GEOTHERMAL ENERGY AND ETHICAL RISK ASSESSMENT

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ABSTRACT

From ancient times, people have been exploring the planet for some useful materials. This search has been more than successful: coil, oil and gas became very important world's commodities. Their use however has not done any good to the ecological equilibrium. Today we are exploring other alternative energy sources and one of them – geothermal energy – presents the enormous undiscovered energy deposit our planet has to offer.

No matter what kind of resources we use, our continued reliance on the renewable energy should be safe first. Though replacing fossil fuels with geothermal could be beneficial in many ways, it could also lead to negative outcomes. It is in our responsibility to regulate the technology in an ethical way and assess the consequences so that welfare of the individuals and the society are considered.

The paper is based on a master thesis successfully defended at the Ruhr-University Bochum in Bochum, Germany in June 2018. The goal is to identify, analyze and evaluate the objective risks in different geothermal technologies according to their harm potential by means of historical evidence analysis and analog records methods. Risks are assessed regarding their causes, consequences and likelihoods for which the comparison-based evaluation is used. The research is embedded in the ethical framework: since geothermal risks are generally imposed on other people rather than personally taken the essential conditions of risk acceptability are characterized. The paper reveals what potential geothermal risks should we be aware of and which of them could result in graver harms. The outcome of the risk assessment makes it possible to answer the question what risks could be deemed acceptable from an ethical point of view and what not.

1. INTRODUCTION

Reconsidering our energy strategies, the world has discovered renewable and sustainable energy options – resources that are not replenished when used and leave a minimal impact on the environment.

Between wind, solar and hydropower, geothermal energy is not in the spotlight. Not only because it is "invisible", but also because it is rumored to be more risky than other alternative options. Geothermal triggers in some people's minds danger images: earthquakes, volcanoes, explosions, which contribute to a distorted social perception. Most of the time people pursue geothermal as a risky matter and have an impression that it is an unreliable and unknown energy source.

We know that it is impossible to leave the environment untouched when the energy is converted into such a form that can be utilized by our species. But how bad the ecological impact from the geothermal energy production can actually be? Is what people think true and could geothermal utilization do more harm than good? Or are they just misperceptions and no grave harms to individuals' welfare and well-being could result from its usage?

To answer these questions, first, one need to identify, analyze and evaluate the objective risks in different geothermal technologies. Second, we need to understand all possible consequences from the energy development and define resulting harms and benefits (the latter are not included in this paper). Third, if the impacts are of a negative nature one need to provide the justification criteria for accepting risks, in other words when can we agree to risks with their likelihoods, benefits and harms. Or, to cite B. Fischhof, "to regulate technology in a logical way, one must consider its consequences, assess it in an ethical way and take into account its impacts on the individuals and society".

2. SIX MAIN RISKS IN GEOTHERMAL

Any proposed alternative energy solution requires careful examination, including all its possible shortcomings and advantages. Geothermal energy as one of the renewable alternatives can be utilized for many purposes and technologies used for each of them vary accordingly. Thus, specific technical features that characterize each geothermal installation will determine the possible scope of its implementation, benefits it could provide and harms it could constitute.

The following abstracts describe six major detected objective geothermal risks. They are mentioned regularly in the geothermal literature and occur repeatedly during the geothermal energy development. They also constitute the main sources of concern among the public. The identification of each risk includes its description, risk cause and possible harms.

(1) Air pollution: most geothermal systems contain naturally occurring gases, the quantity of which vary from one resource to another. During the geothermal energy production, gases could be vented into the atmosphere. The most common ones include CO_2, H_2S and CH_4.

The total amount of non-condensable gases from the geothermal power plants represents 5% of all steam emitted, but the biggest part of this percentage is attributed to the carbon dioxide: it forms 90% of the total gas emissions. Though CO_2 does not pose any direct threats to human health – rather its effects are distributed in time – in the long run it does contribute to the global warming and as a result might impact the individuals' well-being.

As for the H_2S, its amount released differs from site to site but on average, it is estimated to be < 1 ppm, which can be detected by the smell but does not cause adverse effects on health. The problems start with the higher concentrations of H_2S: a person exposed to 50-100 ppm might suffer from a headache, nausea and experience other indispositions. The higher concentration of hydrogen sulfide (500-700 ppm) are known to be lethal after prolonged exposure.

Another common greenhouse gas is methane, which emissions are minimal and constitute about 0.5% of all gas release. Methane contributes to the global warming but does not affect human health. Estimations of CH_4 from geothermal power plants are very uncertain, since this gas is not always present in the geothermal systems: its amounts are usually insignificant and too negligible to be calculated.

