage the public about the technology. Hornsey and Fielding (2017; 2020) have shown that tailoring pro-environmental messages around people's values can enhance attitudinal change in situations that would normally entail resistance (e.g., motivating climate change deniers towards climate action; Bain et al., 2012; Feinberg and Willer, 2019). In parallel, tailoring messages around moral values have been shown to induce long-term changes more resistant to temporal decay compared to non-value-based messages (Luttrell et al., 2019). Therefore, the effect of biospheric values on information processing can be leveraged by tailoring positive information about the benefits of shallow geothermal systems to align with those values, in order to create lasting positive perception of these energy systems.

Overall, our findings highlight that citizens holding biospheric values in high regard can become either the keenest supporters or the staunchest opposers of geothermal energy production depending on the information they receive, at least in the short-term, and join recent evidence on the promises and pitfalls of the influence of values in environmental persuasion (Hahnel et al., 2020).

5.2. *Limitations*

Although promising, our findings should be balanced with the study's limitation. We used a single-item, self-report measure to assess affect. Flake and Fried (2020) comprehensively criticize single-item measurements and their validity – or lack thereof. Our choice was taken weighing measurement depth against the twenty-fold increase in questions during the information provision. Future studies can complement our longitudinal findings coupling a single information provision with granular measures of affect, such as the Geneva Emotion Wheel (Scherer, 2005). The information provision instead could benefit from the brain-as-a-predictor approach (Berkman and Falk, 2013) to move from less reliable self-reports to measuring the association between information-induced changes in affect and activation in brain regions involved in value-updating during information processing (e.g., Cooper et al., 2017).

A second limitation involves the directionality of the relationship between affect and evaluations. Measuring only affect during the provision did not allow us to discern if affect updating was the prime mover for the changes information elicited for the other variables, such as for acceptance. Our theoretical position was informed by the affect heuristic literature bestowing temporal primacy to affect (Slovic and Peters, 2006; see also Lodge and Taber, 2013). One potential future direction to disentangle this issue is to constrain the updating process to affective associations using associative learning paradigms, such as evaluative conditioning (De Houwer, 2007), to limit the influence of information and rely only on affective associations. However, whether this mechanism is purely associative or not remains an open question (see Corneille and Stahl, 2019).

A final limitation revolves around the choice of shallow geothermal system as our focus: in particular, we did not measure whether our participants were able to correctly differentiate across the different types of geothermal systems (deep, medium, and shallow), which holds important connotations for the evaluation of this energy technology (Cousse et al., 2021). Participants' choice of proportion of electricity produced by deep geothermal systems to meet Switzerland's 2035 electricity demand at Time 2 suggests similar susceptibility to the information-induced asymmetrical changes found with shallow-specific measures. This result possibly suggests a moderate spillover across evaluations of the two types of geothermal systems. However, we cannot conclude whether this was due to an affective spillover across types of geothermal systems (akin to that reported by Cousse et al., 2021) or due to participants' inattention to the difference between shallow and deep geothermal systems when interacting with the Riskmeter.

6. Conclusion and policy implications

The short and long-term dominance of negative information over positive has important implications for policymakers and industry engaged in informational campaigns about shallow geothermal energy and renewable energy more broadly. On the one hand, it highlights that public perception of geothermal energy is largely susceptible to negative campaigns, campaigns that are more numerous in the news than positive portrayals of the technology during policy implementation and salient events such as democratic referendums. On the other hand, it shows that public perception of geothermal energy is affected by positive factual information only in the short-term. Both issues can be proactively addressed by policymakers.

First, policymakers should aim to protect citizens' overall positive perception of geothermal systems. This can be achieved through psychological inoculations, where policymakers preemptively provide counterarguments to negative information about geothermal systems that are predicted to enter public discourse. Policymakers should focus on information about the induced seismicity risk of geothermal systems, developing pre-emptive counterarguments that explain why shallow geothermal systems have substantially lower seismic risks compared to deep geothermal systems.

Second, whenever the values endorsed by specific population segments are known, policymakers can tailor positive information so that it resonates with citizens' important values (e.g., protecting the environment, patriotism), to maximize the positivity and the temporal stability of citizens' affective associations with geothermal systems. Importantly, policymakers should do so *early* in informational campaigns. Joining the public discussion later increases the risk that citizens will ignore any positive information beyond the first few information statements, and also increases the risk that citizens will be exposed to negative information first which will consolidate negative affective associations with geothermal systems. Therefore, maximizing the amount of initial positive information that citizens receive about geothermal systems through value-based messages is a promising approach to foster a robust positive perception of these energy systems.

Psychological inoculations and value-based messages can complement each other: policymakers and industry actors designing informational campaigns should focus on positive, value-based messages that are complemented with pre-emptive and detailed counterarguments against negative aspects of the technology that are likely to be publicly discussed. Combining these two techniques may offer an increased chance to maximize positive affect and resistance to adversarial persuasive attacks, especially if they are delivered when public knowledge is still low.

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CRediT authorship contribution statement

Tobia Spampatti: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Ulf J.J. Hahnel:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Evelina Trutnevyte:** Conceptualization, Resources, Writing – review & editing, Supervision, Funding acquisition. **Tobias Brosch:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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