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Harmful routines? Uncertainty in science and conflicting views on routine petroleum operations in Norway

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ABSTRACT

Offshore petroleum activities are the focus of highly politicised debates globally. Typically, public debate is sparked by catastrophic events, such as the 2010 oil spill in the Gulf of Mexico, and decision-making processes fuelled by the assessment of 'worst-case scenarios'. However, everyday 'routine' petroleum operations also impact the marine ecosystems and adjoining socio-economic sectors, but the extent and severity of the impacts are uncertain. This paper takes as its point of departure routine operations and their surrounding uncertainties. Particularly, it focuses on the debates of whether to extend routine petroleum operations in vulnerable and valuable parts of Norway, such as the Lofoten area and the Sula Ridge. These conflicts draw on important and for some, epistemological uncertainties that surround the impacts of routine operations. The paper argues that it is necessary to first highlight these uncertainties, rather than marginalise them, and second, recognise that uncertainties are not simply a scientific challenge, but can be a powerful political tool. This paper unpacks and explores uncertainties associated with three phases of routine operations, that are used to steer political actions: (i) the impacts of seismic surveys on fish and marine mammals; (ii) the impacts of drilling mud and drill cuttings on benthic communities such as deep-sea coral reefs; and (iii) the impacts of produced water on the marine environment. The paper discusses the importance of transparency in addressing these uncertainties, and emphasises the need to implement the precautionary principle in a more participatory way. It thus proposes participatory exercises in order to allow the recognition of the epistemological nature of uncertainties.

1. Introduction

The acceptability of offshore petroleum activities has been the focus of highly politicised debates globally, conjuring up powerful images of oil-drenched beaches and wildlife. Typically, public debate is sparked by catastrophic events, like the 2010 Deepwater Horizon oil spill in the Gulf of Mexico. Likewise, decision-making processes are fuelled by the assessment of 'worst-case scenarios', mapping potential futures in the case of oil spills and their environmental and economic impacts.

However, present everyday 'routine' petroleum operations, which concern the planned unfolding of petroleum operations from site prospecting to petroleum production (see Table 1), also impact marine ecosystems and adjoining socio-economic sectors. Conflicting interests and values together with uncertainty related to the impacts of these routine operations have led to competing claims among actors and among experts. For instance, a substantial amount of polluting substances is discharged during the exploration and production phases [1], and fishermen complain about a decrease in catches as a consequence of exploration activities [2]. The debates concerning the area off the Lofoten and Vesterålen islands and Senja (from now on referred to as the Lofoten area) (see Fig. 1) are particularly heated. The area is known for its rich bird life and serves as an important spawning and nursery area for several abundant fish stocks [3]. It is therefore considered as both valuable and vulnerable [4]. However, the management of marine resources in the Lofoten area is undertaken in the context of uncertainty, such that policies need to be based on the precautionary principle [4,5] (see Section 2.2

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for the definition). But the concrete implementation of this is challenging.

Proceeding with precaution is problematic given the fact that, while some uncertainties regarding the impacts of routine operations can be quantified statistically and reduced through more research with adequate time and resources, other uncertainties can be described as 'epistemological'. Funtowicz and Ravetz [6] discuss 'epistemological uncertainties' in terms of 'ignorance', and describe them as a function of the inherent complexity, non-linearity and dynamics of socio-ecological systems (such as the system formed by routine petroleum operations and the marine environment). They can be a result of the inability to discern significant trends in the data, or a more fundamental ignorance of the ways in which complex socio-ecological systems work. Although the border between science and ignorance is continuously being pushed outwards by scientific advancements, epistemological uncertainties may be irreducible. Indeed, these uncertainties do not conform to our current quantitative or qualitative means of reducing uncertainty, and they demand a reflection on something that may be, for the time being at least, beyond our imagination. Such uncertainties legitimate multiple perspectives on the conceptualisation of the systems studied, and the way the issue is framed relative to these systems. This sees uncertainties as a powerful political tool in debates, either to encourage or prevent action.

In this context, the paper aims to discuss some key uncertainties surrounding routine petroleum operations in order to move the current focus of political debates from the definition of a 'worst-case scenario' to present petroleum activity. Indeed, the impacts of routine operations are very difficult to monitor, especially on the long-term; it is therefore important to discuss these uncertainties more transparently in the political sphere. The paper is written by researchers from the field of Science, Technology and Society studies (STS), interested in the way science (and more broadly, knowledge) is mobilised for decision-making, and by scientists from the Institute of Marine Research (IMR) in Norway. Through discussions among the authors, uncertainties surrounding three phases of routine petroleum operations were elicited: (i) the impacts of seismic surveys on fish and marine mammals; (ii) the impacts of drilling mud and drill cuttings on benthic communities such as deep-sea coral reefs; and (iii) the impacts of produced water on the marine environment. It is worth keeping in mind that these are only examples among others, of impacts and associated uncertainties of routine operations. However, the paper focuses on these three particular examples, as they have been assessed as very salient by the authors, and as they are very present in political debates in Norway.

