Entanglement of Top-Down and Bottom-Up: Sociotechnical Innovation Pathways of Geothermal Energy in Switzerland

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Abstract

By looking at deep geothermal energy in Switzerland, this article illustrates how innovation pathways in federal countries take entangled forms between top-down and bottom-up. The Swiss federal government presents deep geothermal energy as an important technology to decarbonize electricity production. Setbacks in early projects have slowed these efforts. Despite strong policy incentives from the federal government, no electricity is being produced from geothermal projects in Switzerland in 2019. Based on four case studies, we analyze how some cantons and cities have taken different pathways: Rather than implementing federal objectives, they favor heat production instead of electricity generation. The relative success of these initiatives led federal authorities to modify their approach to promoting geothermal energy. This study shows that federal mechanisms and instruments alone are not enough to make energy infrastructures acceptable locally. To learn from bottom-up experiences and adapt federal policies to local reality, better coordination between the federal and subnational levels is needed.

Keywords

geothermal energy, energy transition, federalism, innovation pathways, Switzerland

Decarbonizing the energy sector is a key component of greenhouse gas (GHG) mitigation efforts. Many countries are now engaged in energy transitions that will require a major shift in their energy systems, replacing the use of fossil fuels with renewable energy sources.

After the Fukushima nuclear accident of 2011, the Swiss public called for an energy transition away from nuclear and to renewable energy in a referendum held in May 2017. This led to the formation of a Federal Energy Strategy 2050 and was subsequently enforced in a new Energy Act in 2018. The strategy relies on increasing energy efficiency and promoting the development of renewable energies, including geothermal energy, while phasing out nuclear power plants. Scenarios for the Energy Strategy 2050 aim for a geothermal electricity production of 4.4 TWh by 2050 or about 8% of electricity production (Prognos AG, 2012).

Geothermal energy is the energy resulting from the decay of mineral elements in the Earth's mantle diffusing as heat through the earth crust. It has been used by humans for millennia for bathing, cooking, and district heating, and since the early 20th century to produce electricity. In its special report on renewable energy sources, the Intergovernmental Panel on Climate Change (IPCC) views geothermal as having "the potential to provide long-term, secure base-load energy and GHG emissions reductions" (Goldstein et al., 2011, p. 404). In vol- canic regions such as Iceland, Kenya, Hawaii, or the Philippines, geothermal energy can be captured easily and is largely used for electricity provision. In nonvolcanic countries such as Switzerland, capturing geothermal energy requires drilling into the Earth's crust at depths of several thousands of meters. This type of geothermal use is called deep geothermal energy (DGE).

Two types of technologies are used for DGE exploitation. Hydrothermal DGE consists in capturing heat from the Earth by drilling into hot aquifers at depth of over 1,000 m, where water is flowing in fractures in the rock. The flow rate must be sufficient to enable the water to reach the surface with enough heat. This heat can either be used directly, for instance, in a district heating system or be used to produce electricity if the water temperature arriving at the surface is over 100^{o}C. Hydrothermal DGE is dependent on the location of those hot aquifers. Petrothermal[1] DGE involves drilling at depths of over 3,000 m in bedrock or other geologic formations. Once the targeted depth is reached, an artificial reservoir is created by hydraulic stimulation, the industry's term for hydraulic fracturing (fracking). Water or brine is injected into the reservoir through one well, travels through the hot rock, and finally comes back to the surface heated through another well. Again, this heat can be used directly to produce electricity. When the reservoir is located deep enough, the likelihood to have enough heat to produce electricity is much higher. Therefore, petrothermal systems do not depend on hot aquifers. However, the use of hydraulic fracturing for the creation of

petrothermal systems comes with the risk of provoking earthquakes. Hydrothermal systems, on the other hand, are less prone to induced earthquakes. Their downside is that they come with the risk of not finding enough water flow in the targeted aquifers to produce the expected amount of geothermal energy (especially when the goal is electricity production).

The Swiss federal system is organized in three hierarchical levels: municipalities, cantons, and the federal state. It offers a high degree of autonomy to its member states, the cantons (Linder & Vatter, 2001). With different legal regulations across the 26 cantons, any national matter needs to overcome a number of administrative and cultural barriers and complications to take form. The direct democratic system provides opportunities to citizens and actors from civil society, including nongovernmental organizations and professional corporations, to intervene in the planning and implementation of policies and projects, especially ones with a local impact (Kübler, 1999; Linder & Vatter, 2001). Instruments such as national or local referenda and initiatives enable citizens to oppose or propose laws, policies, and projects provided enough signatures are collected. Moreover, several legal and administrative procedures allow stakeholders to contest projects. To avoid lengthy legal or political processes with uncertain outcomes, policy makers and project managers are therefore prone to engage with concerned stakeholders and the public in early phases (Kübler, 1999).

The importance of public and stakeholder engagement is especially visible in new and emerging sectors that do not yet have either clearly defined legal regulations or routinized decision-making processes or that are strongly context dependent, such as DGE (Ejderyan, Ruef, & Stauffacher, 2019). There is less experience with geothermal energy than other renewable energy sources put forward to decarbonize energy production worldwide (Pellizzone, Allansdottir, De Franco, Muttoni, & Manzella, 2015). Therefore, there is also comparatively little research on the social aspects of geothermal energy compared with solar or wind power (Manzella, Allansdottir, & Pellizzone, 2019; Moser & Stauffacher, 2015), and even less so on issues relating to the governance of this renewable energy source (Trutnevyte & Ejderyan, 2018).

