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Negotiating salt worlds: causation and material participation

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ABSTRACT

In this article, we analyze the role of measurement practices in a public dispute about the impacts of mining in the Netherlands. Drawing on studies of material participation and agential realism, we analyze how measurement practices shape the boundaries of subsurface objects. We detail how these boundaries become relevant for assessing mining impacts and show how this enables and constrains material participation. Simply put, if a process or thing is not measured into being, it cannot participate in negotiations about causality and impact. Our analysis shows that scientific conventions narrowly determined what measurements are credible and, consequently, limited the participation of other objects and processes in negotiations about damage and compensation. This underscores how ontological disagreements about the existence and measurability of subsurface processes affect what claims can be made. We conclude by discussing conditions for pluralist and equitable processes of material participation in measurement practices.

KEYWORDS

Ontological justice; intra-action; mining; knowledge controversy; material participation

1. Introduction

The impacts of mining operations are frequently contested politically. Moreover, questions about what these impacts are, how they come into being, and how they can be managed, are part of scientific and participatory procedures that govern mining, such as scientific assessments of impacts on the immediate environment and stakeholder participation procedures (Lawrence and Kløcker Larsen 2017; Meesters et al. 2021). Within these procedures, mining impacts are difficult to establish with absolute certainty and often involve different claims about the cause and nature of impacts that reflect diverse understandings of the behavior of materials (Floor 2018; Fox and Sneddon 2019).

Competing causal claims about mining impacts can become part of knowledge controversies (Lawrence and Kløcker Larsen 2017; Barry 2012). Decisions about which truth and whose knowledge are considered legitimate to establish mining impact have direct political, social and economic implications: they prescribe whether mining is allowed or prohibited, what impact mitigation activities are mandatory, and who can be considered an affected community (Barandiaran 2015; Wylie, Shapiro, and Liboiron 2017a; Birch 2016; Whyte 2011; Jalbert, Malone Rubright, and Edelstein 2017). The measurements of

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mining impacts can thus be described as a performative ordering between underground matter and political practices that influence both human understandings and material realities (Barry 2013; Kinchy, Phadke, and Smith 2018; Vera et al. 2019).

We apply the notion of ‘posthumanist performativity’ – inspired by quantum physicist and queer theorist Karen Barad – to make sense of measurements of the underground that are part of knowledge controversies surrounding mining. STS scholarship on underground matters, shows us that knowledges about the subsurface shape how we get to know the ‘world that can never be seen’, and that these knowledges translate into decisions about where to dig (Ballesterio 2019, 780; Kinchy, Phadke, and Smith 2018; Chailleux 2020; Smith and Smith 2018; Porter 1995; Bijker and Latour 1988). Some STS Underground scholars have also focused on the inclusion and exclusion of knowledges, and demonstrate that the selection of models and maps matters for the ways in which material resources are brought into being (e.g. Kinchy, Phadke, and Smith 2018; Smith and Smith 2018; Kroepsch and Clifford 2021; Kroepsch 2018). We further explore this aspect of the social and political lives of knowledge practices via Barad’s understanding that measurements are *in situ* performative within processes of materialization. This means that we consider matter to be responsive to measurements and possible interferences, and that those measurements and knowledges themselves have political – i.e. inclusionary and exclusionary – effects, in addition to the actors who use them and the disciplines they are part of (Hollin et al. 2017; Barad 2013).

Embracing the notion of posthumanist performativity means recognizing that measurements and materials co-constitute each other at the moment that matter is measured (Barad 2007a). Materials and measurements therefore do not *interact*, which assumes preexisting entities, but they *intra-act*, as measurements interfere with the material, alongside related processes in the domain of human politics. Hence, measurements of the underground can be considered performative in multiple directions: in shaping human politics and knowledge, which STS has richly documented (see e.g. Kinchy, Phadke, and Smith 2018; Smith and Smith 2018; Vera et al. 2019), but also in shaping the material world itself, which we find has been less explored in STS Underground scholarship. Accordingly, this article scrutinizes how measurements impact the *matter* that is being measured in parallel with human understandings of that matter (Barad 2013).

In political contestations about mining, measurements are used to establish mining impacts and causality, which are subsequently used to attribute blame and responsibility. Thus, measurements shape what humans understand as causal relations, for example between an activity and its presumed environmental impacts, and in so doing, they (re) order relations between and among the underground matter by casting some parts as causes and other parts as effects (Barad 2007a). This (re)ordering happens in relation to the particularities of the measurement, including prevalent assumptions and routinized practices that determine what should be measured and how (Singleton and Law 2013a; Stengers 2010; Panikkar and Tollefson 2018). These assumptions and routines enact specific socio-material realities, which become inscribed into methodological standards for measuring mining impacts. Standardized measurements stabilize how we understand things and how we order the (causal) relations between things.