The paper also aims to explore how these uncertainties legitimate different perspectives regarding how to manage petroleum activities in the Lofoten area, and how these uncertainties are thus employed as powerful political tools. IMR is one of the key scientific institutions advising the Norwegian government on issues related to marine resources and marine environment. Because of its advice against petroleum activity in the Lofoten area and the Sula Ridge (see Fig. 1), IMR has been part of the controversy on offshore petroleum activity, making it an interesting starting point to discuss the political role of uncertainties.

After providing background information in Part 2, Part 3 explores key uncertainties related to impacts of routine operations and the debates surrounding these. Part 4 argues that the precautionary principle should be implemented in a more participatory way, in order to better focus our discussions on the uncertainties surrounding present petroleum activities.

2. Background

2.1. Conflicting interests in the Norwegian EEZ

The Norwegian Exclusive Economic Zone (EEZ) spreads over three large marine ecosystems: the North Sea, the Norwegian Sea and the Barents Sea (see Fig. 1).

With its geographical spread, the EEZ hosts a vast variety of marine species and contains significant petroleum reservoirs. While petroleum production in the North Sea started in 1971 with the discovery of the 'Ekofisk' field, the opening of the Norwegian and Barents Sea for petroleum activities was a more hesitant process, which gradually took place in the 1980s. This was because the northern areas of Norway were perceived as more vulnerable, both in terms of ecological value and as a key fishing area. The ecological value has been shown to be especially high in the Lofoten area, which is described by the Integrated Management Plan for the Barents Sea and Lofoten area as particularly valuable and vulnerable [4]. Indeed, the area constitutes a spawning ground for Northeast Arctic cod and Northeast Arctic haddock, and is a nursery area for cod, herring, saithe and haddock larvae [3]. It is also home to the world's highest density of migratory seabirds, such as kittiwakes, auks and puffins [7], to diverse communities of marine mammals (12 species of large cetaceans, 5 species of dolphins and 7 pinniped species) [8], to the world's largest deep-sea coral reef (about 100 km^2, West of the Røst Island) and other benthic communities such as sponge aggregations [9,10]. In addition, the Sula Ridge hosts another important deep-sea coral reef (see Fig. 1). The Sula Ridge is outside the Lofoten area, which is the focus of this paper. However, since it is located in an area where exploratory petroleum operations are allowed, it will be included in the discussions (especially in Section 3.2) to illustrate debates among the petroleum industry and scientists.

This ecological diversity in the Lofoten area nurtures a flourishing traditional fishery sector, in particular for Northeast Arctic cod, which is economically the most important wild capture fish in Norway [11] as well as shipping activities. In 2011, 3,40,000 t of cod were caught, with a value of ca. 4 billion NOK [12]. In addition, the variety and uniqueness of the wild life of the Lofoten area support a lucrative tourism sector, evaluated to be worth 2.75 billion NOK for the period from 2005 to 2011, and parts of Lofoten are on the UNESCO's tentative list 'Protection of the World Natural and Cultural Heritage' [13].

Today, the Lofoten area is, after intense political deliberations, closed for petroleum production because of the richness of the area [4]. However, the promising oil and gas reservoirs fuel an on-going debate on whether to open the area. Exploratory drilling in the Lofoten area indicates important petroleum resources, of about 1300 billion barrels of oil equivalent, which is estimated to contribute to the creation of between 720 and 1340 jobs, depending on the industrial scenario that is chosen [2]. The projected benefits of petroleum activity in the area of Lofoten could amount to 105 billion NOK [13], making petroleum resources worth more than the fishery and tourism sectors together, at least in the short-term. In sum, the key conflicting interests in this area are petroleum production, fisheries and nature conservation, and their coexistence is described as very challenging (see the debates in Section 3.2 for instance).

So far, nearly 5200 wells have been drilled in the Norwegian EEZ, about half of them for production [14]. During this time, substantial amounts of contaminating substances have been discharged on a daily basis, stemming from drilling and produced water. Because of ecological risks from this activity, petroleum activities are controlled and regulated by the Norwegian government.