This raises the question of the adoption of geothermal energy across Switzerland if the goals of the Energy Strategy 2050 are to be met. In face of the necessity to transition the energy system, federalism might lead to heterogeneous adoption across states and hence jeopardize GHG emissions reduction goals (Glicksman, 2010). DGE might be perceived as essential on a national level, but concrete consequences of its deployment will be put under scrutiny at local levels, which in return might again have an impact on the national level. However, federalism might also prove beneficial by enabling lower state levels to develop their own pathways to innovations (Schreurs, 2008).

In this article, we examine how national- and regional-level policies for geothermal energy are entangled. By entanglement, we refer to the fact that

the development of geothermal energy in Switzerland follows two pathways: top-down for electricity production and bottom-up for heat production. These two pathways influence each other. Events happening for one type of geothermal use will influence the perception of the other. Moreover, many projects combine heat and electricity production. Using one technological characteristic of geothermal, namely, the role of electricity versus heat production, we investigate this entanglement of top-down and bottom-up using case studies. This will enable us to highlight the role of different features of Swiss federalism as well as federal policy instruments in these entangled dynamics. Our case studies illustrate the sociotechnical character of technological development, as neither technological requirements nor social aspects alone account for these processes.

Geothermal Energy in Switzerland

Development of DGE

Switzerland is a world leader in terms of the density of heat pump installations (Rybach, 2013). These shallow geothermal installations that are mainly used to heat individual buildings are not the focus of this article. Still, the widespread use of heat pumps positively influences the perception of geothermal energy, more generally, including when it is derived from greater depths (Stadelmann-Steffen & Dermont, 2016).

As of January 2019, no electrical power was being produced from geothermal resources in Switzerland. Early developments of DGE were stymied by notorious incidents. One particularly serious one was tied to the Deep Heat Mining project in Basel, which was supported by the local energy utility Industrielle Werke Basel AG and city government; it was heralded as what was to be the first commercially operating petrothermal power plant in the world. In 2006, how- ever, project-related work triggered a 3.2M earthquake in 2006, forcing a project stop. Another 3.5M earthquake occurred in 2013 when drilling for a hydrother- mal project carried out by the energy utility St. Gallen Stadtwerke and city authorities of St. Gallen unexpectedly hit a natural gas reservoir. Although drilling operations resumed after the earthquake, the project was terminated because of its low hot water flow.

Despite these two failed flagship projects, there are about 20 projects underway or in planning; they are different in their scale and technologies; most are hydrothermal systems (Ejderyan et al., 2019). Among those, the actively producing systems are mostly mid-depth projects with drilling depths varying between 300 m and 2,371 m. The largest active project is the Erdwärme Projekt in Riehen near Basel with a capacity of 5 MWt of heat. All other projects are very small in comparison, with a capacity of 1.35 MWt or less. One

reason often invoked to explain this slow development is a lack of knowledge about the Swiss underground. Other explanations focus on the legal institutional framework and social acceptance (Wiederkehr & Abegg, 2015).

Support for DGE in Switzerland

The Swiss federal structure and direct democratic system result in a wide range of actors influencing the development of DGE. Energy policy in Switzerland is shared among the three federal levels (Thaler et al., 2019). At the federal level, the Swiss Federal Office of Energy is in charge of developing and overviewing energy policies, while cantons and municipalities are responsible for their implementation.

Regarding electricity production, the federal government has considerable influence. With the Energy Strategy 2050, the federal government decided to phase out nuclear power and strengthen its support for the development of renewable energy. The federal government has various instruments; it can use to steer such development, for instance, by setting the level of feed-in tariffs. It also oversees the national electricity grid (Thaler et al., 2019).

The Energy Strategy 2050, which was backed by a public referendum, led to the establishment of a basic law for DGE and increased this renewable energy source's legitimacy. Prior to this time, the Swiss Federal Office of Energy supported single geothermal projects from its own budget. It also sought to implement an exploration risk guarantee covering 50% of exploration costs for projects aiming to produce geothermal electricity but had insufficient resources to carry this out. Since the inception of the Energy Strategy 2050 and the Energy Act of 2018, however, the share of exploration costs guaranteed by the federal government has risen to 60%. The Energy Strategy 2050 foresees a significant role for DGE in the Swiss energy mix with a target of 4.4 TWh electricity production by 2050 (Prognos AG, 2012). In Switzerland, knowledge about the deep underground is low compared with countries that have an oil and gas industry. The presence of deep geothermal resources can only be determined through exploratory drilling (Hirschberg, Wiemer, & Burgherr, 2015). In Switzerland, such drillings cost the equivalent of several tens of millions of dollars depending on their depth. Therefore, large deep geothermal projects are usually initiated by public utilities, cantons, or big cities. Geo-Energie Suisse, the only private operator for DGE in Switzerland, is owned by a consortium of public utilities.

As part of the Energy Strategy 2050, geothermal energy infrastructure is now considered to be of national interest (as is all renewable energy infrastructure), making it more difficult for opponents to contest such infrastructure based on local concerns alone. Moreover, the Energy Act introduces a preferential price for electricity produced by geothermal energy. Finally, the Swiss Federal Office of Energy supports DGE development through the funding of pilot projects and

research programs.