This article draws on studies of material participation, agential realism and STS Underground scholarship to examine how measurements shape which matters are brought into existence, what their political capacities are, and how these capacities shape and distribute stakeholders' influence in participatory processes. To explore how measurements are performative in the constitution of the material world, we analyze how causal claims that are expressed by impact measurements are addressed and how they become contested, via an in-depth case study on salt mining in the Netherlands. Our analysis centers on how measurement practices constitute the boundaries of objects, such as soil, water, and houses and the relations between these objects.

2 Material participation and causation

Our conceptual approach connects studies on material participation with work informed by Karen Barad's agential realism. Studies of material participation have shown how 'entities can acquire political capacities in certain settings and associations' (Hawkins 2014, 5), and help enact particular arrangements of influence and authority (Winner 1980; Hawkins 2014). Such political realities are both discursive and material, as reality is performed rather than observed (Mol 2014; Mol 1999; Birkenholtz 2018). In this conception, material participation is the process of shaping what matter comes becomes relevant and how (Barry 2013; Chilvers and Kearnes 2016; Chilvers and Longhurst 2016; Grove and Pugh 2015). While many studies of knowledge controversies situate contestation in the epistemological domain, focusing on competing knowledge claims about a singular reality, studies of material participation suggest that the role of measurements and knowledge in controversies is not just a matter of perspective, but also a matter of being (Chilvers and Kearnes 2020; Watts 2013). Thus, they understand scientific controversies as an expression of ontological politics involving the clashing, coordination or exclusion of multiple emergent worlds (Mol 2002; Verran 2018; Singleton and Law 2013b). This means that things or entities can be multiple things at once, depending on how they are practiced and enacted and what knowledge constellations they are enrolled in (Mol 2002; Mol and Mol 2014). For scholars of material participation, multiplicity involves the embodied enactment of objects in practice, while epistemological understandings of controversies consider multiplicity to be about the existence of multiple perspectives on singular objects, which leaves the objects themselves untouched, only watched.

Barad's agential realist framework can be seen as part of this conceptual lineage as it equally rejects the separation between ontology and epistemology. The framework is particularly well suited for an in-depth analysis of material participation because it emphasizes 'the processes through which particular material properties emerge and other realities are excluded from being' (Hollin et al. 2017, 933). Barad draws on insights from Bohr, the pioneering quantum physicist, to conceptualize measurement as a process that generates boundaries between entities in assemblages. According to Barad, worlds come into being when relations between different elements are materialized in entanglement (Barad 2007a). Such entanglements are established by what Barad calls *intra-action*: the activity of assembling and re-assembling. In contrast to the idea of interaction that assumes preexisting entities, the concept of intra-action emphasizes that entities only emerge as separate as a result of their engagement with

each other. This occurs by establishing what Barad calls *agential cuts*. Agential cuts enact distinctions so entities become separately recognizable – the observer and the observed, the one that acts and the one that is acted upon (Kaiser and Thiele 2014). The cuts are agential because one part of the world makes itself intelligible to another part of the world through the intra-action. This means that when the observer and that which is observed intra-act, both change (Barad, 2007a). Agential cuts result from boundary making practices that selectively enact how matter comes to matter. Measurements are such boundary making practices; they separate the measuring entity from the ‘object’ that is being measured (Pranckunaite 2019). Thus, in Barad’s understanding, the practices through which we come to know the world are inseparable from the constitution of material reality – the fundamental inseparability of entities makes that no ‘propertied entities exist [. . .] “behind” or as the causes of phenomena’ (Barad 2007b, 128).

Repetitions of similar intra-actions over time stabilize agential cuts between entities, thereby creating stable practices and measurable qualities of things (Singleton and Law 2013a). Importantly, this includes the constitutive exclusions that are simultaneously enacted. Once specific measurement practices become institutionalized, their patterned and material consequences can crowd out alternative agential cuts from becoming meaningful (Giraud 2019; Schwartz 2021). This is why Barad refers to an inseparable ethico-onto-epistem-ology (Barad 2007a). For example, the invention of the microscope enacted a world filled with bacteria and metamorphosing larvae, which led to dismissal of theories of spontaneous generations of organisms such as fleas from sand (Encyclopedia Britannica n.d.; Reitsma 2011). Before this invention, the material had been agentially cut by hitherto existing measurements into separations between sand and flea. The microscope enabled measurements that could and did make distinctions between sand, larvae, and winged insects carrying the flea eggs, fostering completely different relating with the world. In other words, measurements and instruments discover, invent, and exclude at the same time – they enact one possibility, where a plethora of possibilities had existed before. Moreover, when one possibility is brought into being, this also enacts political significance and determines whether a thing can participate materially. Larvae became political actors that could change practice, but only after new cuts had been made and new measurable entities were created.

