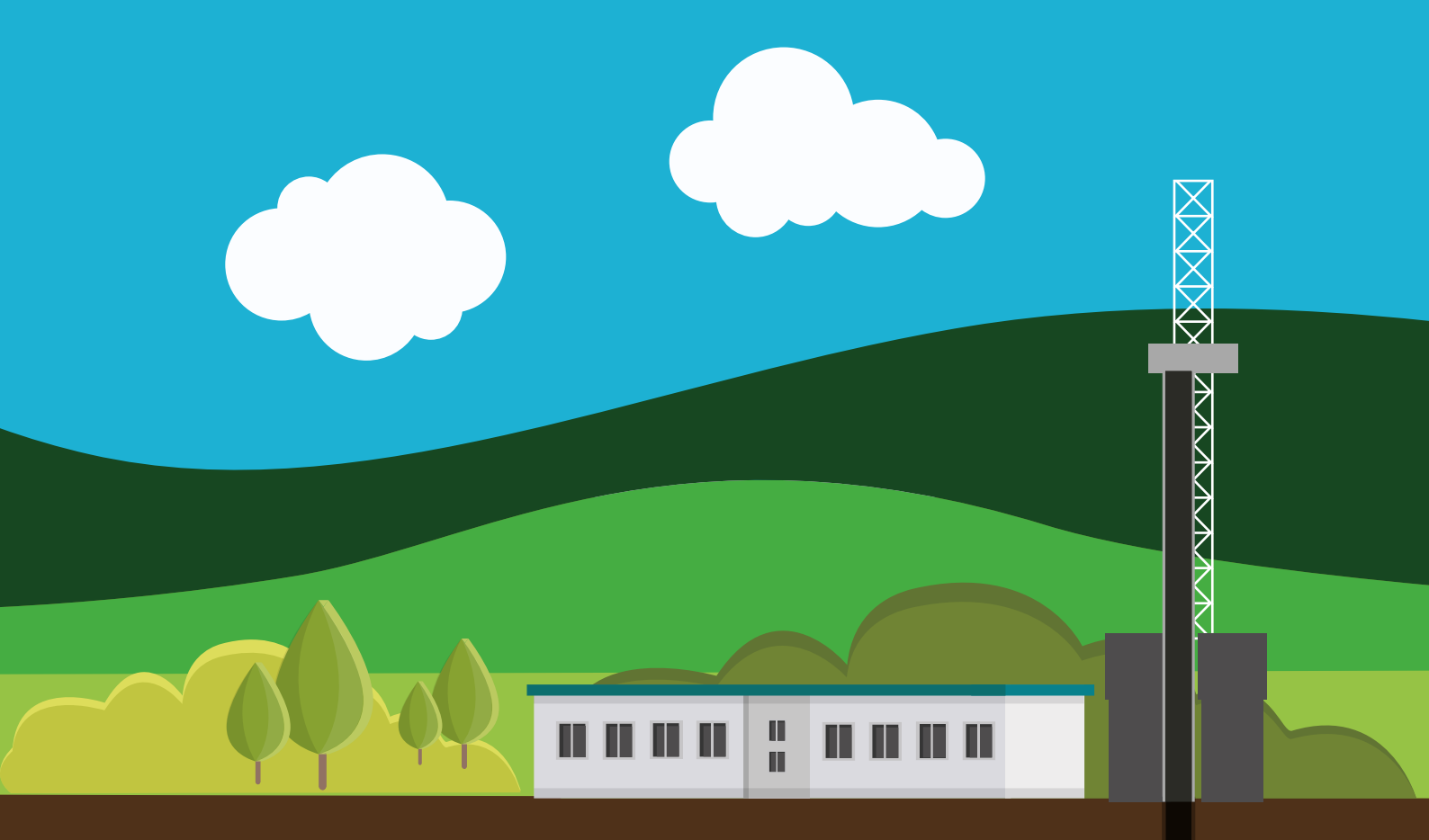

Considering geothermal energy regulations in the UK

Corinna Abesser; Stacia Ryder and Melanie Rohse

December 2023

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UKUH Unconventional Hydrocarbons in the UK Energy System
UKRI Economic and Social Research Council
UKRI Natural Environment Research Council

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December 2023

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1 Abesser et al., (2023) A deep geothermal energy white paper – The case for deep geothermal energy – unlocking investment at scale in the UK
2 Northern Ireland Department of Economy (2022) Research into the Geothermal Energy Sector in Northern Ireland, Geothermal Technology and policy review
3 Abesser & Walker (2022) POSTbrief 46: Geothermal energy
4 https://www.push-it-thermalstorage.eu/
5 https://www.energyrev.org.uk/about/

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Executive Summary

For deep geothermal energy, there are currently no planning rules, environmental regulations or licensing arrangements that are specific for the planning and operation of geothermal schemes. Activities are regulated through existing planning, environmental and health and safety regulations, typically subject to consent and controls by several regulatory bodies, including local planning authorities (LPA), environmental regulators, the Health and Safety Executive (HSE), and, if drilling encroaches on coal seams, the Coal Authority (CA) in Great Britain or the Department for the Economy (DfE) in Northern Ireland.

This report highlights the practical aspects of geothermal energy regulation in the UK and what stakeholders suggest an effective regulatory system could look like. It combines investigations of how operators and regulators experience the current regulatory landscape with learnings from the UK's experience with regulating shale gas exploration.

Data collection was based on semi-structured interviews with key stakeholders, including eight industry representatives, two local planning authority representatives and four representatives from national regulatory bodies.

Several themes emerged in relation to geothermal energy regulations:

Several participants highlighted that *geothermal energy itself currently is not recognised as a natural resource in UK legislation* and that there is *no regulatory authority in the UK with remit for managing the geothermal energy* (i.e. heat) resource. The lack of clarity on the ownership of the resource and the absence of a licensing system for geothermal energy extraction activities in the UK were identified by many participants as the main gaps in regulation.

Regulators acknowledge this gap in legislation but feel that all other aspects of geothermal activities (except for the resource aspect) are covered by existing regulations. While acknowledging that regulations were not written with geothermal in mind, regulators see existing regulations as fit for purpose thus far. Given the limited experience in regulating deep geothermal energy projects in the UK, there is currently uncertainty about what changes or additional regulations would be required.

Although not unique to geothermal activities, many stakeholders in industry regard the multi-agency approach to regulation as somewhat disjointed because there is no central point of contact or coordination between the regulating agencies. Operators must therefore liaise separately with the different statutory agencies.

Other limitations in the way deep geothermal projects are currently regulated, as identified by the participants of this study, include:

Environmental regulations: Some environmental regulators operate an evidence-led, risk-based approach to regulations that enables them to impose bespoke regulatory conditions on a case-by-case basis. This can result in differences in decision making and has been perceived by some in industry as producing an "unlevel playing field" within the geothermal sector with different requirements being imposed on operators in different parts of the country.

Drilling regulations: Drilling regulations for geothermal projects are directly adopted from oil and gas drilling. While some participants from industry perceive aspects of this regulation as irrelevant and "over-engineered" for UK geothermal systems, others find that there is still insufficient experience with geothermal drilling in the UK to identify if and how these regulations could be adapted.