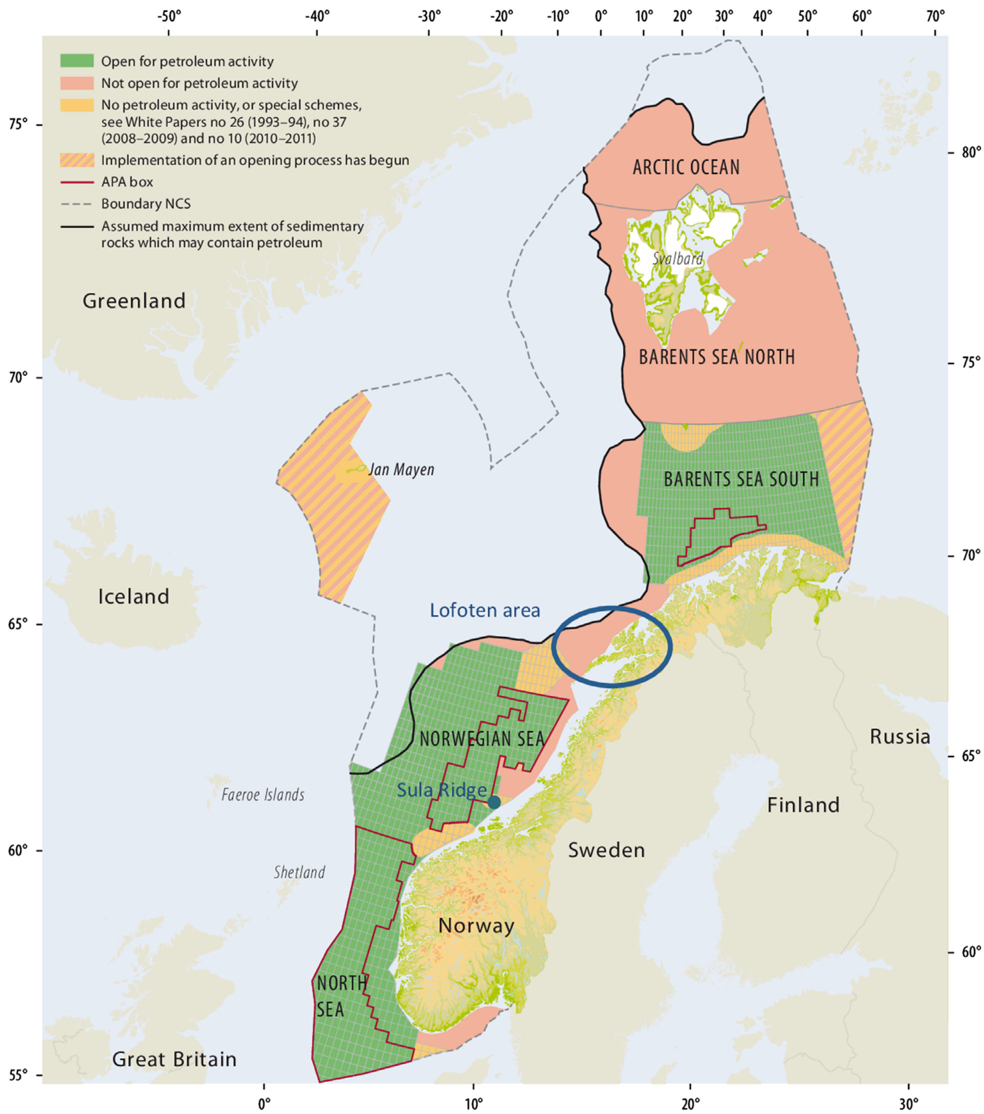

Fig. 1. The Norwegian Exclusive Economic Zone (EEZ) and petroleum areas (map from [1]).

Table 1
The main phases of routine petroleum operations.

Exploration
The exploration phase consists of gravimetric, magnetic and especially seismic surveys, as well as shallow exploratory drilling. Seismic surveys are used to detect the areas of the seabed that contain petroleum. Sound waves propagate through the seabed, and are reflected differently depending on the geological strata they hit; indicating the potential presence or absence of petroleum in reservoirs. Exploration drilling is used after seismic surveys to indicate the presence, quantity and quality of petroleum in the reservoirs, through shallow drilling in the seabed (see 'development and production phase' below for waste produced). If the exploration well does not contain exploitable quantities of oil and gas, the well is sealed with cement to prevent leaks and contamination by drilling fluids. The site is restored to its original state. However, if the well is exploitable, the petroleum company can apply for a production licence.

Development and production
If exploitable quantities of petroleum are found, the development phase starts. This phase includes planning which infrastructures will be used to exploit the petroleum field, and the drilling of wells. The production phase is the period during which a field and its associated pipelines and infrastructure are used to produce petroleum. During the production phase as well as the exploration phase above, two sorts of waste are produced: 'drilling mud' and 'drill cuttings'. Drilling mud is injected into the well as a lubricant for limiting friction-related complications while drilling, such as overheating and corrosion [15]. Drill cuttings are pieces of rocks and soil that are produced while the drill perforates the seabed. Another waste produced during the production phase is 'produced water', a mixture of water that exists naturally in the petroleum reservoirs and water that is injected into the wells in order to push petroleum to the surface of the reservoirs.