In this article, we focus on intra-active causality to empirically shed light on how measurements are performative in a posthumanist sense and how agential cuts are made. The establishment of cause and effect gets iteratively routinized and institutionalized by measurements, measurement instruments, and what is measured (Wagensveld and Jolink 2018). Intra-active causation then is the new (re)enactment of agential separations through agential cuts (O’Brien 2016). In other words, some entities (‘effects’) in a practice become marked in their intra-action with other entities (‘causes’). Intra-active causation then, is the practice through which entities are meaningfully distinguished from one another, which enacts a separately recognizable ‘cause’ and ‘effect’. This notion of causation helps us to understand the causal claims we encounter in our empirical material as intra-active and performative practices (Wagensveld and Jolink 2018).

The sections below offer an analysis of two causal claims to demonstrate how measurements separate entities and the consequences that brings. We look at claims that emerged in stakeholder participation settings in mining to engage with disputes

about causation. Stakeholder participation involves politics about the very being of things and thus, they can provide an open setting for evoking different and conflicting worlds (Grove and Pugh 2015; Yates, Harris, and Wilson 2017). However, as we will show, the scope for participation is inevitably limited and exclusions are always at stake; specific worlds are raised on the basis of some causal claims at the expense of others. In our analysis, we first introduce what causal claims are mobilized and what measurements underpin them. Subsequently, we discuss what material constitution of the subsurface these claims and measurements performed and how this affects human political contestations. Then, we discuss this understanding of posthumanist performativity in terms of political participation.

The empirical research for this article was carried out between August 2019 and December 2020 by the first author (the 'I' in this article) and included 42 semi-structured interviews, numerous informal talks, observations of sites, document analysis, guided car tours and frequent bike rides. I conducted interviews with people active in citizen initiatives, architects, the salt mining managers, a mining technician employed by Frisia, governmental agencies and politicians at the provincial, regional, and local level, including the water boards and technical committee for soil movement (TCBB). I held more informal conversations with city tour guides, secretaries, farmers, and shop owners. The research included two observations at agricultural fields, three at drilling sites, and three houses, and during two stakeholder meetings. The assessed documents included nine technical reports the homeowners and TCBB drew on and produced (see section 4), as well as reports of stakeholder meetings and city council meetings. Car tours as well as bike rides served to get acquainted with the landscape and relevant locations, and allowed these sites to prompt unexpected stories. More formal interviews were transcribed. Informal conversations and observations were recorded in fieldnotes. All conversations were in Dutch, which was the first language of almost all research participants. One research participant's first language was Frysian, Dutch was his second. Transcripts and fieldnotes were analyzed with Atlas.ti through a priori and in vivo coding. The research initially focused on the relationships between stakeholders and mining company, the official participatory possibilities for residents and the labor of protesting residents. However, efforts to stay empirically and conceptually open to the particularities of unfolding worlds turned the analysis to the causal claim's content presented below (Rosiek, Snyder, and Pratt 2020).

3 Delving into the world's deepest salt mine

Our analysis concerns a case study of salt mining and soil subsidence in the Dutch province of Fryslân, where Frisia Salt B.V. manages the deepest salt mine in the world (Breunese 2010). Frisia dissolves high quality salt from a kalium layer, then transports it with pipelines to the salt plant where water evaporates, and a pure salt remains. The kalium layer is located at an unconventional depth (about 3000 meters below soil surface), where the soil's high temperature and pressure turn salt into a gel-like substance. Extracting salt at this depth required Frisia to engage with techniques that were untested in practice. The biggest issue for salt mining is soil subsidence, which was only predicted, tested, and translated in models and in the laboratory. Importantly, the models predicted that the soil would subside less than ten centimeters over ten years. However,

the soil subsided almost thirty centimeters in the ten years after salt mining started (Alterra 2006). To explain this unexpected subsidence, Frisia assessed the subsidence allocation, did additional laboratory measurements, and produced new models to account for the subsidence (De Waal, Muntendam-Bos, and Van Thienen-Visser 2016). Based on these adjusted models, the government permitted to continue mining on land, with a maximum soil subsidence of 35 centimeters (Fokker et al. 2018).

