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Review of Environmental and Social Aspects and Best-Practice Mitigation Measures from an IEA-Geothermal Perspective

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ABSTRACT

The technical collaboration program of IEA Geothermal, has, since 1997, through its Working Group 1, undertaken cooperative research studies on environmental and social issues relevant to advancing development of new renewable geothermal resources and sustaining production from existing geothermal systems, by using state-of-the-art technology and best-practice procedures. The goals of the group are: 1) to encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner; 2) to quantify and balance any adverse and beneficial impacts that geothermal energy development may have on the environment, and 3) to identify ways of avoiding, remedying or mitigating adverse effects. Tasks include: a) addressing impacts on natural features by monitoring surface thermal feature and ecosystem changes and devising techniques to avoid or mitigate adverse impacts, while encouraging beneficial effects; b) rectifying discharge and reinjection problems, including gas emissions (CO_2 & H_2S), chemical contamination of water, subsidence, scaling and corrosion, treatment options, and reinjection strategies; c) developing methods of impact mitigation and environmental procedures through an analysis of issues, procedures, efficient policies, protocols, effective compliance, and successful strategies to address social and environmental effects; d) sustaining utilisation by undertaking long-term reservoir simulations, optimizing future operational strategies, improving recharge factors and recovery times, improving reservoir performance, and applying holistic sustainability protocol indicators.

This paper summarizes the recent outcomes of that collaboration amongst eight participating countries: Australia, Iceland, Italy, Japan, New Zealand, Norway, Switzerland and the United States. One highlight has been the raising of international awareness of successful mitigation schemes and beneficial environmental or social outcomes.

1. INTRODUCTION

Working Group 1 (WG1, Environmental Impacts) of the IEA-Geothermal TCP (see Carey & Wissing, 2020, for a description) has three principal goals: a) to encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner; b) to quantify and seeks ways to balance any adverse impacts that geothermal energy development may have on the environment; and c) to identify ways of avoiding, remedying or mitigating any adverse effects.

These collaboration activities commenced in 1997. WG1 was then known as IEA-GIA Annex 1. The tasks have changed over time, as different environmental and social issues were identified and discussed by participants at meetings and during workshops. The history of IEA-Geothermal involvement in environmental impacts and sustainability issues can be tracked through a series of World Geothermal Congress summary papers (Bromley et al., 2005, 2010, and 2015). To date, outputs have consisted mostly of published articles (including three Geothermics Journal Special Issues), protocols and environmental workshops or conference sessions. Currently, there are four active Working Group 1 tasks. They are listed and briefly described below:

a) Impacts on natural features: monitoring surface thermal feature and ecosystem changes and devising techniques to avoid or mitigate adverse impacts, while encouraging beneficial effects.

b) Discharge and reinjection: gas emissions (CO_2 & H_2S); chemical contamination of water, subsidence, scaling and corrosion, and treatment options (e.g. injection).

c) Methods of impact mitigation and environmental procedures: analysis of issues, procedures, efficient policies, protocols, effective compliance, and successful mitigation strategies to address social and environmental effects.

d) Sustainable utilisation strategies: long-term reservoir simulations, optimized future operational strategies, recharge factors, recovery times, improved reservoir performance, and sustainability protocol indicators.

Ongoing WG1 efforts include:

1) Preparation of a document describing international geothermal environmental codes-of-practice, and effective protocols and policies for environmental management of geothermal projects. Topics will include: construction and drilling environmental effects; injection or production induced seismicity; other production & injection effects (noise, effluents, emissions); social impacts; ways to promote beneficial effects and mitigate adverse effects; methods of drilling/producing/injecting deep beneath protected areas with negligible surface impact; subsidence mitigation by injection; avoiding groundwater contamination; biochemical remediation and treatment of condensates; monitoring of casing integrity to protect groundwater; appropriately allocating geothermal systems for protection or development using categories and ranking criteria; streamlining environmental impact assessments (EIA) by standardising common issues and good practice procedures; addressing cooling, stimulation and

make-up water issues; improving tools to monitor, model and manage sustainable reservoir performance and long term reinjection; and developing good practice communication with local and indigenous stakeholders.

