**Environmental Impacts of Oil and Gas production**

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## Post-workshop summary of impacts

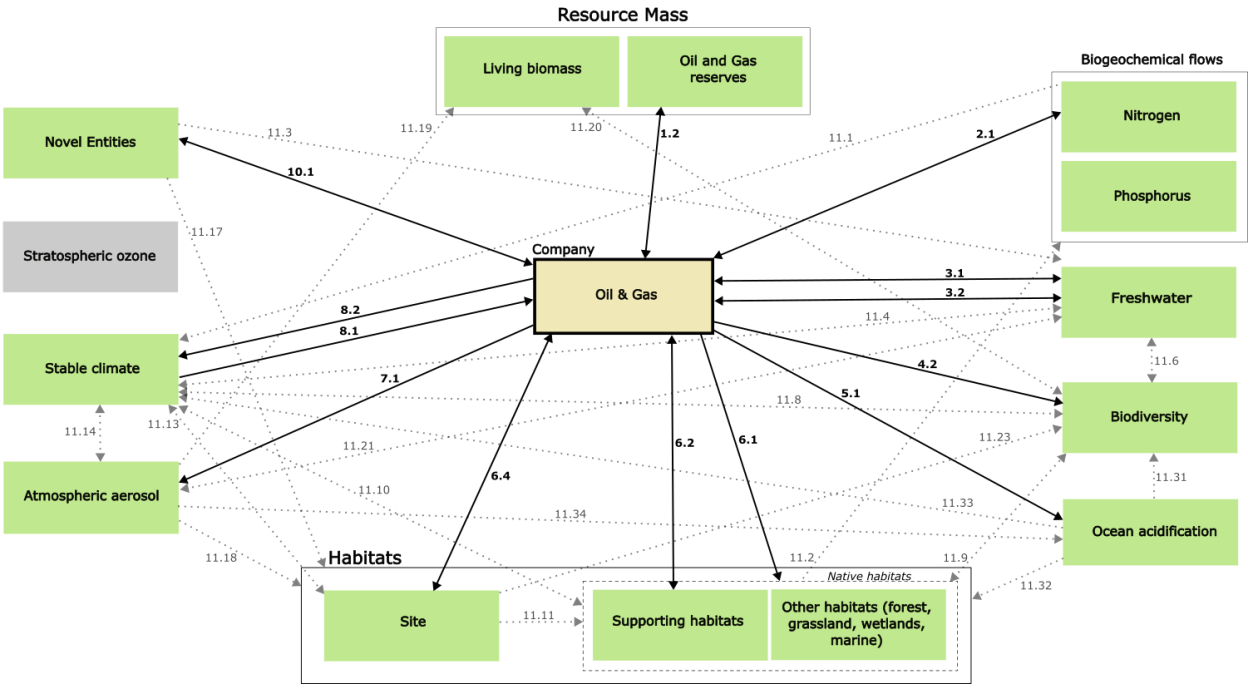


**Figure 1.** Conceptual systems diagram showing potential interactions between a company (yellow box) and various environmental dimensions. Dimensions are based on processes captured by the planetary boundaries framework, with the addition of natural resources. Solid lines represent direct impacts and/or dependencies of the company on various environmental dimensions. Dashed lines represent interactions between environmental dimensions. Viewed together, solid, and dashed lines represent the indirect impacts and dependencies of the company. Numbers refer to Tables 2 and 3 in this document. Boxes are shaded depending on if mechanistic links (i.e. arrows) are present (green) or not (grey).

**Table 1.** Direct environmental impacts and dependencies of oil and gas sector, shown as solid lines in figure 2. Links between a company operating in this industry, and the different environmental dimensions, are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

| No. | Category | Sub-category | Impact, Dependency or Both | Description of Mechanisms | References |
|---|---|---|---|---|---|
| 1.2 | Resource mass | Non-living mass | Both | Use of non-living resource mass as an input. However, this may lead to resource depletion, e.g. global oil depletion | 1 |
| 2.1 | Biogeochemical flows | Nitrogen | Both | Use of Nitrogen in Enhanced Oil Recovery | W |
| 3.1 | Water | - | Both | Large volumes of water are used for water injection, construction, drilling and well completion, upstream processing. This affects hydrological flows. | 2, 3, W |
| 3.2 | Water | - | Both | Dependency on good water quality for injection into oil fields. However, processes of secondary and tertiary (enhanced) oil recovery involve injection of various substances and/or produced water, e.g. brine, water-soluble toxic elements like Cadmium, natural gas, $CO_2$, Nitrogen, alkaline solutions, surfectants, polymers. This causes water pollution, such as groundwater contamination which affects drinking wells. | 2, 3, W |
| 4.2 | Biodiversity | - | Impact | Direct impacts on biodiversity. Noise and light disturbances impact fauna, especially marine mammals. Gas flare stacks cause massive avian mortality events due to stack emissions, roads and pipelines can represent barriers to fish passage. Infrastructure creates novel habitats and increases connectivity which can provide corridors for invasive species (e.g. invasive lionfish, invasive corals). | 4, 5, W |
| 5.1 | Ocean acidification | - | Impact | Emissions of $CO_2$, especially the downstream emissions of the oil and gas sector, increase the acidity of surface seawater | 6 |
| 6.1 | Habitats | Native habitats | Impact | Direct impacts of operations on native habitats. High risk of explosions, which cause fires. Seismic activity causes mass flows. Exploration surveys disrupt marine environments, esp. when span large exploration blocks. Habitat pollution includes drilling fluids, metal cuttings, oil spills, exhaust fumes and produced water. | 2 |
| 6.2 | Habitats | Supporting habitats | Both | Dependencies on supporting habitats, e.g. mass stabilization, buffering and erosion control, and flood and storm protection | 2, W |
| 6.4 | Habitats | Appropriated habitats | Both | Use of space of appropriated habitats, including for pipelines. This has negative flow-on effects to native habitats. | 7 |
| 7.1 | Atmospheric aerosol | - | Impact | Release of atmospheric aerosols, e.g. fine particulate matter (PM2.5), coarse particulate matter (PM10), Volatile Organic Compounds (VOCs) interact with nitrogen or sulfur oxides to form ground-level ozone | 2, 8 |