Induced Seismicity: There is consensus that induced seismicity for geothermal projects needs to be regulated. For the monitoring of induced seismicity from geothermal activities, most participants favoured an approach based on Peak Ground Velocity (PGV), rather than an amplitude-based approach.

For most aspects (environmental, health & safety), the overarching regulations applied to geothermal projects are national, but decision making associated with their implementation for specific projects is

often based on local knowledge. Other aspects (including induced seismicity) are not covered by national regulation and rules about their management are developed locally. There was no consensus on whether geothermal projects should be regulated locally or nationally. Some considered local regulators to have insufficient capability (and capacity) to build the necessary expertise to regulate these complex geothermal systems. Others regarded the local route as adequate. From a regulator's perspective, there currently isn't a case for national-scale regulation of geothermal energy, because of the low numbers of geothermal projects and the type of operation. Also, the level of interest and concern from the public towards geothermal is seen as very different compared to shale gas, and hence some regulators and participants from industry do not currently perceive an immediate driver for nationalising regulation (e.g. for induced seismicity). They consider gaining and maintaining public acceptance as more important for the success of the industry than introducing a bespoke national framework of regulations for geothermal activities.

The following recommendations were identified for consideration:

1. Development of a geothermal energy industry in the UK will require that geothermal energy is recognised as a natural resource (in UK law) with clearly defined ownership. **A review of UK legislation (including legal status and ownership for other natural resources) is recommended to identify how this might be achieved.**
2. Concordantly, it is recommended **that a "regulatory home" is identified** for geothermal energy resources and that a **regulatory body is assigned** that has remit for the effective stewardship of geothermal energy resources including the management and licensing of its exploration and exploitation.
3. As the UK's experience in the development, operation and regulation of geothermal projects grows, it is recommended that consideration is given to **reviewing (and streamlining) existing regulations**. In the absence of a regulator with responsibility for the management and licensing of the geothermal energy resource (see recommendation 1), the appointment of a **coordinating authority** that coordinates the approval procedures between the different regulators could simplify the process for the developers, while ensuring that the regulatory process is fair and consistent for all applicants.
4. **Developing a licensing system** for the exploration and operation of deep geothermal projects (and appointing a licensing authority) will become important as the sector matures and demand for using deep geothermal resources increases. This requires legal recognition of geothermal energy as a natural resource (recommendation 1).
5. Induced seismicity is currently regulated differently for different subsurface activities. Development of **national guidance on how seismicity should be assessed and mitigated for deep subsurface activities**, including what metrics to use, how to define thresholds and how to monitor it, would contribute to more consistency in decision-making by the regulator(s).
6. Once drilling conditions for deep geothermal projects in the UK are better understood, **a review of drilling regulations** should be considered, including a comparison with regulations from countries with similar geologies and operations, to ensure that the regulations are fit for the purpose of geothermal drilling in the UK.

Other themes emerging from the stakeholder interviews included the importance of public engagement as well as the need for financial support for geothermal technologies. Whilst not examined in this study, we highlight these here as areas for further consideration and investigation.

Another fundamental question is: Can the current regulatory framework meet the objective of achieving a safe and effective industry and/or industrial operation? Answering this question was beyond the scope of this study. It could form part of subsequent investigations that analyse the risks and impacts associated with the different geothermal activities and how they are mitigated against in the current regulatory framework.

1. Background

Deep geothermal energy is regarded as an important renewable source of heat and power that has the potential to occupy a central place in a just energy transition as part of the UK's strategy to meet its Net Zero Commitment. Already established in other countries (e.g. The Netherlands, Germany), it is a nascent technology in the UK and therefore a key area of research in the country's move to a decarbonised energy system (Gluyas et al. 2018). Whilst the exploration and exploitation of geothermal energy is intrinsically technical, geothermal developments also include regulatory, social, spatial, and political aspects that have so far been neglected in geothermal energy research (Pellizone et al. 2019).

Access to deep geothermal energy can involve subsurface techniques for enhancing flow pathways within the rock[6] similar to those used in shale gas development, a practice met in the UK with much public concern and controversy (Short & Szolucha, 2019). While perceptions around induced seismicity were of particular importance (Bradshaw et al. 2022), opposition to energy projects (including renewable energy technologies - RETs) is not always about the technology itself but can also be about top-down models of decision-making, insufficient or insincere community engagement practices (Wolsink, 2007) or concerns relating to environmental impacts (e.g. Susskind et al., 2022).

There are currently no bespoke planning rules, environmental regulation or licensing systems that are specific for the planning and operation of geothermal schemes. Schemes are regulated through existing planning, environmental and health and safety regulation. How these rules are applied to individual geothermal projects, in the absence of clear regulatory guidance, is decided by officers in local authorities (for planning) or by staff in area and regional offices of national authorities (for environmental and H&S). There is therefore the risk that geothermal could be perceived by the public as not sufficiently regulated or that regulations are seen as being applied differently in different parts of the country, thereby creating an uneven playing field for the industry. This could cause opposition such as the distrust that was seen in shale gas, highlighting the importance of achieving both effective regulations and public support, for the success of renewable energy technologies (RETs) (Devine-Wright, 2011).

This paper reports the outcomes of interviews with operators and regulators to investigate how they experience current geothermal regulation and compares these with learnings from the UK's experience with regulating shale gas. The aim of this paper is to capture stakeholder experiences and perceptions and to explore their views of what an effective regulatory system for geothermal energy could look like.

The study reported here is part of the **Underground energy on-the-ground project**[7] which combines social science methods with geoscience understanding of the subsurface. It compares shale gas governance, regulation and processes of community engagement as experienced by operators, regulators and communities with those of emerging geothermal energy developments. Other investigations in this project have focussed on community engagement - as reported in Ryder et al. (under review).

Overall, the project aims to combine scientific knowledge on geothermal development risks and community perceived risks to lay the foundations for better regulation and responsible community engagement in geothermal projects. This in turn will contribute addressing concerns about climate change and ensuring that the renewable energy transition is fair.

6 Geothermal drilling and well development can involve stimulation techniques such as hydraulic fracturing to improve well performance through opening up new or existing fractures. This is done by injecting water at high pressure into the rock at depth. The technique is similar to that used for shale gas exploitation but involves smaller volumes of water. It may use chemical additives. As with other (non-geothermal) deep drilling or hydraulic fracturing activities, there is a risk that pressure or temperature changes associated with water injection may trigger seismic events. Most of these events are too small to be felt at the surface. However, some Enhanced Geothermal Systems have triggered larger events in some locations (Buize et al. 2020).

7 Full title of the project is: Underground energy on-the-ground: risk perception, community engagement and lessons learned for geothermal energy in a post-shale energy landscape.