As the Energy Strategy 2050 focuses on electricity, no target has been set for heat production from geothermal. The strategy puts a strong focus on developing alternative renewable electricity infrastructure, and geothermal is framed as a source of baseload electricity because of the ability of geothermal power plants to produce electricity continuously and in stable quantities. The exclusive focus placed on electricity production was later challenged in economic analyses which showed that without the additional heat benefit DGE would not become profitable in the Swiss context (Hirschberg et al., 2015; Knoblauch & Trutnevyte, 2018). In addition, the use of excess heat as well allows for a lowering of CO_2 emissions; heat produced by DGE can replace fossil fuels (Menberg, Pfister, Blum, & Bayer, 2016). The federal level has, however, fewer instruments in place to promote heat production than it has electricity production. The main reason for this is that the largest share of heat consumption comes from heating buildings. According to the federal constitution, the cantons are in charge of regulating the energy consumption of buildings. The federal is largely limited to an indirect influence on heating policies through the taxing of carbon emissions (Thaler et al., 2019).

Switzerland's 26 cantons are responsible for implementing the Energy Act. Sovereignty over the underground lies with the cantons, and as such, they are the authorizing bodies for any DGE project. Cantonal legal bases for regulating DGE vary strongly across the country (Wiederkehr & Abegg, 2015). In some cantons, the responsibility for geothermal energy projects is delegated to the municipalities. Cities that have enough financial capacity might even develop their own projects through their public utilities, as in the case of St. Gallen, or in partnership with private operators.

Public Acceptance of DGE

At the national level, geothermal energy is perceived either rather positively or relatively ambivalently by the population; it is less well known in comparison to other renewable energy sources (Moser & Stauffacher, 2015; Stadelmann-Steffen & Dermont, 2016). In a national survey on the acceptance of renewable energy based on a representative sample, over 55% of respondents indicated their support for the expansion of geothermal infrastructure for electricity production (Stadelmann-Steffen & Dermont, 2016). Another study comparing support for hydropower and DGE in Switzerland found similar results (Blumer, Braunreiter, Kachi, Lordan-Perret, & Oeri, 2018). National environmental non- governmental organizations generally have a positive attitude toward DGE. They consider geothermal as an alternative to fossil fuels for heat and—to a lesser extent given the potential of wind, solar and biomass—as a replacement for nuclear energy in electricity production.

Public acceptance at the national level is important as in Switzerland's direct

democratic system, citizens can have a direct influence on policies promoting DGE, through legal procedures or referenda. However, public support at the national level does not mean that the implementation of single projects will go smoothly, especially in a federal country. Residents living near sites of potential geothermal power plants might oppose specific projects, as has been the case with some DGE projects. Especially in cases where there is a low-probability high-consequence risk associated with DGE, perceptions of the technology can be impacted (Knoblauch, Stauffacher, & Trutnevyte, 2018).

Evolution of Public Discourse on Geothermal Energy

In the absence of national debates and social mobilization over DGE, analyzing media discourses offers a suitable proxy for understanding the evolution of public discourse on DGE (Moser & Stauffacher, 2015). Reporting in Swiss daily newspapers on geothermal energy has undergone various trends in the past 20 years, providing indications of the evolution of expert and policy dis- courses on DGE, as well as on the expectations associated with it.

A media analysis of the Swiss-German-speaking press from 1997 to 2013 showed that geothermal energy is mainly discussed in terms of risk, strongly impacted by the induced seismic events in Basel and St. Gallen (Stauffacher, Muggli, Scolobig, & Moser, 2015). A similar pattern was found by an analysis of the Swiss-French-speaking press covering the 1997 to 2017 period (results partly published in Ejderyan et al., 2019).

Reporting about DGE over the period analyzed followed similar patterns in both studies, with an initial low level of interest, that rose quickly after the 2006 Basel earthquake and then fluctuated in response to specific events (see Figure 1, showing similar results as in the study of the Swiss-German-speaking press by Stauffacher et al., 2015).

Prior to 2006, the main narrative in the Swiss press was that DGE had the potential to cover a large share of the country's energy needs (both electricity and heat) while reducing GHG emissions. During this period, there were very few negative arguments about DGE in the press, the main ones being the high investment costs and the fact that the technology was only in an early development phase. There were no mentions of seismic risk.

This changed dramatically with the Basel earthquake in 2006. The event generated high media attention and became a constant reference point for subsequent reporting on DGE. During the period 2006 to 2009, most articles reporting about DGE in Switzerland focused on seismic risk and questioned the possibility of its further development.