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| 8.1 | Stable climate | - | Dependency | Climate regulation provides protection to production processes. A changing climate and more frequent extreme weather events represent physical risks to the oil and gas sector, especially in low-lying coastal areas and areas exposed to extreme weather events. | 2, 9 |
| 8.2 | Stable climate | - | Impact | Impacts on climate. Greenhouse gas emissions, mainly $CO_2$ and $CH_4$ e.g. from fires, methane leakage, diffuse methane emissions in shale production, petroleum well-to-refinery emissions, gas flaring practices, and scope 3 emissions from consumption. Sector also responsible for large loss of biomass carbon, because oil and gas developed in areas with carbon-rich land cover, e.g. such as clearing forest for drilling sites. | 2, 10 |
| 10.1 | Novel entities | - | Both | Release of novel entities includes oil spill contamination, toxic materials from gas flares, fluids used to fissure rock formations in hydraulic fracturing (fracking) contain hundreds of chemicals, some of which are highly toxic. A major downstream impact of the oil industry is plastic production, which pollutes many habitats (especially marine) and is a driver of biodiversity loss. | 11, 7, W, 12 |

**Table 2.** Interactions between environmental processes relevant to oil and gas sector, shown as dashed lines in figure 1. Links are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

| No. | Categories | Description of Mechanisms | References |
|---|---|---|---|
| 11.1 | Biogeochemical flows (Nitrogen), Stable climate | Production of Nitrogen requires a large amount of energy and creates GHG emissions, contributing to climate change | W |
| 11.2 | Biogeochemical flows, Habitats (Native) | Removal of living biomass from an ecosystem causes effects on biogeochemical cycles, e.g. corals have a major role recycling nitrogen and in ecosystem productivity, so destruction or disturbance of coral habitats by oil and gas operations has consequences for N cycle | W |
| 11.3 | Freshwater, Novel entities | Release of novel entities causes freshwater pollution, e.g. surface-water contamination from hydrofracking fluids and produced water | 11 |
| 11.4 | Freshwater, Stable climate | Interactions between climate and hydrological cycle, e.g. climate change can lead to increased drought in some areas and increased precipitation in others, affecting water availability | 13, 14 |
| 11.6 | Freshwater, Biodiversity | Interactions between hydrological cycle and biodiversity, e.g. biodiversity provides clean water and flow regulation, which also supports biodiversity. Oil and gas development poses a risk to fish and wildlife, partly due to alteration of stream flows. | 3 |
| 11.8 | Biodiversity, Stable climate | Interactions between stable climate and biodiversity, e.g. GHG emissions from oil and gas sector not only drive climate change, but are also an indirect driver of biodiversity loss through climate change | 15 |
| 11.9 | Biodiversity, Habitats (Native) | Interactions between native habitats and biodiversity, e.g. fires, seismic activity and pollution of habitats from hydrocarbon activities have immediate harmful impacts on the fauna in that area. Oil and gas blocks cover highly biodiverse areas (including species-rich areas of the Amazon). | 7 |
| 11.10 | Habitats (Native), Stable climate | Interactions between native habitats and climate regulation, e.g. tropical rainforests are large carbon sinks, so deforestation for oil and gas extraction is detrimental for climate stability. Forests also benefit from climate regulation. | 16 |
| 11.11 | Habitats (Appropriated), Habitats (Native) | Habitat conversion to create space for company operations leads to degradation, loss, fragmentation and clearing of native habitats in species-rich areas, e.g. deforestation for access roads, platforms and pipelines | 7 |
| 11.13 | Habitats (Appropriated), Stable climate | Oil and gas projects involve replacing vegetation and topsoil with impermeable surfaces, reducing potential for natural carbon sequestration and increasing carbon emissions. | 2, 4 |
| 11.14 | Atmospheric aerosol, Stable climate | Aerosols have complex interactions with the climate system. They have both a cooling effect, by reflecting incoming solar radiation, and a warming effect, by absorbing heat radiation and changing surface albedo, but the net impact is a cooling effect. Uncertainty arises from complexity of aerosol absorption and impacts of aerosols on cloud microphysics. | 6, 17 |