Field abandonment
When the petroleum field is exhausted, the removal of the petroleum infrastructure starts. Permission can be given to leave in place parts of the infrastructure if they do not disturb other activities and ecosystems.

2.2. 'Routine' petroleum operations and their regulation

Routine operations concern the everyday, planned unfolding of petroleum operations, from site prospecting to petroleum development and production, and to field abandonment.

All these phases of routine operations are regulated by the Norwegian Petroleum Act, to ensure that petroleum activity in the EEZ is carried out with 'a long-term perspective for the benefit of the Norwegian society as a whole', with 'due regard to regional and local policy considerations and other activities', such as fishing, shipping and tourism (Norwegian Petroleum Act, Section 1.2). The Act thus emphasises that routine operations should be undertaken with minimal environmental impact (Norwegian Petroleum Act, Section 10.1).

In order to undertake routine operations, petroleum companies must obtain a licence from the Norwegian authorities, which is delivered if (i) they report the details of the exploration phase in advance, (ii) they provide an impact assessment, describing the area and the assumed environmental and socio-economic impacts, (iii) they continuously reassess their security routines, (iv) they monitor the external environment, to map potential changes caused by routine operations: this monitoring includes impacts on benthic habitats (e.g., sediments, molluscs, deep-sea coral reefs) and on the water column (fish and mussels), and (v) they apply for emission permits to the Norwegian Climate and Pollution Agency.

The Integrated Management Plans for the Barents Sea – Lofoten area and Norwegian Sea aim for sustainable use of natural resources while maintaining the environmental value [4,5]. To ensure this, both plans refer specifically to the precautionary principle, as defined in the Nature Diversity Act.

> When a decision is made in the absence of adequate information on the impacts it may have on the natural environment, the aim shall be to avoid possible significant damage to biological, geological or landscape diversity. If there is a risk of serious or irreversible damage to biological, geological or landscape diversity, lack of knowledge shall not be used as a reason for postponing or not introducing management measures [4: 17].

However, as shown in Part 3 below, the question of how to apply the precautionary principle in the various phases of petroleum operations remains debated, and the conflicting interests, from petroleum production to fisheries and nature conservation, use uncertainties around the impacts of routine operations as a tool to influence decision-making processes.

3. Uncertainties around routine petroleum operations: powerful political tools

This section looks at some key uncertainties linked to three phases of routine petroleum operations. These uncertainties are argued to be epistemological and/or used as political tools in debates. The way they form the basis for controversies, and reveal power relationships among the various actors concerned by the question of petroleum activities in the Lofoten area and on the Sula Ridge, is explored.

3.1. Impacts of seismic surveys on fish and marine mammals

When searching for petroleum resources during the exploration phase (see Table 1), geological surveys are of crucial importance, and seismic surveys are the most effective and frequently used method. However, sound energy is emitted into the water column, from air guns towed near the surface, which may have a negative impact on the marine life that relies on sound for communication and predator or prey detection.

Scientific studies show that anthropogenic sound may affect a wide range of marine life [16], including fish and marine mammals. Such underwater sounds, at intense exposure levels, can lead to hearing loss, physical damage and behavioural changes [17]. During seismic surveys, hearing losses may occur [18], but the risk is reduced where fish can move away from high intensity sources. Other scientific studies reported behavioural changes (such as a 'scare effect') in the areas of seismic surveys, both for fish [19] and whales [16].

However, knowledge around the impacts of seismic surveys on marine life is incomplete, as it is very hard to access for at least two reasons. First, there are not many studies reporting on this issue in the Lofoten area since seismic surveys only occurred in the summers of 2007–2009 (to not disturb the spawning season of fish). Because it is often difficult to obtain new knowledge of a system, scientists often extrapolate results from other ecosystems, other species and life stages, or other contexts (e.g., caged fish versus fish at sea). This adds limitations and uncertainties to the results with regard to the transferability of the data. Second, there is currently no means to monitor the long-term effects of sound on fish and marine mammals in the sea. Therefore, even if a reaction (for instance, a scare effect) is observed on a particular fish species, knowing what it implies for the long-term development of that species is currently extremely difficult to study.

These uncertainties can be argued to be epistemological, as the complexity of the issue results in inconclusive knowledge regarding long-term effects, and varying impacts from fish species to others. These uncertainties lead to conflicts between the petroleum industry and the fishery sector on the way to frame the issue. On the one hand, petroleum industries prefer to talk in terms of 'viability' and 'mortality rate' [2]. Indeed, seen from this perspective, seismic surveys have negligible effects: lethal effects for fish occur only within 5 m from the source of the sound-waves, and account for a low mortality rate of 0.0012% per day on average [20]. On the other hand, fishermen rather focus on the increasing 'vulnerability' of fish stocks, which is threatening their source of income in the long-term [2]. These different ways of framing the issue set the basis for deep-rooted conflicts. As a representative of the Coastal Fishermen's Unions stated in the Norwegian weekly magazine 'Teknisk Ukeblad': 'coexistence with the petroleum sector is utopia' [21]. If the conflicting parties frame the issue in incompatible manners, no resolution will be possible.