2) Organising workshops or special sessions on, for example, sustainability and surface features,

3) Collating results of field trials for: a) targeted shallow reinjection of fluids to remedy adverse effects; b) gas injection; and c) water treatment to remove toxic chemicals.

Official participating countries in the Working Group are Australia, Iceland, Italy, Japan, New Zealand, Norway, Switzerland and the United States. This paper reviews efforts and outputs achieved over the past few years and suggests some future directions.

2. HIGHLIGHTS

Recent highlights of WG1 activities have included:

- Completion of a Virtual Special Issue of Geothermics Journal, focussing on the topic: 'Environmental Aspects and Social Acceptability of Geothermal Developments'.
- Networking and cooperation amongst researchers, operators, policy-makers and funding-agencies within the participating countries, thereby contributing to accessible publications on environmental or social topics.
- Helping to raise international awareness of successful mitigation schemes and beneficial environmental or social outcomes through presentations by researchers from member countries at international conferences and workshops.

Other highlights in the past few years included invited presentations on environmental topics. An example is a Japan/New Zealand collaborative workshop held by GNS-JOGMEC in November 2017, at Rotorua. Community engagement was also discussed at a meeting of GeMEX (cooperation between European and Mexican researchers) held in Akureyri, Iceland, in conjunction with the final IMAGE conference, held in October 2017.

3. ENVIRONMENTAL ASPECTS AND SOCIAL ACCEPTABILITY OF GEOTHERMAL DEVELOPMENTS

A virtual special issue of Geothermics, under the above title, was completed in 2018. Its purpose was to publicize, share and compare environmental and social acceptability issues and solutions between participating countries. Special issue topics addressed include: environmental impacts; social acceptability; integrated natural and social environment; socio-economics; pollution; monitoring tools; and thermal feature preservation. Nine countries were represented: USA; New Zealand; Mexico; Italy; Japan; Germany; Iceland; Finland; and Chile. A summary of key outcomes of this work is given in the following subsections.

3.1 Environmental aspects

Papers that addressed this topic provided examples from several projects and discussed environmental impacts. From the Tuscany region of Italy, Manzella et al. (2018) contributed a comprehensive description of the effect of geothermal development on the local air, water and soil environment, and discussed the potential disturbances from noise, subsidence, and seismicity, as well as the visual impact of a new geothermal power project (Figure 1).



Figure 1. Architecturally innovative designs of San Martino & Nuova Monterotondo power plants, Tuscany (photos: Fabio Sarton).

Using a case study from Iceland, Atlason & Unnthorsson (2017) showed that the environmental benefits, in terms of green-house gas emission reduction, of converting to renewable energy sources, such as geothermal, are substantial, but should account for the 'rebound effect'. This rebound factor accounts for changes in energy consumption behaviour over time. The provision of cheap renewable energy (geothermal heating) can increase energy consumption per capita, but also increases the economic benefit (especially tourism) and overall well-being of the population.

An example of the benefits of long-term monitoring of thermal water discharge from geothermal systems under production is documented by Sorey & Spielman (2017), using chloride flux data from Steamboat Springs, Nevada, USA. The natural discharge of deep-sourced thermal chloride water has remained relatively constant for more than 50 years, unaffected by reservoir production. The explanation offered is that the power plant uses a binary system with 99% liquid reinjection, which conserves overall mass balance. By way of comparison, the surface thermal feature monitoring reported by Heasler & Jaworowski (2018) uses remote

sensing (thermal infrared mapping) to illustrate the variations in hot spring activity that can occur naturally (examples from Norris Basin in Yellowstone Park).

Finally, a paper from Finland (Majuri, 2018) discussed the environmental impacts and complications of ground-source heat-pumps through a survey of problems encountered by GSHP installers. The most common issue reported was related to collapsed boreholes and potential contamination of groundwater aquifers by heat exchanger fluids.