2. Regulation of geothermal energy in the UK

In the UK, regulation of geothermal energy exploitation is determined by the devolved administrations. None of the four nations has bespoke planning rules, environmental regulation or licensing systems that are specific for the planning and operation of geothermal schemes. Currently, deep geothermal activities are regulated through existing planning, environmental and health and safety regulations. None of these regulations directly relate to the extraction and use of geothermal energy. The only regulatory provision that explicitly covers geothermal energy is section 43 of the Infrastructure Act 2015, which defines the right to access deep-level land[8] for the exploitation of geothermal energy. Whilst regulations might not specifically mention geothermal, it is important to recognise though that there is a degree of commonality between geothermal and other regulated industrial activities and that regulations are transferable/applicable in some cases.

Typically, deep geothermal projects are subject to consent and controls by several regulatory bodies, including local planning authorities (LPA), environmental regulators (Environment Agency (EA) in England, Scottish Environment Protection Agency (SEPA), Natural Resources Wales (NRW), and Northern Ireland Environment Agency, (NIEA)), the Health and Safety Executive (HSE), and, if drilling encroaches on coal seams, the Coal Authority (CA) in GB and the Department for Economy (DfE) in Northern Ireland.

To date, Scotland is the only UK nation that has published some regulatory guidance for geothermal systems (Scottish Government, 2024). The document outlines the regulatory framework for exploring and exploiting geothermal energy in Scotland. It highlights the key primary and secondary legislation relevant to projects involving the exploration and extraction of geothermal heat from the ground. As for all nations, the different aspects of a geothermal project require interaction with a range of regulatory bodies including the Health and Safety Executive, the environmental regulator and the relevant Local Authority.

Local Planning Authorities are responsible for granting planning permission for a geothermal scheme, including works associated with borehole construction and wellhead development. They decide whether an Environmental Impact Assessment (EIA) will be required as part of the planning application. Where it is decided that an EIA is required, the applicant must prepare and submit an Environmental Statement that identifies any "significant" (above-ground) environmental effects to which a development is likely to give rise and outlines measures to avoid, prevent or reduce and, if possible, offset adverse effects on the environment. Such effects include noise, light and/or air pollution as well as ground movements (induced seismicity) arising from drilling, borehole construction or operation of a geothermal scheme. To ensure the completeness and quality of the Environmental Statement, the developer must ensure that it is prepared by competent persons. The Environmental Statement must be accompanied by a statement from the developer outlining the relevant experience or qualifications of such experts.

There is some provision within the Environmental Impact Assessment (EIA) regime that could apply to "geothermal drilling". However, the regime is not specific to geothermal projects but relates to energy/infrastructure projects more broadly, including thermal power stations and other combustion installations. It would only apply to a selected set of geothermal energy projects that fall into one of five specific categories set out in the legislation (McClean and Pedersen, 2023) as (i) those that have a heat output of 300 MW or more, (ii) those that abstract or discharge groundwater of 10 million m^3/year or more, are in a sensitive area (as defined in the legislation), or have an area of the works exceeding 1 ha, (iii) those where the area of drilling works exceeds 1 ha, are within 100 m of controlled water, or within a sensitive area, (iv) those that produce or carry electricity or hot water and the area of development exceeds 0.5 ha or 1 ha respectively or is within

8 The Infrastructure Act defines 'deep geothermal' as more than 300 m but there is no clear definition of the term. Other regulation (e.g. the Renewable Heat Incentive (RHI) Scheme Regulation 2018) defined it as greater than 500 m beneath the surface (Abesser & Walker, 2022).

a sensitive area, and (v) those that form part of an urban development of over 1 ha, including more than 150 dwellings, or within a sensitive area (Town and Country Planning (Environmental Impact Assessment) Regulations, 2017b). Planning decisions for geothermal operations fall under the remit of the LPA. The Minerals Planning Authority (MPA) may prevent development if it falls in Minerals Safeguarding Areas.

Environmental regulators (EA, SEPA, NRW, NIEA) are responsible for regulating activities that may cause pollution or pose a risk to the environment. In respect of conventional deep geothermal, this includes regulation of water abstractions from and discharges to the environment, as well as the management of naturally occurring radioactive material (NORM) – in areas where such materials are expected to be co-produced with the geothermal water. For England and Wales, regulations usually require a groundwater investigation consent (GIC) and an abstraction licence for projects that abstract > 20m^3/ day groundwater. It would usually be expected that this water is reinjected into the underground rock formation which requires an environmental permit (discharge consent).[9] The regulatory controls are aimed at protecting the water environment. An abstraction licence, for example, protects the water quantity, not the available heat. Licensees must demonstrate that their abstraction will be sustainable and will not affect availability of water for other legitimate water interests or features. However, the regulator is not liable for any reduction in available heat if a new scheme takes heat away from an existing operation (UK Government, 2014). In Northern Ireland, there is no regulation in place for deep geothermal projects but rules for water abstraction and discharge are similar to those described above, involving a set of authorisations from NIEA, including a consent to investigate a groundwater resource, a water abstraction licence and discharge consent (Arup, 2022). In Scotland, abstraction and discharge of groundwater for geothermal use is regulated by the Water Environment (Controlled Activities) (Scotland) Regulations (CAR) 2011. A registration or licence is only required if water is not returned to the same geological formation or its chemical composition has been altered, and daily abstraction is > 10m^3. In most other cases, General Binding Rules[10] (GBR) apply. Exceptions include boreholes that are deeper than 200 m which require a license under CAR. [11]

The **Health and Safety Executive (HSE)** oversees the adoption of safe working practices by onshore operators as required under the Health and Safety at Work etc. Act 1974. There is no regulation specific to the drilling of an onshore borehole for the purposes of exploring and exploiting geothermal resources. Existing regulations apply only to boreholes (wells) drilled with a view to the extraction of petroleum.

Applying the broad framework of the Health and Safety at Work etc. Act 1974 (HSW Act), which applies to all workplaces, HSE ascribes specific regulations, standards and guidance for the drilling of boreholes for geothermal exploitation. This approach involves ensuring that drilling operators voluntarily follow the Borehole Sites and Operations Regulations 1995 (BSOR) as well as the Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996 (DCR) which (despite its title) applies to wells both on-shore and offshore. BSOR and DCR form the basis for HSE's approach to managing and controlling the risks associated with the drilling of geothermal boreholes offshore and on land (Scottish Government, 2024).

9 https://www.gov.uk/guidance/deep-geothermal-energy-regulation

10 General Binding Rules are legally binding requirements in regulations that set the minimum standards or conditions that apply. If these standards or conditions are not met, then a permit or licence will be needed.

11 https://www.sepa.org.uk/media/219750/car-licences-for-deep-boreholes-information-requirements.pdf

3. Methodology

To better understand the practical aspects of geothermal regulations and engagement in the UK, we conducted semi-structured interviews[12] with key stakeholders, including industry operators, regulators, local councillors, and government officials. Semi-structured interviews are a common qualitative research method useful for developing an in-depth understanding of people's views, experiences, beliefs, and perceptions (Rubin and Rubin, 2012). While this report focuses on questions around developing effective regulation for deep geothermal energy in the UK, we conducted additional interviews with community members for the purpose of understanding community engagement strategies across geothermal projects at different stages of development. Details of this aspect of our research are summarised in Ryder et al. (under review).