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| 11.17 | Habitats, Novel entities | Pollution has negative chemical effects on habitats and ecosystems, examples of pollution include produced water, drilling fluids and accidental spillages. It is estimated that one drilling platform discharges over 90,000 metric tonnes of drilling fluids and metal cuttings in its lifetime. Potential pollutants in marine habitats include drill cuttings, drill fluids and processed water, which can kill benthic and freshwater vegetation. | 2 |
| 11.18 | Atmospheric aerosol, Habitats (Native) | Aerosols have harmful impacts on native and appropriated habitats, e.g. exposure to ozone can damage crops and natural ecosystems. Acid precipitation causes acidification of water, soil and forest environments. Pollution from the oil and gas sector impacts more distant habitats due to long-range transport in which vaporised chemicals spread through wind. | 18, 8, 19, 2 |
| 11.19 | Atmospheric aerosol, Biomass | Aerosols have harmful impacts on flora and fauna, e.g. exposure to ozone can kill freshwater fish. Particulate matter can have toxic effects depending on chemical and physical properties, e.g. dioxins can accumulate in foods such as meat and dairy products, fish and shellfish, causing human health effects. | 6, 8, 20 |
| 11.20 | Living biomass, Biodiversity | Interactions between living biomass and biodiversity, e.g. acid precipitation leads to fish kills and declining fish populations due to chronic reproductive failure, potentially leading to extinction. This has implications for ecosystem structure and function. | 21 |
| 11.21 | Atmospheric aerosol, Freshwater | Aerosols influence the hydrological cycle by altering mechanisms that form precipitation in clouds. Aerosols may substantially influence the Asian monsoon circulation. | 22, 23, 24 |
| 11.23 | Habitats (Appropriated), Biodiversity | Offshore rigs and platforms for oil and gas extraction provide benthic habitat for certain marine organisms. Decommissioned rigs can be converted into artificial reefs (termed 'rigs-to-reefs' programs). They also provide refuges from commercial fishing, particularly trawling. Their potential to enhance ecological performance in shallow and deep-sea environments is debated. The risks and benefits to using rigs as artificial reef habitat are varied and context-specific, e.g. artificial reefs benefit some species more than others (including invasive species), promotes different community composition than natural reefs, and potential connectivity benefits depend on whether there are other natural or artificial reefs structures in the nearby area | 25, 26, 27,W |
| 11.31 | Ocean acidification, Biodiversity | Many marine organisms are highly sensitive to changes to ocean CO2 chemistry, especially those using carbonate ions to form calcium carbonate shells or structures. Ocean acidification could be deleterious to such organisms, which would constitute a major disturbance to marine ecosystems with highly uncertain impacts. Marine plankton are also vulnerable. | 6 |
| 11.32 | Ocean acidification, Habitats | Ocean acidification may have serious impacts on various marine and coastal habitats. | 6 |
| 11.33 | Ocean acidification, Climate | Oceans remove a large proportion of anthropogenic CO2, but acidification threatens the ability of oceans to continue to function as a carbon sink. | 6 |
| 11.34 | Atmospheric aerosol, Biodiversity | Aerosols have harmful impacts on flora and fauna, e.g. exposure to ozone can kill freshwater fish. | 6, 8 |

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# ELICITATION RECORD – Part 1

The Workshop Context

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| **Elicitation title** | Essential Environmental Impact Variables |
| **Workshop** | Oil & Gas |
| **Date** | 14 December, 2022 |
| **Part 1 start time** | 13:00 |

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| **Attendance and roles** | Facilitator, Note taker, Experts 1, 2 and 3 |
| **Purpose of elicitation** | 1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables.<br><br>2. Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect. |
| **This record** | Participants are aware that this elicitation will be conducted using an adapted Sheffield Elicitation Framework, and that this document, including attachments, will form a record of the session. |
| **Orientation and training** | Participants received a pre-workshop participant brief. |
| **Participants' expertise** | <u>Expert 1</u><br><br>*Expertise:* Education in sustainability and natural resources. Energy research - global energy systems. Background in engineering from the technical side, but moving into economics and security aspects of energy. More recent work on Russia and oil revenues. Expertise includes global oil supply, with a high level rather than specific focus. Has done a couple of case studies but global and national supply, not local production practices.<br><br><u>Expert 2</u><br><br>*Expertise:* Work with forecasting of oil and gas production in future, energy transitions and material requirements for transition to green |