Soil subsidence can lead to flooding, damage to agricultural fields, infrastructure, and buildings. For these reasons, the mining activities sparked protests by neighboring farmers and homeowners. In response to these protests, Frisia decided to shift their operations from under land to under the Wadden Seabed. In 2014, Frisia received a governmental permit to mine under the UNESCO heritage site the Wadden Sea, and production started in September 2020 (Harlingen Courant 2020). The new location incited protest too, particularly considering potential damage to the cultural heritage sites in the nearby town (Veldboom, Colen, and Willemsen 2014; Sys 2019).

Below, we present two variations of the causality claim that link damage to buildings to the salt mining. We describe the material participation processes that emerged around these claims. We will see that soil, houses, and water are recurring central entities with fluid boundaries between them. In each claim, these entities take a different shape relative to each other. The claims concern 1) houses in the village Wijnaldum, and 2) monuments in the town Harlingen. The claims relating to houses in Wijnaldum emerged during the ongoing land-based mining, the claims about monuments refer to the sea-based mining that was about to start at the time of writing. Thus, while the first claim is about materialized impacts, the second is about future potential impacts of mining activities. In our analysis, we show how soil subsidence relates in diverse ways to damage to houses and monuments. Measurements importantly co-constructed all causal claims. We first identify the causal claims that are put forward and highlight how measurements and agential cuts shape the claims. Subsequently, we focus on the performative effects of measurements and thus on the material, social and political implications of causal claims and the measurements that underpin them. We conclude with discussing the implications of measurements' material performativity on public participation.

4 A story of material participation in two claims

Two causality claims emerged that connected salt mining and damage to buildings. Both claims concentrate on salt mining as the cause of soil subsidence, which in turn can lead to damage to houses and monuments. Both claims had mobilized (groups of) citizens who had to convince governmental authorities about the link between salt mining and damage to establish a rationale for receiving compensation. The homeowners in Wijnaldum and the monument owners in Harlingen differed in strategy and political status. Although strategy and status were relevant aspects for the claims' political influence, we focus on the materially performative aspect, i.e. the role of measurements in allowing or substantiating particular claims and disallowing others. Together, they showcase different modes of participating in ontological matters: a hierarchical choosing between two sets of proofs to determine which one counts as evidence and a collective process to determine how evidence is created. Below, we describe how each of these claims got substantiated with scientific measurements and how evidence came to count.

4.1 *If walls could talk*

In 2012, cracks emerged in houses in the salt mining's neighboring town Wijnaldum. The owners of these houses related the cracks to salt mining and asked for compensation. They presented their claim as a link between salt mining, soil subsidence, and damage to houses. The homeowners based their causal claim on multiple sources of longitudinal data of soil movement in the entire area, including GPS measurements. Primarily, they based their causal claim on two logics: 1) they calculated that during and after mining, the soil in the area subsided twenty-eight times faster than in other areas further removed from the mining activity, and 2) their houses showed cracks after mining while they had not shown any signs of damage in the decades before salt mining had taken place (Personal communication architect, 2019). This causal claim was therefore based on the argument that in the past, no cracks occurred, which demonstrated that the houses had a solid foundation, whereas after mining, cracks did appear. The homeowners based their claims on publicly available reports (TCBB 2018; Alterra 2006) and on data they accessed through befriended experts in the field (mainly geologists, hydrologists and architects). Importantly, the homeowners resorted to these data and the indirect causal reasoning, because no baseline measurements had been taken before mining started. Even though the houses were located within the prognosis area where damage could occur (ESCO 2006), no official monitoring system was set up at the start of the mining operation to measure impacts on buildings, and therefore, only indirect measurements could demonstrate the longitudinal effects of salt mining, expressed in a reversed causal claim ('no cracks before mining started'). This lack of baseline knowledge was not a coincidence. A geologist who owns an independent advisory company explained that his firm had advised and offered to install meters that can accurately measure soil subsidence close to the salt extraction sites and that could have generated up-to-date maps prior to mining, but that this has not occurred. This geologist regarded this as 'unwillingness and incompetence' of Dutch mining companies, ministries, knowledge institutes, and the governmental regulator.