3.2 Social acceptability of geothermal energy

Several papers addressed this topic with examples from a wide variety of projects and their impacts on local communities. Manzella et al (2018) discussed impacts of geothermal development on communities in Tuscany and concluded that the environmental monitoring and mitigation measures in Italy have maintained impact values below the thresholds defined by European and Italian regulations. As well as adverse effects, social benefits were also described. However, case studies from consultation reveal that some citizens did not feel that they were sufficiently informed to have a voice in the innovation process. Accordingly, it was recommended that mutual exchange of knowledge between different stakeholders, including local communities, should be strongly encouraged during project preparation and development.

A different set of social issues, related to local community acceptance of geothermal projects, was described by Vargas (2018) with respect to the Villarica-Araucania region of Chile. Here, the key issue was the need for early public education of the net benefits, potential adverse effects and practical mitigation options.

Local acceptability of geothermal installations was also addressed by Meller et al. (2018) in connection with a proposed underground laboratory (GeoLaB) to be sited within south-west Germany, for researching EGS stimulation technologies at scales intermediate between small-scale laboratory and large-scale, deep-drillhole projects.

3.3 Integration of natural and social environment

A novel approach to the task of integrating social and natural environmental concerns, to help solve them, is presented in Yasukawa et al. (2018), with examples from Japan. Here, significant historical use of geothermal waters for ‘onsen’ or bathing facilities, impacts local livelihoods and tourism, and this can cause social and environmental conflicts with large-scale power projects. A local assessment of the hydrological and geochemical relationship between deep geothermal reservoirs (for power generation) and shallow hot water aquifers (typically for ‘onsen’ use) allows for a prediction of interference effects in terms of flow-rate (or pressure), temperature and chemistry. This allows for planning of an appropriate integrated utilisation system acceptable to all stakeholders. An economic assessment of project proposals is combined with stakeholder attitude survey results and regulatory procedures to arrive at an optimal decision.

A study into the socio-economic potential for US geothermal development by Young & Levine (2018) demonstrated how a useful tool to provide a balanced assessment of the pros and cons, at the assessment and project proposal stage, is to conduct an investigation using “GeoReport” software. A new report by Millstein et al. (2019) on the environmental benefits of expanded geothermal deployment in the US out to 2050, provides a discussion of expected improvements associated with water usage, reduced air pollution and reduced green-house gas emissions. Identified benefits included using air-cooled, binary-power systems in arid areas where freshwater availability for cooling is limited. Also, there are beneficial options for supplementary injection of urban waste-water or brackish groundwater, rather than high-quality fresh-water, where and when needed to restore the mass balance in a depleted geothermal reservoir (e.g. The Geysers, California).

3.4 Effects on surface geothermal features and ecosystems

Recommended advances in designing and implementing monitoring schemes for surface geothermal features and associated rare vegetation or geothermal ecosystems are presented in two papers from New Zealand (Seward et al, 2018, and Beadel et al, 2018). Improved monitoring methods, particularly of heat loss from steam-heated ground, provides useful data for reservoir simulators to match. This will improve scenario predictions to inform future production and injection strategies. The objective is to mitigate adverse effects and promote beneficial effects through an adaptive geothermal system management plan and regulatory regime informed by such monitoring. Geothermal feature ecosystems, including thermally tolerant vegetation, are typically rare, and by identifying site specific threats to ecosystem health, and vulnerability to those threats, then effective actions, benefits and priorities of ecosystem management can be identified. Objectively determined indicators such as vegetation height, extent, count, or diversity, assist with quantifying long-term trends in ecosystem health with time, while accounting for natural variability caused by seasonal factors, or rainfall, for example.

Heasler & Jaworowski (2018) provided a good example of the benefits of long-term monitoring by remote-sensing of the natural variability in thermal feature discharges at Norris Basin, Yellowstone Park, USA, using airborne, night-time thermal infrared imagery. The spatial and thermal resolution of annual repeat surveys provides good information on the natural changes in extent and intensity of surface thermal anomalies. The technique is useful to record total surface radiation intensity across such an area, but should not, of course, be inferred to represent a true indication of changes in hot water or steam vent discharges.