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| | technologies, availability of lithium and battery metals. Production side – so, resource mass and freshwater consumption are questions that relate to what I do.<br><br><u>Expert 3</u><br><br>*Expertise:* Oceanographer and ecologist by training. Worked around oil and gas sector a long time. Ongoing research on impacts of Deepwater horizon. All research is applied in some way, including sustainability and conservation. Covers fisheries groups but primarily oil and gas. Solid understanding of impacts and management of offshore drilling around the world. Intersections of oil and gas industry with other offshore industries and management in future, especially wind and transitioning away from oil and gas. Have studied economics and legal aspects, but mainly biologist, ecologist, oceanographer, so, much more the hardcore science side of things. |
| **Declarations of interests** | <u>Expert 1:</u> None<br><br><u>Expert 2:</u> Have done consulting research in the past for oil companies but nothing at the moment.<br><br><u>Expert 3:</u> None |
| **Strengths and weaknesses** | <u>Expert 1</u><br><br>*Strengths:* More on oil than gas. But they have a lot in common, so both. More supply-side.<br><br>*Weaknesses:* I know about environmental impacts in general but not my research area. Also know less about local scale.<br><br><u>Expert 2</u><br><br>*Strengths:* Forecasting of oil and gas production in future, energy transitions and material requirements for transition to green technologies, availability of lithium and battery metals. Production side – so resource mass and freshwater consumption, e.g. future oil production and water injection that will be necessary<br><br>*Weaknesses:* Habitats and biodiversity not really my area. The exact measurements and how to measure them.<br><br><u>Expert 3</u><br><br>*Strengths:* Impacts and management of offshore drilling around the world. Applied research, sustainability and conservation. Intersections of oil and gas industry with other offshore industries |

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| | and management in future, especially wind and transitioning away from oil and gas. Natural science.<br><br>*Weaknesses:* Land-based activities and impacts |
| **Evidence** | *Clarifying question asked:* (Expert 3) The process was clear, it made sense. Everything that was written looked good and well researched. Could not think of major gaps. Took a minute to figure out the numbers, but then did. I understand the impact and dependency relationship. However, in a few places there are arrows that are either, others have two arrows but arrows at both ends too.<br><br>*Answer:* (Facilitator) In some databases, e.g. ENCORE, a dependency goes in and impact goes out. But for us, the dependencies can also be an impact. If there are different arrows, usually different mechanisms or types of dependency. Like with freshwater, we split up quantity and quality.<br><br>Expert 3: That makes sense.<br><br>*Clarifying question asked:* (Expert 1) How detailed should our comments be? Do they have to refer to particular codes [on the diagram]?<br><br>*Answer:* (Facilitator) Just so we understand. You do not have to refer to the codes. |
| **Structuring** | The variables were not elaborated or rephrased at this stage. |
| **Definitions** | 1. Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured.<br><br>2. Assessment of which are the *greatest* impacts on nature, meaning that impacts have either 1) a large globally cumulative impact, or 2) impacts are more locally incurred but are the largest for individual firms. |

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| **Part 1 end time** | 13:28 |
| **Attachments** | |

# ELICITATION RECORD – Part 2: Outcome 1

Eliciting Expert Knowledge on Qualitative Outcomes

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|---|---|
| **Elicitation title** | Essential Environmental Impact Variables |
| **Workshop** | Oil and Gas Production |
| **Date** | 14 December, 2022 |
| **Outcome** | 1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables. Specify if any impacts are missed, should be rewritten/rephrased or removed. |
| **Anonymity** | Experts are identified as Experts 1, 2 and 3 (aligned across all elicitation records). |
| **Start time** | 13:40 |

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| **Definition** | Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured. |
| **Evidence** | A participant brief was provided in advance, containing a background review and evidence. |
| **Individual elicitation** | **Missing –**<br><br><u>Expert 2:</u><br><br>Ensure the following are properly covered:<br>• Volume of petroleum and natural gas produced<br>• Gas flaring, leakages or venting<br>• Injected produced and treated water<br>• Injected gas and materials (including Nitrogen)<br><br><u>Expert 3:</u><br>• You captured most of it. I have a couple of small details to add.<br>• 4.2 – biodiversity impacts, one of the major concerns is impact of noise on marine mammals. A lot of regulation, 3D seismic surveys and impacts on noise. Sound travels far and is intense |

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| | in the marine environment. Coming up in a lot of sectors. New regulation Gulf of Mexico - no vessels can go faster than 10 knots and not at night.<br>• Habitat section – direct impacts on native habitats, I think we are all aware of that. Those impacts might extend into supporting habitats, it is listed just as dependency but it could go both ways.<br>• Novel entities - some of the toxic materials – hydraulic fracking you talk about – but there is a lot of barite, barium, oil-based fluids in some Exclusive economic zones (EEZs) including Africa, where nation states do not have regulations to prohibit. Companies re-use oil-based fluids, greatly increasing impacts.<br>• 9.23, appropriated habitats and biodiversity. I have thought a lot about it, it is complex.<br>• Habitats - You talk of appropriated but also novel habitats in rigs-to-reef program. Another issue that comes is that you are introducing a habitat type that didn't exist before, it is built. Impacts with fishing interesting. You talk about connectivity benefit but there are also detractions: you now provide a corridor for invasive species. Problem in Gulf of Mexico with invasive lionfish, invasive coral from Caribbean to Mexico.<br>• Nitrogen –<br>o N is a major limitation on productivity in the marine environment in particular, though also the case in terrestrial. Any impacts on biogeochemical cycle will affect generation of nitrate and have major impacts on productivity. It is harder to quantify and hasn't been done really well, but I am sure it exists. Nitrogen is important for plankton of course. You do mention N at some point. But on corals, shallow and deep, they have major role recycling nitrogen, fuelling productivity, if you impact those systems there are knock on effects. We don't understand them as not much work to draw those connections but they do exist.<br>o Facilitator: To clarify, the impact on habitats and biodiversity in terms of plankton etc., will change N flows, having a knock-on effect. |