Although governmental authorities failed to provide baseline information, governmental authorities did not readily accept the claim that salt mining caused the cracks and did not grant the requested compensation. Instead, they asked a technical committee to determine whether a causal relationship between mining and damage to houses could be established. The TCBB was a multidisciplinary committee (including legal experts, architectural engineers, geo(hydro)logists employed at governmental knowledge institutes and universities). The TCBB's role was to formulate an expert judgment in the form of an advice to homeowners and governments. The committee considered it possible to decide about causality without baseline measurements and drew on measurements and data that differed from the homeowners' information sources. While the homeowners had focused on long term soil subsidence in general, the TCBB's research included data about the houses' construction and foundation, water streams, salt extraction and (historic) changes in ground water levels (Personal communication employee, Water Board Fryslan, face to face interview, Februari 5, 2019; personal communication, TCBB secretary, telephone interview, April 22, 2020). These data had not featured in the homeowners' assessments, because they considered it either inaccurate or impossible to establish causality based on these crosscutting measurements.

While differences in causality assessments are sometimes linked to scientific disciplines and respective connotations (Kroepsch 2018), the controversy studied in this article rather pointed to differences in (temporal) understandings of how causality could be established (e.g. cross-sectional or longitudinal data, causality without adequate data) and at what point such established causalities would make sense beyond the members of the measuring committee. Thus, what we see here is the entanglement of ethics and measurements that goes beyond disciplinary boundaries – similar disciplines were engaged in both the homeowners and TCBB's impact assessments, with different causal outcomes. The differences in causal claim seem to be stooled on diverse understandings of the very possibility to measure the impact or not. The political implications of how the subsurface is understood and measured were recognized by the homeowners. One of them said: 'that's why the TCBB rejects all compensation applications. The only assumptions and facts that the committee uses, are the ones that suit her well'.¹ Based on measurements that were rejected by homeowners, the TCBB concluded that the most likely cause of the cracks is the inadequate construction of the houses, which implied that no compensation was granted. While the TCBB was tasked with establishing a causal relation, the committee also recognized that it is impossible to determine the cause with absolute certainty. As one member of the committee explains: 'There are always twenty other potential causes. It is always about defining the possibility' (Personal communication TCBB secretary, telephone interview, April 22, 2020).

The measurements done by the TCBB enabled an understanding of the subsurface as subdivided into different entities with complex inter-relations. Here, the soil-water system and the houses were measured into different entities, which complicated a direct link between soil subsidence and walls of buildings. In comparison, the homeowners' measurements shaped the subsurface into a singular entity that enabled attribution of causality to salt mining. This was grounded in a longitudinal understanding of the subsurface, while the technical commission used a cross-sectional approach to understand the relations. Consequently, responsibility for the damage to the houses became fractured among the multiplicity of processes that were part of the TCBB's measurements. In other words, the TCBB's measurements produced a crowded subsurface full of different processes and water systems, which negated the possibility of a singular causal relation between the subsurface-as-a-whole and the houses. Consequently, this crowded subsurface replaced the singular soil that the homeowners mobilized and reduced the homeowners' political influence. We can say that while the homeowners measured the soil *level* as proxy for the soil and enacted a simple relation between soil and houses, the TCBB used a multitude of proxies to identify what the underground was and how different underground processes related. The TCBB never incorporated measurements about the soil level as stand-alone measurements; such measurements were always complemented by assessments about the construction and foundations of houses, water flows in the subsurface and potential earthquakes (personal communication TCBB, telephone interview, April 22, 2020). In other words, the soil as a singular entity was never measured into being by the TCBB, and therefore could not exist in their claims and hence not participate politically. Based on these measurements, governmental authorities decided to not grant compensation to the homeowners because processes of the fragmented subsurface were deemed more likely to have caused the cracks.

What is at stake in the competing causal claims by the home-owners and the TCBB is not a matter of uncertainty but one of episto-ontological indeterminacy (Barad 2007b) since the different claims relied on different agentic cuts. The measurements that the TCBB deemed necessary were grounded in ontological assumptions of differentiation of and enacted cuts between the below-ground systems. This implied not only that the subsurface was understood as being differentiated, but also that it could only be made relevant by a multitude of measurements. This understanding of the subsurface could gain traction because it was also practically *possible* to measure all these different systems. It is important to note that complex, fragmented subsurfaces prove more difficult to link causally to extractive practices (Kroepsch 2018; Shackley, Wynne, and Waterton 1996). Such fragmentation, in combination with the lack of baseline measurements, can be linked to strategic ignorance strategies of the extractive industries, in particular through hindering monitoring and intentional nondisclosure (Wylie 2018; Lawrence and O’Faircheallaigh 2022; Kroepsch and Clifford 2021; Mcgoey 2012; Knorr Cetina 1999; Kinchy 2020). Because monitoring infrastructure lacked at the start, the subsurface processes as well as their relations were not established, and the TCBB had to resort to what they called ‘technical causality’ – a causal explanation that was perhaps not conclusive but – in their words – the most likely relation. The establishment of this ‘most likely relation’, however rigorous and independent the research process may have been, is inherently limited and exclusive. This is because the procedure to enact the underground was not designed for multiple undergrounds, which meant that the homeowners and their allies were not able to influence what subsurface came into being.