A surface environmental geochemical investigation of the possible impacts of heavy metal enrichment from air-borne emissions of water vapour around the cooling towers of the Cerro Prieto Geothermal Power Stations in Mexico, was described by Gonzalez-Acevedo et al. (2018). Of all the potential carry-over elements tested, only one, sulphur, was found to be enriched. Increased concentrations (by up to 5 times) were found in leaves of a plant species growing near the power stations. The source of the sulphur is H_2S emission. Sulphur is also used locally as a fertilizer, as it enhances plant growth. The study gave a useful methodology for investigating potential sources of soil or plant contamination through airborne vapour emissions from geothermal cooling towers.

4. REVIEW OF RECENT ENVIRONMENTAL RESEARCH

In addition to the Special Issue discussed in Section 3, a review has also been undertaken of the past few years of geothermal conference publications on environmental topics and social impact studies. These are accessible for download through the IGA papers database. We focus on contributions by researchers from participating IEA-Geothermal nations. The topics canvassed are diverse.

4.1 Licensing, monitoring and regulation

A collaborative study on comparing Iceland and New Zealand project licensing and official monitoring of geothermal resources (Ketilsson et al., 2020) provides insights into the different ways that practical environmental regulation can be achieved and their relative pros and cons. Complementing this, the issue of how to best manage surface geothermal features to protect highly valued springs from adverse development effects is also addressed in Scott et al. (2018) in a significance ranking exercise for the local regulators in New Zealand. Figure 2a illustrates an example of successful adaptive injection management. Figure 2b is an example of an 'outstanding' feature from a protected geothermal system.



Figure 2a. Adaptive management of shallow reinjection at Rotokawa, New Zealand, has successfully restored this hot pool (Ed's/Toby's Spring) to its original state after a period of increased pressure had caused an overflow of acid-chloride water. (Photo - Duncan Graham)

Figure 2b. Champagne Pool, 'Waiotapu Thermal Wonderland', New Zealand; a monitored and protected natural geothermal system. (Photo – GNS Science)



Figure 3. Example of 'addressing' social impacts: hanging the washing under a geothermal pipeline (Philippines). (Photo-Brian Carey)

4.2 Social Impact studies

Five papers give excellent recent examples of social impact studies by participant researchers across a wide range of communities in geothermal areas around the world. Manzella (2018), Yasukawa et al. (2018), Levine et al. (2018), Nakagawa et al, (2017), and Bahr et al (2017) reported studies conducted in Italy, South East Asia, USA, and Japan. Manzella et al (2018) also provides a book on societal aspects with a collection of empirical geothermal case studies from across the world. Yasukawa & Anbumozhi (2018) prepared a report that includes social aspects in a critical examination of barriers to increased geothermal uptake in East Asia. The key messages are that communities respond well to early information dissemination and open communication. Participation or

some way of buy-in by the local community helps with a sense of local ownership or stewardship of the environment, and a common goal of enhancing social well-being for all. An example of community engagement is illustrated in Figure 3.

4.3 Geochemical and geophysical studies

Several recent papers have contributed to many previous articles addressing H_2S gas emission issues. Ben & Morrison (2018) and Gill et al. (2018) provide practical advice on dealing with H_2S scrubbing in power station turbines and condensers, while Fridriksson et al (2018) comment on greenhouse gas emissions from power plants relative to other energy alternatives. In this regard, Millstein et al (2019) calculate a levelized health-cost benefit of 0.5 USc/kWhr for geothermal generation relative to fossil fuel generation emissions in the US (specifically displacing emissions of SO_2, NO_x and particulates). Anticipated growth of ground-source heat pump heating for buildings in the US also displaces fossil-fuel noxious-gas emissions which has an even greater net benefit in health costs (up to $61B, avoiding up to 8700 premature mortalities, over the 35-year modelled timeframe).

The issue of accounting for geothermal non-condensible-gas (NCG) emissions to the atmosphere is still controversial, given that the origin of the gases (mostly CO_2 with small amounts of H_2S) is considered natural and any operational increase will eventually be balanced by a subsequent decrease from ground surface venting. However, the short-term effect of a temporary increase in atmospheric discharges arguably outweighs the longer term no-net-emission argument, because of the urgency of greenhouse gas emission reduction to minimize the adverse effects of climate change. Hence, it is important to find economic ways of reducing CO_2 and H_2S gas emissions from steam condensers through gas reinjection or treatment.