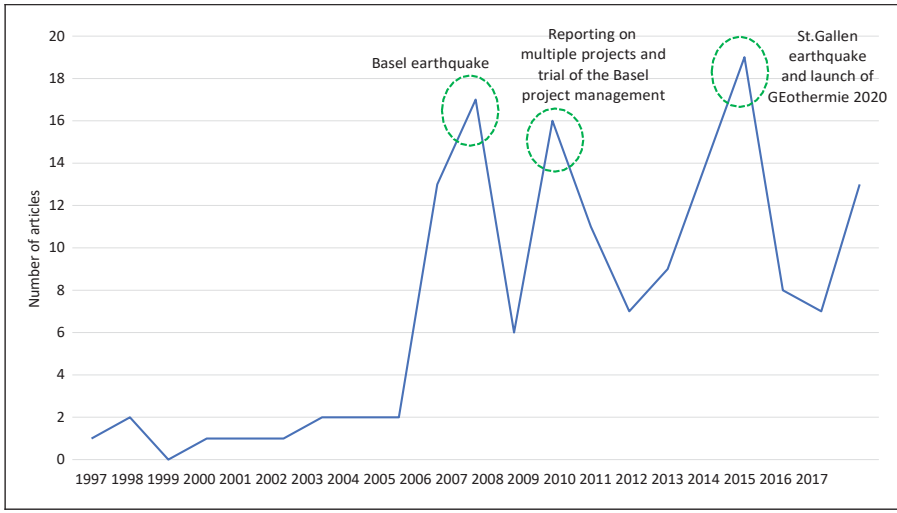

Figure 1. Frequency of newspaper articles with at least a paragraph on geothermal energy in *Le Temps* and *Tribune de Genève* over time (*N¼*152 articles).

Several plans to develop DGE projects were put on hold immediately after the Basel earthquake, but they resumed eventually. On the Swiss-German-speaking side, these were mainly the Triemli project in the city of Zurich[2] as well as the St. Gallen project. On the French-speaking side, there were also reports about these projects as well as reports about small projects in the canton of Vaud and about the planned Genevan geothermal program, GEothermie 2020. Most of the projects initiated at that time were hydrothermal and the promoters took care to emphasize that they were using a different *less risky* technology than in Basel. A recurrent narrative in the Swiss press was thus the distinction between hydrothermal and petrothermal projects. However, because of constant reference to Basel, all geothermal projects remained clearly associated with seismic risk.

The 2013 earthquake in St. Gallen initiated an increase in reporting both in the French- and German-speaking press. In the French-speaking press, a peak in reporting occurred in 2014 corresponding to the termination of the St. Gallen project as well as the first phase of exploration of the Genevan geothermal program. In relationship to the St. Gallen earthquake and the termination of the project when it was discovered that there were insufficient geothermal water resources, media reporting in both linguistic regions continued to highlight the seismic risks associated with geothermal energy. The French-speaking press, in contrast, did not associate the St. Gallen earthquake with a potential end to DGE, contrary to the situation after the Basel earthquake.

In the Swiss press, DGE has been discussed predominantly in relationship to specific projects and less in terms of national policy goals. In 2011, however, it was increasingly mentioned as an alternative to nuclear energy in articles reporting about the decision of the federal government to phase out nuclear power following the Fukushima accident. Subsequently, DGE was also discussed in reporting about the Energy Strategy 2050.

The study of the German-speaking press by Stauffacher et al. (2015) found that negative arguments about DGE in Swiss newspapers were more frequent in articles reporting about specific events or projects. This indicates that project- related dynamics might be prevalent in influencing the development of geothermal energy in Switzerland. This is in line with observations about the importance of contextual factors made in the previous studies about acceptance of DGE and DGE project development (Blumer et al., 2018; Ejderyan et al., 2019).

The importance of contextual factors is examined through four case studies in an effort to understand how local project dynamics were influenced by federal instruments and mechanisms, such as funding schemes, federal strategies, or the prerogatives of the federal states (i.e., the cantons). We then discuss what these instruments and mechanisms mean for geothermal energy and the meeting of the Swiss federal goals for geothermal energy.

Methods: Qualitative Case Studies

Geothermal projects in Basel, St. Gallen, and Haute-Sorne and the integrated geothermal program in the canton of Geneva are examined. These widely discussed cases have largely shaped debates about geothermal energy in Switzerland. Each is unique in terms of project scope, type of geothermal energy used or planned to be used, the actors involved, and—particularly interesting in light of the special issue's focus—levels of involvement of the federal states and resulting implications. The analysis and comparison show the importance of the canton in which a project takes place and the different roles they play.

The case study of the Basel geothermal project is based on a content analysis of the media and project documentation. Articles were analyzed to reconstruct the course of events and public discourses. The St. Gallen case study was conducted in 2015 and is based on an analysis of all written communications to the public by the project developers. Special emphasis was placed on how risks and benefits were communicated. In addition, to assess public perceptions, focus group discussions and interviews with the project management and residents were carried out by master students in a course supervised by two of the coauthors (see Muratore et al., 2016, for a detailed report). The Haute-Sorne case study has been ongoing since 2016. It is based on a content analysis of project documents and local media reporting, semistructured interviews with the

project developers, cantonal authorities, local politicians and residents (*n* 9), and participant observation at public events involving the local population. The case study in Geneva started in 2017. It relies on document analysis, participant observation of meetings of the program managers (35 meetings with 33 different participants) and focus groups with residents of municipalities in the canton of Geneva (six focus groups with a total of 52 participants). Table 1 summarizes the case studies and presents their main characteristics in terms of the technology used, the main actors carrying out the project, how the project was framed, and the main reactions it provoked.

To assess the relationship between local projects and federalism, we paid specific attention to statements and events that linked what is happening in the case studies to federal goals, policies, and instruments. This includes references to the national Energy Strategy 2050, more general statements about reducing national GHG emissions as well as mentions of specific institutions or mechanisms of Swiss federalism. This enabled us to learn more about how the different policy levels (municipal, cantonal, and federal) intertwine and overlap in energy transition discourses.