These uncertainties are used as political tools in debates, and legitimating conflicting scientific studies employed towards various political ends. During the seismic surveys of 2007–2009, fishermen in the Lofoten area reported a decrease in commercial catches that they linked to these exploration activities [2]. This claim was validated by several scientific studies, with Engås et al. [22] showing a reduction of respectively 50% and 20% in trawl and long-line catches of gadoids during seismic surveys near the North Cape of Norway (Nordkappbanken), and Løkkeborg and colleagues [23] showing a decrease in long line catches for Greenland halibut and haddock off the Vesterålen Islands in 2009.

In contrast to these findings, however, Løkkeborg et al. [23] observed a doubling of redfish and Greenland halibut in gillnetting in Vesterålen during the 2009 seismic survey, and attributed these results to the increased swimming ability of these two species. Using the uncertainties around the impacts of seismic surveys on fish, petroleum companies criticised fishermen for using seismic surveys as a "convenient explanation for an event ('black sea', no fish) which is less than uncommon in these waters [2: 185]". Moreover, other fishermen that were more open to petroleum development in the Lofoten area reported that catches in the vicinity of seismic surveys were satisfactory [2].

This illustrates how uncertainties around impacts of seismic surveys on marine life are not only a scientific matter, but are used as political tools to legitimate conflicting scientific studies and steer political decisions. Epistemological uncertainties lead to conflicts based on different worldviews and values, which cannot be resolved by more or better science alone.

3.2. Impacts of drilling mud and drill cuttings on benthic communities such as deep-sea coral reefs

As mentioned in Table 1, when undertaking drilling operations in the exploration or development phase, two sorts of waste are produced: drilling mud and drill cuttings. With drilling mud and drill cuttings representing 75.5% of the total chemical discharges from routine operations in Norway [1], they are at the centre of the debates when discussing whether to allow petroleum exploitation close to the Sula Ridge and in the Lofoten area, which host large and important deep-sea coral reefs.

Deep-sea coral reefs constitute habitats for numerous benthic invertebrate species, and are seen as possibly important habitats for fish species such as rockfish and cusk [24]. However, coral reefs are fragile and particularly sensitive to disturbances [25]. They are also slow growing (10–25 mm/year) [26], and damages such as suffocation, contamination or physical harm can therefore take a long time to recover, with repeated disturbance potentially leading to permanent destruction [9]. Nevertheless, many qualities of deep-sea corals remain unknown, and further research is needed to understand the environmental factors and biological processes that regulate their life and distribution [10]. The associated uncertainty can thus be characterised as epistemological, as there is currently no means to measure these environmental factors and biological processes.

When deciding upon pipeline tracks, petroleum companies seek advice from IMR to avoid areas with coral reefs and other benthic species that are considered particularly valuable or vulnerable. However disagreements, notably between IMR and petroleum companies, arise around drilling locations, as the uncertainty concerning the impacts of drilling mud and drill cuttings is high. In anticipation of complementary studies, IMR advocates for a precautionary approach forbidding drilling in areas with coral reefs [27]. In response, petroleum industries point to their horizontal drilling technology, used during the production phase, which makes it possible to drill at a distance from vulnerable benthic communities, with reduced risks of contamination by drill cuttings [28]. But this poses questions of the 'safe' minimum distance between drilling operations and benthic communities such as corals. Marine scientists have been reluctant to give a specific distance, putting forward the complex and changing nature of ecosystems. Indeed, the different species of deep-sea corals may react differently to disturbances, and because the exposure of particles from the drilling operation is also determined by ocean currents, it is very difficult to give a unique threshold that would be valid within the whole Norwegian EEZ.

This issue illustrates the temporal dimension of uncertainty: there are no current scientific tools and data to reinforce the knowledge base on deep-sea coral reefs, but a decision needs to be taken now. This leads to different framings of the solution. Broadly, IMR scientists put forward the precautionary principle as a solution, while scientists and engineers representing the petroleum industry advocate in favour of technical innovation.

Further, the epistemological uncertainties around the impacts of drilling muds and drill cuttings are used as political tools, revealing in this case power relationships among the actors concerned. Indeed, where there are uncertainties, and when it is impossible to evaluate impacts, which aspects will be favoured in the political decision? Who will be given the benefit of the doubt? In the case of drilling mud and drill cuttings, it can be argued that epistemological uncertainties have led to a situation where the fishery sector is subjected to more stringent measures than the petroleum sector. In 1999, the Norwegian Ministry of Fisheries and Coastal Affairs prohibited bottom trawling in an area of about 1600 km^2 around the Sula deep-sea coral reef as a consequence of its negative impacts on coral reefs [24]. However, the Ministry of Petroleum and Energy gave the petroleum company GdF Suez was given permission to drill within this protected area, providing they undertook a strict environmental survey including measurements of currents and sedimentation, and samplings of sediments to be analysed for heavy metals [29].