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| | ○ Expert 3: It would be a dashed line. It is a big question mark in my mind. Overlooked in the research.<br><br><u>Expert 1:</u><br>• Aerosols impact human health – smog in cities one of largest problems for humans<br>• Microplastics as scope 3 impact of oil – ends up in sea, falls under category novel entities<br><br>**Rephrase –**<br><u>Expert 2:</u> See above – double check if those are covered, potentially involves rephrasing.<br><u>Expert 3:</u> None<br><u>Expert 1:</u> Methane leakage is not just shale oil or gas. It is also from conventional gas.<br><br>**Remove –**<br><u>Expert 2:</u> None<br><u>Expert 3:</u> None<br><u>Expert 1:</u> None |
| **Matches/ Mismatches** | Mainly agreement |
| **Group discussion** | **Oil spills**<br>• Facilitator: How can you have continuous oil spills?<br>• Expert 1: Main example is Nigeria as Expert 2 talked about – pipeline systems not well maintained or there are thefts. Still in category of accidents. Maybe continuous oil spills not best description. Maybe it is more 'mismanagement', not 'accident'.<br>• Expert 2: Lack of regulation – oil-contaminated water is pumped into local river or pond. These things happen when environmental regulation is weak. Can be solved when institutions established. |

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| | • Expert 3: In Nigeria, it has been almost continuous. For offshore drilling – companies are decreasing production from Norway, North Sea, UK, and moving to Africa, Indonesia where there are no regulations, there isn't monitoring for leakage. And there is leaking in every oil field. It can be methane – this is difficult to track. Liquid hydrocarbons are somewhat easier to see but not 1500m depth. There is always some leakage entering the environment.<br>• Facilitator: If every site has leakage but regulation can minimize it. How?<br>• Expert 3: Engineers would be better able to explain. But mostly about maintaining equipment. Other ways to minimize methane. Oil production, a lot of hydrocarbons are in gas form: that is why they allow gas flaring. Designed to collect liquid hydrocarbons. Not equipped to capture gas. So, they burn it so it as $CO_2$ rather than Methane. Different amounts are permitted in different areas.<br>• Expert 2: As an engineer, I can comment that in some places, especially in developing countries, you may not be able to afford good new technologies to solve problems. With standard equipment from the 1970s, you can't do the same thing as far more expensive equipment. Sometimes, it's about having access to best technology. Then, maintenance, the regulation and inspections. So, enforcement, matters with inspections.<br><br>**Injected / Produced water**<br>• Facilitator: Injected water – what is it for?<br>• Expert 2: Water injection is typically something people do to maximise the oil they can recover. It is like an upside down bowl with fluid. Initially, you conduct primary recovery. Pressure pushes oil to the surface. By injecting water under oil, because oil is lighter so you push it to production wells. You extract far more by injecting water. All who can, do it. That counts for 50-60% of all oil. Otherwise, 30% comes from primary recovery.<br>• Facilitator: Where does the water come from?<br>• Expert 2: It depends. If you have it nearby… In the Middle East it comes from the sea and you desalinate. You can recycle the water several times. Some fields produce 99% water and 1% oil. Some of world's largest seawater processing units are for injection to oil fields.<br>• Facilitator: Is that usual, using desalinated? |