Basel

The Deep Heat Mining project in Basel was to develop a plant that would deliver 6 MWe of electricity and 17 MWt for heat uses. The project was developed by Geothermal Explorers Ltd and Geopower Basel AG, a sister company of the local public utility Industrielle Werke Basel AG. The parliament of the canton of Basel city approved funding for the project in 2004. Being a pilot project, it also received funding from the Swiss Federal Office of Energy. The project developers communicated about the project through media releases, exhibitions, and guided site tours. They emphasized its pioneering character and highlighted its potential benefits but did not refer to seismic risk. Although the project received some national media coverage, no active information and public engagement campaigns targeted the local population.

In December 2006, the injection of high-pressured water for the hydraulic stimulation of the geothermal reservoir provoked a 3.2M earthquake, causing strong reactions from the public. Minor damage to buildings was reported. The event triggered controversies criticizing communication about the project, the quality of the project management, and the absence of a prior risk assessment study. The canton of Basel city filed a lawsuit against the operator for causing the earthquake. Although the court did not hold the operator liable, in 2009, the project was definitively terminated.

Table 1. Summary of the Case Studies.

	Basel	St. Gallen	Haute-Sorne	Geneva
Type of technology	Petrothermal	Hydrothermal	Petrothermal	Hydrothermal
Purpose of project	Electricity and heat production.	Electricity and heat production.	Electricity production.	Heat production.
Project carriers	Joint venture between a private developer and the local public utility. Supported by the cantonal government.	Project initiated by the municipal government of the city of St. Gallen and the municipal utility.	Project developed by a private operator, with political support from the cantonal government.	Geothermal program carried jointly by the cantonal government and the local public utility.
Project frame	Pilot project to develop the world's first commercial petrothermal plant and produce clean electricity.	Being a pioneer community in the decarbonization of electricity and heat production to meet CO_2 reduction goals and becoming less dependent on oil and gas imports.	Pilot project to develop petrothermal technology for electricity production to support DGE at national level. Opportunity for local development through tax income and visibility.	Decarbonize heat production to meet CO_2 reduction goals and become less dependent on oil and gas imports. Develop a new local economic value-chain around geothermal energy.
Status	Abandoned	Abandoned	On hold	Ongoing

(continued)

Table 1. Continued.

	Basel	St. Gallen	Haute-Sorne	Geneva
Public reaction	The public appeared poorly informed about the project. After the project triggered an earthquake, reactions were hostile and demanded an end to the project. The government retracted its support for the project.	The project had strong public support. Funding was approved in a referendum by 83% of voters. Support remained high after the project triggered an earthquake. The project was abandoned because it did not find sufficient hot water flow.	The project started with strong support from the cantonal government, political parties and NGOs. A group of residents of Haute-Sorne initiated a campaign criticizing the authorization procedure, emphasizing potential risks and underlining the lack of local benefits. The project is now questioned by a growing number of local politicians.	Apart from localities where projects have been completed or are planned there is little public awareness of DGE. Stakeholders such as NGOs or potential collective end users are rather positive. In areas where projects are completed or ongoing, public reactions are favorable.

Note. DGE ¼ deep geothermal energy; NGO ¼ nongovernmental organization.

St. Gallen

In 2009, the city government of St. Gallen together with the local utility launched a feasibility study for a DGE project. The study was followed by large-scale seismic monitoring and in August 2010, the St. Gallen City Parliament approved the project. In November, the population of St. Gallen approved the project budget of CHF 159 million (138 million euros or about 150 million U.S. dollars) in a public vote with 82.9% in favor. Parallel to the planning of the geothermal energy project, the city also launched a preliminary study on the perceptions, hopes, fears, and knowledge of the people associated with geothermal energy (Holenstein, 2009). The first deep-well drilling and subsequent production tests were to be carried out in 2013. Unexpectedly, one drilling effort encountered gas that had to be blocked by injecting water. This injection provoked a 3.5M earthquake in July 2013. This was a setback for the project because it had been emphasized from the outset that the seismic risk of hydro- thermal systems is significantly lower than that of petrothermal systems and that earthquakes comparable to those caused in Basel were not to be expected. However, benefiting from the public's strong support, the drilling resumed to the planned depth. Due to insufficient water production rates and increased earthquake risk, however, the project was discontinued in 2014 (Muratore et al., 2016). It is worth noting that the reaction of the population to seismic events in St. Gallen and Basel, though they were physically very similar, was quite different: The intensity in St. Gallen was perceived less strongly than that in Basel (Edwards, Kraft, Cauzzi, Kastli, & Wiemer, 2015). This was certainly a consequence of the far better local information and engagement strategy in St. Gallen compared with Basel (Muratore et al., 2016).

Analysis of focus group discussions held in St. Gallen indicates that the benefit most often mentioned by participants was potential energy independence. Participants also discussed whether deep geothermal would be a way to phase out nuclear power and showed pride in having a pioneering image and being one of the first places to explore this technology.

Although not successful, St. Gallen's project influenced federal strategy on geothermal energy. The project targeted primarily heat production as a decarbonization strategy enabling the replacement of fossil fuels for heating buildings. In addition, it tried accessing hot water and explicitly did not follow the example of Basel, which fractured hot rock. Still it benefited from a federal guarantee that covered half the exploration costs in case of insufficient water resources. The support from the federal guarantee was an important argument municipal authorities could use during the referendum on the project budget: They argued that in case of failure, the city—and thus the local taxpayers—would not be alone in bearing the cost. As such, St. Gallen can be considered an early laboratory contributing to the fine tuning of the federal

strategy to develop geothermal energy.