While there is a broad acceptability of the precautionary principle, it cannot be applied in a universal way, but needs to be adapted to the individual circumstances of each case or issue. However, the precautionary principle should not be distorted from what it initially means, under cover that it should be case-specific. Therefore, it emphasises the need to justify why it is applied in a particular way; thus highlighting actors' values and influences, and explaining where risks are taken and how they are balanced with potential gains [30]. The example of drilling muds and drill cuttings indicates that Norwegian authorities at least implicitly attach a higher ethical value (perhaps in terms of economic consequences) to oil industry than to fisheries, perhaps reflecting the higher economic value of the oil industry. One may question whether the Norwegian authorities are prepared to argue this point with the Norwegian public.

3.3. *Impacts of produced water on the marine environment*

Produced water is a mixture of water that exists naturally in the subterranean petroleum reservoirs and water that is injected into the wells in order to push petroleum to the surface of the reservoirs. The water is in continuous contact with the oil and gas in the reservoirs, and water-soluble petroleum components are dissolved in the water, making it toxic. On the platform, the water is separated from crude oil, which is transported for further production and sale. In 2010, 131 million m^3 of produced water was discharged into Norwegian waters [31], making it the second largest discharge of pollutants during routine operations, after drilling mud and drill cuttings [1].

In the 2000s, laboratory studies started to point at a potential disruption of fish hormones due to alkyl phenols contained in produced water [32]. Alkyl phenols were also shown to affect cod's reproductive system, even at low concentrations [33,34]. Other laboratory studies reported the possibility of bio-concentration of chemicals from produced water in marine organisms [35,36]. However, fieldwork studies in the sea are much more challenging, and even though modelling and extrapolation techniques contribute to a better understanding of how chemicals behave in the sea, many uncertainties remain. With ocean currents and the swimming ability of the different fish species at their different life stages complicating scientific observations and measurements, there are currently almost no means to evaluate the long-term impacts of low concentrations of produced water on the marine environment and precisely assess the magnitude and type of these impacts [37].

With these epistemological uncertainties surrounding the biological impacts of produced water, IMR again advocates for a precautionary approach, in order to stop discharges of produced water from all new routine operations in the Barents Sea and Lofoten area [38]. The precautionary principle is manifest in a policy measure of 'zero discharge to sea', including drilling muds, drill cuttings and produced water [4,13]. When this measure was adopted, the oil companies argued that it was possible to re-inject these substances back into the wells. However, there is now doubt whether re-injections will be possible in the new fields. The regulations in the North Sea and the Norwegian Sea focus only on environmentally harmful components, thus being less stringent for petroleum activities:

> As a rule, oil and substances that may be environmentally hazardous may not be discharged to the sea. This applies both to substances added as part of the production process and to naturally occurring substances. The precautionary principle is to be used as the basis for assessing the potentially damaging impacts of the discharges [13: 64].

There have been disagreements on whether cleansed produced water, that can legally be discharged to the sea, is environmentally hazardous or not. Scientific studies show that after having monitored the impacts of produced water in the sea in the last decade, biological effects only occur for concentrations of 0.1–1% [39,40]. Since produced water at sea is quickly diluted down to concentrations below this limit, exposure to produced water in the Norwegian EEZ is argued by the Norwegian authorities to be 'too small to cause significant reproduction effects on marine populations' [41,26]. The petroleum industry therefore claims that precautionary policies should allow discharge of cleansed produced water below 30 mg/l, thus arguing for a policy based on thresholds.

However, recent field monitoring in the North Sea, in the region of Tampen, has revealed increased levels of DNA adducts (DNA bonded to cancer-causing chemicals) in the liver of wild haddock, at levels that were not expected in open seas [42–44]. These levels of DNA adducts were accompanied by increased levels of Polycyclic Aromatic Hydrocarbons (PAHs) in the bile of haddock and also cod [42], with PAHs found in oil compounds and in produced water. The Tampen region is an area where petroleum activity has been taking place for several decades, and in recent years, approximately 60% of the total produced water of the Norwegian petroleum sector has been discharged in this area. The PAHs could therefore stem from the on-going discharges of produced water in this region. On the other hand, numerous mud piles from oil drillings are found in the vicinity of petroleum platforms in this area. These piles can also include traces of oil, and therefore PAHs, as oil-based mud was allowed for drilling until 1993.