From the period of July 2021 to June 2022, our team conducted 30 semi-structured interviews. In this report, we draw on 10 semi-structured interviews with 14 participants from industry and regulatory bodies with relevant regulatory experiences and roles. The interviews were conducted virtually, as individual interviews or in groups (conducted with no more than 3 individuals at one time). Interviews were focused on ensuring that we speak to the appropriate representatives from active industry organizations and local governments with experience in regulating shale gas or geothermal projects, as well as representatives from regulatory bodies at the central government level. Interviewees were recruited via email and further participants were identified by these early interviews.

Of the 14 participants in the regulatory aspect of the study, 8 represented energy industries, two were local planning authority representatives and four represented national regulatory bodies. Transcriptions of recorded interviews were analysed using thematic coding (see Rubin and Rubin, 2012) to explore questions about regulation, ownership, and engagement as it relates to geothermal practices in the UK.

12 Semi-structured interview is a qualitative research method. It combines pre-determined open questions with further exploration by the interviewer of particular themes and responses.

4. Results

4.1. General themes

Participants from industry identified a general lack of recognition by decision makers of geothermal energy as a source of renewable heat or power in the UK and perceive this as a key barrier for UK-wide deployment. They found that "there is no culture of geothermal in Britain ...", while one planning authority representative observed that geothermal energy "to date has been seen very much as an opportunity for Cornwall and not for the UK". According to them, it has been difficult to get national governments engaged with geothermal technologies, and while it is acknowledged that there is some interest now, the approach to geothermal energy exploitation and its regulation are still seen as "siloed" and "disjointed". "Public acceptance[13]" is considered by representatives from some in industry and planning authorities as more important at present for the success of the industry than the regulation itself. Both groups expressed the belief that the terminology used by industry and authorities during their engagement with the public will determine how accepting the public will be of the technology and the way it is regulated. In addition, geothermal energy in the UK could be negatively impacted by perception spillover from other industry sectors, specifically shale gas (Westlake et al., 2023). Perception spillover, in this context, describes the notion that people respond to new technologies by drawing on earlier experiences with a similar technology elsewhere, or with earlier experiences with other technologies in their vicinity (Cuppen et al., 2020).

However, Westlake et al. (2023) suggest that rather than outrightly rejecting the technology, many people might be willing to consider deep geothermal technologies if they represent a shift away from fossil fuels and are designed and deployed in a well-controlled and transparent manner.

4.2. Regulations

Regulatory approaches vary between regulators. Most regulators have adopted hybrid approaches which have clearly defined regulatory goals (e.g. to protect the work force or the environment), but often also include specific rules and conditions that define the expected actions and behaviours. Such approaches provide some level of flexibility to make site-specific decisions.

With only two projects in development at the time of interviewing, and one in planning, there is very limited experience in regulating deep geothermal energy developments and operations in the UK. In the absence of specific regulations for deep geothermal projects and depending on their regulatory role and remit, one regulator has reported that they had to fill a gap in existing regulations and have developed new regulations for the development and operation of geothermal schemes. Others have applied existing regulations.

One regulator highlights that there is not enough experience with deep geothermal energy developments and operations in the UK to determine if there are gaps in the available regulation or additional aspects that the regulators should consider. With the HSE addressing drilling risks, environmental regulators addressing risks to the environment (including water bodies), and seismicity being managed by the local planning authority, it is felt that all regulatory aspects of geothermal are covered by existing regulation. The regulators acknowledge that the regulations were not formed with geothermal in mind. However, in their view and acknowledging the limited experience with geothermal operations, the current regulations are

13 There are important distinctions to be made between the concepts of public or social "acceptance" and public or social "support." While the former is often the language used by industry and government stakeholders (indeed the case here), social scientists have shifted to be more critical of the idea of acceptance pursued instrumentally and suggest focusing more broadly on thinking about public and community support and other varied responses to engagement (see Aitken et al. 2010; Batel 2018; Cotton and Charnley-Parry 2018; Ryder et al. 2023).

fit for purpose thus far. Presently, it is not clear to them what changes should be made or what additional regulations would be required.

Where regulators have developed new regulations, such as Induced Seismicity Management Protocols (ISMP) for geothermal projects, they worked closely with operators to co-develop them. This collaborative approach was described by those involved as very positive. The resulting ISMPs are based on existing British Standards and planning guidelines for blasting, quarrying and mining, using ground vibration measurements rather than a magnitude-based approach (which is used in shale gas regulations) for monitoring induced events from geothermal developments and operation. The approach was selected based on their experience with local mining operations (which are regulated via a set of British Standards) rather than drawing on experience from shale gas exploration operations. Parties involved felt that these locally developed protocols for monitoring and mitigating induced seismicity (e.g. EGL, 2021) were successful and could provide a blueprint to inform national regulation or best practice guidelines that might be applicable elsewhere.

4.2.1. Environmental regulations

For England, decisions relating to the application of national environmental regulations are made at the local area level by experts with local technical and hydro/geological knowledge. Decisions are backed up by a national team that provides overarching oversight. Environmental regulators highlight that, while the overarching regulations are national, the decisions on environmental risks associated with specific projects are based on local knowledge of environmental conditions/factors and are made on a case-by-case basis. In general, the regulators operate an evidence-led, risk-based approach, as well as a "yes, if" approach which enables them to adopt bespoke regulatory conditions as part of a process that will allow an operation to safely proceed. For example, rather than withholding permits, they would say "Yes we [the regulator] will permit this activity if you [the applicant/ operator] meet the following condition(s)...." These conditions can relate to environmental monitoring requirements, acceptable parameter ranges or additional activities that need to be undertaken to obtain the required permissions.

Within the context of geothermal, environmental regulators describe their decision making as "site-specific decisions based on the [geothermal] operations and the local geology". For example, the regulator decided that some geothermal projects do not require an abstraction licence or environmental permit. Licensing in these cases was deemed to add no benefits or enhanced environmental protection, but rather was "regulation for the sake of it". The regulator stressed, however, that this is "not a national position" and that they do not expect all geothermal projects to fall into this category. In concordance, participants from industry reported that geothermal projects in other areas/ geological settings are required to obtain abstraction licences and environmental permits.

As they were not clear how the regulations are applied, some industry participants perceived these differences in decision making as producing an "unlevel playing field" within the sector with different rules and regulations being applied in different parts of the country. They called for national guidance for geothermal energy regulation to ensure consistency of approach across the country. They further argue that consistent regulation would help to strengthen the geothermal sector in the UK.

Based on the current level of experience with deep geothermal energy developments in the UK, environmental regulators, planning authorities and industry regard existing regulations as sufficient to cover the potential environmental risks. However, planning authorities with experience in regulating shale gas projects highlight that coordination between different regulators and the order in which permissions or licences are granted can be important. For example, they reported that it was difficult, in some cases, to issue conditions during the planning process relating to reducing environmental impacts when environmental permits for the project had already been granted.

4.2.2. Drilling regulations

Drilling of geothermal wells in the UK is regulated by the Health and Safety Executive (HSE) and requires that drilling operators voluntarily follow the regulations for boreholes (wells) drilled with a view to the

extraction of petroleum. This regulation is perceived by some participants from industry as "not relevant" for geothermal drilling. Others find that there is still insufficient experience with geothermal drilling in the UK to identify if and how these regulations could be adapted.