Haute-Sorne, Canton of Jura

The Haute-Sorne project led by the operator Géo-Energie Suisse (2017), a national geothermal operator, plans to build a MW petrothermal power plant by capturing heat from an artificial reservoir created in a crystalline bedrock at a depth of 5,000 m. The project was presented to local authorities and the population in 2013. The government of Jura supports the project and delivered the building authorization in 2015. To ensure local support, Geo-Energy Suisse early on began an information campaign related to the selected site, Haute-Sorne.

Although cantonal and municipal authorities support the project, opposition from the local population has delayed its implementation. A group from Haute-Sorne is contesting the planning process in federal court. They argue that the project will cause noise, impact the landscape, and create risks for groundwater resources and seismicity. They also argue that there is little benefit for the population, as it is placed in a rural area where the additional heat benefit cannot be exploited economically (Knoblauch & Trutnevyte, 2018; Mascitelli, 2000). The operators tried to produce tangible local benefits by contracting with local companies for transportation or the printing of their communication materials. It even decided to have its local office in Haute-Sorne registered as a local company in order to pay cantonal taxes. However, these efforts did not produce sufficient benefits for the opponents to change their position.

In December 2018, the federal administrative court ruled in favor of the cantonal government, stating that the planning process had been conducted correctly and that all issues had been properly addressed. In parallel, citizens from the canton of Jura launched signature drive calling for a vote on a complete ban of DGE in the canton. The initiative was declared void by the cantonal constitutional court on the ground that it went against the federal Energy Act that mentions renewable energy infrastructures as of national interest. This ruling was possible because the Energy Strategy 2050 was approved in a federal referendum.

As of January 2019, the completion of the project remains uncertain. After a project in South Korea using a similar technique was declared likely to have triggered a 5.5M earthquake (Grigoli et al., 2018), the cantonal government has put the authorization on hold until an expert commission returns a full evaluation report of the earthquake.

The Haute-Sorne case is illustrative of the difficulties of implementing federal policies that rely on the construction of contested infrastructure. The project was to be a pilot for the type of geothermal power plants that would be needed to reach federal targets in terms of geothermal electricity production. Thus, from the beginning, it was an integral element of the national research and development program on renewable energies (Swiss Competence Center for

Energy Research-Supply of Electricity, 2017).

The Genevan Geothermal Program

The last case study is on the GEothermie 2020 program launched in 2014 and jointly led by the canton of Geneva and the local public utility Services industriels de Genève. The program, which includes several projects, has avoided the pitfall of single geothermal projects that stand and fall depending on one project outcome. Looking for hydrothermal uses of geothermal the locality is of crucial importance, as projects will only be developed in sites with suitable underground conditions. However, program managers realize that it is crucial to combine underground potentials with surface needs. The program needed to involve interested stakeholders, develop collaboration with universities, promote trans- national concertation due to the proximity to the border with France, and finally develop new industrial know-how as geothermal was a new activity for Services industriels de Genève.

The geothermal program in Geneva is mostly interested in geothermal explorations for heat, as heat constitutes the biggest part of energy use in the canton. This approach was chosen by the program managers despite the earlier focus on the federal level on geothermal for electricity production. In discussions with the Swiss Federal Office of Energy, the Geneva program management team was able to make a case for geothermal for heat projects, by emphasizing that it would contribute to reduce fuel oil consumption.

GEothermie 2020 gained visibility and traction within the Swiss Federal Office of Energy through direct contact between cantonal and federal officers, discussing the benefits of the program and possibilities to support it from a technical point of view. Program managers are well represented in the organization Geothermie-Schweiz, an organization where professionals active in geothermal energy convene and that promotes and lobbies for DGE. Being part of the board of this organization, the program managers of the Geneva program have a strong influence on its agenda and the communication materials developed. In the biannual conferences organized by Geothermie-Schweiz, there are regular talks and inputs on the Geneva perspective and an increased interest in geothermal heat projects can be observed.

Although GEothermie 2020 is focused on hydrothermal DGE, opponents to fracking in the Lake Geneva region were concerned that the geothermal pro- gram might eventually need hydraulic stimulation. Indeed, the Geneva geothermal program does not exclude the use of petrothermal technologies. Opponents to fracking have argued that this might also open the way to fracking for shale oil and gas. Although several members of the federal government have made public statements against fracking for fossil fuels, there is currently no ban or moratorium against the technology at the federal level. To avoid opposition to the geothermal program based on a mistaken assimilation to fracking, the Genevan government introduced a

law in 2017 banning the exploitation of fossil fuels as underground resources. The strategy has so far been a success, as two exploratory wells were drilled without any significant contestation as of March 2019.