(2) Water pollution: whether the wastewater disposal or the geothermal fluid leakage – both could lead to the water contamination. In the first case, the waste brine if discharged to a river, lake or another closely located body of water could affect the natural ecosystems and be toxic to some aquatic forms of life. In the second case, the unpredicted leakage of a geothermal fluid through the damaged well casing could contaminate water aquifers, which if used by the local population as a potable water resource might endanger their well-being and have adverse effects on their health.

Geothermal brine could be dangerous due to the heavy metals contained in it e.g. arsenic, boron, mercury. As with the greenhouse gases, the number of chemical constituents and their concentration levels vary significantly and is determined by the reservoir characteristics and the geothermal fluid properties. The information on water pollution in geothermal is very scarce: either such cases are non-existent or just not being reported on consistently. One of the extremely rare examples includes contamination of the shallow ground waters at the Balcova field, Turkey. The polluted waters were not used for the human consumption but for the agricultural purposes, so apart from reducing crops' production rates no other harms were detected.

(3) Soil subsidence: due to their specific location, some geothermal areas are prone to mass movement, therefore it is hard to attribute soil subsidence solely to the geothermal development. In most cases when the water is extracted from the reservoir it leads to the downward surface deformation. But usually the movement is confined to the site area and is not distributed to longer distances. The notorious exception is the Wairakei field in New Zealand, where major subsidence (15 m/yr) has occurred. Other than this, cases of dramatic soil subsidence are very rare.

Even though it is not a catastrophic process, soil movements might cause damages to the nearby buildings and facilities, constituting harms to the well-being of people in the process.

(4) Noise pollution: it normally occurs during the drilling, testing, construction and operation of the geothermal power plant. The highest noise level originates from the construction phase and corresponds to 65 dBA in case the necessary silence equipment is in use. If no precautions are taken, the noise level could reach 71-83 dBA, which almost does not exceed the urban noise limits of 80-90 dBA. When the power plant is installed, the noise from the normal operation is diminished to 15-28 dBA. This corresponds well to the maximum allowed noise level established by the World Bank: in the residential areas, it should be limited to 45-55 dBA, depending on the day/night cycle.

To constitute permanent damage to human hearing noise levels should be above 85 dBA (the level, which is not transgressed by geothermal). High noise levels could also affect animals (increased heart rates, scarce milk production etc.).

(5) Disruption of natural geothermal features: when geothermal facilities are built near natural geothermal manifestations, e.g. geysers and hot springs they usually affect them. Many geysers have already disappeared when geothermal power plants started to operate in a close proximity to them. For instance, Steamboat Springs site in Nevada, USA used to have natural geysers that are now extinguished because of the geothermal energy production. The total number of such examples is hard to calculate, moreover it is not clear how could the disruption of natural wonders affect the environment, or what harms could it cause for that matter.

It is worth mentioning that geyser and fumaroles could also appear and disappear without anthropogenic intervention. While many springs and geyser were disrupted after geothermal development, the new manifestations appeared or old ones were enhanced. This adds up to the confusion and makes it impossible to state the cause of change – anthropogenic influence or natural power.

(6) Seismicity: many geothermal areas are located in the seismic active regions, so usually seismicity is regarded as a natural geothermal phenomenon. There is a high probability that earthquakes occur naturally, not being related to any kind of geothermal exploration.

In the majority of cases the standard reinjection/extraction cycle cannot lead to the high-level seismicity. The reservoir stimulation however could trigger earthquakes when large water volumes are injected into the hot rock area. "Geothermal reservoir enhancement or EGS has in general shown a higher propensity to produce large magnitude events", - says A. Zang.

So far, EGS has led to many seismic events, some of them resulting in the harms to human welfare and economic well-being. The most recent induced seismic event happened in November 2017 in Pohang, South Korea with 5.5 M. The Pohang earthquake was "the largest and most damaging earthquake ever to have been associated with the EGS". While being probably the most harmful one – extensive damages to the city with 70 people injured – it is in no way unique. There is plenty of evidence from other EGS sites, which shows that site stimulation is closely related to the induced seismicity. Some examples include Southeast Geyser, USA with 4.6 M; Berlin, El Salvador with 4.4 M; Copper Basin, Australia with 3.7 M; Monte Amiata, Italy with 3.5 M (around 50 buildings reported damaged) and 3.4 M enhanced seismicity in Basel, Switzerland that also considerably damaged the city. Most of these projects are now abandoned due to the exceeded acceptable levels of seismicity.

Usual induced seismic events during geothermal enhancement fall under M 3 and are hardly felt by the local population. M 2 and less denotes the microseismic events that are not noticed by people. The actually damaging earthquakes start from M 5.