Peterschmitt et al. (2018) address the potential environmental issues linked to chemical stimulation of deep EGS wells in the Rhine Graben of Germany. Chemical stimulation is an alternative low rock-stress method of enhancing permeability where induced seismicity from high pressure hydraulic fracturing might be too hazardous for the local infrastructure and population. However, this paper reminds us of the risks of contamination of groundwater aquifers, and damage to well casings, that might result from inappropriate choice and use of chemical stimulants such as strong acids.

The occurrence of subsidence resulting from pressure decline in some geothermal fields has also been an important issue. Advances in monitoring ground deformation, understanding mechanisms, modelling compaction and predicting future subsidence, has remained an active topic for research. A recent study from Wairakei, New Zealand (Sepulveda et al, 2017), where up to 16m of local subsidence has been documented in the past 60 years, provides a good illustration of these advances. In-elastic yielding of highly-compressible hydrothermal clays, that are subjected to the effects of boiling and pressure changes over time, is a key mechanism. An example associated with a buried hydrothermal eruption crater is discussed in Bromley et al. (2019). As conceptual understandings improve, forecasting models become more reliable, and mitigating pressure management to avoid future adverse effects becomes more robust.

5. FUTURE PLANS

Gas emissions, reinjection of non-condensable gases (NCG, e.g. CO_2), and H_2S abatement technology remain important topics of research for the future. Improvements in surface thermal feature and ecosystem monitoring using drones, thermal imaging and satellite imagery are also continuing. Subsidence monitoring and improved modelling of reservoir deformation processes is ongoing. Induced seismicity has remained a significant environmental issue for many communities. Because of its importance, collaborative IEA-Geothermal research on this topic moved to Task D (Induced Seismicity) in Working Group 13.

Additional activities of Working Group 1 participants are planned to address the following topics:

a) shallow thermal ‘interference’ extent in groundwater (heating or cooling);

b) insurance industry information dissemination (communication of risks & solutions);

c) power-plant visibility (promotion of acceptable designs for a given landscape environment);

d) casing integrity (monitoring corrosion rates and recommending appropriate well designs); and

e) sustainability protocols in practical applications to assist regulators.

Environmental and social-economic concerns cover a wide variety of topics, and the relative importance of these is often site-specific. Figure 4 shows a site-specific example of a beneficial microbial ecosystem that has evolved at the hot-water outfall from an operating geothermal power station to the ocean. Never-the-less, it is useful to compile the topics that have proven to be important in the past. These provide a useful check-list and they can be ranked in importance for each new geothermal location. For example, tables that can be used as a check list of potential environmental effects are shown in Table 1 (for drilling and construction activities) and Table 2 (for ongoing geothermal operations).

Table 1: Environmental issues for drilling and construction activities

	Environmental Risks	Avoidance measures	Remediation measures	Mitigation measures	Relative cost	Relative Risk
1	Drilling effluent-surface water	Drilling waste sumps	Contain, treat, inject	Riparian planting	Minor	Low
2	Drilling effluent-groundwater	Treat, deeply inject drilling wastes	Pump out, treat, or deeply inject	Alternative local water supply	Moderate	Low
3	Noise	Muffled motors	Noise screens	Accommodate residents	Minor	High
4	Vegetation destruction	Directional drilling, road planning	Replacement planting	New planting	Minor	Medium
5	Excessive drilling water take from small streams	Seasonal schedule, pump from large stream/lake	Restore flow & stream habitat	Stream habitat enhancement	Moderate	Medium