Discussion

These case studies illustrate how the national and local dynamics on geothermal energy innovation processes are intertwined and mutually influential. Until the earthquake in Basel, public discourses on geothermal energy were largely positive. After the episode, reporting began to focus on seismic risk. This became the dominant frame of reporting about geothermal energy. Although the Deep Heat Mining project in Basel involved a local operator and was supported by the city government, it did not manage to connect locally, mainly because of a lack of local public engagement. The project developers' narrative emphasized that the project will constitute the first commercially operating petrothermal power plant in the world. It thus characterized the project's pioneering role rather than its local context. This project can be characterized as a local public–private partnership with little indication of a role for federalism, apart from the fact that it received federal subsidies because of its pioneering character. The failure of the Deep Heat Mining project raised questions about future geothermal developments in Switzerland, especially with regard to seismic risk. It is therefore not surprising that St. Gallen, the first major project to emerge after the failure of Basel, was hydrothermal and that it emphasized its local character. Developers of the St. Gallen project repeatedly stressed that their project relied on a different technology than the one employed in Basel. They emphasized that seismic risk was lower in hydrothermal projects as these do not necessitate fracking. The St. Gallen project diverged from the federal priority at the time to push for the development of petrothermal projects, as only such projects could be installed everywhere across the country. Project promoters in St. Gallen emphasized the local geological characteristics that would enable them to exploit geothermal energy and the potential for local use of the heat generated. In contrast to the Basel project, the municipal government of St. Gallen engaged with the local public early on and put the project to a public vote.

Although the project in St. Gallen was framed as a local initiative relying on specific geological conditions, it also benefited from federal incentives. This federal guarantee was an important argument during the public vote in favor of financing the geothermal project. The pioneering aspect of the project helped St. Gallen appear as a path setter for other cantons. The failure of the project, however, put into question the ability of hydrothermal projects to be implemented at the national level. It demonstrated that such projects are very dependent on specific local conditions. So in a way, the *localness* advantage that the project started with, turned against it in discussions about the possibility for scale-up.

The failure of the St. Gallen project was used as an argument by promoters of petrothermal systems as the only alternative for a large-scale deployment of DGE in Switzerland. Learning, from the experience in Basel, the main developer of petrothermal plants, has sought to engage the public early on, like they did for the Haute-Sorne projects. The strong public reactions that followed the earthquake as well as the high costs for damages incurred also lead to discussions about potential benefits in terms of acceptance of siting petrothermal plants in rural areas (Giardini, 2009). However, the example of Haute-Sorne is illustrative of how challenging it is to foster local support for a project when its main goal is to serve as a pilot project to scale-up a technology, with few perceived local benefits. Because the project was only for electricity generation and did not plan for any direct local use of heat it gave the local population the impression that they would have to bear the risks while not seeing any direct benefit. It appeared as a project imposed from outside. It did not help that the operator was from Zurich, the economic center of the country. That the discourse on being a pioneer or innovator that was so successful in St. Gallen did not function to create adhesion in Haute-Sorne illustrates the importance of context.

Haute-Sorne confirms the necessity to develop technological infrastructures from the start that could have a strong and positive local impact and to do this in collaboration with local actors. Indeed, although the project in Haute-Sorne is in line with the federal goals of the Energy Strategy 2050, it is strongly opposed locally. At the moment, it remains unclear whether the decision of the federal administrative court will provide sufficient legitimacy to the project for its continuation.

The Geneva program focuses on heat and, like in the case of St. Gallen, emphasizes the unique and favorable geological conditions that can make it possible to exploit geothermal energy. The program is framed as local, being executed, and planned by the local authorities and utilities. It differs from the St. Gallen project in that it prioritizes direct use for local heating, including at low temperatures. Although the program was not initially in line with the federal priority of increasing the share of renewable electricity production, its managers argued that developing a new technology—and hence a new economic sector— requires creating appropriate socioeconomic conditions. This requires public acceptance and local operators and investors that can realize the projects. The initial success of the geothermal program in Geneva, with the drilling of two wells at mid-depths, and a further one planned have shown that it is possible to advance geothermal energy in Switzerland for industrial and district heating purposes. The managers of the Genevan geothermal program have lobbied at the federal level to inflect the all-electricity prioritization of the Swiss Federal Office of Energy when it comes to geothermal. Their efforts have led to a proposal to extend the federal guarantee for exploration costs to geothermal heat projects. This extension was inscribed in the first version of the federal act on the

reduction of CO_2 emissions, which was refused by the Swiss National Council in November 2018. In the meantime, the second chamber, the Council of the States, proposed a new, much more ambitious, version of the act that still awaits ratification.

These four case studies illustrate different mechanisms through which a federal state can seek to influence the development of emerging energy technologies. Core narratives and the interplay between local and national levels of engagement and action vary as a result of local context and the chosen technologies. The Energy Strategy 2050 and the associated Energy Act are the main federal instruments supporting the development of geothermal energy in Switzerland. The Energy Strategy 2050 sets objectives to be reached for electricity production, thus formulating a political priority for a specific form of geothermal energy. In the Swiss geological context, this means pushing for the development of petrothermal systems as only these can deliver a large deployment of geo- thermal power plants. However, such projects come with a stronger need to justify their siting choices and to make potential benefits visible to local com- munities. Since in the Swiss federal system the cantons are responsible for implementing the Energy Act and authorizing geothermal projects, this implies that projects must be accepted at the level of individual members' states as well as the local population. The project in Haute-Sorne illustrates the difficulty for petrothermal projects have becoming embedded in a local context, although there is no technological determinism with regard to this. In a nonfederal con- text in the French region of Alsace in France, petrothermal projects managed to create local legitimacy by framing themselves as a green revival of former mining- and oil-related activities (Chavot, Masseran, Bodin, Serrano, & Zoungrana, 2019). But the Energy Strategy 2050, as well as the decision of the federal administrative court, did not manage to do the same in Haute-Sorne. Financial mechanisms such as the federal guarantee might help to make DGE projects more acceptable as the case of St. Gallen illustrates. That citizens of St. Gallen would not agree to bear the whole cost of the project in the case of exploration failure was an important argument during the campaign for the referendum. This was the case because the project was developed with taxpayers' money. For projects developed by nonlocal operators, such a guarantee is not likely to play a role in terms of local acceptance.