4.2 Monuments and monitors

In response to persisting protests against salt mining on land, Frisia decided to relocate the salt extraction to the UNESCO world heritage site the Wadden Sea. Preparations to start mining from the Wadden Sea seabed started in 2007, including political negotiations and feasibility investigations (Veldboom, Colen, and Willemsen 2014). Extraction started in September 2020 (Harlingen Courant 2020). With this relocation, a new causal claim emerged that concerned the possible future impacts of salt extraction on monuments in Harlingen. This claim was again about the possibility of damage to houses, but this time in Harlingen – the town closest to the new mining location. Harlingen is characterized by hundreds of houses and other buildings that have the cultural heritage status of ‘monuments’ and that are actively protected by their owners. After Frisia obtained the necessary permits, a group of concerned monument owners lobbied for better monitoring and measurements, including baseline measurements (Stichting Bescherming Historisch Harlingen n.d.). The monument owners learned from the damage in Wijnaldum that longitudinal measurements were needed to attribute possible damage to the mining. The monument owners also learned that ‘collecting facts’ was not sufficient to receive compensation in the future. Therefore, the strategy was to lobby for binding measurement instruments and procedures. The lobby was successful and the monument owners, the company, and the local, regional, and national governments agreed that extra monitoring would start shortly before commencing extraction to secure baseline measurements and the stability of future causal claims in cases of damage.

To support their lobby, the monument owners in Harlingen employed the same causal claim as the homeowners in Wijnaldum. Both identified salt extraction as a cause of (future) damage to the monuments, with soil subsidence as the process linking them. By promising to establish baseline measurements, governments substantiated the possibility of this causal claim for future damage. One aspect of the governments' willingness to do so was because a new measuring instrument had been developed: the so-called tiltmonitor. This device was rendered able to measure causation and had become a conventional monitoring instrument in the decades between mining under land started and mining under sea would start (Bal, Smyrou, and Bulder 2019).

Tiltmonitors detect subtle changes in the earth (IRIS Earthquake Science 2010). They measure soil subsidence in real time, compare that to model projections, and – in case soil subsidence deviates from the models – allow for the timely adjustment of the amount of extracted salt. In this situation, 'the tiltmonitors enable the generation of good soil subsidence maps, measuring the relation between the amount of salt extracted and soil subsidence, measuring the acceleration of soil subsidence and warn when the soil subsides too fast' (Personal communication with geologist, email conversation, December 11, 2020). In so doing, tiltmonitors are considered able to establish causal relations. However, as a tiltmeter manual articulates, drawing conclusions about causality based on the tiltmonitor implies a large discretionary and interpretative element. According to the manual, the device is designed to 'measure differential angles in the X or Y directions' (RST Instruments LTD 2016, 1). Other phrases similarly stipulate causal attribution of the data as a matter of interpretation and inference.

This recognition of the role of interpretation and inference implies an understanding that tiltmonitors do not in and of themselves measure causality. Instead, a tiltmonitor works to reinforce particular boundaries between entities: it divides the material into multiple processes; it quantifies a difference between above surface and sub-surface; and it renders the distance between location A and B significant. While it cannot directly measure causal relations between these entities, this remains a matter of inference, governmental authorities and stakeholders considered it capable of doing that. We also see that data analysis and data-based decision making are only possible when the public shares the ontological assumptions about the items that are built into and enacted by the device. For example, only when the public agrees with the measuring apparatus about the measuring possibilities as well as its relevance, then can the measurements make sense. Because all parties agreed on the tiltmeter's ability and credibility to measure the relation between soil subsidence and damage to houses, they established a stand-alone measurement of the subsurface-as-a-whole (cf. Ureta 2018). This had been impossible for the Wijnaldum homeowners, because such a singular subsurface was not measured into being, and therefore did not exist and could not participate. The installation of extra tiltmonitors in the historical town of Harlingen prior to extraction (Frisia Zout 2019) enabled the enactment of the subsurface-as-a-whole and its participation in negotiations about and authorize causal claims between salt mining and damage to houses.