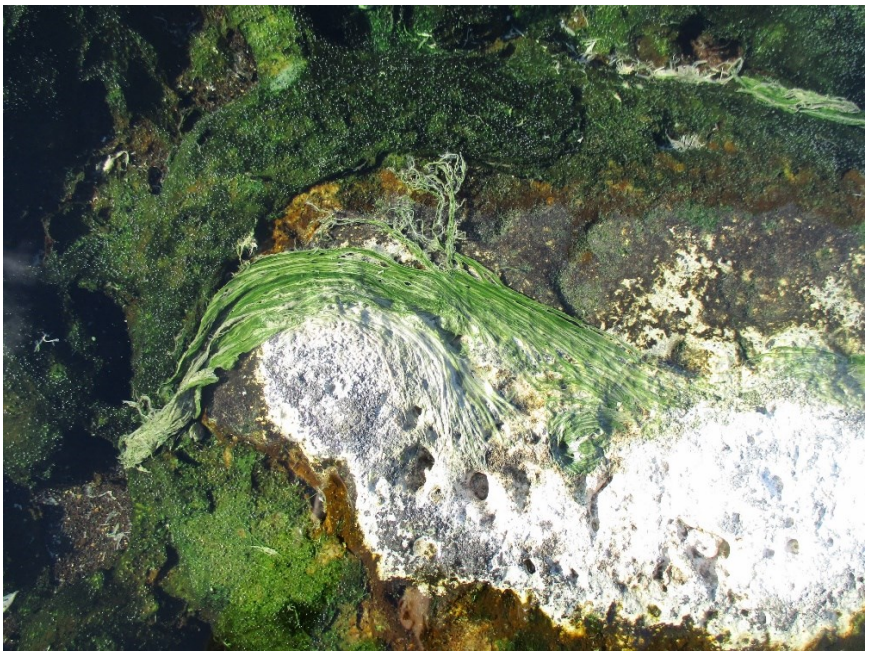


Figure 4. Thermal algae growing at the hot water ocean outlet of Reykjanes project (Iceland) illustrates ecosystem adaptation. (Photo-Chris Bromley)

6. CONCLUSIONS

Cooperation between Working Group 1 participating countries continues to be strengthened, and members are involved in a range of local and international research projects. Progress reports on WG 1 activities are presented at the Executive Committee meetings and as a chapter in IEA-Geothermal Annual Reports (IEA-Geothermal, 2019). Emphasis remains focussed on networking and connecting researchers, policy makers and operators from different countries to increase awareness of environmental improvements and successful strategies to mitigate adverse effects.

Activities are recommended to address the following additional issues: shallow thermal 'interference'; insurance industry outreach; power-plant visibility; casing integrity; and sustainability protocols. Reinjection of CO_2 and H_2S abatement technology remain important topics. Surface feature and ecosystem monitoring (e.g. Figures 2 and 3) are improving along with subsidence monitoring and improved modelling of reservoir deformation processes. Researchers from Mexico, USA, New Zealand, Italy, Switzerland and Germany have contributed their study results in advancing policy initiatives and sustainability.

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Table 2. Environmental issues for ongoing geothermal operations

	Environmental Risks	Avoidance measures	Remediation measures	Mitigation measures	Relative cost	Relative Risk
1	Discharge effluent - surface water contamination	Reinject all mineralised liquid discharges	Re-instate natural surface water quality	Replace or treat affected water supplies	Large	High
2	Discharge effluent - groundwater contamination	Avoid injection into potable aquifers of groundwater	Pump out & treat, or reinject into geothermal aquifer	Replace or treat affected water supplies	Large	Medium
3	Gas emissions (H2S, Hg, CO2)	H2S abatement, NCG injection	Plant forests	Compensate or relocate affected inhabitants	Moderate	Medium
4	Hot spring interference	Use injection to sustain shallow pressure/temperature	Restore dormant thermal features by targetted injection	Create new thermal features using waste hot water/steam	Minor	Medium
5	Induced subsidence or heave	Use injection to manage pressures	Repair/relocate affected structures	Enhance public amenities	Moderate	Low
6	Large magnitude induced seismicity	Limit injection pressure/temperature gradients	Repair induced seismicity damage	Construct quake-safe public amenities	Moderate	Low
7	Hydrothermal eruptions-landslides	Control shallow steam pressure, slope stabilisation	Repair damage, restabilize slopes	Reconstruction, enhance new features	Minor	Low
8	Noise	Remote site selection, low noise fans/pumps	Noise screens	Compensate or relocate residents	Minor	Medium
9	Powerplant/pipe visual effects	low profile structures, buried pipes	Camoflage painting, vegetation screening	Tourist facility enhancement	Minor	High
10	Unsustainable utilisation rate	Conservatively sized development stages	Production-injection strategy changes	Retire resource to allow recovery	Large	Low

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