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| | • Expert 2: Can be freshwater. Some places inject salty seawater, and this can damage the field. So desalinated is good, or, good quality is good for production.<br>• Facilitator: Does it stay there or seep out?<br>• Expert 2: Essentially, the water is replacing oil. Other places, it could use to prevent land subsidence. With subsidence there can be an 8m drop. In the Netherlands, there are cracks in buildings, even earthquakes. Injected water prevents land subsidence. But some water can be contaminated. Brine, 40,000 mG per litre of salinity in produced water. Water also contains soluble toxic elements like Cadmium, depending on the geochemical properties of the reservoir.<br>• Facilitator: Would the other experts like to add anything?<br>• Expert 1: Nothing to add, it is good description.<br>• Expert 3: Hydraulic fracturing, I can't explain as well as the others but when you do it to access harder-to-access reservoirs, pollution of surrounding drinking wells can come after. Basic process is done everywhere, the aim is to maintain pressure in those wells.<br>• Facilitator: Expert 2, you mentioned earlier the injection of gases and other materials. Natural gas, $CO_2$, and nitrogen.<br>• Expert 2: Yes, similar to water. Comes after water. You can conduct secondary and tertiary, or enhanced oil recovery. Could be to inject polymers or other things to squeeze water. Alkaline solutions, surfectants that change properties of oil to flow, make it lighter. Thermal – using hot water vapour, because heat makes oil flow more easily. Depending on technologies, one way is to inject $CO_2$, N or polymers. This can introduce man-made substances deep underground. Polymers and interesting compounds that can alter everything from microorganisms' thriving, contaminating groundwater and so on. Some follow oil to surface and are processed. In other cases, they seep into surrounding structures. Tracing and understanding it is tricky. Depends on specific technologies in field.<br>• Expert 1: Could be difference between conventional and shale oil, gas and fracking. Conventional: the resource is trapped. For shale gas and oil, not trapped but in the source rock. The company must fracture artificially and create fracture networks. Not covered by trap formation. More likely to find cracks and that substances spread upwards - higher risk. Still many km below ground, below aquifers. But the main problem is where you have drilling rods and pipes you can have leakage around well. With fracking and shale oil |

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| | you drill a lot of wells, thousands rather than a few. This also increases risk of water leakage or leakage up to aquifers. Something to add is that companies should state what kind of oil production: shale or offshore.<br><br>**Methane emissions**<br>• Expert 2: Would like to clarify regarding methane. Methane leakages can come from poor joints and so on, and this is applicable to all forms of industries. Specifically for shale, diffuse emissions of methane come through the ground, this is called "diffuse methane emissions" or seepages.<br>• Expert 1: How big are those?<br>• Expert 2: Life cycle – larger than leakages from processing. 1-3% of hydrocarbon compounds from reservoirs seep up through ground.<br>• Expert 1: Activated by fracking process?<br>• Expert 2: Yes<br>• Expert 1: So, two different points. One is leakages from pipes etc., and the issue is the same for both shale and conventional gas. Second point is diffuse methane emissions from shale. |
| **Group elicitation** | **Missed –**<br><br>Noise on marine mammals, effects on biodiversity through invasive species through increased connectivity, double-headed arrow to supporting habitats, interactions between habitats and biogeochemical flows, direct use of nitrogen for company, novel entities (e.g. plastic) is created from resources (with all associated impacts).<br><br>**Rephrase –**<br><br>Methane leakage from pipes etc. is currently noted as impacts of shale production – however, no need to specify shale because methane leaks from all. It is diffuse methane emissions/diffusion which are specific to shale production.<br><br>"Water use and pollution" is a better term rather than freshwater<br><br>**Remove –**<br><br>None |

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| **Chosen outcome** | See above |
| **Discussion** | Point raised by Expert 2 about how some types of oil are worse than others – suggestion to use ecolabelling or different classes of oil. Some have much higher carbon intensity, or other impacts. Even if all or most oil needs to be phased out, it makes sense to phase out the worst part first.<br><br>Overall the workshop went smoothly and the structure followed well. |

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| **End time** | 16:00 |
| **Attachments** | |

# ELICITATION RECORD – Part 2: Outcome 2

Eliciting Expert Knowledge on Qualitative Outcomes

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| **Elicitation title** | Essential Environmental Impact Variables |
| **Workshop** | Oil and Gas Production |
| **Date** | 14 December, 2022 |
| **Outcome** | 2. Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect. |
| **Anonymity** | Experts are identified as Experts 1, 2 and 3 (aligned across all elicitation records). |
| **Start time** | 13:50 |

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| **Definition** | Assessment of which are the *greatest* impacts on nature, meaning that impacts have either 1) a large globally cumulative impact, or 2) impacts are more locally incurred but are the largest for individual firms. |
| **Evidence** | A participant brief was provided in advance, containing a background review and evidence. |
| **Individual elicitation** | <u>Expert 2</u><br><br>**Impact:** Petroleum / natural gas extraction (non-living resource mass)<br><br>**Reason:** Volumes of extracted oil & gas, as it relates to greenhouse gas emissions downstream and for end-users<br><br>Produced oil that gets spilled in and near oil operations can also contaminate soils and local environments, while combustion of oil by the end-user will lead to formation of aerosols and GHG emissions<br><br>**Impact:** Gas flaring/leakage/venting & diffuse methane emissions (atmospheric aerosols and stable climate)<br><br>**Reason:** Oil & gas operations can release significant volumes of gas to the atmosphere if it is vented or flared, leading to major GHG |