Albeit the local government, the mining company, and the group of monument owners agreed to use tiltmonitors to measure subsurface systems, this agreement did not guarantee that resulting causal and compensation claims would also be agreed upon. The committee that would in the end decide about whether causation was proven had not been involved in the ontological agreement and, therefore, might not be committed to the

established consensus. In the future, this committee may discard the tiltmonitor data, or complement them with other measurements that enact different agential cuts. This could unsettle causal claims, which may mean that when damage occurs, no direct responsibility could be attributed (Stichting Bescherming Historisch Harlingen 2020). Also, this committee rejected the monument owners' request to partake in designing the measurement network, because they considered it inappropriate and not objective to both design the monitoring system and determine causality afterward (Commissie Mijnbouwschade 2020, 1). This rejection to contribute to the design of the baseline measurements and monitoring system also demonstrated that the committee's members were aware of the politics that exist within the measurements and thus that there was a need to disassociate themselves from the initial measurements.

5 Constituting a material public

Our analysis showed how causal claims about the role of subsurface in damage to buildings proved to be production sites of different material realities (Waterton 2003). In both causal claims, measurements helped to enact entities and shape the possibilities for participation. Measurements were also a key component in the articulation of the claims and for the establishment of the possibility to be compensated. For the houses, the composition of the subsurface was contested and specific measurements and arrangements of the subsurface were dismissed at the expense of the homeowners. What mattered is that the homeowners understood and measured the subsurface-as-a-whole, while governmental authorities rendered the subsurface as existing of a multiplicity of underground processes. The corresponding multitude of measurements crowded out the possibility to measure the subsurface-as-a-whole. As a result, both homeowners and the subsurface they measured were disempowered to partake in negotiations about compensation of damages to houses. In the causal claim about the monuments, stakeholders agreed that tiltmonitors could measure the subsurface-as-a-whole prior to mining, which enabled the establishment of a direct causal link between salt mining and damage to monumental houses in case this would appear in the future.

Our analysis adds to our understanding of the role of measurement and the establishment of harm in political controversies. Studies on material participation have demonstrated that different knowledges and measurements compete and thereby affect the realm of human politics, including who is able to participate in deciding about mining interventions (Kroepsch 2018; Ruckstuhl, Thompson-Fawcett, and Rae 2014). We show that measurements do more than just that: they also affect how matter comes into being. In our case, measurements not only registered but also constituted the subsurface as either a singular or a fragmented entity. Measurements are thus political in their relation to the matter being measured; measurements, the data they produce, as well as their interpretation all become part of controversies, because they enable particular intra-actions at the expense of others. Our analysis also how matter actively participates by resisting to or cooperating with different ways of making sense of the world. For example, the different subsurface systems under the houses of Wijnaldum were measurable, in contrast to the subsurface-as-a-whole due to a lack of baseline measurements. This resulted for the TCBB in a causal claim focusing on the different subsurface systems,

while the homeowners resorted to a reversed causal claim. Twenty years later, the tiltmonitor did allow the subsurface-as-a-whole to participate in negotiations about monuments.

It is an achievement rather than a given for an entity to be brought into existence and to become relevant for participation (Hawkins 2014; Wylie 2018). Measurements, mainstreaming measurement instruments and creating agential cuts to enact entities all require work, especially when measurements and the entities they enact do not fit with dominant methodologies and understandings of the subsurface. Our study demonstrates that when dominant actors such as governmental authorities can dismiss the existence or measurability of an entity, participation of this entity and the publics formed around them becomes futile. In the case of the Wijnaldum houses, creating space for the participation of different and competing ontologies would have required the open consideration of the data of the homeowners and the joint deliberation of what is considered reliable evidence and what measurement instruments can produce this evidence. Such a materially informed mode of participation is able to recognize contestation and controversies over ontologies as necessary aspects of doing politics (Barry 2013; Law and Singleton 2014). To ensure such ontological political participation, it is necessary to make explicit which assumptions, measurements and agentic cuts are performed through causal claims, prevent the naturalization of particular dominant classifications, and do justice to the ontological heterogeneity of extractive publics (Tsosie 2012; De Santos 2016; Temper 2019).