Some perceive aspects of existing UK drilling regulations as "overengineered". For example, the need to install blow out prevention (BOP) equipment is seen by some as unnecessary for UK systems, adding time and costs to a geothermal project. BOPs were developed for use in drilling deep wells for the recovery of oil and natural gas. They protect surface operations, the environment, and life from uncontrolled venting and "blow outs" when encountering formations with high static pressures during drilling (Lyons et al., 2021). Although overall views on existing drilling regulations were mixed, there was some consensus amongst industry participants that specific requirements of the existing drilling regulation (such as the need to install BOPs) could be revised for areas where the geology and drilling conditions (such as reservoir pressure) are better understood (e.g. after drilling multiple deep wells).

Some industry participants commented on a lack of regulatory expertise in the UK with regards to observing and managing health and safety during geothermal well testing, in particular in relation to injections. They regard some aspects of well safety procedures from oil and gas drilling as not directly transferrable to geothermal wells and highlighted that different examination parameters and procedures (e.g. related to the monitoring of well/reservoir pressure) are used in other countries to ensure well safety during geothermal drilling. They recommended introducing specific regulations for geothermal drilling and proposed adopting them from other countries such as Germany or the Netherlands where geothermal drilling regulation already exist.

4.2.3. Induced seismicity

Regulation of induced seismicity is different for different technologies. For shale gas, for example, specific regulations exist for the monitoring of hydraulic fracturing operations, including an obligation for the operator to develop Hydraulic Fracture Plans (HFP) as well as to undertake seismic monitoring. As part of this regulation, a traffic light system (TLS) was developed by the regulator (the North Sea Transition Authority, previously the Oil and Gas Authority) based on expert studies (Green et al., 2012). The TLS requires operators to suspend injections and investigate seismic events with magnitudes greater than 0.5M_L. Surface vibrations arising from blasting activities during quarrying and mining are regulated via a set of British Standards, including BS 5228 Noise and Vibration Control on Construction and Open Sites; BS 6472 Guide to Evaluation of Human Exposure to Vibration in Buildings (BSI, 2008a,b); BS 7385 Evaluation and Measurement for Vibration in Buildings (BSI, 1993). These are based on ground vibration measurements using peak ground velocity (PGV) rather than a magnitude-based approach. For geothermal operations, regulation of induced seismicity is the responsibility of the Local Planning Authority which can impose conditions for managing induced seismicity as part of the planning consent. Where councils in the UK have developed guidelines for induced seismicity monitoring from geothermal operations, they adopted methods similar to those used for Blasting and Quarrying, i.e. using a PGV- based rather than a magnitude-based approach. The approach was chosen because the regulator already had some experience in applying these regulations for other subsurface operations and could draw on existing procedures.

There is consensus that induced seismicity for geothermal projects needs to be regulated. The industry acknowledges that deep geothermal drilling and operations are linked with induced seismicity but most of these events are too small to be felt or to cause damage. They agree that the occurrence of such events cannot be fully predicted or ruled out, and that there remains a risk of triggering felt seismic events during all stages of geothermal project development and operation that needs to be mitigated against and managed.

Some participants identified risks to be higher for certain reservoir types/geologies, such as fractured reservoirs, as well as for specific activities, such as water injection under high pressures during well testing, or as part of hydraulic stimulation (fracturing). These activities are seen as disturbing the local stress regime of the geothermal system, and, as one participant explains, "we don't always understand what the implications of that are". Stimulation through hydraulic fracturing is used by some geothermal projects to open up existing pathways within the geothermal reservoir. However, according to one participant from industry, only about 0.1% of all geothermal projects in UK settings are expected to use such stimulation methods.

To ensure that induced seismicity is adequately monitored and managed, it was suggested by industry participants that the technical guidance, developed alongside any regulation in the UK, should include directions for operators on how to set up the seismic networks. For the monitoring, participants generally favoured the PGV approach used in the regulation of mining and quarry blasting (British Standards, 2008). As a reasons for their preference, participants stated that amplitude and frequency of surface vibrations are the two criteria that indicate the risk of causing damage at the surface. The alternative approach of earthquake magnitude, as used in the regulation of induced seismicity from shale gas developments or to measure natural seismic events, was considered by some to be "very old-fashioned" while others criticised the magnitude model for being a poor indicator of the impact of induced seismicity (i.e. intensity of ground shaking) at the site, due to its dependence on depth and distance to the earthquake source (intensity decreases with increasing distance from the source) as well as on surface geology. One participant, who had experience in shale gas regulations, expressed a preference for a magnitude-based model. They considered the PGV approach as too focussed on the local impacts of induced seismicity, pointing out that geothermal drilling takes place at greater depths than quarrying or mining and, hence, could induce events that might be felt more widely.

Overall, the way regulation of induced seismicity has been set up locally for the geothermal projects that are currently in development in the UK was described by many participants as "good because it's site and location specific." It is based on a traffic light system (using the PGV approach) that was developed by the local planning authority in collaboration with the industry. By adopting existing regulations from mining and quarrying regulations, the development and decision making was described by participants as rethinking the existing traffic light system, including "what the triggers needed to be ... the risks, the reality of the situation, how likely it was to happen, what the impact might be. How people might perceive it." While the principle of traffic lights systems was not explored in detail in this study, most participants were comfortable with "a fully open, fully transparent traffic-light system" for monitoring and managing risks from induced seismicity. Some difficulties were highlighted with the traffic light system generally, mainly relating to the non-linear behaviour of seismic events (i.e. "...seismic events can jump in order of magnitude"), which makes it difficult to predict successive events.

Participants highlighted the importance of measuring the natural seismicity baseline carefully before setting out the thresholds. As one participant explained, "it's not about the principle of a traffic-light system, ... it's not about how you implement the system. It's about how you set the threshold." Induced seismicity is specific to the local site, the local areas, hence, it is important to measure the natural seismicity baseline carefully before setting out thresholds. A few hundred natural earthquakes are recorded in the UK every year, with 20-30 large enough to be felt by people. These are natural events unrelated to human activities that should be considered.

Several participants highlighted the importance of distinguishing between "seismic hazard" and "seismic risk" when setting the thresholds. They stressed that the risks are likely to be lower in less populated areas (even though the hazard might be the same) and expressed their preference for risk-based induced seismicity regulation.

It was further suggested by several participants from industry that there should be a requirement for developers/operators to set up a network for seismicity monitoring, including upfront baseline assessments (to understand the historical nature of seismicity in the area) as well as to monitor induced events during site development and operation.

It was acknowledged by some in industry that a national framework for regulating induced seismicity would "make sense". However, there was a general preference for detailed regulation to be determined locally. Several benefits to local regulation were highlighted, including:

- The ability to set suitable seismic thresholds based on local context and data, considering local and project-specific parameters such as natural seismic baseline, geology and project-related risks.
- The ability to engage locally to enable building of trust between community and developer, consideration of local perspectives and maximisation of local benefits.
- The opportunity " ... to put in place a more transparent ...and .... sure-footed process in order for people to be able to understand and accept".