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| | emissions. Leakages and diffuse emissions can release methane into the atmosphere.<br><br>**Impact:** Injected, produced, & treated water<br><br>(non-living resource mass, novel entities)<br><br>**Reason:** Oil fields can require large volumes of water for injection to maintain production flows. Simultaneously, oil fields do generate large volumes of produced water as the water cut often increases as the field matures. This can result in large volumes of water being treated and transported around with consequences of surrounding systems and society.<br><br>Some of the produced water (PW) may be salty and depending on how such brine is treated or handled, there is a risk that soils are contaminated by oil and brine. Due to the large buried depth of the reservoir, the PW contains many inorganic ions and the salinity is generally between 1000 and 40,000 mg per litre.<br><br>The types and contents of ions in the PW vary greatly under different geological conditions. PW may contain Fe2+, Ca2+, Mg2+, K+, Ba2+, Sr+, Al2+, Li+, Cl-, CO32-, HCO32-, SO42-, OH-, and CN-. The SO42-, Ca2+, Fe2+, and CO32- ions can react with each other to generate CaCO2, CaSO4, and FeS2, which can accelerate the corrosion of equipment and pipelines.<br><br>Synthetic organic matter in PW refers to various chemical substances and their by-products added artificially in the process of oil recovery and crude oil treatment. The common synthetic organic matter for the treatment of PW include oil displacement agents, drag reducing agents, corrosion and scale inhibitors, wax removers, defoamers, and demulsifiers.<br><br>The specific toxic elements in PW are affected by the source geology. Take North Sea for example, the input load of toxic metals to North Sea by PW is less than 1% of the total anthropogenic load. The common toxic elements in PW include, but not limited to, Hg, Cd, Pb, Zn, Cu, Cr, Ni, and As. The types and contents of toxic metals vary between oilfields.<br><br>The solid substances in PW mainly include suspended solids and colloids such as clay particles, silt, corrosion products, fine sand, and asphaltenes.<br><br>Inorganic salts and organic compounds in PW provide a good environment for bacteria to grow. The three most common |

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| | microorganisms include algae, bacteria, and fungi, among which bacteria are the most harmful, and their sizes range between 0.2 and 10 μm. The bacteria in PW usually include saprophytic bacteria, sulfate-reducing bacteria, and iron bacteria, which may cause the corrosion of pipelines, valves, and containers and plugging of cores.<br><br>Naturally occurring radioactive material (NORM) originate from geological formations and can be transported to the surface with PW. The most abundant NORM compounds in PW are 226Ra and 228Ra, which are derived from the radioactive decay of 238U and 232Th, respectively, and can generate 210Pb by continuous radioactive decay. In the North Sea, where ambient concentrations of 226Ra are 0.027–0.04 Bq per litre, the measured concentrations in PW are in the range of 0.23–14.7 Bq per litre. The 226Ra contamination in PW is a serious risk to human health.<br><br>PW also shows remarkable biological toxicity because of the existence of many toxic organic compounds, including but not limited to, benzene, toluene, ethylbenzene, and xylenes (BTEX), total polyaromatic hydrocarbons (PAHs), and high molecular weight alkylphenols.<br><br>**Impact:** Injected gas & material<br><br>(non-living resource mass, novel entities, biogeochemical flows)<br><br>**Reason:** Sometimes gases like natural gas, CO2 or nitrogen is injected into fields as a way to enhance oil production. This can require substantial volumes of input (the Cantarell oil field complex in Gulf of Mexico had the worlds largest N2-plant to supply it with nitrogen for injection).<br><br>Some production methods also include injection of polymers or other chemical compounds into oil fields that would include man-made substances being placed in new settings. Several countries have oil fields where polymer-flooding technologies (PFT) or Alkaline-surfactant-polymer-flooding technologies (ASPFT) have been used.<br><br>**Expert 3**<br><br>[Note: The following are ranked]<br><br>**Impact:** The redistribution of Carbon, and impacts on climate<br><br>**Reason:** Clearly number 1, global scale impacts lasting millennia. |

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| | **Impact:** Habitats<br><br>**Reason:** Scale - can be wide-reaching impacts, especially marine environments where impacts travel. Compounded with nitrogen cycle. Where you impact habitat, you impact the services it provides. Includes the problem of connectivity. Species move between habitats in different live stages. If you remove a stepping-stone, they have problems completing their life cycle, e.g. if they don't have a breeding ground or offspring can't disperse to a certain place – habitat and population connectivity is a big issue<br><br>Problem could be both fragmentation and creating connectivity. Some places, creating habitat can create connectivity, but as novel habitat may not be favourable to native species. It is context-specific and interpreted as a positive or a negative.<br><br>**Impact:** Biodiversity<br><br>**Reason:** Biodiversity is next in scale. It can recover faster than an entire habitat, so the temporal scale is smaller. There is generally redundancy, which only works to certain degree. As you decrease biodiversity, ecosystem function will follow. Scale, both temporal and physical, a bit smaller than climate and habitat, but still really significant.<br><br><u>Expert 1</u><br><br>[Note: The first, climate, is a clear number one, and the remaining impacts are considered equal]<br><br>**Impact:** Climate / Stable climate<br><br>**Reason:** A clear number one, as the others said, and many indirect effects from that. Both scope 3 and upstream emissions.<br><br>**Impact:** Aerosols<br><br>**Reason:** Smog affects both humans and wider environment<br><br>**Impact:** Water pollution, withdrawals and scarcity problems |