While scholars showed how certain participatory activities (e.g. consultation) perform a public that responds to those activities (Barry 2013; Meesters and Hendrik Behagel 2017), we demonstrated that coming to understand the world with measurements should also be seen as a participatory activity that performs a heterogeneous public and in so doing prevents others from being constituted. Knowledge practices enact worlds with entities that respond to the activities and the underlying presumptions at hand, while excluding those that do not respond or fit to the measurement or agreement. Agential cuts only enact the agencies that are cut together-apart through the intra-action – other parts of the world do not make themselves intelligible. Matter that is not measured does not come into being as a recognizable entity that can act; the only matter that comes to matter is measured matter. Moreover, the only matter that can join in ontological negotiations is matter that is measured by someone who is in the end able to decide what the world is. This brings the ethical and political implications of measurements into sharp relief and it underscores the importance of Barad's notion of ethico-onto-epistemology (Barad 2007a, 185).

From this perspective, a more inclusive approach can be based on the recognition of multiplicity; the simultaneous emergence of different material realities. However, the houses example shows that (perhaps strategically informed) limited space for multiple ontologies (in this case, that the subsurface can be both one entity and multiple) hinders mining justice (Giraud 2019). The houses controversy involved ontological collisions because different worlds were enacted through measurements, whereas compensation claims demanded a singular world. In this controversy, the demand for singularity prevented the participation of alternative worlds and this prioritized science- and business-as-usual over other ways of measuring. In contrast, the monuments example provides an illustration of how multiple worlds can be allowed to co-exist through

collective inquiry, by suspending judgment about what the world is (see e.g. Waterton's (2017) participatory knowledge collective). It is not surprising that it is a future-oriented case in which impact assessments perform differently, because impact assessments have been criticized for 'aggressively pushing forward and almost never looking back at the epistemic violence in its wake' (Lawrence and O'Faircheallaigh 2022, 1). Our analysis suggests that when there is limited room for the participation of multiple worlds, structural interventions, such as the co-designing of the monitoring system in the case of the monuments, may be needed to support fair ontological negotiations (Van Dunné 2005; Law and Singleton 2013; Giraud 2019). Or, in the words of Haraway, it is important to institutionalize processes that allow to 'stay with the trouble' (Haraway 2010) and critically examine the political implications of different worlds, causality claims or agential cuts (Tollefson and Panikkar 2020).

6 Conclusion

Negotiations about what exists are not equal, as the possibilities to enact material realities are not equal either. When citizens do ontological work that complicates scientific and governmental procedures, the knowledge they produce and the worlds they enact are easily discredited. We demonstrated that the privilege of scientists depends not only on their networks, backgrounds, or status, but also on their ability to enact specific materialities and exclude others. Driven by an imperative to come to a verdict about causality, it becomes increasingly hard to argue that water flows or the construction of houses are not legitimate factors in establishing causation when they suit scientific conventions and are so easy to measure. As we have seen in our analysis, measurement strategies easily align with extractivist practices (Scott 2010; Panikkar and Tollefson 2018), often supported by appeals to complexity (Shackley, Wynne, and Waterton 1996; Lahsen and Turnhout 2021; Lamb et al. 2020; Lawrence and O'Faircheallaigh 2022).

More democratic and participatory ways to decide about *what is* and *what is relevant* require the deliberation about appropriate measurement instruments and models as much as it requires the mobilization of counter expertise (Kroepsch 2018; Ureta 2018). Careful consideration of the agential cuts that are enacted and how, as we have done in our study, can support such opening up because it facilitates critical scrutiny not only of what is measured and what comes into being, but also what is excluded and marginalized. This attention to posthumanist performativity and to the political consequences of knowledge practices can be seen as a way to further not just epistemological but ontological justice, which is increasingly recognized as a vital component of environmental justice (Temper 2019; Shakhnoza, McGuire, and Cardello 2019).

Our call for attention to posthumanist performativity goes beyond a call for the inclusion of diverse and marginalized stakeholders and knowledge systems. Reconsideration of prevalent measurementalities, and the values and interests they reinforce and reflect are important for fostering ontological inclusivity (Turnhout et al. 2014). One way to do so is to map out and integrate the value-laden *effects* of measurements within the design of impact assessments in terms of the worlds they enact, and the material objects and relations they create and exclude. The inclusion of diverse forms of knowledge and measurement instruments is, then, a way to not just strengthen

participatory legitimacy in a traditional and procedural sense, but also to counter structural exclusions by enabling matter coming into being by being known and by being measured otherwise.

Notes

1. The TCBB did establish causal relations for damage related to gas and coal extraction (TCBB 2015, 2016; 2017).

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