Involving developers in baseline monitoring for the definition of thresholds is seen as very important by some in industry. They argue that having undertaken the baseline monitoring and contributed to defining of the thresholds, a developer already understands the local seismic behaviour and is less likely to operate their site in a way that risks creating "gigantic impact". Recent experiences with UK schemes confirmed that project developers managed induced seismicity event themselves, as per the agreed protocol, without any need for the regulator to get involved. "They knew ... the limits and they managed [the induced seismicity] themselves".

Overall, the ability for local authorities to make judgements on monitoring requirements and thresholds was noted to be a "good thing" although some expressed concern about the lack of experience and expertise within local authorities and highlighted the need for national guidance and expert involvement. Some in industry suggest that the requirement for setting up adequate seismic monitoring networks should be defined as part of a national regulation.

In terms of public perception and "acceptance" of geothermal energy projects, there was agreement amongst industry and planners that induced seismicity is a key risk for public perception of geothermal technologies and a recognition that residents are most concerned about that potential induced seismicity in their area. Participants felt that setting up regulation locally was an opportunity to put in place a transparent process for people to influence, understand, and accept. Regulators found that using the existing regulatory route for ground movement in mining/quarry regulations (PGV approach) resulted in more local buy-in and understanding. Various participants from industry and local planning authorities pointed out the importance of terminology when explaining the concept of induced seismicity to local communities. "Earthquake ... sounds a million times worse than ... ground vibrations."

A few participants highlighted that induced seismicity is "differently regulated in geothermal energy in the UK compared to ... shale gas". They felt that "It's really a different rule for one sector than it is for another, effectively."

There was no consensus amongst participants whether differences in regulatory approaches are justified. It was not part of this study to examine this question and would require more detailed investigations and comparison of the risks associated with the different activities – which is beyond the remit of this study. However, such as study would seem pertinent given the observed differences in regulation. Furthermore, development of national guidance on how seismicity for geothermal projects should be assessed and mitigated, including what metrics to use and how to define thresholds, would ensure that regulation and decision-making in the local planning offices is consistent across the country.

4.3. Single versus multiple regulators

Regulation of geothermal energy falls under the remit of multiple regulators which operate at local to national level.

Many stakeholders in industry regard the current approach to regulation as somewhat disjointed as there is no central point of contact, and developers must liaise separately with the different statutory agencies. While most participants would like to see a single, centralised regulator for geothermal, it was recognised that there are some fundamental hurdles to such a setup (e.g. breadth of expertise required; existing regulatory setup for similar activities; small size of industry), and several participants expressed scepticism as to whether it could work in practice, considering the different regulatory aspects that need to be covered.

In England, a body to co-ordinate regulation and act as a single point of contact had been created for regulating shale gas - the Shale Environmental Regulator Group (SERG). It was formed by three national regulators (EA, OGA, HSE). Through the Planning Authority Liaison, SERG also involved the Mineral Planning Authorities. Regulators found the formation of SERG useful for enhancing their engagement and collaboration while maintaining their separate identities and roles. Whilst the regulators perceived that "the public were happy with what was being done", one developer reported that there seemed to remain some ambiguity between the regulators as to who was doing what. According to them, this made the interactions "difficult and ... doubly painful for a developer".

The regulators' view is that the multi-agency approach is not unique to deep geothermal activities especially as it is a complex and still emerging technology. They regard the application of the SERG model to geothermal as theoretically possible ("we could always improve links [between the regulators]") but highlight that the small size of the sector and the uncertainty of the scale to which it will grow makes creation of a joint regulator group presently unfeasible.

In fact, as several stakeholders from industry highlighted, the key requirement for them is an understanding of who deals with what. While industry agreed that the regulatory roles were relatively clear for deep geothermal, they found that having to deal with each of them individually can make the permitting process very slow. They expressed a preference for a coordinating body who can help a developer through the permitting process and takes the lead in coordinating applications with the other regulators.

4.4. National versus local regulators

There was no consensus on whether geothermal should be regulated locally or nationally. It is recognised that there is more flexibility but also a higher likelihood for variations if regulations are set up and/or applied locally and that variations can be justified (e.g. by different environmental conditions / geology) or be due to inconsistencies arising from differences in expertise, interpretation of the regulations, or quality of decision-making.

Having national regulators who set out and apply the regulations was seen by some in industry as advantageous because they consider local regulators to have insufficient capability (and capacity) to build the necessary expertise to set and/or apply regulations for these complex geothermal systems. Some participants expressed concerns that "big players .... [may] roll over local councils and district councils" and that with local regulation there "are less checks and balances than you would get with a national system".

Others suggested that "... keeping ...regulation, ... planning and the focus local with councils .... is the right way to go" and that "... trying to engage national government [in geothermal regulations] has been really difficult."

Some highlighted that the expected size of geothermal projects in the UK (current and planned projects expected to deliver 3-5 MW electric and 10 -20 MW thermal capacity) is not suitable to be considered as nationally significant infrastructure. Going through the local planning route was seen by some in industry to be adequate as the environmental and amenity impact of geothermal projects are considered to be like those of other local projects such as housing developments or small windfarms. Furthermore, local planning allows building of close working relationship to be built between the planning authority and the developer. This was noted as an advantage because it maximises engagement and creation of local benefits. If coordinated through national planning, some planning authorities perceive a risk that projects become very nationally focussed and that developers will not need to engage the local community.

From a regulator's perspective, there currently isn't a case for national-scale regulation of geothermal energy, because of the low numbers of geothermal projects and how they are operating. Public interest was seen as one of the driving forces behind the national regulation of shale gas and the formation of the Shale Environmental Regulator Group (SERG). Participants felt the scale of interest from the public towards geothermal is currently very different and hence did not currently perceive an immediate driver for nationalising regulation in the way it was done for shale gas.

4.5. Gaps in regulation

The main gaps identified by participants were the lack of clarity on the ownership of the resource and the absence of a licensing system for geothermal in the UK: "nothing like this [the oil and gas licensing scheme – PEDL] exists for geothermal...". This is regarded as a main barrier for geothermal development because investors and heat customers require some assurance of their right to exclusive use of the resource over the run-time of their operation: ".... to get a heat purchasing agreement signed for 20 years, the first thing the client/customer will ask is who owns the heat, and where's the bit of paper that says that you can exploit this for 20 years....". According to one participant, under the current situation "...it could be a complete free for all...", while another regards the lack of licensing as the ".... single most likely reason that we [operators] won't end up operating in the UK...".

Participants highlighted that there is no regulatory authority in the UK with remit for regulating the geothermal energy resource itself, and that geothermal energy itself currently is not recognised as a natural resource. The regulators confirm that geothermal energy falls outside of their remit but add that they recognise "the benefits of regulating heat ..., the way that the oil and gas industry do." The North Sea Transition Authority was suggested by some participants as a potential regulatory authority for the geothermal energy resource because of their existing onshore energy remit and expertise.