The Geneva geothermal program illustrates bottom-up dynamics at work in the Swiss federal system. The canton of Geneva chose to prioritize a heat pro- vision through DGE, instead of electricity production. It set up an important geothermal program which it finances. Partly given the importance of the local public utility and because of the high density of the population in the canton, this makes it economically viable. Similar developments of geothermal energy have occurred in the South of Paris. There municipalities started developing DGE for heating networks in the 1970s. These projects were supported by national subsidies and realized with little public awareness. In 2013,

about 187,000 homes were heated with geothermal energy (Poux & Bel, 2013). The projects around Paris are often mentioned by the managers of the Geneva geo- thermal program to illustrate the possibility of hydrothermal plants in densely populated areas.

Genevan authorities were able to develop a legal framework that suited the necessities of its geothermal program while simultaneously addressing local concerns. Similar legal frameworks can be pursued by other member states that wish to follow a similar path and offers more guarantees for the scaling up or diffusion of successful experiences. Efforts like those undertaken by the Geneva program to integrate the use of different levels of heat available in the underground can have a larger, positive impact on the Swiss energy transition. Such efforts could also result in more control from the federal state over heating policies. Encouraging the use of aquifers at shallower depths than those required for electricity production could lead to a diffusion of mid-depth geothermal and have a strong impact on carbon reduction in the heating sector, which still relies heavily on fossil fuel consumption.

Conclusion

The Swiss case illustrates that federal mechanisms play a role in the development of geothermal energy. In the case of a new and emerging technology-like DGE, influence is not a one-way street. In the four cases presented here, different aspects of federalism played a role.

Geothermal energy's development in Switzerland is following entangled processes that are typical for federal countries. Although the Swiss Federal Office of Energy has a clear agenda to support the development of high-temperature DGE for electricity production, some cantons and cities are successfully developing other pathways.

St. Gallen and Geneva have shown that the direct use of geothermal heat can play an important part in making DGE locally acceptable. The use of hydrothermal resources for heat can be more easily linked to local benefits by project promoters when the technologies used are perceived as less risky. They can contribute to decarbonization given that heat production is still dominated by crude oil and the insulation of houses is lagging far behind targets. Even the earthquake in St. Gallen did not signify the end of the project.

Current developments and potential changes in federal policies to support geothermal energy indicate that the federal administration is learning from what is done in the cantons and the cities. This could be done more systematically, as different contexts will ask for locally adapted technologies. This is needed to broaden learning at the national scale by multiplying and diversifying such experiments. Although geothermal energy might not contribute to the increase of renewables in the electricity sector as much as was projected by the Energy Strategy 2050, it might become central in reducing CO_2 emissions from heating.

Our study shows the necessity in federal countries to relate federal policies to local realities. Although transitioning the energy system is a political goal that was popularly legitimized by the referendum for the Energy Strategy 2050, this does not mean that specific implementation measures and single projects all have the same level of acceptance. Federal mechanisms and instruments alone are insufficient to make new energy infrastructure acceptable to local populations. Acceptance is mainly created at the local level by taking into account contextual factors (Ejderyan et al., 2019). Specific federal mechanisms and instruments, such as the federal guarantee that enables the sharing of financial risks among subnational states, or the ability of states to develop regulations that address local concerns might play a role for making energy projects more acceptable locally.

Finally, in order to systematize learning from bottom-up initiatives and make their experience transferable, the flow of information and coordination between the federal state and the cantons should be improved. This would enable a better tailoring of federal policies to cantonal needs and possibilities. Currently, exchanges take place bilaterally or informally in events such as the conferences organized by Geothermie-Schweiz. Permanent platforms enabling exchanges between the Swiss Federal Office of Energy, cantonal offices, cities, and operators could be set up. These platforms could take the form of commissions or working groups involving representatives of federal and cantonal offices in charge of areas relevant for the development of geothermal energy as well as representatives of municipalities that have the capacity to develop geothermal projects and operators. Such platforms exist already in other policy sectors, such as the National Platform for Natural Hazards (PLANAT, 2019).

More nonvolcanic countries are planning to develop DGE in order to meet GHG reduction goals. The Swiss experience can be useful to federal countries like Belgium or Germany that are engaging or have already engaged in developing DGE projects. The way the relationships between the federal state and member states are organized might vary between countries. But the Swiss experience illustrates the importance of coordinating between the different state levels in order to enable an effective implementation of top-down policies and to scale-up local successes.

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Notes

1. Although there are some technical differences, we use petrothermal as a generic term for stimulated DGE. Another widely used term that covers related technologies is EGS for engineered or enhanced geothermal systems. Other terms such as deep heat mining, hot dry rock, or stimulated geothermal systems partly or completely overlap with the notion of petrothermal (Geothermal Energy Association, 2016; Swiss Federal Office of Energy, 2015).
2. The Triemli project was a hydrothermal project that aimed to provide heat to the city hospital of Zurich. It was abandoned in 2010 after an exploratory drilling that found not enough waterflow.

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