When compared to the naturally occurring earthquakes geothermal seismicity will seem harmless. One of the largest natural earthquakes with 8.8 M happened in 2010 in Chile: it costed the lives of 521 people, injured 12.000 and left 800.000 homeless. Though none of the geothermal technologies has resulted in such extensive numbers, one should keep in mind that "the probability of triggering earthquakes as a consequence of geothermal development is far greater than might be inferred from a review of the literature on injection technology".

The above list of risks is not fully comprehensive, because some of them were intentionally left out. They include landslides and different technical issues. As regards the first one, landslides do not represent risk as such, but rather come in consequence of other risks: seismicity and subsidence. It is highly unlikely that geothermal development could lead to landslides. Technical issues including maintenance and operational problems like scaling, blowouts, corrosion, cavitation etc. are also not included in the list since they are dealt with during the geothermal facility construction and operation phases and so should be reserved to the technical experts.

3. ASSESSMENT OF RISKS IN VARIOUS GEOTHERMAL TECHNOLOGIES

It is not enough to simply identify the most common risks in geothermal, one need to evaluate them according to their harm potential. For this purpose risk matrix is used, which shows the probablity distribution over consequences.

Probabilities represent the relative frequency data of a specific outcome based on the previous evidences. According to the risk literature, such probability is regarded objective because it is based on empirically known frequencies. Harms are differentiated by damage potential in three respects: harms to well-being, economic welfare and environmental hazards. Both harms and probabilities involve a descriptive commentary and thus they remain partially relative i.e. they are accurate only to a certain degree. Probablity and harm values shall be understood as such:

- 'highly probable risk' describes an event that is expected to occur;

- 'probable risk' refers to an event that is likely to occur;

- 'highly improbable risk' is an event, which is not expected to occur, but the potential still exists;

- 'negligible harms' means none or minor injury or illness (well-being), none or minor damage to household, possessions or equipment (economic welfare), none or minimal damage to ecosystems, fauna and flora, small release of GHG (environmental hazards);

- 'moderate harms' refer to no life-threatening injury or illness, when no hospitalization required (well-being), reversible damage to household, possessions or equipment (economic welfare), disruption of ecosystems, fauna and flora, medium release of GHG (environmental hazards);

- 'major harms' involve severe injury or illness resulting in a hospitalization or death (well-being), complete loss or severe damage to possessions, household or equipment (economic welfare), complete destruction of ecosystems, fauna and flora, huge release of GHG (environmental hazards).

Figure 1 shows the risk matrix and the probability distribution over consequences. The risks in the green zone involve negligible consequences and likelihoods thus they are potentially the least severe ones. The risks in the yellow and red zones correspond to moderate and major harm potential.

Probability	*Highly probable*	3	6	9
	Probable	2	4	6
	Highly improbable	1	2	3
RISK MATRIX		*Negligible*	*Moderate*	*Major*
		Harms		

Figure 1: Risk matrix: probability distribution over consequences.

By assigning the values from the matrix to geothermal risks described above, one can evaluate them with respect to different technologies. The research of geothermal technologies is confined to three main types of power plants (dry steam, flash, binary), geothermal heat pumps system – the most utilized direct use application – and the Enhanced Geothermal Systems (EGS).

The evaluation and assessment of the objective historically recorded risks connected to different geothermal technologies is presented in the Figure 2. Apart from determining the nature of risk by estimating the distribution of probabilities over harms, one extra factor is introduced i.e. data volume.

RISKS	**POWER PRODUCTION**			**EGS**	**DIRECT USE**
	Dry steam	**Flash**	**Binary**		**GSHP**
Air pollution *(C)*	3	6	0	0	0
Water pollution *(L)*	0	(*)	(*)	(*)	(*)
Soil subsidence *(P)*	0	(4)	(2)	0	0
Noise pollution *(P)*	(3)	(3)	(3)	(3)	1
Disruption of natural features *(L)*	*	*	*	*	0
Seismicity *(C)*	3	2	2	9	0

Figure 2: Risk assessment of the objective historically recorded risks connected to different geothermal technologies.

Geothermal risk assessment is largely determined by information at hand. Sometimes the data is unavailable due to the lack of statistical frequencies and historically recorded precedents. While information is sufficiently available in some cases, it is unsatisfactory in others. In order to ensure the reliability of estimations the 'foolproof' stage was implemented.

(CLP) refers to estimation of data volume that should help us see how reliable the likelihood values are and increase the efficiency of the method used. Overall, almost 150 papers were analyzed. The data volume is identified to be convincing (C) when the particular risk is mentioned in ≥ 90 scientific literature entries. Partial (P) accounts for approximately 50-60 papers and limited (L) for ≤ 20. The latter case represents the lack of substantial data on either harms or probabilities making it quite problematic to evaluate either of them. The example of water pollution risk represents exactly the case. No systematic data on the risk has been published, so the indication '*' is adopted to show that probabilities cannot be adequately assessed. It does not mean that the probability of such risk is zero rather it should be regarded as chance-like.