When the findings of increased DNA adducts and PAHs in wild fish were presented, the petroleum industry was reluctant to link these observed effects to produced water and argued that these effects were caused by the oil-based mud piles. As the observed effects in wild fish in the region of Tampen could be caused by all petroleum related sources that contain PAHs, it is scientifically very difficult to determine the proportion of these effects being caused by on-going discharges of produced water versus other sources such as mud piles. This uncertainty was used by the petroleum industry as a way to discredit the scientific findings, so that they would not be transformed into policies.

In the face of these epistemological uncertainties, how is the toxicity question dealt with, and who is given the benefit of the doubt? Petroleum industries put forward their efforts to minimise their environmental impact. They have indeed invested in expensive cleansing technology and play an active role in finding substitutes for the toxic chemicals that were earlier injected into reservoirs. This has resulted in a substantial reduction of the toxicity of produced water over the last few years [45]. However, privileged industry secrets regarding the composition of chemicals added to produced water in the drilling and production process limit access to knowledge on the toxicity of the components. The Climate and Pollution Agency has full access to the petroleum companies' knowledge on the composition and the chemicals' toxicity, as the Agency regulates pollution control. However, IMR, which serves as a quality control for the petroleum discharge permits, does not have full access to the composition of the chemicals. This lack of access prohibits IMR scientists from undertaking the required quality control of decisions on permits.

This case presents another example of the close relationship between epistemological uncertainty and political positioning. It shows the petroleum industry arguing that, where there is a lack of certainty, they should be given the benefit of the doubt owing to their previous efforts. IMR suggests that the implied uncertainty should cause stricter discharge regulations, and institutions representing impact assessments and regulations of pollution call for transparency regarding discharges.

4. Towards a more participatory way of addressing uncertainties around routine operations

It is important, when considering opening new areas for petroleum activity, to explore not only a potential 'worst-case scenario' and the impacts of accidents, but also the impacts of routine operations. This paper has focused on present routine operations, specifically on the role their surrounding uncertainties played in decision-making processes. To this end, the paper displayed three examples showing that uncertainties around routine operations should not be marginalised as a simple hole in the science. Rather, one should recognise the epistemological nature of uncertainties, sometimes used as political tools conveying different interpretations of the sustainability of petroleum activities. Epistemological uncertainties lead to conflicts based on different worldviews, values and interests, which cannot be resolved by more or better science alone. Consequently, any favouring of one perspective over another is also a value decision and not only a scientific one [46]. As political tools, uncertainties are used to legitimate conflicting scientific studies and steer political decisions, thus unveiling power relationships between the various actors.

The first example looked at the impacts of seismic surveys on marine mammals and fish. It revealed complexity and dynamics characterising the systems studied, especially relative to the different behaviour of different species of fish in different spatial and temporal contexts. This leads to competing claims on which aspects of the ecosystem deserve attention: in this case, 'vulnerability' or 'viability' of the fish stocks.

The second example looked at the impacts of drilling mud and drill cuttings on benthic communities. It illustrated the temporal dimension of uncertainties and their ensuing debates. Notably, that it takes time to reduce uncertainty, but that a decision needs to be made now. The future will likely bring improved tools and measurement for building a more robust knowledge base for this issue, but to date such methods and data are not available. This leads to different framings of the solution: shall decision-makers implement a more stringent precautionary principle, and ban all discharges of chemicals to the sea, or trust techno-solutions in their ability to clean these chemicals before they are discharged? With a limited knowledge base and the absence of objective truth, particularly on long-term effects of these chemicals on the marine environment, power asymmetry between actors may be a concern for political decision [47] (e.g., the Sula Ridge, where petroleum companies are allowed to undertake exploratory drilling, while fishermen cannot access the area). While power as such may not necessarily be seen as discrediting any perspectives, disguising power as scientific evidence can be argued as democratically questionable.

The third example looked at the impacts of produced water on the marine environment. It particularly demonstrated the clear politicisation of uncertainty regarding whether discharged water is proven to be hazardous or not, where the stance taken will influence decisions on management measures. This example introduces the normative question on how one makes the precautionary principle operational: do decision-makers adopt a strict precautionary principle and protect the environment from discharges that may not cause any harm, or do they make a decision on some other normative basis, such as what is fair to an industry that has been long improving their environmental impact? Both are legitimate arguments.