Several participants highlight the lack of a registration system and standards for geothermal installations in the UK (for both deep and shallow geothermal systems). They regard this as a potential risk ("real issue") for the industry as a whole, "because bad actors or bad deployments or bad usage of geothermal ... [in one area] ... will impact how geothermal happens everywhere."

Participants also conveyed the need for regulations and standards that are specific to geothermal.

5. Considerations for developing geothermal regulations

5.1. Geothermal energy as a natural resource

Different models exist in the UK for the management of natural resources. In all cases, ownership of the resource is clearly defined. For minerals, the default position is that surface ownership includes all strata to the centre of the earth (the *cuius est solum* principle). Exceptions include gold, silver, platinum and oil and gas which are owned by the Crown, and coal which is owned by the Coal Authority on behalf of the country (Deady et al., 2023). This exclusivity (ownership) provides the foundation for minerals and hydrocarbon licencing and permitting systems. Geothermal energy is not legally defined as a natural resource; hence ownership of geothermal energy remains unclear (Abesser et al., 2018). According to McClean and Pedersen (2022), it is unlikely to be owned by the owner of the land (under the *cuius est solum* principle). In addition, there has been no statutory vesting of geothermal energy in the Crown. Consequently, the regulatory controls for deep geothermal energy extraction in the UK currently lack a 'natural regulatory home' (McClean and Pedersen, 2022).

In other countries like Germany, the Netherlands and France, geothermal energy is recognised as a natural resource. Where legal definitions did not exist for geothermal energy, legislation was amended or introduced to enable regulation and licensing of geothermal energy projects. In the Netherlands, for example, the Mining Act was amended in 2003, aligning geothermal energy regulation with the statutory provisions for the exploration and extraction of underground minerals (including oil and gas). According to this Act, the resource is owned by the State, but exploration and exploitation activities typically require authorisation from the private landowner (Borović et al., 2021).

5.2. Regulation of the geothermal resource

Regulation of deep geothermal energy projects in the UK involves three different regulators which regulate the main risks identified for conventional geothermal systems (Jharap et al., 2020). Such a multi-regulator setup is not unique to geothermal. For example, onshore oil and gas development and production in England involves the North Sea Transition Authority (NSTA), the Environment Agency (EA) and relevant local mineral planning authorities[14] as well as the Health and Safety Executive (HSE).

The difference between the regulation of onshore oil and gas and geothermal is that the NSTA has overall responsibility for the oil and gas resource. For geothermal energy, there is currently no authority in the UK with a remit for regulating the actual resource. Neither the environmental regulators nor the local planning authorities have the regulatory power to ensure that the geothermal energy resource is used sustainably.

To enable the wider uptake and development of geothermal energy in the UK, consideration should be given to identifying a regulatory body that could take on the effective stewardship and regulation of geothermal energy. To ensure that the potential regulator is provided with the appropriate remit, resources and legal powers, a review of existing legislation is recommended to clarify the status and ownership of geothermal energy. Some changes to the legislative framework may be needed to ensure that geothermal energy is recognised as a natural resource that can be licenced, regulated and managed.

14 Planning decisions for geothermal operations are made by the Local Planning Authority, not the Mineral Planning Authority.

5.3. Geothermal licensing

For the industry, establishing a licensing system is a priority to enable investment in the geothermal sector and for securing agreements with customers (heat purchase agreements). Exploitation of other natural resources in the UK typically require licences. The exploration and extraction of oil and gas, for example, requires exploration and development licences issued by the North Sea Transition Authority (NSTA, previously the Oil and Gas Authority) under the Petroleum Act 1998 (UK Government, 1998).

Permitting and licensing exists in many countries for both deep geothermal and shallow geothermal systems. These arrangements are considered to provide confidence to investors and developers as well as to regulators. Typically, separate licences are granted for exploration and extraction. In the Netherlands, the new Mining Act for geothermal energy (that came into force in 2023) has replaced the traditional exploration and abstraction permits with three new permits: an area allocation permit, a start-up permit, and a follow-up permit. The area allocation (1-2 years) allows an initial assessment of the site and planned extraction. It checks whether the applicant's plan is feasible and gives them economic exclusive right to investigate. The start-up phase of 2 years duration will allow the operator to investigate and develop the heat resource. It also permits the production of some geothermal heat (almost) immediately after drilling. The follow-up permit is only granted once more certainty exists about the environmental and safety impacts of the extraction and the amount of available recoverable heat. The length of the permit is adapted to reflect the available resource to ensure safe and economically viable exploitation in the long term. Durations of 30+ years are typical.

During the various stages of the project, the Dutch Mining Act requires operators to meet several monitoring and reporting conditions concerning the geothermal site and wells. In addition to these, conditions with respect to monitoring, reporting, research, risk mitigation measures and/or provision of information to the public can be imposed as part of the permit.

5.4. Streamlining the regulatory process

Participants have expressed a need for streamlining the existing regulatory process. While a single regulator is not likely to fit with the UK regulatory systems, streamlining could be achieved by appointing a body with overall responsibility for coordinating the application process for geothermal developments.

In the Netherlands, for example, the approval and licensing process is coordinated by the Ministry of Economic Affair and Climate (EZK). The ministry issues the licence but seeks input from different regulators and agencies during the different licensing stages and on different aspects of the licensing related to planning, water resources, drilling, environmental impact, geological and financial advice. It consults with the province, municipality and water board, the Supervision of Mines Authority (SodM), the Mining Council (Mijnraad), the Geological Survey of the Netherlands (GDN - part of TNO) and the Netherlands Enterprise Agency (RVO).

5.4.1. Environmental regulation

Overall, there is still very little experience with regulating geothermal systems in the UK.

Geothermal energy operations are regulated by proxy. For example, groundwater activities are regulated by the Environmental regulators under existing water resources and environmental legislation, which vary between the devolved administrations (see Section 2). They include regulation of water abstractions from and discharges of water to the environment, as well as the management of naturally occurring radioactive material (NORM). These regulations protect the water quantity and quality but do not consider or manage the extraction of heat. At present, existing environmental regulations are regarded as fit for purpose from an environmental protection point of view, although the regulators acknowledge that gaining more experience in regulating geothermal systems as the industry grows will enable more robust controls to be developed if necessary. While the lack of tailored rules provides

some regulatory flexibility, it has resulted in the perception that rules are applied differently by the environmental regulator in different parts of the country. Overall, there appears to be a lack of clarity in the industry of how decisions are being made by the regulator about the level of environmental regulation needed for different geothermal systems. It highlights the need for better (national) guidance on environmental regulation for geothermal systems. To date, Scotland is the only UK nation that has developed a regulatory guidance document for exploring and exploiting deep geothermal resources (Scottish Government, 2024).