The risk of disrupting natural features is also marked with '*', but unlike water pollution, where probabilities could not be assessed, here harms are unknown: it is not clear what the disruption of natural manifestations could result in. Considering that only very limited amount of data on this risk exists, it is not possible to adequately assess harms. This should not be considered as a lack of significance, but as a reflection of a scarce data.

When values include '()' this indicates that the occurrence of risk is highly dependent on the proper operational management. Such technical risks include water and noise pollution and soil subsidence. All of them are usually avoided using the appropriate equipment.

4. ACCEPTABILITY OF RISKS IN GEOTHERMAL

1.1 Acceptability set

Above all things, risk is an ethical issue and the question of risk justification represents a central issue in the risk science.

Though sometimes overlooked in the technical risk assessment, the discussion on risk justification, or acceptability (these words are used as synonyms) is important for many reasons. First, it is significant from a moral point of view: if we know that our actions will expose others to risk, what could justify our choices? Second, it is significant from the social and political standpoints. Since risk acceptability is a part of a risk-decision problem, providing sufficient grounds for risk imposition would help one make ethically acceptable risk decisions.

So, what geothermal risks could be deemed acceptable from an ethical point of view? The following acceptability criteria represent an ethically plausible, somewhat restrictive but not too confining basic set of conditions.

Risks in geothermal are justified if:

- they involve negligible harms and their probability is low. Risks should be treated with regard to their harms and probabilities. Low-probability risks with negligible harms are more desirable than high-probability risks with severe levels of harm. Therefore, risks are acceptable if their consequences are acceptable. Such risks are located in the green zone of the risk matrix.

- they imply the avoidance of a greater disaster and provide other global benefits. This condition corresponds to the idea of 'preventing the risk of a greater harm'. In other words, if the effects of the risk materialization are rather small compared to the consequences of not taking that risk it is permissible to impose risk on others. In this case, as K. Steigleder puts it, "risks associated with not having the benefits are higher so the technology should be justified". In the case of geothermal energy preventing an even greater risk would mean the mitigation of global warming.

- enough reliable information about the risk is provided to risk bearers. It is often the case that technological risks are imposed on others without any warning or information. Those who partially control the risks (risk owners) have the superior knowledge about them and it is highly crucial they provide information to those affected by them (risk bearers). Since risks tend to be imposed on risk bearers, the burden of proof should be on risk owners to demonstrate the need for the technology.

Providing enough information to risk bearers is important for many reasons. First, it is a vital condition for ensuring the democratic control over the socially valued risk decisions. It is of great significance that "risk decisions are made in accordance with such process that recognizes the rights of individuals to make such decisions". Second, giving the public an opportunity to familiarize oneself with the geothermal energy and technologies is important for the productive communication. One of the main challenges in geothermal sphere is the lack of contacts between the experts and the public. Filling this gap is vital for the education purposes, but also for the promotion of geothermal energy.

Each of these conditions is of high value, but none of them alone would suffice to justify risks. Only taken together, as a set, they are powerful enough to make risks in geothermal acceptable. One must keep in mind that this set comes with its own challenges: almost each point leads to further considerations such as what do we define as a negligible harm and is it the same to everyone, what benefits should we consider etc. Complicated as they may be, these three conditions taken together could provide the necessary justification of risks in geothermal.

1.2 Acceptable risks in geothermal

Combining the acceptability set with identified risks in geothermal, one can see that among energy generation technologies binary and dry steam power plants are the least damaging and the risks they pose could be justified provided that other conditions are met. The use of the ground source heat pumps could be also justified, since it results in low probability risks and the harms associated with them are also negligible.

The most serious concerns should relate to the induced seismicity from the EGS, since reservoir enhancement could lead to grave harms. Mitigation of the seismic risks should be one of the priorities for the technical geothermal research.

The geothermal risk assessment introduced here relies on the assumption that comprehensive historical records are adequate to reveal the pattern of geothermal risks. Due to the changing technologies and innovations, the model applied in this analysis would not be very successful in predicting the distant future risks. However, it would be very helpful in clarifying and evaluating the general levels of risk in geothermal facing us at a current state. It could also point to risks and hence geothermal applications that require more attention from the geothermal experts.

5. CONCLUSION

The risk assessment of geothermal technologies embedded in the ethical framework has been conducted. Six objective major risks in geothermal have been identified and analyzed with regard to their causes, harms and probabilities using the comparison-based evaluation. The ethical evaluation was made about the risk's acceptability and the risk justification set was proposed. Such approach and the use of an interdisciplinary model aims to ensure that prosperity and well-being of the global community and the environment is not undermined and that we are careful with our choices, exploring all pros and cons of a particular energy source and making sure it is not only clean but also secure.

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