Such uncertainties need to be addressed in a more transparent way, to better distinguish between knowledge and values. The past 20 years have seen a number of approaches put forward for mobilising knowledge in support of decision-making, which give effect to a more transparent treatment of uncertainty. These approaches have found increasing credence in philosophy of science, and its neighbouring field STS (Science, Technology and Society studies), in the form of 'post-normal science' [6] and 'Mode 2' science [48] for instance; and in resource management in the form of, among others, 'civic science' [49]. All of these approaches offer useful insights, and are characterised by a number of common principles. First, all of these approaches begin from a notion of complex and dynamic systems, with implications for the ways society can claim to know about a given issue within these systems, and inviting a transparent discussion of all forms of uncertainties. Some of these uncertainties go beyond the domain of science alone, thus opening up for other forms of knowledge. For routine petroleum operations in northern Norway, it seems that the involved parties have addressed uncertainties as a scientific problem only, as if better and more science will in the end lead to the 'right' decision. Awareness of the extreme difficulty of reaching such complete knowledge should be encouraged.

A second important principle is that mobilisation of knowledge ought to be done through a participatory dialogue involving all knowledge (and value-) systems salient to an issue. The management plans for the Barents Sea and for the Norwegian Sea result from a vast expert and public consultation process, where petroleum activity has been a key subject [4,5]. However, the implicit expectations of what science and experts can achieve are too high, and discussions on how to handle uncertainty are lacking. The recognition that epistemological uncertainties exist, and that they should be addressed transparently in a participatory way, is encouraged by the precautionary principle [50,51].

Third, bringing together diverse knowledge systems in dialogue demands reflexivity, so that each actor recognises the legitimacy, credibility and also limitations of the other's knowledge, and indeed their own. Central to this reflexivity is the recognition of the nature of uncertainties, as spanning knowledge, values and politics. In other words, reflexivity in the process of knowledge generation and assessment demands of actors to reveal their presuppositions, knowledge limitations, objectives and interests. In our case, more attempts should be encouraged implying alternative communication channels other than scientific data and publications.

Finally, these approaches emphasise transparency in the policy process, so that uncertainties are highlighted, and expectations towards science are adapted to what it is able to provide. While transparency is a general norm in science more effort could be placed on communicating uncertainty. However, transparency may be more challenging for the petroleum industry due to its confidentiality terms based on keeping competitive knowledge secret. For high-stakes issues, transparency is central to the democratic legitimisation of the political decisions. In the case of routine operations in Norway, it seems that decision-makers use the argument of 'scientific objectivity' to justify their decisions, rather than playing out their implicit assumptions and value-stances in their assessment of these decisions.

The above points represent broad principles that can find practical expression in numerous ways. The authors of this paper would, however, like to emphasise two tools in particular to help structure discussions among the actors concerned by routine petroleum operations in northern Norway. First, the precautionary principle, already applied for the issue at hand here, does imply a number of explicit judgements and constraints, such as (a) the plausibility of potentially harmful consequences based on acceptable science, (b) the assessment of whether a potential harm represents an ethically unacceptable harm, (c) the explicit listings of possible strategies to avoid or diminish that harm, (d) the recognition that there tends to be a greater moral responsibility for actions taken than for inaction, (e) the normative restrictions on discounting long-term harms against short-term benefits, and (f) the assessment of the proportionality of the proposed measures against the extent of the possible harm. To our knowledge, no effort has so far been undertaken to systematically map out the consequences of the precautionary principle in Norwegian policy or discuss how to make it operational.

A second tool to help structure discussions around the issue could be the implementation of participatory exercises with a wide range of actors, in order to elicit the various uncertainties, assess their significance for potential political decisions, and identify potential gains and losses resulting from a range of political decisions, assessing whose interest these decisions serve. These exercises would also help widen the scope of alternative actions. Such participatory exercises may also address judgements of balance that enter the decision, such as balancing the local/regional versus the national interests (avoiding mere NIMBY – Not In My Backyard – arguments), balancing short-term versus long-term benefits and harms, balancing various values (economic interest versus quality of life versus non-anthropocentric values), and balancing the weight of alternative knowledge sources. While not in any way restricting the final political decision, such participatory exercises serve three important functions [52]: (1) they are instrumental as tools to uncover hitherto unrecognised sources of knowledge and perspectives on values, (2) they appeal to modern ideals of deliberative democracy in including affected parties, and (3) they lay foundations for robust policies that are embraced by a wider range of societal groups. The authors propose to undertake, in forthcoming research, such participatory exercises before political decisions are reached.

Ultimately, the key message of this paper is that uncertainties around routine operations need to supplement the existing knowledge base in a systematic, explicit and transparent manner.

5. Conclusion

Key uncertainties relative to routine petroleum operations are argued in the paper to be epistemological and used as political tools. They lead to conflicts based on different worldviews, values and interests, and legitimate conflicting scientific studies. This demands an alternative, more transparent way of addressing uncertainties, which allows the actors to acknowledge the multi-dimensional nature of uncertainty, and put them at the centre of the debate. Participatory exercises focussing on uncertainties could help decision-makers in various ways, by showing that uncertainties are inherent to the issue, and that scientific knowledge ought to be combined with value perspectives when deciding upon petroleum activities in the Lofoten area.

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