Under the Town and Country Planning Act (1990c), local planning authorities can impose additional measures and conditions to mitigate potential environmental impacts (noise, emissions, light pollution, induced seismicity) of proposed deep geothermal energy operations as part of the planning permission process. According to McClean and Pedersen (2023), the Act also enables LPAs to regulate for the use of techniques and equipment that reduce the risk of leakage and blowout, and to impose temperature thresholds to prevent undesirable changes in the temperature of the ground or groundwater – areas that also fall under the remit of the HSE and environmental regulators, respectively. The powers afforded by the Town and Country Planning Act put strong reliance on local planning authorities to have the capacity and expertise to identify the environmental impacts of deep geothermal energy projects and identify appropriate means of mitigating them. However, it is important to recognise that the LPAs do (should) not operate in isolation and that all planning applications are subject to a statutory consultation, in which environmental regulators are one of many statutory consultees. Environmental regulators hence have the opportunity to support LPAs in identifying environmental risks, potential impacts and to recommend mitigation measures (conditions) relating to the planning application. They also can recommend that an activity is prohibited if considered to be in breach of any environmental legislation or regulation. If unsatisfied with the way their advice has been considered, they can also challenge the planning decision through the appeal process.

Although participants in this study have highlighted the importance and value of local decision making, some have expressed a preference for a national framework or some detailed guidance to ensure that regulation is applied consistently across the country.

5.4.2. Induced seismicity

Induced seismicity regulation is the responsibility of the local planning authority. This is different to onshore oil and gas for which a national regulatory framework exists that is managed by the national regulator – the NSTA.

In a general review of induced seismicity in the Netherlands (mainly from gas extraction), Muntendam-Bos et al. (2022) conclude that project- or industry-specific risk governance protocols, extensive gathering of subsurface data and adequate seismic monitoring are essential to minimise induced seismicity risk. The most used risk mitigation strategy is the so-called 'traffic light systems' (TLS) – typically based on magnitude –where an operator reduces, pauses, or stops injection if the magnitude of the largest event exceeds a specified threshold.

A TLS has been adopted by Local Planning Authorities in the areas in the UK where deep geothermal developments are already progressing. Rather than developing thresholds based on magnitude, they opted to use a ground motion-based parameters (e.g. PGV) – a system that is supported by most participants in this study. The approach does not require upfront measuring of the natural baseline of seismic activities - information that is an important prerequisite for setting effective TLS thresholds for magnitude based models (see Muntendam-Bos et al. 2022).

Bommer (2017) outlines other methodologies to define, predict and monitor the possible ground motion resulting from hydraulic fracturing operation, including a PGV based approach combined with seismic monitoring. While recognising the advantage of adopting protocols and thresholds from published standards (e.g. BS 7385-2 (BSI, 1993)), he highlights potential issues with this approach, mainly that the nature of vibrations from blasting and demolition activities may be different in duration, frequency content and frequency of occurrence from the ground shaking associated with induced seismic events.

Basing the monitoring approach on existing regulations for mining and quarrying has meant that the local regulator could draw on existing procedures and already had some expertise in setting up and managing such regulations, albeit for different subsurface operations. Such expertise may not be available in local regulators elsewhere. The development of national guidance on how seismicity should be assessed and mitigated for deep subsurface activities, including what metrics to use and how to define thresholds, would contribute to the consistency and predictability of decision-making by the regulator(s).

5.4.3. Drilling regulation

Drilling regulations fall under the remit of the HSE, who has assigned the same regulatory requirements to geothermal drilling as already exist for onshore oil and gas drilling. While it has been highlighted by some participants as being "not fit-for-purpose" for geothermal drilling and adding time and costs to projects, there is currently not enough knowledge of deep geothermal drilling conditions in the UK to make specific recommendations for improvements. Some countries like the Netherlands, Germany, and France, have developed geothermal drilling regulations for similar geological and temperature settings. A review of their regulations could provide valuable insights into how regulations in the UK could be adapted for geothermal drilling operations.

6. Conclusions

The geothermal industry in the UK is still in its infancy. Only one deep geothermal project has been operational over a prolonged period (commissioned in the 1980s and in operation until recently). A few deep geothermal projects were being developed at the time that this study was undertaken, but overall, the experience in regulating and operating deep geothermal energy projects in the UK is still very limited.

In this study, we have carried out early engagement with representatives from industry and regulatory bodies to investigate their experiences with the current regulatory system for geothermal energy projects. The following themes were identified for urgent consideration:

1. Development of a geothermal energy industry in the UK will require that geothermal energy is recognised as a natural resource with clear ownership and regulations to control its management and exploitation. A review of existing legislation is recommended to identify how this might be achieved.

2. Concordantly, it is recommended that a "regulatory home" is identified for geothermal energy resources in the UK's regulatory system and that a regulatory body is assigned that has remit for the management of geothermal energy . The regulator could be formed by one or several existing regulators and could support the development of the sector by taking on the effective stewardship of geothermal energy resources, including the management and licensing of its exploration and exploitation. As a prerequisite for enabling this body to assume the appropriate remit, resources and legal powers, geothermal energy must be recognised as a natural resource that can be licensed, regulated, and managed (see Recommendation 1 above).

3. As the UK's experience in the development, operation and regulation of geothermal projects grows, it is recommended that consideration is given to reviewing existing regulations and making processes more relevant and efficient (i.e. streamlining) for geothermal applications. Further engagement with the responsible regulator(s) and stakeholders will be required to investigate if available regulations and processes are suitable for geothermal operations and for supporting timely and effective decision making. In the interim, some regulatory guidelines for deep geothermal energy projects could be developed that clarify how existing regulations apply to geothermal energy projects and that can be shared and adopted by industry, local authorities, and regulators in all parts of country to ensure that the regulatory processes are understood and applied consistently across the UK. The appointment of a coordinating authority that coordinates the approval procedures between the different regulators could simplify the process for the developers, while ensuring that the regulatory process is fair and consistent for all applicants.

4. Developing a suitable licensing and permitting system for the exploration and operation of deep geothermal projects will become important as the sector matures and demand on use of deep geothermal resource increases. Licences would provide security for developers and investors by specifying ownership and conditions of use. In addition, permits (to carry out the activities) would enable regulators to manage and protect the UK's deep geothermal resources through defining monitoring and reporting requirements. Licences could also be used to specify additional conditions, e.g. related to requirements for data sharing or public engagement.

5. Induced seismicity is currently regulated differently for different subsurface activities. Development of national guidance on how seismicity should be assessed and mitigated for deep subsurface activities, including what metrics to use, how to define thresholds and how to monitor it, would contribute to greater consistency and predictability of decision-making by the regulator(s). This should consider the risks and impacts associated with different subsurface activities. Many participants expressed a preference for a risk-based approach to regulating induced seismicity, e.g. through a national

framework, based on Peak Particle Velocity (PPV), with flexibility for local implementation that considers local geology, project type and risks.

6. Once drilling conditions in the UK are better understood, a review of drilling regulations should be considered, including a comparison with regulations from countries with similar geologies/ drilling conditions, to ensure that the existing regulations are fit for the purpose of geothermal drilling in the UK.

Other themes emerging from the stakeholder interviews included the importance of public engagement as well as the need for financial support for geothermal technologies. Whilst not examined in this study, we highlight these here as areas for further consideration and investigation.

Another fundamental question is: Can the current regulatory framework meet the objective of achieving a safe and effective industry and/or industrial operation? Answering this question was beyond the scope of this study. It could form part of subsequent investigations that analyse the risks and impacts associated with the different geothermal activities and how they are mitigated against in the current regulatory framework.

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