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| | **Reason:** [None provided]<br><br>**Impact:** Habitat – pipelines, fragmentation<br><br>**Reason:** [None provided]<br><br>**Impact:** Oil spills (Novel entities)<br><br>**Reason:** Locally, very significant. Countries with poor regulation can have almost continuous oil spills due to mismanagement. However, not comparable to global climate change. |
| **Matches/ Mismatches** | Mainly agreement |
| **Group discussion** | **Climate**<br><br>• Facilitator: There seems to be consensus that climate is by far the biggest impact. Covers the end product as well as production.<br><br>• Expert 3: Also, carbon intensity of extraction process itself, component resource use during extraction. Not every type of extraction has the same impacts.<br><br>• Expert 1: Regarding upstream emissions—the emissions from a barrel of oil is maybe 90% from combustion, 10% upstream. The end use is really big. Upstream processes also important and that is where we see variable intensities. End use emissions are more or less the same. The ability to influence emissions [from the company] is upstream. Some oil has really high upstream impacts, maybe 50% upstream.<br><br>**Produced water and pollution**<br><br>• Expert 2: I have sent you an email with issues of produced water - radioactive materials to salt. When you extract oil you get salt water. I would say that 'water use and pollution' is a better term rather than freshwater.<br><br>• Facilitator: Do the others agree?<br><br>• Expert 3: Agree that it is definitely a huge impact.<br><br>**Oil spills** |

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| | • Expert 2: Does 'Habitat' include contamination by oil spills?<br>• Facilitator: Should we put oil spills under habitats?<br>• Expert 3: It is currently under novel entities.<br>• Facilitator: Should we put in greatest?<br>• Expert 3: Difficult. Most oil spills are very small and unreported. A daily occurrence - they happen everywhere. Then every couple of years is a much larger one, which gets people's attention. This is a constant issue. We break it into 'typical impacts' and 'accidental impacts'. The impacts themselves are on habitats and biodiversity. In your scheme they are introducing novel entities. How to categorise it?<br>• Facilitator: Should it be at forefront of disclosure?<br>• Expert 3: I would keep it under novel entities, as you talk about planned or unplanned release of substances where they do not naturally occur. These have knock-on effects. The reporting is at release point.<br>• Facilitator: So, unplanned oil spills categorised under Novel entities.<br>• Expert 3: Yes, and the planned release, like what Expert 2 said about drilling fluids and produced water. Loss of biodiversity removes ecosystem function from the system. The biodiversity is the role those species play, different species have different sensitivity to different disturbances. The direct biological effect of different types of pollution. Impact on biodiversity affects Ecosystem services.<br><br>**Aerosols**<br>• Expert 2: Could make addition on aerosols. Part of the problem is onsite combustion and flaring. I can't remember specific studies, but a big fraction is related to end use. [Could add a] statement declaring that part is from extraction and other part is downstream.<br>• Expert 1: Cumulative emissions from burning fuel one of biggest parts. Hard to say where smog comes from. Part from gasoline, diesel, heavy oil. Kills a lot of people. Depends how much to factor in human cost [in the scope of this study].<br>• Facilitator: Good to have it there. The environmental and social are intertwined. |

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| | • Expert 3: They all need to be in there. The next step is hardest: what variables to monitor. Carbon is one thing, some other effects hard to attach to variables.<br>• Facilitator: Part of this process is to mention what impacts are, we can highlight where more work to be done. |
| **Group elicitation** | **Impact:** Climate<br>**Reason:** A clear no. 1. Impacts are from resource use/volume, method + flaring, venting, leakage effect, carbon intensity of production. Approx. 90% of impact is from end use, approx. 10% is from upstream (but here is where you can have an influence on amount of impact).<br><br>**Impact:** Water use and pollution<br>**Reason:** Huge amounts are needed, and pollution of water results from activities<br><br>**Impact:** Habitats<br>**Reason:** Direct usage/destruction of habitat area and indirect effects such as fragmentation.<br><br>**Impact:** Novel Entities<br>**Reason:** Planned or accidental release of novel entities. Accidental is e.g. oil spills that can have very large local effects. Planned is drilling fluids/water pollution.<br><br>**Impact:** Biodiversity<br>**Reason:** Habitat impacts have knock-on effects on biodiversity which are also great. Also impacted by pollution/novel entities. Biodiversity loss impacts ecosystem services.<br><br>**Impact:** Aerosols<br>**Reason:** Smog/aerosol production is large and has effect on environment (as well as human health). Part is from extraction (e.g. flaring), but part is from end use of production. |
| **Chosen outcome** | See above |

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| **Discussion** | Point raised by Expert 2 about how some types of oil are worse than others – suggestion to use ecolabelling or different classes of oil. Some have much higher carbon intensity, or other impacts. Even if all or most oil needs to be phased out, it makes sense to phase out the worst part first.<br><br>Overall, the workshop went smoothly and the structure followed well. |

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| **End time** | 16:00 |
| **Attachments** | |